Energy efficiency tools of buildings design solutions in information and analytical management systems for construction and overhaul process

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Abstract. The energy efficiency of construction and overhaul of buildings, including the optimization of energy consumption in production of building materials, construction and technological support of construction, has a significant role in energy efficiency assessment of construction as a whole, being the most important component of the implementation of green building principles. At the same time, the organizational-economic balance of interests of construction investors and authorities in the field of environmental rationalization in structural design as well as the motivation of developers to use green building materials and technologies, as assessed within economic tools, has still not developed in the Russian construction community. The paper proposes to consider the basic principles of the author's methodology for assessment of energy efficiency of construction and optimizing the structural design, which allows one to implement the tool into the information-analytical systems for managing the construction and overhaul process of buildings an instrument of promotion of green building, operating with quantitative energy efficiency assessments and cost indicators of design solutions.

1. Introduction

Construction industry is one of the most energy-intensive industrial sectors, including energy consumption at the phase of construction, mechanization, logistic and maintenance of buildings. Life-cycle construction project duration highlights a significant research potential of technical and technological decisions for resource optimization taken at the design stage of construction projects.

Energy audit of completed buildings and energy efficiency analysis of building functioning, determining its energy efficiency class and rate of compliance with national and international green standards are a common modern practice of assessing energy efficiency in completed construction projects and its subsequent facility and infrastructure improvements. At the same time economic evaluation (cost effectiveness or better cost utility analysis) of using green building materials and technologies often is taken into account empirically or declaratively. At the national level, using of green constructive solutions incenting by economic mechanisms for developers is insufficient, especially for BTS-developers who are not involved with the process of further maintenance and do not share the owner's potential risks of insufficient energy efficiency [1]. An essential obstacle to creation of effective national system of environmental and energy audit of construction materials and construction projects is the absence in the normative field of domestic construction of legislative directives. It is important to

establish specific financial obligations incurred with respect to manufacturers of construction materials and investors that comply or not with green building standards [2].

The purpose of the paper is to propose the key principles and offer for consideration and implementation the tool for reasonable economic stimulation of using green building technologies in information and analytical management systems for construction and overhaul process.

2. Materials and Methods

A distinctive feature of environmental problems is their global nature. The Russian Federation is one of the countries with the worst environmental situation [3]. In recent years, environmental pollution has deteriorated on a number of indicators, despite ongoing activities and programs for environmental monitoring and protection. Environmental protection activities in construction industry of Russia is local in nature, and is implemented at the level of normative legal acts of municipalities, i.e. do not contain universality focused on preservation of overall eco-balance on the scale of territories, countries, continents. Economic assessment of environmental impact is defined as practical and permissible resource and monetary losses due to anthropogenic exposure on qualitative and quantitative parameters of environment affecting in general and its individual eco-resources (hydrosphere, lithosphere, atmosphere, biosphere) [4]. However, the regulatory framework of pricing in construction in Russia and in most developing countries does not provide adequate quantitative assessment of civil construction environmental impact [5]. According to Russian legislation, environmental expertise is mandatory element of the Comprehensive State Expert Examination, and economic project assessment is declared from perspective of sustainable development and resource conservation at the initial stages of any project. Nevertheless, methods for quantifying the cost of environmental potential harm during construction phase still remain the subject of scientific discussions and research.

There are several methodological approaches for assessing environmental harm caused by industrial enterprises, including construction sector. There are two main ones: indirect (enlarged) and recipient (based on direct account) [6]. Indirect approach is characterized by simplicity and methodological completeness but provides low validity of the result and subjectivity of expert peer reviews. Exposure assessment on the basis of recipient approach is a time-consuming and long-term process requiring significant expenditures of time and resources, inconvenient for widespread use in economic calculations. This approach is used as a tool to create an information base in indirect methods development.

At the same time, three main methods are used to determine the components of pollution damage: focus districts (based on comparison of indicators of conventionally polluted and clean areas), analytical dependencies (based on obtaining mathematical dependencies, e.g. by means of multivariate analysis between indicators of the state of corresponding economic system and level of environmental pollution), and combined [5]. The methods listed are solving different problems and differ in their functionality.

Energy efficiency management of buildings should begin with the optimization of technical and technological constructive solutions at the start of invest construction projects - at the design phase. At this stage, information modeling technologies allow contractors to provide more environmentally friendly technical solutions without inefficient labor costs and to achieve efficiency on a number of criteria for sustainable development: reduction of resource intensity, minimizing energy inputs for building materials production, machinery and mechanisms; increasing of using recycled materials, united by a common efficiency assessment [7]. A key feature of such assessment should be it focusing on environment and economic − evaluation and quantitative accounting of negative environmental factors from extraction of raw materials till production, building-and-assembly works, etc. The method based on full information accounting of all construction process resource components is necessarily accompanied by obtaining an economic assessment of negative environmental impact of the construction project on through standard objective and cross-checked audit algorithms [8].

We will provide key aspects of the proposed eco-oriented assessment of constructive project solutions by comparing alternative design solutions under construction with traditional and green technologies.

Primary comparative cost estimation of construction is determined by standard methods of estimated pricing based on data of information modeled bill of quantities and classifiers of current resources market value.

Table 1. Volumes of the main resource- and energy-intensive building materials

Resources	Regular constructive technologies	Green constructive technologies
Building materials		
Concrete, m^3	3672	3024
Steel reinforcements, t	250	241
…		
Machines		
Tower Cranes, hrs	4856	4475
Mobile Cranes, hrs	356	41
…		
Total cost, thousand rub.	65600	72000

Comparison of alternative design solutions at the pre-project stage is most effective method from the standpoint of minimum cost of appropriate changes to the project. At this stage, compared projects already have preliminary space-planning solutions, however, there is an acute lack of information about details of design solutions that are subject to quantitative comparison. In order to improve this process the method of quantitative assessment of key building energy-harmful resources was proposed upon the established regression between resources and indicators of space-planning solutions (area, number of stories, etc.). For approximation in techno-economical processes what are always consist of non-linear (irregular, stochastic) and linear (regular, systematic) parts, K-polynomials proposed by author are useful, relevant and confident [9].

K-polynomial of nth degree means the symmetrical mathematical expression of normal and inverse powered variables as follows:

$$Y = a_{(-n)} x^n + a_{(-(n-1))} x^{n-1} + \ldots + a_0 x^0 + \ldots + a_{n-1} x^{-(n-1)} + a_n x^{-n}, \tag{1}$$

where Y – resources estimated costs,

x – quantitative indicator of the building space-planning decision,

a_i – constants,

x^0 – dummy term (always equal to 1), used for structure's clearness.

Left part of K-polynomials ($a_{(-n)} x^n + a_{(-(n-1))} x^{n-1}$) used for approximation of non-linear parts in approximated processes, right one ($a_0 x^0 + \ldots + a_{n-} x^{-(n-1)} + a_n x^{-n}$) — for approximation of linear parts in approximated processes.

Proposed K-polynomial could be easily converted to linear function ($i = 1$; $a_{(-1)} \ldots a_0 = const$, $a_1 = 0$); polynomial of nth degree ($a_{(-n)} \ldots a_0 = const$; $a_1 \ldots a_n = 0$); exponential of nth degree ($a_n \ldots a_0 = const$; $a_{(-n)} \ldots a_{(-1)} = 0$) or used to combine advantages of all above types.

In the study, the authors confirmed universality and expediency of use of K-polynomials for regression between key energy-intensive building materials and space-planning indicators and high correlation of used regression exceeding on R2 default trend lines of standard spreadsheet applications as well. The results are given in the authors' figures (figure 1).
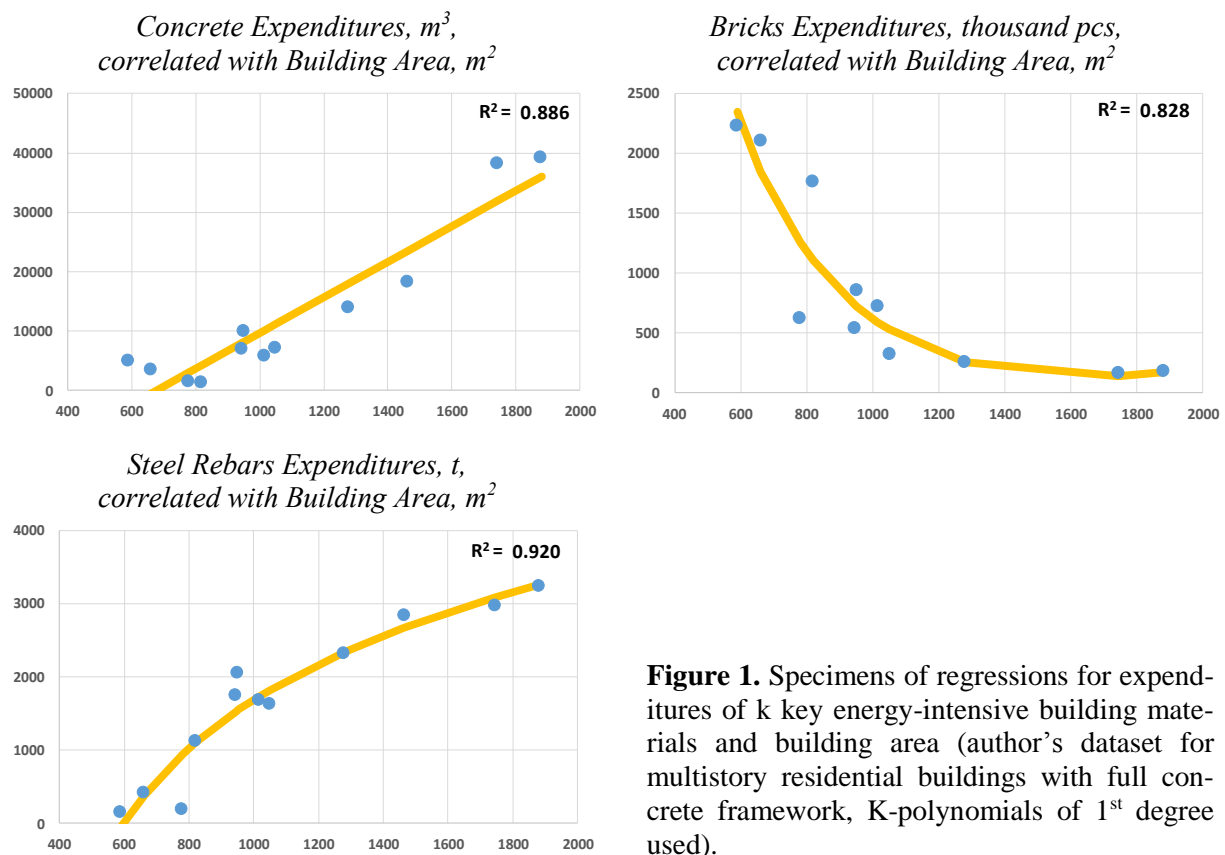
Concrete Expenditures, m^3,
correlated with Building Area, m^2

Bricks Expenditures, thousand pcs,
correlated with Building Area, m^2

Steel Rebars Expenditures, t,
correlated with Building Area, m^2

Figure 1. Specimens of regressions for expenditures of k key energy-intensive building materials and building area (author's dataset for multistory residential buildings with full concrete framework, K-polynomials of 1st degree used).

Table 2. Embedded Energy Calculator, expected emissions of aggregated GHG converted to CO_2.

Energy source	Regular constructive solution	Green constructive solution
Materials		
Concrete		
Expected emission of concrete producing, g/kg	100	
Concrete density, kg/m^3	2100	
Concrete volume, m^3	3671	3024
Expected embedded CO_2, t	771	635
…		
Machines and appliances		
Tower crane (67 kWt, loading capacity 8 t)		
Estimated working time, hr	4856	4475
Estimated GHG emission, g/kWt*hour	790	
Estimated GHG emission total, t	257	237
…		
Total GHG emission caused by materials, t	**1643**	**1507**
Total GHG emission caused by machines, t	**1901**	**1747**

Based on obtained resources' consumptions and correlation of greenhouse gases (GHG) converted to CO_2 produced by technical and technological sources of energy at the construction site, which are currently being developed by the authors, including information on the energy intensity of materials extraction and production from the standpoint of life cycle assessment analysis (LCA) [10]. The in-

formation on materials and energy required during mining to material production, transportation of material to construction site, construction activities and operational energy during use stage has been considered to conduct LCA analysis. It is proposed to include in analysis the calculator of embedded energy (shown above). By means of it one evaluates the expected weight of aggregated GHG emitted, caused and embedded within alternative design solutions, materials and technology of construction what are being compared (Table 2).

Presented estimate of reduced GHG emission in physical terms directly characterizes the degree of energy efficiency of the compared design decisions and needs to be transformed into a comparative cost estimate added to the estimated earlier construction cost. An algorithm for such transformation is the tool of conventional environmental taxation (EcoT) of construction projects (Table 3), which are alternatively implemented according to the compared design decisions [11].

Table 3. Tools of conventional environmental taxation (EcoT) of construction projects.

Group of EcoT	Reasons for EcoT
Construction material (for 1 measurement unit of consumed material)	Concrete, m3 Steel for rebars, t Steel for framework, t
Transportation (for 1000 t/km of average distance to construction plants)	up to 20 km 21-49 km more than 50 km
Installation (for 100 machine-hours of machine/vehicle in installation processes)	up to 20 machines/vehicles 21-49 machines/vehicles more than 50 machines/vehicles
In-situ energy consumptions for facilities and workers accommodation (for 10 worker-day at construction site)	up to 50 workers 51-199 workers more than 200 workers
In-situ energy consumptions for tools and engines (for 1 day of 10 tool/engine at construction site)	up to 20 tools/engines 21-49 tools/engines more than 50 tools/engines

EcoT, being an instrument that objectively assesses the environmental safety and energy efficiency of construction, is also an effective state regulatory mechanism that allows for the implementation of an additional project assessment that is obvious to all project participants and system customers in the information and analytical system of building management, taking into account penalties for the development of the project proposed by the regional market of green materials and solutions and the regional specifics of the construction industry [9]. For effective and transparent algorithm for the formation of such an assessment the marginal assessment is proposed, obtained from the available boundary data on the estimated construction costs (ECC_{max} and ECC_{min}) and reduced energy efficiencies (CO_{2max} and CO_{2min}) of construction projects implemented or being implemented in the region similar real estate. Local authorities are given the opportunity to adjust the amount of tax on a quarterly published multiplier *M*, which allows one to selectively assess and regulate the degree of economic interest of developers in green construction by industry and type of construction products being created.

$$EcoT = \frac{ECC_{max} - ECC_{min}}{CO_{2max} - CO_{2min}} \cdot M \tag{2}$$

3. Results

The presented tool for assessing environmental and economic effectiveness of alternative design decisions of construction, placed in the information-analytical system of construction management, includes an automated assessment of the information on the materials and technologies used in the compared design decisions, generates individual and general project estimates environmental potential harm and conventional energy efficiency of projects, transforms them into a universal amount of conventional environmental tax on public authorities that control the regional construction market and the environmental situation on construction sites, quantitatively highlights the design decisions that are insufficient from the standpoint of sustainable development and green building. Table 4 shows authors dataset of compared building frames referring to probable alternative green constructive solution and EcoT calculated on the basis of contractors' equipment, construction site amenities (Table 3), embedded energy calculations (Table 2) and M multiplier recommended for local authorities. Calculated efficiency of using an alternative green technology, expressed in ratio of eco taxes and extra green cost commonly is quite significant (up to 51%, 22% in average). Obviously, this creates an understandable and acceptable by market participants and universally applicable by the regulator flexible tool for the economic motivation of regional building communities to active and purposeful implementation of green construction and support the production and use of green building materials [12].

Table 4. Comparative assessment of construction costs in alternative design solutions taking into account conventional environmental taxation

Building frame #	Cost before EcoT, mln. rub.	Cost of alternative green frame, mln. rub.	EcoT, %	Cost after EcoT, mln. rub.	Green efficiency
1	81.3	101.4	31.8%	107.2	7%
2	113.7	122.9	35.2%	153.7	27%
3	114	136.5	11.0%	126.5	-9%
4	62.4	74.4	56.4%	97.6	37%
5	89.1	109.8	57.0%	139.9	34%
6	57.8	68.1	20.6%	69.7	3%
7	54.9	67.8	11.2%	61.0	-12%
8	72.6	77.0	46.6%	106.4	41%
9	113.5	119.5	37.6%	156.2	32%
10	54.7	65.8	39.4%	76.3	19%
11	63.2	68.8	35.4%	85.6	27%
12	78	82.0	56.4%	122.0	51%
13	96.5	115.7	47.8%	142.6	28%
14	76.7	86.3	10.0%	84.4	-3%
15	58.2	66.1	26.8%	73.8	13%
16	110.9	122.0	56.6%	173.7	47%
17	107.9	119.9	29.4%	139.6	18%
18	66.8	69.5	14.4%	76.4	10%
19	91.4	114.1	40.8%	128.7	16%
20	115.3	128.8	52.2%	175.5	41%
21	97	98.4	19.2%	115.6	18%
Average	**84.6**	**95.9**		**114.9**	**22%**

4. Discussion

Analysis of existing methods and approaches to environmental potential harm assessment allows us to conclude that there is no universally approved system of indicators of environmental harm, which al-

lows to consolidate data on possible harm caused by enterprises of different production technologies, products and operating modes, etc. [13]. It does not allow to bring ecological damage to uniform universal equivalent (conventional unit of environmental harm) and to construct on this basis formalized algorithms of practically eco-oriented pricing and estimated rationing in construction. In Russian pricing and estimated system in construction the factor of "environmental pollution" associated with the production of construction works and the use of building materials, products and structures is taken into account only declaratively. According to [14] in design and budget documentation section of environmental harm assessment caused by construction project is not included. The concept and definition of environmental harm, mentioned in [15] do not have a full comprehensive justification and are not enshrined in law. The state examination of project documentation in accordance with [16] does not provide for a full and comprehensive analysis of possible environmental harm. Appropriate methodological approach to this issue is the proposed universal sets of generalized natural indicators (on the main pollutants, the main harmful effects, etc.) and the method of converting these figures into monetary equivalent ("eco-cost") with subsequent implementation of the resulting algorithms in software for compiling building estimation . Thus, in practice, it can be implemented relevant and promising eco-oriented pricing, based on the methodology of multifactorial and step-by-step predictive environmental harm assessment as part of the existing system of construction estimates.

5. Conclusion

The tools considered in the work of energy-efficient optimization of design decisions of buildings and structures in information-analytical systems for managing construction and overhaul process allow to optimize structural, space-planning decisions and technological solutions of construction, repair, reconstruction of buildings and structures from the perspective of minimizing future production and materialized in building materials expended energy expressed in aggregated GHG emissions. This is a key factor threatening irreversibility of global negative environmental changes. An effective environmental audit in investment and construction activities should be based on popularization of green standards, supported by a transparent and effective methodology for valuation of environmental harm caused by construction industry activities. Proposed methodology will allow quantitatively substantiating rational approaches for design in construction projects, forming a motivating system for the effective management and regulation of regional construction markets with a standpoints of green processing. It makes environment more sustainable, will be an effective supplement to the practice of green design and real estate certification established in the country and the world.

Acknowledgments

References

[1]   Avilova I P and Krutilova M O 2018 Methodology of ecooriented assessment of constructive schemes of cast in-situ RC framework in civil engineering *IOP Conf. Series: Earth and Environmental Science* **3** 012127

[2]   Avilova I, Krutilova M and Peresypkina E 2017 Economic incentives of green standards in civil and municipal engineering *Int. Multidisciplinary Scientific Geo Conf. SGEM* vol 53 pp 551-7

[3]   Wen-Hsien Tsai, Chih-Hao Yang, Cheng-Tsu Huang and Yen-Ying Wu 2016 The impact of the carbon tax policy on green building strategy *J. of Environmental Planning and Management* **60(8)** 1-27

[4]   Avilova I, Naumov A and Krutilova M 2017 Methodology of cost-effective eco-directed

structural design *Int. Multidisciplinary Scientific Geo Conf. SGEM* vol 53 pp 255-61

[5]   Naumov A E, Shchenyatskaya M A and Tovstiy V P 2016 Kachestvennye pokazateli ob"ekta nedvizhimosti kak faktor ekonomicheskoy optimizatsii organizatsionno-tekhnologicheskikh resheniy investitsionno-stroitel'nogo proekta [Qualitative indicators of the property as a factor in the economic optimization of organizational and technological decisions of the investment and construction project] *Vestnik BGTU im. V G Shukhova* [*Bulletin of BSTU named after V G Shukhov*] **5** 202-6 [In Russian]

[6]   Kara K A, Dolzhenko A V and Zharikov I S 2018 Influence of processing factors over concrete strength *IOP Conf. Series: Materials Science and Engineering* **327** 032027

[7]   de Beer J, Harnisch J and Kerssemeeckers M 2000 Gas Emissions From Major Industrial Sources - III Iron and steel production (RK Utrecht: ECOFYS)

[8]   2016 *Conference of the Parties Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Part two: Action taken by the Conference of the Parties at its twenty-first session. Decisions adopted by the Conference of the Parties* URL http://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf

[9]   Krass D, Nedorezov T and Ovchinnikov A 2013 Environmental Taxes and the Choice of Green Technology *Production and Operations Management* **2 (5)** 1035-55

[10]   Grabovyy P G and Manukhina L A 2014 Natsional'naya strategiya vnedreniya energoresursov i ekologicheski bezopasnykh (zelenykh) tekhnologiy i proizvodstv v stroitel'stvo i ZhKKh [The national strategy for the implementation of energy resources and environmentally friendly (green) technologies and industries in construction and utilities] *Nedvizhimost': ekonomika, upravlenie* **1-2** 6-8 [In Russian]

[11]   Keane M, Siert A, Stone S and Chen B T 2016 Profiling stainless steel welding processes to reduce fume emissions, hexavalent chromium emissions and operating costs in the workplace *J. of Occupational and Environmental Hygiene* **13** 1-8

[12]   Metz B, Davidson O R, Bosch P R, Dave R and Meyer L A 2007 *IPCC, 2007: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (New York: Cambridge University Press)

[13]   Krutilova M O 2018 Napravleniya sovershenstvovaniya ekonomicheskikh mekhanizmov minimizatsii vybrosov parnikovykh gazov v techenie zhiznennogo tsikla zdaniya [Directions for improving economic mechanisms to minimize greenhouse gas emissions during the life cycle of a building] *Ekonomika stroitel'stva i prirodopol'zovaniya* **1(66)** 63–71 [In Russian]

[14]   Avilova I P, Naumov A E and Krutilova M O 2019 Methodology of GHG emissions assessment caused at the construction of energy facilities. Case study: Hydropower *IOP Conf. Ser.: Mater. Sci. Eng.* **552** 012018

[15]   Abakumov R G and Naumov A E 2018 Building information model: advantages, tools and adoption efficiency *IOP Conf. Series: Materials Science and Eng.* **11** 022001.

[16]   Telichenko V I and Benuzh A A 2016 Sostoyanie i razvitie sistemy tekhnicheskogo regulirovaniya v oblasti zelenykh tekhnologiy [Status and development of the technical regulation system in the field of green technologies] *Academia. Arkhitektura i stroitel'stvo* **1** 118-21 [In Russian]