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THE ADVISABILITY OF APPLICATION OF A UNIFIED ENVIRONMENTAL ASSESSMENT TO BUILDING OPERATIONS THROUGHOUT ALL LIFE CYCLE STAGES

Dmitriy Yu. Zheldakov [1], Vladimir T. Erofeev[2], Yury L. Skolubovich [3], Sergey I. Pakhomov [4], Valery P. Meshalkin [5], Irina V. Stepina [2]

[1] Research Institute of Building Physics of the Russian Academy of Architecture and Building Sciences, Moscow, RUSSIA
[2] National Research Moscow State University of Civil Engineering, Moscow, RUSSIA
[3] Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Novosibirsk, RUSSIA
[4] Russian Academy of SciencesMoscow, RUSSIA
[5] D.I. Mendeleev Russian University of Chemical Technology, Moscow, RUSSIA

Abstract: This paper proposes a method for calculating the environmental impact of constructional materials used in buildings and structures. The method is based on a broader - as compared to the currently accepted assessment pertaining solely to greenhouse gas emissions - approach to environmental impact assessment of building operations and erected structures. As a functional unit, the proposed method employs the maximum single-exposure permissible concentration (MPC) of carbon dioxide in the air of the work zone. This approach enables the assessment of a building's environmental impact with account to all harmful gas emissions into the atmosphere, expressed in CO_2 equivalents. The assessment encompasses all stages of the life cycle. The paper presents the results of surveys of enterprises engaged in manufacture of constructional materials along with a methodology for converting gas emissions into equivalent to CO_2 quantities. The analysis of emission calculations reveals that prioritizing CO_2 emissions in the latter provides a distorted picture of the manufacture's burden on the environment. The paper also describes a technology for purifying manufacture emissions from harmful gases as a result of using the methodology to identify the most environmentally damaging areas of manufacture.

Keywords: harmful gas emissions, carbon footprint, constructional material manufacture, calculation method, survey methodology

ПРИМЕНЕНИЕ ЕДИНОЙ ОЦЕНКИ ЭКОЛОГИЧНОСТИ СТРОИТЕЛЬСТВА НА ВСЕХ ЭТАПАХ ЖИЗНЕННОГО ЦИКЛА

Д.Ю. Желдаков [1], В.Т. Ерофеев [2], Ю.Л. Сколубович [3], С.И. Пахомов [4], В.П. Мешалкин [5], И.В. Степина [2]

[1] Научно-исследовательский институт строительной физики Российской Академии Архитектуры и Строительных наук, г. Москва, РОССИЯ
[2] Национальный исследовательский Московский государственный строительный университет, г. Москва, РОССИЯ
[3] Новосибирский государственный архитектурно-строительный университет (Сибстрин), г. Новосибирск, РОССИЯ
[4] Российская академия наук, г. Москва, РОССИЯ
[5] Российский химико-технологический университет имени Д.И. Менделеева, г. Москва, РОССИЯ

Аннотация: В работе предлагается метод расчета экологичности строительных материалов зданий и сооружений. В основу метода положен более широкий, по сравнению с общепринятой в последнее время оценкой производства только по выбросам газов, создающих парниковый эффект, подход к оценке воздействия на окружающую среду строительства и эксплуатации зданий. При этом в качестве функциональной единицы предложено считать значение максимально разовой в воздухе рабочей зоны ПДК диоксида углерода. Такой подход дает возможность оценивать воздействие здания на окружающую среду по всем выбросам вредных газов в атмосферу в объемах, эквивалентных выбросам углекислого газа. Оценка

производится на всех стадиях жизненного цикла. В работе приводятся результаты обследования предприятий по выпуску строительных материалов, методика пересчета выбросов в эквивалентное CO_2 количество газов. Проводится анализ расчета выбросов, делается вывод о том, что расчет по выбросу CO_2 в атмосферу дает искаженную картину нагрузки производства на окружающую среду. Приводится технология очистки выбросов производства от вредных газов, как результат использования методики с целью определения наиболее вредных участков производства.

Ключевые слова: выбросы вредных газов, углеродный след, производство строительных материалов, методика расчета, методика обследования

TITLE

The life cycle of any building or structure consists of the following stages: raw material extraction, transportation to factories, preparation and manufacture of constructional materials; delivery of materials to the construction site, building operations, operation of a capital facility; demolition and waste processing (disposal) of a capital facility [1, 2].

There is a significant number of methodologies assessing the environmental impact of each stage of a life cycle [3, 4, 5]. However, the main problem is that, to date, there is no methodology that makes it possible to compare each of these stages using a unified set of characteristics.

A second, equally important problem is that when assessing pollution, it is not taken into account that any manufacture, generation of heat and power (electricity), operation of vehicles, release a significant amount of gases into the atmosphere. The impact of these gases on the human body is much more significant than the impact of CO_2. These gases include the well-known nitrogen and sulfur oxides, carbon monoxide, saturated and unsaturated hydrocarbons, ammonia, and others. The danger of these gases to humans is defined in the Sanitary Rules and Norms SanPiN 1.2.3685-21 «Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans» [6], which specifies over 2300 substances for which permissible concentration limits (PCLs) of pollutants in the air of the work zone are defined. A significant amount of harmful gases, posing a danger to humans that in some cases exceeds the danger of CO_2 by millions of times [7, 8], is released into the atmosphere during the manufacture of constructional materials and the population breathes them in.

Meanwhile, the GOST standards, which are identical to the ISO 14000 series, only consider carbon dioxide emissions, neglecting other harmful gases [9, 10]. This, in turn, disincentivizes factories from adopting manufacture technologies that would reduce the quantity of these emissions [11-13].

Quantifying carbon dioxide emissions during the production of various wall structures is essential for accounting for anthropogenic greenhouse gas emissions. Research [14] has shown that timber and wood-frame buildings sequester more carbon compared to the energy consumed in their production, making these types of building structures the most environmentally friendly. The combination of a traditional renewable material—wood—and modern insulation materials provides the required energy efficiency of buildings, as mandated by European legislation. In North America and Scandinavia, a set of measures has been developed to promote the use of wood in construction. Traditionally, brick buildings are widely common in Hungary and Russia, indicating a significant additional potential for carbon sequestration. The recent trend of increasing the share of wooden housing construction could be further enhanced through specific state support measures [14].

It’s important to note that our reliance on foreign standards focused on reducing the so-called “carbon footprint” is often inappropriate in many cases. A telling example of issuing non-operational documents is the standard. The authors of this standard write that it was copied not even from foreign standards, but

from the documents of Western public organizations such as BREEAM, LEED, Code for Sustainable Homes, Living Building Challenge, Home Quality Mark, and Green Globes. This article proposes a unified methodology developed to enable comparative analysis of the environmental performance of any buildings and structures throughout all stages of its life cycle. Furthermore, the methodology allows for the assessment of environmental impact not only from gases defined as greenhouse gases, but also considering all harmful emissions into the atmosphere. As a specific outcome of the calculation, the environmental performance of a single stage can be determined, or an assessment can be made focusing only on specific gases. For example, assessing the environmental performance of the constructional material manufacturing stage will allow for evaluating the environmental impact of each material used in the construction, while calculations of CO_2, CH_4, and N_2O content let assess the greenhouse effect.

The results obtained from calculating the environmental performance of a construction project will incentivize the formulation of measures and proposals as well as their implementation in order to reduce environmental impact during the building operations.

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ASSESSMENT METHODOLOGY

1.1 Key Indicators

The main goal of the developed assessment method is to justify the need for modernization of the manufacture of materials, products, and structures in order to improve the environmental performance of manufacture processes throughout all stages of the building's life cycle. It also aims to conduct a comparative environmental analysis of technological measures implemented at the enterprise.

In the developed methodology, it is proposed to introduce a functional unit for assessing environmental impact, equal to the value of the maximum permissible single-exposure concentration (MPC) of carbon dioxide in the air of the work zone. The value of the maximum permissible single-exposure concentration in the air of the work zone was set on condition that there is no assessment of the maximum permissible concentration of CO_2 under other exposure conditions (e.g., average daily or average per work shift) using SanPiN [5].

Table 1 presents the results of the analysis of MPCs using SanPiN as per [5, Table 2.1]. It can be seen that the harmful effect of all gases on humans is much more significant than that of carbon dioxide, and for some, such as benzo(a)pyrene, this difference is 180 million times greater.

Table 1. Harmful emissions and conversion factors with account to the functional unit for assessing environmental impact

№	Gas	Maximum Permissible Single Exposure Concentration (MPC) in the Air of the Work Zone, mg/m^3	Position in table 2.1 [5]	Conversion Factor to Equivalent CO2 Quantity
1	Carbon Dioxide, CO_2	27000	2124	1,0
2	Carbon Monoxide, CO	20	2122	1350
3	Nitrogen Dioxide, NO_2	2	4	13500
4	Nitric Oxide, NO	5	5	5400
5	Ammonia, NH_3	20	178	1350
	Nitric Acid, HNO_3	2	7	13500
6	Sulfur Dioxide, SO_2	10	1837	2700

7	Inorganic Dust: 70-20% SiO_2			
8	Benzo(a)pyrene, $C_{20}H_{12}$	0,00015*	253	$1,8 \cdot 10^8$
9	Mixture of Saturated Hydrocarbons, CnHm	900	2120	30
10	Formaldehyde	0,05	2172	$5,4 \cdot 10^5$
11	Phenol	0,1	2171	$2,7 \cdot 10^5$

* average daily MPC per work shift

It is proposed that the carbon dioxide-equivalent amount of gas entering the atmosphere, considering the concept of the functional unit, be calculated by multiplying the mass of the emitted gas by the ratio of the MPC of CO_2 against the MPC of the emitted gas. The calculations use maximum permissible single-exposure concentrations in the air of the work zone, as this is the only mention of carbon dioxide in [5].

It should be noted that the indicator of the carbon dioxide-equivalent amount of gas differs significantly from the indicator defined in the normative documents for the carbon footprint as per ISO 14001:2004 11, where the carbon dioxide-equivalent amount of gas is determined by emissivity.

A carbon load factor (CLF) is introduced, equal to the ratio of pollutants (by mass) entering the atmosphere in the amount equivalent in hazard to the amount (by mass) of carbon dioxide at the stages of raw material extraction and transportation, construction materials manufacture, building operation and its disposal to the mass of the building materials [kg/kg]. Also, a building environmental performance indicator (BEPI) is introduced, defined against the amount of CO_2 equivalent the total mass of the materials used in construction to the volume of the building.

1.2 Calculation of Key Indicators and Values

The mass of pollutants entering the atmosphere in the amount equivalent in hazard to the carbon dioxide amount during the raw material extraction and transportation stage is calculated considering the electrical and thermal energy consumed by machinery and equipment during loading and transport of the raw materials to the manufacturing facility.

The mass of pollutants entering the atmosphere during the constructional materials manufacture stage in the amount equivalent in hazard to the amount of the carbon dioxide is calculated based on emissions of pollutants into the atmosphere during manufacture, as well as the electrical and thermal energy consumed when manufacturing the materials [15, 7].

The mass of pollutants entering the atmosphere during the building operations in the amount equivalent in hazard to the amount of CO_2 is calculated based on the electrical and thermal energy consumed directly on the construction site by machinery, equipment, and transport vehicles, including the transportation of constructional materials to the site and for everyday needs.

The mass of pollutants entering the atmosphere during the operational stage in the amount equivalent in hazard to the amount of CO2 is estimated based on the electrical and thermal energy consumed by building's dwellers over its entire operational period (design life), excluding urbanistic loads. In this case, the total heat loss of the building during the heating period, kWh/year, should be determined according to Appendix G SR 50.13330.

The mass of pollutants entering the atmosphere during the demolition and disposal stage in the amount equivalent in hazard to the amount of carbon dioxide is calculated considering the electrical and thermal energy consumed directly during demolition and disposal by machinery, equipment and transport vehicles, including the transportation of dismantled constructional materials for recycling and disposal.

Therefore, the impact on atmosphere at all stages of the life cycle can be expressed through fuel consumption, making the calculation universal. During the constructional materials manufacture, the environmental load determined by manufacture emissions is additionally assessed.

1.3 Calculation of emissions from the generation of thermal and electrical energy

When an enterprise consumes thermal and electrical energy, the emissions of pollutants are converted to the emissions from the combustion of natural gas at combined heat and power (CHP) plants and enterprise's boiler facilities. The specific heat of natural gas combustion is taken to be equal 8000 kCal/m3 (9.3 kW/m3, 33.5 MJ/m3) [16, 17]. The composition of natural gas is assumed to be 75% CH_4 and 25% H_2, with fuel combustion occurring at α = 1.05. The calculation is performed according to the methodology presented in [18]. These characteristics of natural gas are provided as being the most common to the majority of natural gas fuel consumed by CHP plants, but they can be modified and recalculated using the presented methodology.

The amount of natural gas consumed to generate electricity and heat at the enterprise is then calculated.

$$Vg = Q/8000 \text{ kCal}, \text{ m}^3 \quad (1)$$

The volume of combustion products is equal to:

$$V_{cmb.pr} = Vco_2+V_{O2excess}+V_{H2O}+V_{N2}, \text{ m}^3 \quad (2)$$

where Vco_2 is the volume of carbon dioxide entering the atmosphere with the combustion products $Vco_2 = 0.75Vg$, m^3 (3)

Then the mass of CO_2 with the exit gases is:

$$Mco_2 = Vco_2*44/22.4, \text{ kg} \quad (4)$$

V_{H2O} - the volume of water vapor entering the atmosphere with the combustion products:

From hydrogen combustion:

$$V_{H2O} = 0.25*Vg, \text{ m}^3 \quad (5)$$

From methane combustion:

$$V_{H2O} = 0.75*2*Vg, \text{ m}^3 \quad (6)$$

V_{N2} - the amount of nitrogen in the combustion products is derived from the volume of oxygen required for the combustion of methane and hydrogen:

$$V_{N2} = 2*0.75*Vg+0.25*Vg, \text{ m}^3 \quad (7)$$

$V_{O2excess}$ – the volume of excess oxygen in the combustion products. At α = 1.05, the following holds:

$$V_{O2excess} = Vo_2*(\alpha - 1), \text{ m}^3 \quad (8)$$

$$V_{N2} = Vo_2*79 / 21, \text{ m}^3 \quad (9)$$

Since the concentration of pollutants is determined in dry combustion products, we determine their volume, Vdg, considering (2), (5), and (6):

$$Vdg = Vco_2+Vo_{2excess}+V_{N2}, \text{ m}^3 \quad (10)$$

1.4 Calculation of Emissions for Diesel Engines

The calculation of emissions for diesel engines is based on the chemical composition of diesel fuel, which is assumed to be as follows: carbon 86,2%, hydrogen 12,8%, oxygen 1,0%. Fuel combustion occurs with an excess air coefficient of α = 1,10. The theoretical (stoichiometric) amount of air required for complete combustion of 1 kg of fuel is calculated according to [18].

1. The theoretical (stoichiometric) amount of air required for complete combustion of 1 kg of fuel is calculated using the formula:

$$Vo = Vmolar/0.21(C/12+H/2–O/32) =$$
$$= (22.4/0.21)*(0.862/12+0.128/2 – 0.01/32) =$$
$$=12.1 \text{ m}^3/\text{kg} \quad (11)$$

2. The volume of carbon dioxide in the combustion products is calculated as:

$$Vco_2 =22.4*C/12 = 22.4*0.862/12 = 1.61 \text{ m}^3/\text{kg} \quad (12)$$

Then, the mass of CO_2 emissions is:

$$Mco_2 = Vco_2 * 44 / 22.4 = 3.16 \text{ kg/kg} \quad (13)$$

3. The volume of oxygen and nitrogen in the combustion products is calculated as:

$$Vo_2 = 0.21*(\alpha - 1)*Vo = 0.21*(1.1 - 1)*12.1 = 0.254 \text{ m}^3/\text{kg} \quad (14)$$

$$V_{N2} = 0.79 *\alpha*Vo = 0.79 * 1.1 * 12.1 = 10.51 \text{ m}^3/\text{kg} \quad (15)$$

4. The volume of dry combustion products is:

$$Vdg = Vco_2+Vo_2+V_{N2}=1.61+0.254+10.51 = 12.374 \text{ m}^3/\text{kg} \quad (16)$$

The amount of emissions is calculated as the volume of dry gases multiplied by the concentration of the pollutant.

The concentration of pollutants in the combustion products of diesel fuel [19] and natural gas [20, 21] are taken from Table 2.

Table 2. Concentration of Pollutants in Combustion Products

№	Pollutant	Emission Concentration, mg/m³	
		From Diesel Fuel Combustion	From Natural Gas Combustion
1	Carbon Monoxide, CO	1250	300
2	Nitrogen Oxides on conversion to NO_2	200	125
3	Sulfur Dioxide, SO_2	28,6	--
4	Formaldehyde	13,4	--
5	Unsaturated hydrocarbons	67	--
7	Benzo(a)pyrene	0,0005	$2 \cdot 10^{-6}$
8	Carbon Dioxide (CO_2)	As per calculation	As per calculation

RESULTS AND DISCUSSION

The authors have conducted a survey calculating the environmental load for several enterprises using the developed methodology. This article presents an analysis of the survey results from the Rockwool mineral wool production plant in Zheleznodorozhny, Moscow Oblast. The first two stages of the life cycle are examined in detail: raw material extraction, transportation, and the manufacture stage itself. The production volume is 1,390,000 m³ or 98,000 tons of mineral wool per year. The plant has 42 emission sources. Electricity consumption is 126,777,532 kWh (2022-year data). On-site transportation is provided by 7 diesel-powered forklifts.

During the manufacture, a survey encompassed all 42 emission sources. At each sampling point, the diameter of the process pipeline, the gas velocity, and the gas temperature were recorded. When selecting a gas analyzer for analyzing harmful emissions in industrial gas samples and hydrocarbon fuel combustion products, it is important to consider their potential concentrations. For example, the concentration of carbon dioxide in combustion products is approximately 10%, while in process gases, it is often equal to the concentration in air, that is, 0,03% by volume. The concentration of NO_2 also varies from 150 – 350 mg/m³ in combustion products to 0,1 – 1 mg/m³ in urban air. A «Polar-7» portable multi-component gas analyzer (manufactured by Promekopribor LLC) was used to measure high concentrations, and a «Signal – 44» gas analyzer (manufactured by Gasoanalit LLC) to deal with low concentrations.

A summary of the survey and calculated emissions of harmful gases released into the environment during manufacture are shown in Table 3.

Diesel fuel consumption at the enterprise is 18,772 l or 14,435.7 kg, and electricity consumption is 126,777,532 kWh, which is equivalent to 13,631,993 m³ of natural gas.

The calculation of harmful substance emissions, converted to the equivalent hazard-weighted emission, is performed using equations (1) – (10) for natural gas and (11) – (16) for diesel fuel. The concentration of harmful gases in the emissions is taken from Table 2. The results of calculating harmful substance emissions from the operation of diesel transport and electricity

consumption at the manufacturing stage are shown in Table 4.

Table 3. Manufacturing emissions

№	Emission substances	Total emission in tons per year	% of general emission	Conversion factor	Amount of Gas Equivalent to Carbon Dioxide, tons/year	% of total emission
1	**2**	**3**		**4**	**5**	**6**
1	Nitrogen Dioxide	39,639	0,20	13500	535 126,5	15,3
2	Nitric Oxide	8,175	0,04	5400	44 145,0	1,26
3	Ammonia	53,837	0,27	1350	72 680,0	2,07
4	Sulfur Dioxide	7,078		2700	19 110,6	0,55
5	Inorganic Dust: 70-20% SiO_2	177,368	0,90	2700 (in SO_2 with account of 50%)	239 446,8	6,85
6	Carbon Monoxide	157,973	0,80	1350	213 263,6	6,10
7	Benzo[a]pyrene	$4,18*10^{-7}$		$1,8*10^{8}$	75,2	0,002
8	Mixture of Saturated Hydrocarbons	2,101		30	63,0	0,002
9	Formaldehyde	3,959	0,02	$5,4*10^{5}$	2 137 860,0	61,15
10	Phenol	0,795		$2,7*10^{5}$	214 650,0	6,14
11	Carbon Dioxide	19671,9	97,76	1	19 671,9	0,56
	Total				3 496 092,6	

Table 4. Calculation results concerning harmful substance emissions from diesel transport operation and electricity consumption during manufacture

№	Pollutant	Pollutant Emissions					
		Diesel vehicle operation			Electricity from CHP (Combined Heat and Power Plant)		
		Concentration, mg/m^3	Emission, tons	Equivalent emission, tons	Concentration, mg/m^3	Emission, tons	Equivalent emission, tons
1	Carbon Monoxide, CO	1250	0,22	297	300	30,35	40 972,5
2	Nitrogen Oxides, as NO_2	200	0,036	482,3	125	12,65	170 775,0
3	Sulfur Dioxide, SO_2	28,6	$5,1*10-3$	13,79	--		
4	Formaldehyde	13,4	$2,4*10^{-3}$	1296,0	--		
5	Unsaturated hydrocarbons	67	0,012	0,36	--		
7	Benzo[a]pyrene	0,0005	$0,09*10^{-6}$	16,1	$2\cdot10^{-6}$	$2,02*10^{-7}$	36,4
8	Carbon Dioxide CO_2	As per calculation 3,16 kg/kg of fuel	45,6	45,6	As per calculation 1,47 kg/m^3 of natural gas	20 039,0	20 039,0
	Total			2 151,15			231 822,9

During the raw material extraction and transportation stage for mineral wool production, according to the survey results, the plant receives per year up to 125000 tons of dolomite, bauxite, tuff, and blast furnace slag as raw materials, with an average transportation distance of 400 km.

The excavator's work rate is 20 m^3/h, and its fuel consumption is 30,0 L/h. The density of bauxite and dolomite can be assumed to be 3000 kg/m^3. The excavator loads 60 tons per hour onto transport vehicles; therefore, extracting and loading 125000 tons (calculated for bauxite and dolomite) will require 2083.3 hours of operation. The fuel consumption will be 62,500 L, or 48062,5 kg of diesel fuel.

Transportation is carried out by rail. The specific electricity consumption depends on the track profile, type of rolling stock, speed, weather conditions, etc. In freight traffic on flat terrain, it is 10–12 W-h/(ton-km), and on mountainous sections, it is 25–32 W-h/(ton-km). We will assume 15 W-h/(ton-km). Then, the electricity consumption for transporting 125 000 tons of raw materials to the distance of 400 km will be:

15 W-h/(ton-km) * 125000 t * 400 km = 750 000 kW-h, which corresponds to a calorific value of 80 645,2 m^3 of natural gas.

The calculation of pollutants' emissions, converted to the equivalent hazard-weighted emission, is performed using equations (1) – (10) for natural gas and (11) – (16) for diesel fuel. The concentration of harmful gases in the emissions is taken from Table 2. The results of calculating harmful substance emissions during the extraction and transportation stage, in the volume required for manufacture, are presented in Table 5.

Table 5. Calculation results for pollutants during the extraction and transportation stage

№	Pollutant	Pollutant emissions					
		Raw material extraction			Raw material transportation		
		Concentration, mg/m^3	Emission, tons	Equivalent emission, tons	Concentration, mg/m^3	Emission, tons	Equivalent emission, tons
1	Carbon Monoxide, CO	1250	0,74	1004,6	300	0,18	243,0
2	Nitrogen Oxides, as NO_2	200	0,12	1606,5	125	0,075	1009,94
3	Sulfur Dioxide, SO_2	28,6	0,017	45,9	--		
4	Formaldehyde	13,4	$8,0*10^{-3}$	4305,4	--		
5	Unsaturated hydrocarbons	67	0,04	1,20	--		
7	Benzo[a]pyrene	0,0005	$0,3*10^{-6}$	54,0	$2 \cdot 10^{-6}$	$1,61*10^{-8}$	0,22
8	Carbon Dioxide CO_2	As per calculation 3,16 kg/kg of fuel	151,88	151,88	As per calculation 1,47 kg/m^3 of natural gas	118,55	118,55
	Total			7 169,48			1 371,71

The total emission of pollutants during the extraction, transportation, and manufacture stage is presented in Table 6.

Table 6. Total emission of pollutants during the extraction, transportation, and manufacture stages

№	Source of emission	Equivalent emission, tons/year
1	**Extraction and transportation stage** (Table 5)	8 541,19
1.1	Extraction	7 169,48
1.2	Transportation	1 371,71
2	**Manufacture stage**	
1	Release of toxic gases from manufacturing process (Table 3)	3 496 092,6
2	Harmful gas emissions from enterprise's vehicles (Table 4)	2 151,15
3	Harmful gas emissions from electricity/power generation (Section 4)	231 822,9
	Total	3 730 066,65

Considering the production volume of 1 390 000 m³/year or 98.0 tons/year, the Carbon Footprint Coefficient (CFC) will be 3 730 066.65 / 98 000 = 38,06.

The analysis of the survey results and the proposed calculation methods allows us to draw several important conclusions:

1. If the enterprise's emissions are assessed solely by the mass of harmful gases released into the atmosphere, carbon dioxide emissions significantly outweigh the emissions of other gases. For example, according to Table 3, which assesses the technological emissions from mineral wool production, carbon dioxide emissions account for 97,76% by mass. However, when considering the same production process against the amount of gas equivalent in hazard to the amount of carbon dioxide the carbon dioxide emission only accounts for 0,56%. In this case, the highest value, equal to 61,15%, belongs to formaldehyde emissions – an aliphatic aldehyde of methanol and formic acid, which is a colorless gas with a pungent odor. This approach, defined by the developed calculation method, leads to the conclusion that, to reduce atmospheric pollution, it is primarily necessary to reduce the formaldehyde content in the enterprise's emissions. In [22], it was shown that a technological solution could be the afterburning of formaldehyde by directing it to the burners of the production boiler plant.
2. The developed method provides the opportunity to assess the environmental burden on the atmosphere at each stage of the life cycle, as well as for different functional production processes within a single stage. Table 6 shows that the extraction and transportation of raw materials contributes only 0,23% of the pollution released into the atmosphere across the two stages: extraction - transportation, and the production of mineral wool. Within the production stage, according to Table 6, it can be estimated that the enterprise's diesel motor transport emits only 0,06% of the total hazard-equivalent mass of emissions, while the generation of electricity/power sourced externally by the enterprise accounts for 6,6%.
3. The method allows, if necessary, for the estimation of greenhouse gas emissions alone. Furthermore, a comparison of the results for carbon dioxide emissions, according to the developed methodology and that one approved by Order No. 15-r issued by the Ministry of Natural Resources and Ecology of the Russian Federation dated April 16, 2015 [20], shows complete correlation. However, the developed methodology provides an opportunity to assess carbon dioxide emissions more accurately, taking into account the chemical composition of the fuel consumed.
4. Calculation of the Carbon Footprint Coefficient (CFC) using the developed methodology allows to determine the environmental performance of constructional materials and life cycle stages as objectively as possible.

CONCLUSION

The proposed methodology gives a more accurate account of the environmental burden throughout all stages of the buildings and structures' life cycle due to calculation of emissions of all harmful gases released into the atmosphere. The method is based on the introduction of a functional unit for assessing environmental impact, equal to the maximum permissible concentration (MPC) of carbon dioxide in the air of the work zone at a single exposure. This makes it possible to compare emission quantities at each stage, as well as to identify the most environmentally sensitive areas at each stage of manufacture. Of great importance in the presented methodology is its simplicity and illustrative nature.

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Zheldakov Dmitry Yuryevich - PhD in Engineering, Leading Researcher, Lab. #12, NIISF RAASN, Lokomotivny proezd, 21. Moscow, Russia. djeld@mail.ru

Erofeev Vladimir Trofimovich - Doctor of Engineering, Professor, Professor of the Department of Construction Materials Science, National Research Moscow State University of Civil Engineering, 129337, Yaroslavskoe sh., 26, Moscow, Russia. erofeevvt@bk.ru

Skolubovich Yury Leonidovich - Doctor of Engineering, Professor, Rector of NGASU (Sibstrin), Leningradskaya str., 113, Novosibirsk, Russia. rector@sibstrin.ru

Pakhomov Sergey Ivanovich - Doctor of Chemical Sciences, Professor. Head of the Department for Support of the Organization of State Scientific Certification of the Russian Academy of Sciences, 119334, Leninsky Prospekt, 32A, Moscow, Russia. Sipakhomov@pran.ru

Meshalkin Valery Pavlovich - Doctor of Technical Sciences, Academician of the Russian Academy of Sciences, Director of the International Institute of Resource-Saving Logistics and Technological Innovation (REC), D.I. Mendeleyev University of Chemical Technology of Russia. 125047, Miusskaya Square, 9, Moscow, Russia. vpmeshalkin@gmail.com

Stepina Irina Vasilievna - Candidate of Technical Sciences, Associate Professor, Associate Professor of the Department of Construction Materials Science of the National Research Moscow State University of Civil Engineering, 129337, Yaroslavskoe Highway, 26, Moscow, Russia. sudeykina@mail.ru

Желдаков Дмитрий Юрьевич - кандидат технических наук, ведущий научный сотрудник лаб. #12 НИИСФ РААСН, Локомотивный проезд, д.21. Москва, Россия. djeld@mail.ru

Ерофеев Владимир Трофимович – доктор технических наук, профессор, профессор кафедры строительного материаловедения Национального исследовательского Московского государственного строительного университета, 129337, Ярославское ш., 26, Москва, Россия. erofeevvt@bk.ru

Сколубович Юрий Леонидович - доктор технических наук, профессор, ректор НГАСУ (Сибстрин), ул. Ленинградская, 113, г. Новосибирск, Россия. rector@sibstrin.ru

Пахомов Сергей Иванович - доктор химических наук, проф. начальник управления сопровождения организации государственной научной аттестации РАН, 119334, Ленинский пр., д 32А, Москва, Россия. Sipakhomov@pran.ru

Мешалкин Валерий Павлович - доктор технических наук, академик РАН, директор международного института логистики ресурсосбережения и технологической инноватики (НОЦ), Российский химико-технологический университет имени Д.И. Менделеева. 125047, Миусская площадь д. 9, г. Москва, Россия. vpmeshalkin@gmail.com

Степина Ирина Васильевна – кандидат технических наук, доцент, доцент кафедры строительного материаловедения Национального исследовательского Московского государственного строительного университета, 129337, Ярославское ш., 26, Москва, Россия. sudeykina@mail.ru