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## Systematization of factors influencing the formation of carbon footprint value during the life cycle of capital construction objects

The purpose of the paper is a system representation of the factors influencing the formation of the carbon footprint value formed during the life cycle of capital construction objects. The main methods of work are analysis and systematization. The results of the work are presented in the form of a matrix of factors. The use of this matrix makes it possible to make more accurate calculations of the carbon footprint value formed during the life cycle of capital construction objects, as well as to develop databases for the calculation of the identified factors.

**Keywords:** carbon footprint, capital construction objects, factors, systematization

### INTRODUCTION

Reducing the carbon footprint (hereinafter referred to as the "CF") formed during the life cycle (hereinafter referred to as the "LC") of capital construction facilities (hereinafter referred to as the "CCF") remains a relevant topic of scientific research. According to the Intergovernmental Panel on Climate Change (hereinafter: IPCC), the built environment generates 40 % of annual global CO<sub>2</sub> emissions. Of these total emissions, construction work account for 27 % per annum, while building and infrastructure materials and structures (embodied carbon, causing indirect emissions) are responsible for an additional 13 % per annum. We are currently seeing the largest wave of construction in human history, with about 2.6 trillion feet (240 billion m<sup>2</sup>) of new building construction expected to add to the global building stock from 2020 to 2060. In 2040, approximately 2/3 of the global building stock will be buildings that exist today. Without widespread decarbonization around the world, these buildings will continue to emit CO<sub>2</sub> (direct or indirect) and the Paris Agreement target of 1.5 °C will not be reached<sup>1</sup>.

Despite the fact that the issue of decarbonization is relevant, both in Russia and abroad, to date, in domestic practice, a methodological apparatus has not been fully developed that takes into account all the factors in the formation of the CF, with software and relevant information databases, which makes it possible to produce calculations of the value of the CF of the CCF, depending on the various factors that form it and on the stages of the life cycle at which they are located. However, identifying and taking into account all the factors influencing the formation of the CF of buildings will improve calculation methods, create databases for information systems and services for calculating the CF, develop systems for low-carbon certification of construction projects and solve a number of essential government tasks.

### MAIN PART

Factors that make it possible to evaluate the design of a future building from the standpoint of low-carbon design solutions used (construction resources, space-planning solutions) were identified in the study [1]. However, the above factors do not take into account the carbon footprint of energy-saving engineering equipment used in construction projects (water supply, heating, and air conditioning systems), the use of energy-saving windows with low-emission coatings and other active and passive energy saving methods indicated in [2] and others. Accounting for these factors is extremely important, since there is a directly proportional relationship between energy saving and carbon footprint [3]. It has been proved that engineering systems and technologies are the determining factor at the stage of building operation [4]. The carbon footprint of the operation of engineering systems is primarily determined by their energy consumption

The longest stage LC of CCF is the operational stage, the energy costs for its provision are the most significant. Around 43 % of energy resources are spent on heating, 31 % on electricity supply [5]. According to a UNEP worldwide report, energy demand in buildings has increased by about 4 % compared to 2020 (to 135 EJ), while CO<sub>2</sub> emissions from building operation have reached an all-time high of about 10 gigaton of CO<sub>2</sub>, which is 5 % more than in 2020, and 2 % more than the previous peak recorded in 2019<sup>2</sup>. Multi-apartment and individual residential buildings, public and business buildings form 80 % of the total area of buildings in Russia and consume 927 million Gcal of thermal energy for heating needs per year, which is more than 75 % of the total consumption of thermal energy in the country. The production of thermal energy for these buildings results in annual greenhouse gas emissions of 252 million tons of CO<sub>2</sub>-eq. is 12 % of

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<sup>1</sup> Why the built environment? URL: <https://architecture2030.org/why-the-building-sector/> (accessed: 08.15.2023).

<sup>2</sup> United Nations Environment Programme. Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. Nairobi, 2022.

▶ the total greenhouse gas emissions in the country<sup>3</sup>. Therefore, the stage of operation LC of the CCF contains a number of important factors that form its carbon footprint during the life cycle.

The analysis of scientific works of domestic authors showed that the determination the value of the CF of CCF has the following methodological foundations:

1. Dividing the total value of the CF into direct and indirect emissions.
2. Formation the CF during the life cycle of the CCF.
3. Directly proportional dependence the value of the CF on the applied solutions for energy saving and reducing the resource intensity of the life cycle of the CCF.
4. Use of information modeling technologies [6–8].

An analysis of the works of foreign authors showed that there are four most important criteria that determine buildings with zero carbon emissions: decarbonization, electrification, efficiency and

digitalization [9, 10]. The methodological basis for determining the CF during the LC is the life cycle analysis (LCA — life cycle assessment), used in various modifications [11–14].

The factors affecting the size of the carbon footprint of buildings during the life cycle are heterogeneous, therefore, for their systematic presentation and further work on the formation of an information system, the authors systematized and compiled on the matrix of factors (Figure). This form of presentation allows to evaluate the factors by types of influence on the formation of the carbon footprint (matrix rows) and distribute them according to the stages of the life cycle of the CCF according to ISO 22263 in conjunction with the stages of forming the CCF information model according to CP 333.1325800.2020 (matrix columns).

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Stages of the life cycle of CCF according to ISO 22263	Preliminary steps	Pre-construction stages	Construction stages	Stages after completion of construction		
Stages of formation of an engineering model of the CCF according to SP 333.1325800.2020 Model type	Engineering survey	Architectural and construction design (design)	Construction	Exploitation	Reconstruction, capital repair	Demolition and disposal (liquidation)
	Engineering digital terrain model (EDTM)	EDTM, DIMCS CCF — design model	EDTM, DIMCS CCF — building model executive model	EDTM, DIMCS CCF — Operating model	EDTM, DIMCS CCF — building model executive model	EDTM, DIMCS CCF — Demolition model and dismantling
<b>Direct Impact Factors</b>	—	—	The mass of greenhouse gases released during the generation of electrical or thermal energy to ensure the operation of the construction site	The mass of greenhouse gases released during the generation of electrical or thermal energy for heating and (or) cooling of the facility, as well as gas supply	The mass of greenhouse gases released during the generation of electrical or thermal energy to ensure the operation of repair and construction work	The greenhouse gases emitted during the use of construction machinery and mechanisms with electric drive and diesel engines in the process of dismantling and disposal
			The mass of greenhouse gases emitted during the use of construction machinery and mechanisms with electric drive and diesel engines	The mass of greenhouse gases emitted from materials used in engineering systems during operation	The greenhouse gases emitted during transportation, disposal and processing of construction waste and waste after repairs	
<b>Factors of indirect influence</b>	The mass of greenhouse gases emitted during the work on the project (energy costs for the operation of the project office and data centers, consulting, transport emissions associated with the selection of a land plot)	The mass of greenhouse gases emitted during the work on the project (energy consumption for the work of the project office and data centers)	The mass of greenhouse gases emitted during the extraction, production and transportation of materials, products, structures and human resources	—	The mass of greenhouse gases emitted during the use of construction machinery and mechanisms with electric drive and diesel engines during repairs	

Matrix of factors influencing the formation about CF of the CCF throughout the LC

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## CONCLUSIONS

The factors indicated in the matrix that influence the formation about CF of the CCF during the life cycle are expressed as the mass of greenhouse gases emitted directly or indirectly at various stages LC of the CCF. Working with this matrix will make it possible to create advising databases on the amount of greenhouse gases with reference to one or another factor for carrying out multivariate calculations on the value of the CF at different stages of its life cycle or throughout the life cycle as a whole.

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## Систематизация факторов, влияющих на формирование величины углеродного следа в течение жизненного цикла объектов капитального строительства

Целью статьи является системное представление факторов, влияющих на формирование величины углеродного следа, формирующегося в течение жизненного цикла объектов капитального строительства. Проведен анализ ряда работ отечественных и зарубежных ученых, выявлены общие методологические основы расчета величины углеродного следа объектов капитального строительства. Результаты работы представлены в виде матрицы факторов, влияющих на формирование углеродного следа объектов капитального строительства в зависимости от этапов жизненного цикла и этапов формирования информационной модели объекта капитального строительства. Факторы сгруппированы по способу влияния на формирование углеродного следа: прямое и косвенное. Использование данной матрицы позволяет производить более точные расчеты величины углеродного следа, формирующегося в течение жизненного цикла объектов капитального строительства, а также разрабатывать базы данных для расчета выявленных факторов.

**Ключевые слова:** углеродный след, объекты капитального строительства, факторы, систематизация

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