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Зміст

REPAIR AND STRENGTHENING OF CONCRETE AND REINFORCED CONCRETE STRUCTURES USING ECOLOGICAL CONCRETE AND MORTAR

Azizova Anna Genadiyevna
National University «Yuri Kondratyuk Poltava Polytechnic»,
galinskata@ukr.net

Due to the long-term operation of buildings and structures, reinforced concrete and concrete structures undergo physical wear and tear and over time require repair, modernization and strengthening.

Table 1

Requirements for the performance characteristics of cement-based materials (products) according to DSTU EN 1504-3:2022 [3], which are intended for structural and non-structural repairs

Name of the performance characteristic	Testing method	The meaning of the requirement			
		structurally		not structurally	
		Classes			
		R4	R3	R2	R1
Compressive strength, МПа	EN 12190	≥45	≥25	≥15	≥10
Bond strength to concrete, МПа	EN 1542	≥2	≥1,5	≥0,8	≥0,8
Modulus of elasticity, ГПа	EN 13412	≥20	≥15	HR	HR
Freeze/thaw cycle compatibility. Adhesion after 50 cycles	EN 12617-4	≥2	≥1,5	≥0,8	IV
Carbonation resistance, depth (d_k)	EN 13295	d_k < control concrete			
Thermal shock resistance in dry state. Adhesion after 30 cycles	EN 12617-4	≥2	≥1,5	≥0,8	IV
Resistance to thermal shock (storm rain). Adhesion after 30 cycles	EN 12617-4	≥2	≥1,5	≥0,8	HR
Capillary sorption (capillary transfer coefficient), кг/м^2.ч-^{0,5}	EN 13057	≤0,5		≤0,5	HR
Chloride content, % by weight	EN 1015-17	≤0,05			
Note: HR – has no requirements; IV –visual inspection					

As scientists note in [1], extending the service life of concrete and reinforced concrete structures through their repair and strengthening will reduce harmful emissions associated with their manufacture and construction and improve the ecological condition of the area. One of the methods of strengthening concrete and reinforced concrete structures and elements is the method of strengthening them by increasing their cross-section, which consists in restoring or increasing their bearing capacity by building up an additional layer of concrete or mortar on the outside and increasing the cross-sectional size of the initial components of their reinforcement. The advantage of this method is that after its application, the rigidity, bearing capacity and deformability of structures (elements) are restored or increased, and their operational reliability is also increased. This method is widely used for the repair and reinforcement of reinforced concrete columns, beam and slab structures. An additional layer of strengthening made of concrete or mortar is arranged in the tension zone of the cross-section, performing a protective function for the bars of the working reinforcement, or it can be located in the compression zone of the cross-section of the structure (element), increasing its effective height, thereby improving its bending and shear bearing capacity, increasing its stiffness.

For effective restoration of concrete and reinforced concrete layers, the repair compound must have high adhesion to the restored concrete of the structure, have similar physicochemical parameters to it: minimal shrinkage, low water-cement ratio, and be suitable for easy installation [2]. The performance characteristics of cement-based materials and products used for repair (non-structural repair) and strengthening (structural repair) of concrete and reinforced concrete structures must meet the requirements applicable to them according to the standards DSTU EN 1504-3:2022 [3] (see Table 1). Class R4 includes materials used for the repair and strengthening of main load-bearing structures, and class R3 includes materials for the repair of enclosing and self-supporting structures.

In scientific works [4, 5], studies were conducted on the use of solutions with components of waste from plastic and glass in the restoration of the protective layer of concrete structures. The use of polymer ecological mortars and concrete for repairing the protective layer of concrete and strengthening reinforced concrete structures is not currently widespread, so it is necessary to carry out further scientific research in this direction.

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EVALUATION OF THERMAL INSULATION EFFICIENCY OF A BUILDING WALL BY CALCULATION METHOD

***Krasnianskyi Grygorii* [1], *Gusev Viktor* [2], *Aznaurian Iryna*[1], *Besarab Oleg* [1], *Yurii Pohrebniak*[1]**

[1]*Kyiv National University of Construction and Architecture,*
[2]*Kherson State Maritime Academy,*
krasnianskyi.giu@knuba.edu.ua, aznaurian.io@knuba.edu.ua, besarab.om@knuba.edu.ua

Ensuring high energy efficiency in buildings is the subject of the European Union-wide directive EU 2018/844 [1]. It includes mandatory energy efficiency standards and long-term building renovation strategies.

To design a building's thermal insulation, it is necessary to first assess its necessary and sufficient efficiency. This is advisable to do using calculation methods, based on the fundamental heat transfer ratios and thermophysical characteristics of building, cladding and thermal insulation materials.

Let us estimate the temperature of the outer surface of the wall of the building and the heat loss through the wall, which is covered with a layer of heat-insulating material. We will consider a one-dimensional problem, i.e., assume that heat is transferred perpendicular to the wall surface, and isotherms are planes parallel to it. In a first approximation, we will neglect the direct influence of solar radiation. In addition, we will assume that the conditions outside and inside the building, in particular, the temperature and direction of the air, do not change over time, i.e., the heat transfer is steady.

The density of heat flow rate through the wall can be calculated according to Newton's law of cooling:

$$q = U\,(t_i - t_e), \qquad (1)$$

where t_e i t_i – air temperatures outside and inside the room; U – thermal transmittance of a wall is the inverse of its total thermal resistance R_t:

$$U = \frac{1}{R_t}. \qquad (2)$$

To estimate R_t it is necessary to take into account that heat exchange between the internal and external air occurs through radiation, convection and thermal conductivity. Heat is transferred from the air inside the room to the inner surface of the wall due to radiation and convection, from the inner surface of the wall to the outer surface of the thermal insulation layer – due to thermal conductivity, from the outer surface of the thermal insulation layer to the external air – through radiation and convection.

As a result, the total thermal resistance consists of the thermal resistances of the inner and outer surfaces of the wall – R_{si} i R_{se}, respectively, and thermal resistances of wall and heat insulator materials - R_1 and R_2:

$$R_t = R_{si} + R_1 + R_2 + R_{se}. \qquad (3)$$

And

$$\frac{1}{R_{si}} = \frac{1}{R_{ci}} + \frac{1}{R_{ri}}, \quad \frac{1}{R_{se}} = \frac{1}{R_{ce}} + \frac{1}{R_{re}}, \qquad (4)$$

where R_{ci} i R_{ce} – thermal resistances associated with convection, R_{ri} i R_{re} – thermal resistances associated with radiation. (4) takes into account that in the electrical equivalent circuit, the resistances that are due to convection and radiation are connected in parallel. The values R_{si} i R_{se}, thus, must depend on the emissivity of surfaces, the type of convection, and the speed and direction of the wind.

Their calculation is a complex thermophysical problem. For estimation, typical numerical values for most application problems, which are given in ISO 6946:2017 [2], can be used.

The values of the resistances R_1 i R_2 according to Fourier's law for thermal conductivity can be calculated using the formulas:

$$R_1 = \frac{d_1}{\lambda_1}, \qquad R_2 = \frac{d_2}{\lambda_2}, \qquad (5)$$

where d_1 i d_1 – wall and thermal insulator thickness, λ_1 i λ_2 – thermal conductivity of the corresponding materials.

Temperature of the outer surface of the thermal insulation layer (t_{se}) differs from the outside air temperature. The density of heat flow rate in the air layer outside, which in this approximation is equal to the heat loss of the wall, can be determined by a formula similar to (1):

$$q = \frac{t_{se} - t_e}{R_{se}}. \qquad (6)$$

It follows from this:

$$t_{se} = t_e + R_{se} q. \qquad (7)$$

After substituting in (7) the value of q from (1), with adjustments (2), for the temperature of the external surface of the insulated wall it will be possible to calculate:

$$t_{se} = t_e + R_{se} \frac{1}{R_t} (t_i - t_e). \qquad (8)$$

Thus, the heat loss can be estimated based on (6) using the measured value of the temperature of the outer wall surface and the known value of the ambient air temperature. The temperature of the outer surface of the wall can be estimated using (8) from known values of the air temperature outside and inside the room, the thicknesses and thermal conductivities of the wall materials and the thermal insulator.

For the thermal resistance values of the external and internal surfaces of the wall, which are required for calculations, typical values according to ISO 6946:2017 can be used. For example, in the case of horizontal heat flow R_{se} = 0,04 ($m^2 \times K$)/W, R_{si} = 0,13 ($m^2 \times K$)/W.

So far, we have neglected the influence of solar radiation, the density of heat flow rate of which, when the Sun is at its zenith, is about 1000 W/m^2. In winter, the higher temperature of the building wall, heated by solar radiation, increases the temperature difference between the outer surface of the wall and the atmospheric air and, as a result, the density of heat flow rate from the wall to the external environment. Conversely, due to solar heat gain, the temperature difference between the internal air and the inner surface of the wall decreases and the corresponding density of the density of heat flow rate from the internal environment to the wall decreases. This can be considered as the occurrence of additional heat flows to the external and internal environments, respectively. Both are a consequence of the absorbed solar energy. Therefore, the heat flow caused by solar radiation has two components, and both must be taken into account in accurate calculations.

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INTEGRATED MODEL OF SPATIAL DEVELOPMENT PLANNING OF UNITED TERRITORIAL COMMUNITIES TAKING INTO ACCOUNT THE NATURAL POTENTIAL OF THE TERRITORY

Olga Bakun, Dmytro Prusov

Institute of Innovative Education of the Kyiv National University of Construction and Architecture,

onayko@gmail.com, dmytro.prusov@iino.in.ua

The development of an integrated spatial development planning model for united territorial communities (UTC) is aimed at creating territorial planning prerequisites for ensuring sustainable development of the community territory, taking into account the natural potential of the territory.

The research focused on developing a comprehensive, adaptive, and scientifically sound model for the spatial development of united territorial communities in Ukraine. The proposed model integrates the best European practices of sustainable development, principles of sustainable territorial development, and innovative approaches to territorial planning.

The model is based on an analysis of the planning directions of the united territorial community, the regulatory and legal framework, the legislative framework [1-6], the natural potential of the territory (assessment of natural resources, ecological state, recreational opportunities, risks of natural disasters); engineering preparation and protection of the territory (analysis of the existing engineering infrastructure, the need for its development, measures to protect against dangerous natural and man-made phenomena). On this basis, strategic planning of the territory has been developed, namely the development concept (definition of strategic goals, priorities and directions of sustainable development of the community in the long term); the concept of functional and planning development of the territorial community (definition of functional zoning of the territory, planning of the location of the main types of activities, infrastructure facilities); and operational planning and a set of measures for the implementation of decisions have been proposed.

In particular, the model provides for the application of sustainable development principles (energy efficiency, biodiversity conservation, sustainable use of resources), as well as the use of digital technologies and geographic information systems (GIS) in planning, and mechanisms for intermunicipal cooperation and cross-border planning.

The scientific novelty lies in the creation of a holistic integrated model of spatial development of UTCs, which combines the principles of sustainable development and European planning practices in the context of Ukrainian realities, taking into account the natural potential of the territory, and a comprehensive assessment of UTC territories using indicators of sustainable development and inclusion adapted to the local level.

The practical significance lies in the implementation of the developed model of spatial development planning of united territorial communities, taking into account the natural potential of the territory, for the development of effective strategies and plans for spatial development of united territorial communities in Ukraine. The proposed tools and recommendations will contribute to a more balanced, sustainable development of territories, improving the quality of life of the population and efficient use of resources.

In addition, the developed principles can be used for training and advanced training of specialists in the field of spatial planning and local self-government.

The integrated model is built on the following principles: conducting an analysis of the existing use of the territory and determining the preferred directions of its development; taking into account the design decisions of the higher-level urban planning documentation regarding the planning and use of the territory of the community, based on the requirements of urban planning, sanitary, environmental, environmental protection, fire protection and other legislation; substantiating the needs in the territories for development and other use, as well as determining the preferred directions of their use; ensuring rational settlement and determining the directions of sustainable development of settlements; creating prerequisites for stabilizing socio-economic development with diversification of the economic base and ensuring the appropriate level of service provision in preschool and school education, primary medicine and emergency care, housing and communal services, fire protection and social protection; identification of territories of special ecological, recreational and health, scientific, aesthetic, historical and cultural value, establishment of restrictions stipulated by law on their planning [6], development and other use, development of urban planning measures for their protection and rational use; ensuring further development of engineering and transport infrastructure of the community territory; development of measures for environmental protection and rational use of natural resources, preservation of especially valuable lands, forests and the integrity of land reclamation systems; development of measures for civil protection, fire and technogenic safety.

When developing and implementing an integrated spatial development planning model for united territorial communities, the natural potential of the territory was taken into account, namely natural, geographical and engineering and construction features; climate, geological structure, soil cover, hydrological conditions and water fund lands, nature reserve fund, flora and fauna, engineering and construction assessment of the territory, sanitary, epidemiological and ecological state of the territory: atmospheric air, water basin, soil condition, radiation state, electromagnetic pollution, acoustic regime, etc.

Accordingly, planning restrictions have been developed to comply with the requirements of sanitary, environmental and environmental legislation [3,4] while taking into account state, public and private interests during planning, development and other use of territories, so the model includes the main planning restrictions, including: sanitary protection zones from various objects, planning restrictions of environmental significance, which are represented by a system of coastal protection strips and objects of the nature reserve fund, coastal protection strips for rivers, lakes and ponds, territories of the nature reserve fund included in the state register, etc.

Based on the proposed integrated spatial development planning model, a soil cover scheme, a scheme of hydrographic conditions, a scheme of planning restrictions, engineering preparation and protection of the territory, a scheme of engineering preparation and protection of the territory, and relevant recommendations for further implementation were developed.

As a result of the implementation of the developed integrated model, a Concept of functional and planning development of a territorial community was proposed, taking into account the natural potential of the territory: natural resources, ecological state, recreational opportunities, and risks of natural disasters.

Thus, the development of a comprehensive, adaptive, scientifically based and practically oriented model of integrated spatial development of united territorial communities of Ukraine, taking into account the natural potential of the territory, contributes to the comprehensive development of territories, the creation of territorial planning prerequisites for ensuring the sustainable development of the community territory, taking into account public, state, public and private interests.

The results of the work will become a scientific basis for the development of effective strategies and plans for the spatial development of united territorial communities in Ukraine; the proposed tools and recommendations will contribute to a more balanced sustainable development of territories, improving the quality of life of the population, and the effective use of natural resources.

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IMPROVEMENT OF ENERGY AND ENVIRONMENTAL CHARACTERISTICS OF BOILER HOUSES OF MUNICIPAL ENTERPRISES ON BIOFUELS

Mykola Beliuzhenko[1], Mykhailo Senchuk[2]

[1,2] Kyiv National University of Construction and Architecture,

[1] n.beliuzhenko@gmail.com, [2] smp_21@ukr.net

In Ukraine, there is a growing trend in energy production from alternative fuels, particularly biomass. Overall, during 2022–2023, over 650 MW of new renewable energy capacity was commissioned in Ukraine, including 50 MW from bioenergy facilities (biomass and biogas). Considering the resource potential up to 2050, there are promising prospects for expanding the capacities of CHP plants and bioenergy installations to up to 18 GW [1,2].

An important task for the development of bioenergy is to ensure the reliability of the heating service system, enhance Ukraine's energy independence and security, and increase the share of alternative energy sources in heat production to 40% by 2035 [3].

This study is particularly relevant for Ukraine, as most municipal facilities currently exhibit low efficiency and unsatisfactory environmental performance.

All known measures to improve the energy and environmental characteristics of boiler power plants can be divided into two groups:

1. Implementation of flue gas cleaning systems and deep heat recovery technologies;

2. Development of combustion technologies aimed improving the burning of organic fuels.

Currently, the practice of recovering heat from the flue gases of heat-generating units is widely adopted in the Baltic, Scandinavian, and other European countries. Numerous studies focus on the design, development, and industrial application of high-efficiency recovery systems and condensing boilers [4, 5]. Research indicates that deep flue gas recovery systems, particularly condensing economizers, not only contribute to thermal energy savings but also function as air pollution control equipment, reducing greenhouse gas and particulate emissions. They are especially effective in removing fine — few micron — dust particles and sulfur dioxide.

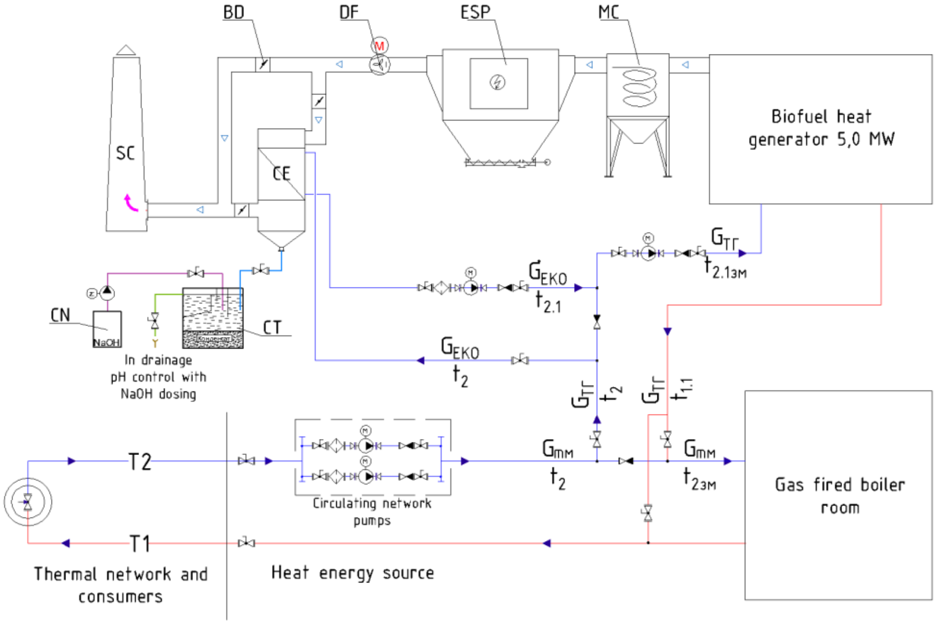

Fig. 1. Schematic diagram of connecting a condensing economizer into the existing district heating system with a backup biomass heat source:
T1, T2 – supply and return pipelines of the district heating network; MC – multicyclone; EF – electrostatic precipitator; CE – condensing economizer; DF – induced draft fan; BD – bypass flue duct; SC – stack chimney; CT – condensate tank; CN – condensate neutralization system.

In centralized heating systems, it is advisable to use the return heat carrier of district heating networks for deep heat recovery, as its temperature varies according to the network's operating temperature schedule. However, high-temperature schedules limit the effectiveness of such recovery systems, as the return water temperature may be not low enough to enable condensation of water vapor in the flue gases. This reduces heat recovery potential and the efficiency of condensing economizers, which strongly depends on the cold water inlet temperature. Lower inlet water temperatures allow for more effective condensation and optimal use of this technology. This can be achieved by modernizing the heating networks and implementing low-temperature heating systems. Figure 1 presents the proposed connection scheme of a condensing economizer to the return pipeline of the district heating network in the modernized heating system of the city of Lutsk [4].

With the prospective integration of a condensing economizer utilizing the heat of flue gases into a district heating system with a combined boiler power plant, it is possible to achieve natural gas savings of up to 16% during the heating season and biomass savings of up to 25% during the non-heating period.

At the same time, improving the efficiency of renewable fuel use — such as wood, biomass, including industrial and agricultural waste, and locally available fuels — in municipal heat generators requires the application of advanced combustion technologies. A major challenge in the long-term operation of solid fuel heat generators is fouling of heat exchange surfaces, which leads to a reduction in the thermal efficiency coefficient (ψ) — defined as the ratio of the heat transfer coefficients of fouled versus clean heat exchange surfaces. This fouling not only reduces thermal efficiency but also degrades environmental performance, cost-effectiveness, reliability, and operational flexibility of heat generators. Addressing this issue requires in-depth scientific research.

According to studies on the condition of heat exchange surfaces in heat generators up to 1 MW capacity, operating on chopped wood at municipal boiler power plants, the authors identified high rates of fouling on convective surfaces. Fouling is especially severe when burning local fuels, particularly wood waste with high ash content. As the mass of fly ash in flue gases increases proportionally with the quality and ash content of the fuel, the use of biomass — often driven by shortages and rising costs of high-quality fuels — significantly increases surface fouling during continuous operation.

Therefore, a crucial step in improving the energy and environmental performance of solid fuel heat generators is to ensure the stability of heat exchange surface conditions during continuous operation under variable heat loads.

Key strategies to address this issue include [6, 7]:

▪ Improving the combustion process through the rational application of combustion technologies, particularly mechanized systems tailored to fuel properties and furnace operation modes;

▪ Implementing a combined combustion process that intensifies the removal of solid combustion products while ensuring high burnout efficiency at the entrance to the convective heat exchange zone;

▪ Mechanical cleaning of heat exchange surfaces during operation.

A combined combustion process scheme involves the integration of multiple combustion stages within a solid fuel heat generator — combustion in a bed, within the furnace chamber volume, and in a secondary ash-settling chamber or in a vortex flow within a cylindrical combustion chamber. This design enhances the cleaning of combustion products. Ash particles are captured at the entrance to the convective heat exchange zone, significantly reducing fouling intensity and thus improving the thermal efficiency of the heat exchange process. Under the combined combustion scheme, the calculated average increase in the heat generator's efficiency at nominal load is nearly 8% compared to a single-chamber combustion system and 4% compared to systems with combustion and ash-settling chambers. This approach meets European energy and environmental standards [8] and enables the effective use of low-cost, locally sourced fuels.

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SOME ASPECTS OF ASSESSING THE EFFECTIVENESS OF FIRE PROTECTION OF BUILDING MATERIALS

Tsapko Yuriy Volodymyrovych[1], Bondarenko Olga Petrivna[1], Tsapko Oleksiy Yuriyovych[1], Kaverin Konstantin Oleksandrovych[1], Yushchenko Alina Vitaliyivna[1]

[1]Kyiv National University of Construction and Architecture, juriyts@ukr.net, bondolya3@gmail.com, alekseytsapko@gmail.com, 1krik.1k1@gmail.com, alinka29yushchenko@gmail.com

The use of highly combustible and flammable materials in construction is one of the main areas of fire prevention, so taking measures to reduce the use of such materials can reduce the risk of fire. Reducing the flammability of wood is achieved through the use of fire retardant coatings applied to the surfaces of structures and materials from which it is made. However, fabrics (curtains, curtains, curtains) are widely used for interior decoration, but due to their increased flammability, such materials are considered fire hazardous [1]. Flame retardant treatment has a significant impact on flame spread, significantly reducing smoke generation and heat generation. In addition, paper and its products are widely used for packaging various materials, including combustibles. The fire protection of such paper eliminates the possibility of fire from low-calorie ignition sources. There is no information available on regulatory documents containing methods and means of fire protection of paper, which is why some companies developing regulatory documents for paper packaging for solid combustible materials try to avoid fire and biological treatment.

It should be noted that the rate of heat release during the combustion of materials affects fire hazard indicators. Flame propagation during the combustion of natural and synthetic materials is a factor that determines the intensity and dynamics of fire development and depends on the effectiveness of fire protection and the mass burnout rate of samples in the process of flame combustion. To determine the characteristics of the heat release of materials during their combustion, an equation is used that relates the rate of heat release during the combustion of a material to the mass burning rate and the lower heat of combustion [2]:

$$Q = \eta \cdot \upsilon \cdot Q_H \ , \qquad (1)$$

where η – is the completeness of combustion of volatile decomposition products in the flame;

υ – is the mass burning rate of the material, kg/(m^2·s);

$Q_н$ – is the lower heat of combustion of the material, kJ/kg.

As a result of fire protection treatment, the possibility of cellulosic materials igniting from low-calorie ignition sources is eliminated, and smoke generation and heat generation are reduced, as well as toxicity.

Standard methods are used to evaluate the combustion characteristics of textile materials used to make curtains, curtains, decorations, awnings, tents, and other products that are used in a vertical position [3], as well as to determine the flammability group of wood [4]. The disadvantage of these methods is that they do not allow determining the effectiveness of fire protection of materials and are used to assess the characteristics of combustion of materials under the influence of flame in controlled laboratory conditions and cannot be used to determine or regulate the fire hazard of materials in a real fire. One way to determine the fire protection effectiveness is to calculate the mass burn rate of the sample after the flammability test and determine the flammability group of the sample, the mass loss of the sample, and the area of its damage using the formula:

$$\upsilon = \frac{\Delta m}{\tau \cdot S} \ , \qquad (2)$$

where Δm – is the mass loss of the sample after testing;
τ – is the test time;
S – is the area of damage to the sample.

A study of the characteristics of fabric combustion [3], which are given in Table 1, was carried out and it was found that in a short period of time, the untreated fabric samples were completely burned. However, for the fabric samples treated with the flame retardant coating, the absence of residual flame burning, material burnout, and the spread of surface flare was found. The calculated mass burnout rate of the samples after the tests for the flame-retardant samples decreased by half.

Table 1

Mass burnout rate of samples after the tests

Specimen material	Mass loss, Δm, g	Test time, τ, s	Specimen damage area, S, m^2	Mass burnout rate of the specimen, υ, kg/(m^2·s)
Cotton fabric: – untreated – fireproofed	 3,55 0,13	 41,6 15	 0,000659 0,000135	 0,129 0,064
Wood – untreated – fireproofed	 79,8 125,1	 300 300	 0,030 0,023	 0,174 0,048

To determine the flammability group of wood protected by the coating, experimental studies were conducted in accordance with [4], which showed a threefold reduction in the mass loss of samples compared to untreated ones, and the mass burnout rate of wood samples was calculated, which is 0.048 for treated samples and 0.174 for untreated samples. It was found that the burnout rate of wood samples treated with fire retardants (compared to untreated ones) decreases by 3.6 times.

The highest and lowest calorific values for cotton fabric and the surface layer of fire-protected pine wood, as well as untreated samples, were determined (Table 2) in accordance with [5].

Table 2

Higher and lower calorific value of cotton fabric and wood

Material	**Calorific value, kJ/kg**		**Heat release rate, kJ/(m^2·s)**
	higher	**lower**	
fireproof pine wood	16751	15360	759,2
pine wood	18635	17000	2514,3
fireproof cotton fabric	15302	13956	626,7
cotton fabric	16240	14893	1633,0

According to Equation (1), the rate of heat release during the combustion of materials was calculated at η = 0.85. It was found that during the combustion of treated samples of cotton fabric and wood, it decreases by 2.3...4.5 times (compared to untreated samples).

Thus, the calculation of the rate of heat release during the combustion of cellulose-containing materials is one of the ways to assess the effectiveness of their fire protection.

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EFFICIENT AND RATIONAL USE OF DOMESTIC AGRICULTURAL LAND: CURRENT REALITIES AND FUTURE PROSPECTS

Petro Borovyk[1], Yurii Kyseliov[1], Roman Rudyi[1], Oleh Ivanchuk[1], Iryna Udovenko[1], Mykhailo Shemiakin[1], Nataliia Prokopenko[1]

[1]Uman National University, borovikpm@gmail.com

The rational use of agricultural land plays a crucial role in ensuring food security, preserving ecosystems, and advancing the development of the agrarian sector of the economy. At the same time, in the context of climate change, intensive land use, and increasing anthropogenic pressure on agricultural land resources, there is a growing need to improve land management approaches.

This is particularly relevant for Ukraine, which, despite possessing significant potential in the form of fertile soils especially black earth faces numerous challenges, including soil degradation, an inefficient land reclamation system, and insufficient environmental sustainability in agricultural production.

It is well know that agricultural land constitutes over 70 % of Ukraine’s territory, with arable land accounting for approximately 82 % of all agricultural land.

This degree of ploughing is among the highest in the world and indicates an excessive agricultural production load on land assets and soil resources [1].

Furthermore, the lack of adherence to scientifically based crop rotations, overreliance on mineral fertilizers, and limited use of organic inputs contribute to ongoing losses in soil fertility.

According to data from a specialized research institute, the humus content in Ukrainian soils continues to decline annually, and over 13 million hectares of agricultural land have already been affect by varying degrees of erosion [2].

Additionally, the current condition of Ukraine’s irrigation infrastructure is critical, with over 70% of the systems requiring major repairs [3].

In the southern regions-where precipitation deficits have not only become a consistent trend but have significantly worsened due to the destruction of the Kakhovka Hydroelectric Power Plant and Reservoir by Russian forces productive agriculture is nearly impossible without artificial irrigation.

The effectiveness of agricultural production directly depends on the use of innovative agricultural technologies, soil quality, and sound legal regulation of agribusiness. For instance, the implementation of precision farming technologies, satellite monitoring and remote sensing of land and crops allows for the optimization of land resource use [4].

The degradation of agricultural land has compelled farmers to adopt soil restoration measures, including biological farming practices, forest and water reclamation, and erosion control initiatives to prevent both water and wind erosion [5].

Moreover, the development of the land market has intensified risks of monopolization and loss of control over the designated use of agricultural lands, highlighting the urgent need for improved regulatory mechanisms governing land use and transactions in a market environment [6].

Given these factors, the optimization of agricultural land use must be bas on an integrated approach that balances economic efficiency with environmental priorities. Specifically, minimal tillage technologies, the use of cover crops, and the application of biological pest control methods should be promoter to preserve soil fertility and enhance biological activity in soils [7].

To improve land management, enhance transparency, prevent violations, and support spatial planning, it is essential to digitalize land accounting and develop a nationwide geospatial data system [8].

Furthermore, state support for organic farming remains highly relevant. Despite favorable conditions, the share of organic agriculture in Ukraine remains low.

Support measures such as preferential taxation and lending, subsidies, and free certification could significantly improve the situation [9].

It is widely acknowledged that the destruction of the Kakhovka Reservoir by Russian forces was a major ecological and agricultural catastrophe for large parts of Ukraine. This event severely affected the environmental condition of vast areas and destabilized agricultural production [10].

Consequently, government programs aimed at restoring irrigation particularly in the Kherson, Mykolaiv, and Odesa regions can play a crucial role in stabilizing crop yields and reducing climate-related risks [11].

Scientific and educational support is a key factor in optimizing the use of domestic agricultural land resources.

Enhancing educational services, modernizing the agricultural education system, developing advisory services, and investing in applied research will aid farmers in adapting to contemporary challenges.

In conclusion, the study revealed that a range of systemic issues that significantly reduce its efficiency and threaten the long-term ecological and economic sustainability of the agricultural sector characterizes the current system of agricultural land use in Ukraine.

Among the key shortcomings identified are:

- Excessive ploughing of agricultural land, leading to decreased ecological stability of agricultural landscapes;
- Progressive soil degradation;
- Failure to observe crop rotations and standards; outdated and deteriorating reclamation infrastructure;
- Low levels of environmental integration in agricultural production;
- Limited adoption of organic farming; inadequate digitalization of land data;
- Risks of land market monopolization due to insufficient regulatory transparency and weak protection mechanisms for smallholders and farmers.

In order to enhance the efficiency of agricultural land use, the following measures are advisable:

- Implementation of integrated models of sustainable farming;
- Large-scale modernization and development of new land reclamation systems;
- Government support for the development of organic agricultural production;
- Active adoption of digital tools for land resource management;
- Further regulatory and legal development of the land market, taking into account social and environmental factors;
- Expansion and modernization of the agricultural education and advisory systems.

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APPLICATION OF SUSTAINABLE DEVELOPMENT PRINCIPLES IN THE REVITALIZATION OF POST-INDUSTRIAL SPACES. MODELS OF FUNCTIONAL-FLEXIBLE RECONSTRUCTION OF ADMINISTRATIVE BUILDINGS IN HOSTELS AND DORMITORIES: EXPERIENCE AND PROSPECTS

Hyzhko Anna, Bridnya Larisa

Kyiv National University of Civil Engineering and Architecture,

artannagyzhko@gmail.com , bridnia.liu@knuba.edu.ua

In the context of post-war reconstruction of Ukraine, the need to transform outdated administrative and industrial buildings into functional temporary accommodation facilities, such as hostels and dormitories, is becoming more urgent. This process is an important component of sustainable development in urban planning, aimed at the efficient use of available resources and the adaptation of the urban environment to the modern needs of the population.

Reconstruction and revitalization of outdated administrative and industrial buildings for residential purposes, in particular hostels and dormitories, is one of the most relevant areas of sustainable urban development in modern Ukraine. Such transformation meets several key challenges at once: it reduces the housing shortage that arose as a result of internal displacement of people, ensures post-war reconstruction of cities, restoration of neglected urban areas, and the formation of new, adaptive space for living and temporary stay of people [15].

This topic acquires particular importance in light of modern realities - Ukrainian cities must be able not only to satisfy the basic needs of the local population, but also to actively prepare for receiving guests from abroad, labor migrants, tourists and representatives of international organizations. The development of hostel infrastructure based on existing structures allows for the creation of flexible, affordable and functionally adapted housing with a minimal environmental footprint [10].

In addition to its utilitarian function, the reconstruction of buildings from the past also has significant cultural and educational value. Objects with history are material witnesses to the architectural, engineering and social past of the city. Their adaptation to new needs allows us to preserve the uniqueness of the urban environment, while creating new opportunities for cultural dialogue between residents and visitors. This can become the basis for the formation of a local identity, which is often lacking in new residential neighborhoods built from scratch [13].

From a technical point of view, the reuse of existing buildings has a number of advantages. It eliminates the need for large-scale new construction, reducing pressure on natural resources and ecosystems. A significant advantage is the already existing engineering networks (electricity , water and heat supply), which do not require newly issued permits, but instead can be partially modernized or optimized. In parallel with the development of such territories, it is possible to conduct a full analysis of the technical condition of the infrastructure, identifying critical nodes and taking measures to update it - in accordance with modern standards of sustainable development [9;12].

Functional and flexible modeling of such territories allows integrating into residential complexes not only living rooms, but also common spaces, recreation areas, study areas, coworking spaces , laundry rooms, bicycle parking spaces , and other elements of social infrastructure. This not only increases the comfort and quality of life of residents, but also contributes to the harmonious development of adjacent territories, ensuring the integration of the reconstructed space into the broader urban context [14].

Thus, consideration and implementation of models of flexible reconstruction of administrative buildings into hostels and dormitories is not only a practical step towards solving housing needs, but also a strategic component of the formation of a sustainable, integrated, socially oriented urban policy of Ukraine in the context of reconstruction and development [11].

Redevelopment of administrative and industrial facilities into residential infrastructure is one of the leading directions of sustainable urban development, especially relevant in the conditions of post-war reconstruction of Ukraine. The concept of "adaptive reuse" (adaptive reuse) has been used for more than one decade in the EU, the USA, Japan, and Canada as an environmentally and economically viable alternative to new construction [1].

In the case of post-Soviet cities, such as Kharkiv, Kyiv, Dnipro or Lviv, where a significant number of administrative buildings from the Soviet period have accumulated, in particular outdated buildings of councils and factories, wide opportunities open up for their flexible reconstruction. The key idea is not only to physically adapt the object to a new function, but also to rethink it in the urban context. Thus, the building becomes part of a new ecosystem - energy-efficient, meaningful, socially useful [2].

One of the most effective approaches is to create functionally flexible reconstruction models that allow for the transformation of premises in accordance with changing needs: for example, floor plans may provide for changes in the layout of dormitory- type rooms, hostels , coworking spaces , or small offices. In such projects, it is important to use modular systems of engineering networks, zoning of space, minimizing capital partitions, and maximizing the mobility of interior solutions [3].

An important advantage of reconstruction over new construction is the minimal impact on the natural environment. The use of existing load-bearing structures, foundations and networks reduces CO_2 emissions, reduces the consumption of new materials, and also reduces the costs of design and permitting procedures [4]. At the same time, the project can be implemented in a shorter time, which is especially relevant in conditions of the need to provide housing for IDPs, students, volunteers or employees of international organizations [15; 16].

An example of the successful implementation of such a practice in Ukraine is the revitalization of the “Manufactura” facility in Zhytomyr, where former industrial premises were transformed into a space for living, co-working, educational and cultural institutions. In Lviv, a project to transform administrative buildings in the Pidzamche district into a modern dormitory and residential quarter with elements of social infrastructure is being actively discussed [5].

Functional and flexible planning allows creating a socially adapted environment that meets not only the requirements of energy efficiency (use of thermal insulation materials, air recovery systems, modern lighting), but also modern ideas about decent living conditions. For example, within the reconstructed space, the following can be provided: shared kitchens, study rooms, rehabilitation spaces, play areas, media libraries , cafes, etc. This creates the effect of "soft integration" of residents into the community, contributing to cohesion and social well-being [6].

It is also important to note the importance of the cultural aspect of adaptive reuse: each such building retains its historical value and can be a carrier of urban identity. This is especially important in the post-war period, when the need to preserve national and local cultural heritage is growing [7].

In parallel with the reconstruction, the revitalization of the surrounding areas, which are often in a neglected state, is taking place. Thanks to the renewal of the urban fabric, the potential for the development of infrastructure is created: cycling and walking routes, public spaces, landscaping, improvement and increased safety. This meets the modern requirements of green urban planning and the concept of the "15-minute city", where basic services are available within walking distance [8].

Thus, the adaptation of administrative and industrial buildings as hostels and dormitories is a strategically justified, environmentally sustainable and socially beneficial solution for Ukrainian cities. It combines environmental responsibility, preservation of cultural heritage, development of social infrastructure and a flexible response to modern urban challenges.

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PRINCIPLES AND PROSPECTS OF GREEN CONSTRUCTION IN UKRAINE

***Sofia Bugaiova*[1]**

[1] *Kyiv National University of Construction and Architecture*

Green construction" is a term used to describe the processes of designing, constructing, and operating buildings that minimize negative impacts on the environment and human health. Modern environmental challenges, such as climate change, air and water pollution, require a comprehensive approach to forming sustainable urban environments.

Green construction is one of the effective strategies that helps reduce resource consumption, decrease greenhouse gas emissions, and promote ecosystem conservation.

Modern concepts of green construction are based on several key principles: energy efficiency, rational water use, the application of environmentally friendly building materials, integration of renewable energy sources, and the creation of comfortable living environments for residents. The application of these approaches aims not only to improve environmental performance but also to reduce costs throughout the entire life cycle of a building. (Fig. 1)

Fig. 1. Principles of "Green" Construction [1]

The Essence and Principles of Green Construction

Energy Efficiency. The use of energy-saving technologies (thermal insulation, modern window systems, "smart" lighting) reduces energy consumption for heating and cooling buildings.

Renewable Energy Sources. Integration of solar panels, wind turbines, geothermal systems, etc. reduces dependence on fossil fuels and cuts greenhouse gas emissions.

Rational Use of Water Resources. Collection of rainwater, installation of water reuse systems, and water-saving faucets and flush tanks.

Use of Eco-Friendly Materials. Application of certified wood, recycled materials, natural insulators, and water-based paints without toxic additives.

Comfort and Health of Residents. Ensuring proper ventilation, natural lighting, non-toxic finishing materials, green zones, and "living walls."

2. Tools for Evaluating Environmental Efficiency

Globally, several well-known certification systems for green buildings exist. The most popular are LEED (USA) and BREEAM (UK). Interest in implementing such standards is also growing in Ukraine. These systems evaluate projects based on various criteria, including energy efficiency, water conservation, material selection, transport accessibility, and waste management.

3. Environmental and Economic Impact

Green construction provides:

- Reduction in energy costs. Investments in energy-saving technologies pay off through lower heating, cooling, and electricity bills.
- Improved quality of life. Healthy indoor climates, adequate natural lighting, and reduced noise levels.

- Increased market value of real estate. Certified buildings become more attractive to tenants and buyers who value environmentally responsible approaches.

4. Challenges and Development Prospects in Ukraine

Challenges:

- Low awareness. Many developers and potential property owners are not fully aware of the benefits of green construction.
- Insufficient regulatory framework. Legislation on energy efficiency and environmental standards is improving but requires further harmonization with international norms.
- Financial barriers. The high initial cost of eco-friendly materials and technologies may deter investors; however, long-term savings often offset these expenses.

Table 1

Indicator Traditional Building "Green" Building

Indicator	Traditional Building	"Green" Building
Energy Consumption	High	Low, thanks to energy-efficient technologies
Water Usage	Unlimited	Optimized, with rainwater reuse systems
Type of Building Materials	Often synthetic, toxic materials	Eco-friendly, recycled, or certified materials
Indoor Air Quality	Depends on ventilation	Improved through filtration and natural ventilation
CO_2 Emissions	Higher	Reduced through the use of renewable energy sources

Prospects:

- Expansion of state support programs. Subsidized loans, grants for energy-efficient projects, and "green" tariffs.
- Growing demand for eco-friendly housing. Society is becoming more environmentally conscious, fostering demand for high-quality "green" buildings.
- Integration of innovative technologies. Rapid development of startups in renewable energy, automation, and smart home systems opens new opportunities.

Examples of Such Projects:

Residential Complex "Diadans" in Kyiv. This complex became the first residential building in Ukraine certified under the international ecological standard BREEAM International New Construction. The certification included an assessment of energy efficiency, environmental impact, resident safety, the use of eco-friendly materials, and the convenience of transport infrastructure. (Fig. 2)

Fig. 2. Residential Complex "Diadans" in Kyiv. [2]

Residential Complex "Fjord" in Kyiv
This complex stands out with its unconventional architecture for Kyiv, featuring cascading floor sections and rocky-shaped walls that emphasize its ecological design. (Fig. 3)

Fig. 3. Residential Complex "Fjord" in Kyiv. [3]

Conclusion

Green construction is an integral part of sustainable development and an effective tool for addressing environmental challenges. It contributes to reducing greenhouse gas emissions, conserving resources, improving public health, and enhancing the investment appeal of real estate.

Ukraine has significant potential for further development of green construction through the expansion of the legislative framework, government support programs, and growing public interest in environmentally friendly solutions.

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DURATION OF PRECIPITATION

Budnik Svitlana Vasulivna,
Borys Sreznevsky Central Geophysical Observatory,
svetlana_budnik@ukr.net

Information about the characteristics of atmospheric precipitation is important for the economic use of any territory. This information is used to form drainage networks, anti-erosion measures, irrigation regimes, etc.[1-3,7,8,10,12-14]. When designing a rainwater or industrial-rainwater sewage system, the concept of the estimated duration of rain is used, which is equal to the duration of surface water flow along the surface, troughs and pipes to the estimated area, determined according to tables for climatic regions and settlements [1], here one can argue about the correspondence of the term to the actual duration of the rain. Also, in production activities, the concept of the average duration of rain for this area per year (taken from the data of the nearest weather station) [2], etc.

The duration of precipitation is one of the main characteristics of rain [7,8,12-15]. Visual observations of the duration of atmospheric phenomena, including the duration of atmospheric precipitation, were organized in the USSR in 1936. Information on the duration of rain can also be obtained from observations of the intensity of precipitation (observations using pluviographs, VOA-1M, etc.). A.N. Lebedev (1964), analyzing visual observations of the duration of precipitation and pluviograph data, found that the pluviograph data give an underestimated duration of precipitation, since the device has insufficient sensitivity to fine precipitation, so in areas with frequent fine and drizzling precipitation, the proportion of unaccounted precipitation duration can be 40-50%.

However, it is fine and drizzling precipitation that create unfavorable conditions for the construction and operation of some facilities.

According to modern approaches to urban planning and not only now, there are requirements to consider the entire spectrum of rain from short-term to the longest [9, 11].

For the analysis, the materials of observations of the State Hydrometeorological Service of Ukraine on rain using pluviographs were taken. The materials of observations at the meteorological stations of Kyiv, Kamyanka-Buzka and Yaremche were considered (Table 1).

Table 1

Measurement ranges at the weather stations under study

Characteristic	Kyiv	Kamyanka-Buzka	Yaremche
Observation period, years	1913, 1924-1929, 1950-61, 1967-81, 1994, 1996- 2020	1963 – 85, 1988-2018	1952-1953, 1955-56, 1958-2020
Number of measured rains, pcs	2261	1972	4374
Rain duration range, min.	1 - 2218	3 - 2505	1 - 3760

The observation series differ considerably in the beginning of the observations, their duration and the number of recorded rains. The change in the duration of rains over time is better observed at the Kyiv weather station and has a tendency to increase, while for the Kamianka-Buzka and Yaremche weather stations it is practically not visible (Fig. 1).

Rains lasting 12 hours (720 min) and more do not occur very often (Fig. 2) 4-6% of all rains. For comparison: natural meteorological phenomena in relation to atmospheric precipitation are usually considered for an interval of 12 hours [4], so, rain with a precipitation amount of more than 20 mm in landslide-prone areas of the Carpathians, which fell within 12 hours or less, is considered landslide-prone, etc. [5].

Studies show that long rains occur very rarely and have a relatively low intensity [6], but their impact on the environment is longer. In time, an increase in the duration of rains, from the considered weather stations, is observed only for the Kyiv weather station. A possible change in the characteristics of rainfall compared to the previous ones may affect the features of the functioning of many structures and technical systems. This circumstance requires an in-depth study of the duration of rainfall at a larger number of weather stations throughout Ukraine.

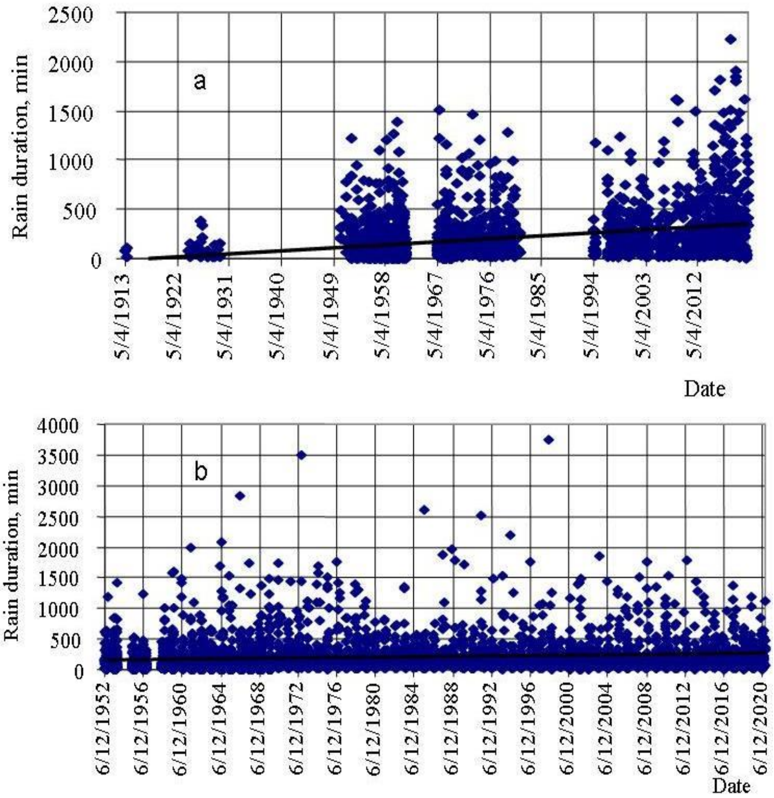

Fig. 1**.** Change in precipitation duration over time at the Kyiv weather station (a) and the Yaremche weather station (b)

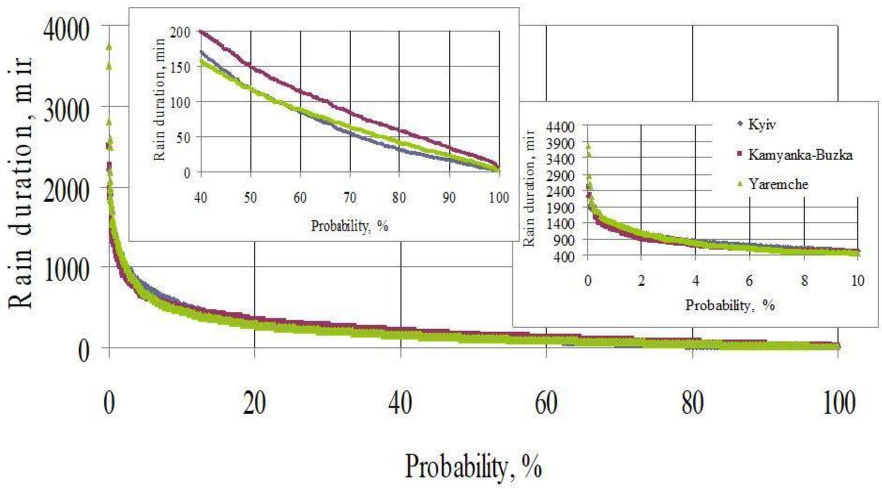

Fig. 2. Availability of rainfall duration at weather stations Kyiv, Kamianka-Buzka and Yaremche

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THE GREEN ROOFS' IMPACT ON THE AESTHETIC PERCEPTION OF URBAN SPACE

Bulhakova D.[1], Akhaimova A.[2]
[1]SEI "Prydniprovska State Academy of Civil Engineering and Architecture"
[2]Language adviser: lecturer, K. Shabanova
24085arc.bulhakova365.pdaba@gmail.com

Urbanization has led to the proliferation of concrete structures, diminishing green spaces and negatively impacting the aesthetic perception of urban areas [1]. Aesthetic perception in environmental psychology is influenced by factors such as color, texture, and perceived naturalness [2]. Green roofs – vegetative layers grown on rooftops – offer a multifaceted intervention that enhances urban aesthetics through visual contrast, seasonal variation, and biomimetic integration. By combining architectural design with ecological principles, they embody biophilic design ideals, which posit that humans have an innate affinity for nature [3].

Research indicates that green roofs can significantly enhance the visual appeal of urban spaces. Ahlfeldt and Maennig found a 5–10% increase in perceived property attractiveness near green-roofed buildings in Berlin [4]. The study of Van der Veen et al. demonstrated that green roof coverage reduces surface temperatures by up to 8°C, indirectly improving visual comfort and perceived freshness [5]. Recent studies also explore the role of color palettes–native wildflowers versus uniform sedum mats–and their differential impact on public preference [6].

Vancouver Convention Centre (Canada): Its six-acre rooftop hosts over 400,000 native plants, creating a mosaic of textures and seasonal blooms. Public surveys rated the rooftop at 4.8/5 for perceived naturalness and relaxation [7].

One Central Park (Sydney, Australia): Incorporates heliostat-reflected light onto walls of ivy and bromeliads. Aesthetic assessments highlight the interplay of light and vegetation as enhancing urban nightscapes [8].

Museé du Quai Branly (Paris): Blanc's vertical garden showcases biogeographical plant zoning: tropical shade species at the base and alpine flora at the top. This stratification enriches sensory diversity and draws high foot traffic as a visual attraction [9].

Ford River Rouge Plant (Dearborn, USA): The industrial-scale installation features contrasting gravel pathways and sedum lawns, emphasizing texture variation. Visitor feedback emphasizes the unexpected 'oasis effect' within a manufacturing context [10].

Various methods of information research were used in this paper:

Quantitative Surveys: Aesthetic metrics include perceived naturalness, color diversity, and textural complexity, rated on 7-point Likert scales. Sampling across 500 respondents in four cities ensures statistical power ($p<0.01$).

Visual Preference Mapping (VPM): GIS-based heatmaps overlay aesthetic ratings onto urban fabric, illustrating spatial distribution of public appreciation.

Qualitative Interviews: In-depth interviews with 20 urban planners and landscape architects reveal design priorities (e.g., seasonal color planning) and maintenance considerations (e.g., irrigation aesthetics).

Aesthetic Ratings: Areas with green roofs scored an average of 6.2/7, compared to 4.5/7 in control sites ($p<0.001$).

Visual Preference Maps: Hotspots of positive perception align with high-density green rooftop clusters, suggesting network effects.

Designer Insights: Planners emphasize the need for mixed planting palettes to avoid monotony and advocate modular green roof systems for visual flexibility.

The findings underscore that texture variation, color seasonality, and strategic lighting are key drivers of aesthetic appreciation. Moreover, the visual continuity between roof gardens and street-level parks amplifies overall urban cohesion.

Governments in Germany and Switzerland offer subsidies covering up to 60% of green roof installation costs–policies that correlate with higher adoption rates and more elaborate aesthetic designs. However, challenges include:

Maintenance Protocols: Ensuring plant diversity without overgrowth requires periodic pruning that, if neglected, can lead to uniform turf and diminished visual interest.

Cost-Benefit Dynamics: Initial installation costs can be 20–50% higher than conventional roofs; lifecycle analyses reveal payback periods of 8–12 years when combining energy savings and aesthetic value uplift.

The figure 1 illustrates:

- World map marking case study cities (Vancouver, Sydney, Paris, Dearborn)
- Bar graph comparing mean aesthetic ratings (with vs. without green roofs)
- Pros and cons list detailing visual benefits and practical challenges
- Biophilic design cycle showing links between integrating nature, aesthetic value, and urban planning

In conclusion, it is worth to say that green roofs not only elevate the aesthetic perception of urban spaces through color, texture, and design innovation but also foster ecological and social benefits. Their integration into biophilic design enhances urban resilience and well-being. Future research should explore longitudinal aesthetic studies across climatic zones, the role of interactive green roof elements (e.g., community gardens), and the application of immersive AR/VR tools to plan and evaluate rooftop landscapes.

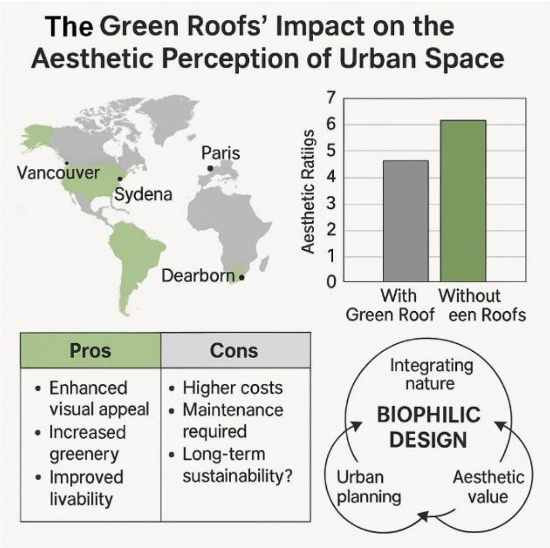

Figure 1. The Green Roofs' Impact on the Aesthetic Perception of Urban Space.

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RELEVANCE OF DECENTRALIZED VENTILATION SYSTEMS WITH HEAT RECOVERY: DESIGN, EFFICIENCY, AND ECONOMIC FEASIBILITY

***Volodymyr Bundzylo*[1], *Bogdan Gulay*[1]**
[1]*Lviv Polytechnic National University,*
volodymyr.p.bundzylo@lpnu.ua

Ensuring proper indoor air quality while simultaneously reducing building energy consumption is one of the key challenges of modern construction. In conditions of constant growth in the cost of energy sources and increased environmental requirements, decentralized ventilation systems with heat recovery are gaining more and more relevance as an effective solution for maintaining an optimal microclimate (Fig. 1).

Decentralized ventilation systems with heat recovery are compact devices that are installed directly in the external enclosing structures of the building and provide air exchange for individual premises. The principle of their operation is based on the use of heat exchangers that provide the transfer of thermal energy from exhaust air to supply air, which allows to significantly reduce heating or cooling costs [1, 2].

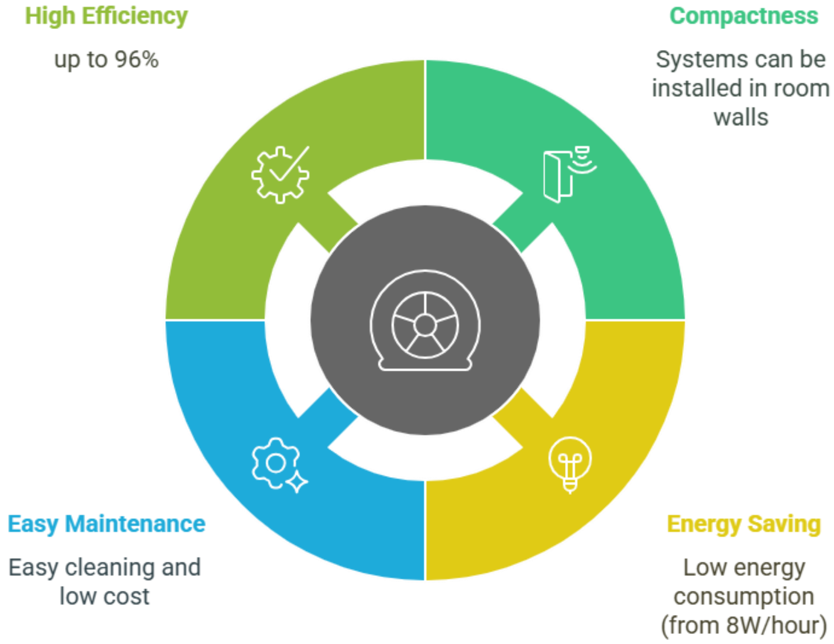

Fig. 1. Advantages of decentralized systems

The modern market offers various design solutions for such systems, which differ in heat exchanger material and design (plate, rotary, with an intermediate heat carrier), recovery efficiency (from 50% to 90%), the method of controlling the air flow and additional functions (filtration, heating, cooling) (Fig. 2).

The regulatory framework, in particular the European standards EN 308:2022 and EN 13141-8:2023, establishes the test methodology and criteria for assessing the effectiveness of such systems [3,4]. Compliance with these standards is an important aspect in the design and implementation of decentralized ventilation systems.

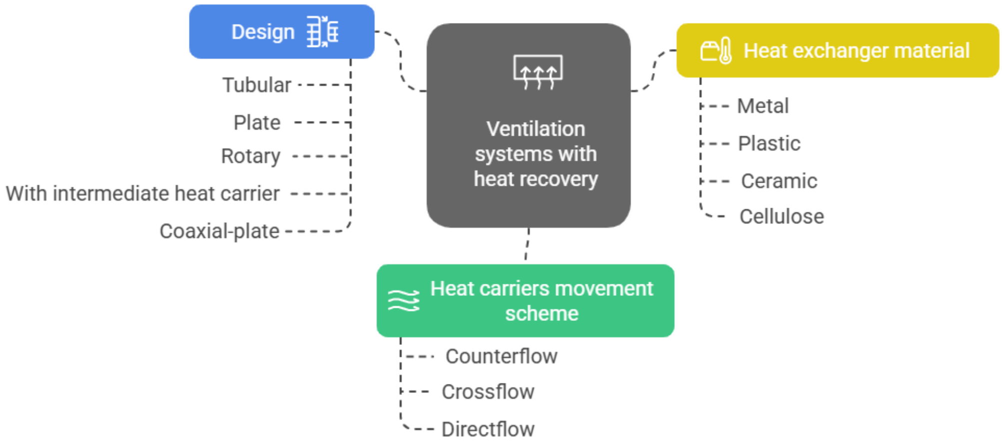

Fig. 2. Classification of ventilation systems with heat recovery

Based on the analysis of literary sources and scientific studies by Manz et al. (2000), Nizovtsev et al. (2016), Carbonare et al. (2020) and other authors [5-8] who studied energy-efficient ventilation systems, a diagram was developed that systematizes and clearly reflects a set of interrelated factors that determine the efficiency of decentralized ventilation systems with heat recovery (Fig. 3). Comprehensive consideration of these factors allows optimizing the design, operating modes, and operation of decentralized ventilation systems with heat recovery to achieve maximum energy efficiency while ensuring the proper quality of the microclimate in the premises.

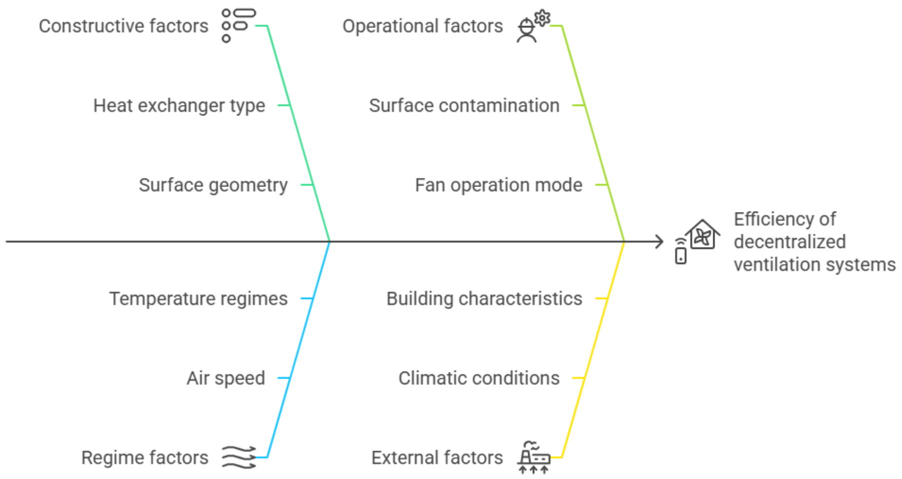

Fig. 3. Cause-and-effect diagram of factors influencing the efficiency of decentralized ventilation systems

The economic feasibility of implementing such systems is determined not only by initial investments, but also by operating costs and potential energy savings throughout the equipment's life cycle. Analysis of these factors also allows us to assess the payback period and financial attractiveness of projects to implement decentralized ventilation systems.

The use of modern computer modelling methods, in particular CFD (Computational Fluid Dynamics) analysis in the SolidWorks software environment [9], allows optimizing heat exchanger designs and predicting their efficiency under various operating conditions without conducting expensive full-scale experiments.

An important aspect of implementing decentralized ventilation systems with heat recovery in Ukrainian realities is the adaptation of such systems to the climatic conditions of the country's regions. Since the efficiency of heat recovery varies significantly depending on temperature conditions and air humidity throughout the year, for western regions of Ukraine with high air humidity, it is recommended to use a system with protection against condensation and ice formation, while for southern regions, it is more relevant to implement a system with the possibility of bypass for summer operation, when heat recovery is impractical.

In the context of growing demands for environmental sustainability in construction, decentralized ventilation systems with heat recovery are becoming an integral component of green building standards such as LEED, BREEAM and DGNB. The implementation of such a system allows to obtain additional points when certifying buildings according to these standards, which ensures their market attractiveness and corresponds to global trends in decarbonization of the construction sector. A comprehensive approach to designing ventilation systems, taking into account the principles of the circular economy and life cycle analysis (LCA), allows to minimize the negative impact on the environment and ensure the sustainable development of the ventilation and air conditioning industry.

Thus, the study of decentralized ventilation systems with heat recovery is comprehensive and covers constructive, technological, economic and environmental aspects, which determines its high relevance and practical significance for modern construction and the energy sector.

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SOME CHARACTERISTICS OF AIR DISTRIBUTION WITH A LINEAR SLOT DIFFUSER

Yaroslav Chemerynskyi[1], Orest Voznyak[1]

[1]*Lviv Polytechnic National University, Yaroslav.R.Chemerynskyi@lpnu.ua*

The thesis considers increasing the efficiency of indoor air distribution when using linear diffusers as air distribution devices. Linear diffusers make it possible to provide comfortable conditions in the room.

Modern requirements of regulatory documents for the indoor environment of premises [4] put forward high standards for the quality of ventilation and air distribution [6], uniformity of temperature regime [3] and ensuring a comfortable microclimate [1]. In conditions of intensive operation of premises, especially office, public and industrial, effective control of air flow movement becomes critically important [5]. One of the important aspects for this is the uniformity of air distribution [2] without the formation of stagnant zones [10] or excessive temperature drops [9].

Ventilation systems with traditional air distribution devices [8] often do not provide the necessary uniformity of air distribution [7], avoidance of the formation of overheating or excessive cooling zones, as well as the prevention of local drafts. This leads to a decrease in indoor comfort [11], deterioration of working conditions and even possible negative consequences for human health [12], in particular the development of respiratory diseases and a general decrease in working capacity. In addition, inefficient use of ventilation and air distribution systems causes increased energy consumption [7], which increases the costs of heating, air conditioning and ventilation [8].

Linear slot diffusers are one of the promising solutions for improving the efficiency of air distribution [6]. Due to their design, they provide uniform and controlled air distribution [10], which helps to reduce local temperature fluctuations and reduce the risk of drafts. They allow to achieve higher energy efficiency of ventilation systems because they ensure optimal mixing of air masses and help to reduce heat or cold losses.

Research in the field of ventilation and air distribution shows that the use of linear slot diffusers can significantly improve the quality of the microclimate in rooms [1]. In particular, experimental and numerical simulations Error! Reference source not found. show that such diffusers provide effective control over air flows, which is important for maintaining comfortable conditions in rooms for various purposes [10].

The task was set to analyze the effectiveness of using linear slot diffusers in ventilation systems, determine the optimal parameters of their operation and assess their impact on the uniformity of air distribution in rooms, as well as to investigate the aerodynamic characteristics of a linear slot diffuser. The study uses numerical modeling methods and experimental measurements [8], which allows us to substantiate recommendations for the design of ventilation systems using louvered slot diffusers to increase comfort and energy efficiency.

Today, many ventilation systems use louvered linear diffusers [6] with two or more slots as air outlet devices. Linear diffusers when operating in supply ventilation, air conditioning and heating systems form flat jets [1].

Flat jets, similarly to compact jets, have a jet core – this is a flow region with constant velocity and temperature, the jet pole (JP), which is the vertex of the conditional outer boundaries of the jet passing through it and through the boundaries of the louvered linear diffuser [4], [7], [10].

The velocity v_y in any cross section "x" at a distance "y" from the axis of the plane jet is determined by the Schlichting's formula:

$$v_y = v_x\left[1-\left(\frac{y}{y_b}\right)^{1,5}\right]^2 \qquad (1),$$

where v_x and v_y are axial and transverse air velocity respectively.

It is recommended to use relative values of velocities, both axial $\overline{v}_x = v_x/v_o$ and transverse, in any cross section $\overline{v}_y = v_y/v_x$. In this case:

$$\overline{v}_x = \frac{0,48}{\frac{ax}{de}+0,145} \qquad (2)$$

where a = 0,078;

d_e – equivalent nozzle diameter.

In non-isothermal flows, the relationship between gravitational and inertial forces at the moment of outflow is characterized by the Archimedes criterion Ar_o:

$$Ar_o = \frac{g\sqrt{F_o}\cdot\Delta\ t_o}{V_o^2\cdot T_{in}} \qquad (3)$$

where g = 9,81 m/s^2;

F_o – nozzle area, m^2;

Δt_o – excessive initial temperature, $\Delta t_o = t_o - t_{in}$, K;

T_{in} – absolute indoor air temperature, K;

V_o – initial speed, m/s.

Depending on the value of Ar_0, tidal jets are conventionally divided into type non-isothermal-A, when the influence of gravitational forces on them is not significant, and type non-isothermal-B, where the influence of gravitational forces is significant.

For horizontally emitted type A non-isothermal jets, the excess temperature $\Delta t_x = t_x - t_{in}$ is determined by the formula:

$$\Delta\ t_x = \frac{N}{x} \tag{4}$$

where x – current longitudinal coordinate;

N – thermal parameter:

$$N = \frac{0{,}54}{tg\alpha}\sqrt{\frac{T_{in}}{T_0}} \cdot \frac{1}{\sqrt[4]{\xi}} \cdot \Delta\ t_o \cdot \sqrt{F_o} \tag{5}$$

where α – jet opening angle, α = 12º25' , and tgα = 0,22;

ξ – local resistance coefficient, $\xi = 1$;

T_o – absolute temperature at the nozzle outlet.

For convenience of calculations, the temperature damping coefficient is introduced n:

$$n = \frac{0{,}54}{tg\alpha}\sqrt{\frac{T_{in}}{T_0}} \cdot \frac{1}{\sqrt[4]{\xi}} \tag{6}$$

and axial excess temperature Δt_x :

$$\Delta\ t_x = n \cdot \Delta\ t_o \cdot \frac{\sqrt{F_o}}{x} \tag{7}$$

Therefore, the excess temperature $\Delta t_y = t_y - t_{in}$ in any cross section "x" at a distance "y" from the axis:

$$\Delta\ t_y = \Delta\ t_x \cdot exp\left(-0{,}7\sigma_T \bar{y}^2\right) \tag{8}$$

where σ_T – turbulent Prandtl number, $\sigma_T = 0{,}65 \div 0{,}7$ for compact jets;

$\bar{y}$ – current transverse coordinate, $\bar{y}$ = y/cx – experimental constant, c = 0,28.

Often use relative values of excess temperatures, axial $\Delta\ \bar{t}_x = \Delta\ t_x/\Delta\ t_o$ and in any cross section $\Delta\ \bar{t}_y = \Delta\ t_y/\Delta\ t_x$.

The experimental setup consisted of a laboratory fan, air ducts, a flexible insert, a diffuser with a wall opening angle α = 12°25' and the studied louvered linear slot diffuser. The experiments were conducted for different numbers of diffuser slots and different slot lengths. The height of the slots was fixed.

The studies were conducted on the following experimental setup, which is schematically shown in Fig. 1.

As a result of the conducted research, the dependence of the relative transverse velocity can be displayed as follows (Fig. 2).

According to Figure 2, it can be concluded that:

- the air flow is sufficiently turbulent, the velocity decay in the jet occurs intensively.

- jet interaction at the diffuser exit causes a sharper axial velocity drop (10 – 20%) compared to traditional distribution grilles.

- louvered linear slot diffusers allow to ensure the supply of the required amount of supply air to a small volume room without creating drafts.

- the design feature of the device causes a specific velocity profile in the cross section of the jet.

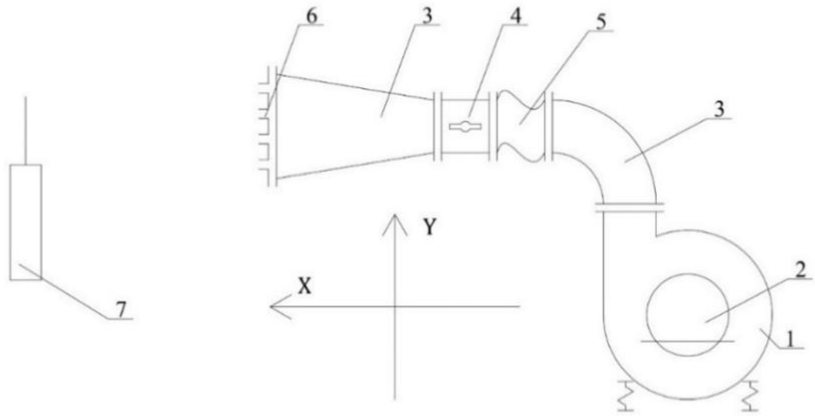

Fig.1 Scheme of the experimental setup - 1 – centrifugal fan; 2 – electric motor; 3 – air duct; 4 – control valve; 5 – flexible insert; 6 – linear slot diffuser; 7 – testo-405 thermal electrical anemometer.

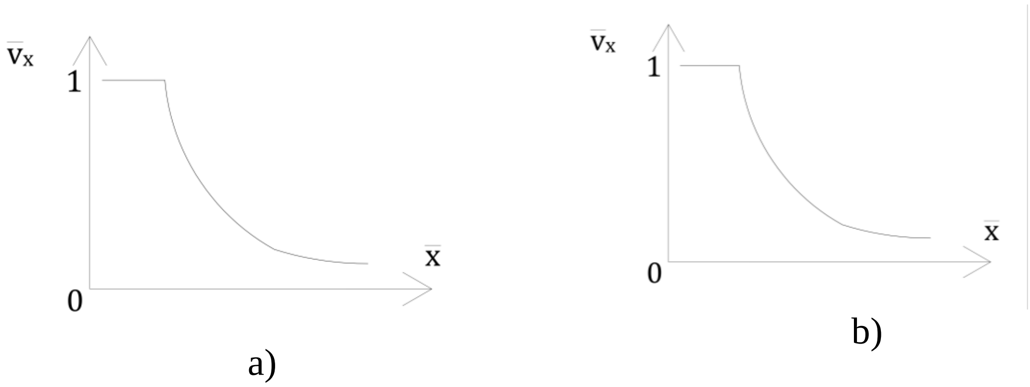

Fig. 2. Dependence a) $\overline{v}_y = f(y)$ and b) б) $\overline{v}_x = f(x)$ for a plane jet of a linear slot diffuser.

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DYNAMICS OF OUTPUT WATER FLOWS IN CIRCULATING COOLING SYSTEMS

Valery Gayevskii[1], Viktor Fylypchuk[1], Oleksandr Syrovatskyi[2]

National University of Water and Environmental Engineering, Rivne, Ukraine,
v.r.haievskyi@nuwm.edu.ua, v.l.fylypchuk@nuwm.edu.ua
O.M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine,
oleksandr.syrovatskyi@kname.edu.ua

Circulating cooling systems (CCS) are resource-saving ecological systems [1, 2]. Although CCS allow saving water resources, from the point of view of environmental control it is necessary to assess the water footprint of such systems [3]. Such a water footprint of the CCS is an important component of the total water consumption of the enterprise and is one of the most water-intensive structural units of the enterprise [4].

The aim of the work is to establish relationships that would allow for the assessment of the water footprint of the CCS. To achieve this aim, an equation was established for calculating water discharge flows, which include blowdown and spray carried of recycled water, and appropriate laboratory studies were performed to confirm the obtained relationships.

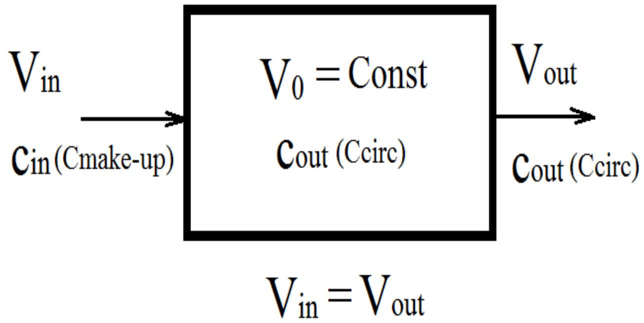

Fig. 1. Scheme of the experiment to determine the dynamics of soluble salt in the volume V_0 during the water exchange process Vout to Vin. Cmake-up – concentration of soluble salt in the feed water; Ccirc – concentration of soluble salt in the circulating water.

The aim of the laboratory experiment is to simulate water exchange in the CCS without taking into account evaporation, to verify the model of concentration of soluble salts and to determine the values of the output flows (blowdown and spray carried). The laboratory experiment is based on the assumption that continuous input and output flows can be replaced by multiple discrete water exchange (Fig. 1).

In the experiment, the change in the concentration of NaCl salt in the basic constant volume during multiple water exchange was monitored. To build the model, we will use the principle of summation of input and output flows from a given volume, which is based on the mass balance, and then in general form we will write:

$$\frac{dM_{circ}}{dt} = \sum_{i=1}^{k} a_i(t) \cdot f_i(t) - \sum_{i=1}^{n} b_i(t) \cdot g_i(t) \tag{1}$$

where M_{circ} - is the mass of the component in the circulating water; $a_i(t)$ - is the kinetic coefficient of the i-th input stream; $f_i(t)$ - are functions that determine the values of the component concentrations in the i-th input stream at a given time; $b_i(t)$ - is the kinetic coefficient of the i-th output stream; $g_i(t)$ - are functions that determine the values of the component concentrations in the i-th output stream at a given time. In the simplest case, $f_i(t)$ and $g_i(t)$ can be the component concentrations, $a_i(t)$ and $b_i(t)$ determine the input and output streams of the given component, respectively. Then, the input stream of the component is the stream in the volume of make-up water and accordingly $a_1 = Q_{make-up}$, and $f_1(t)$ is the concentration of one of the soluble salt components (for example, Cl^-) in the make-up water, i.e. $f_1(t) = c_{make-up}(t)$. Taking into account the above, we write:

$$\sum_{i=1}^{k} a_i \cdot f_i(t) = Q_{make-up} \cdot c_{make-up}(t) \quad (2)$$

For the output streams, according to Fig. 2, we write:

$$\sum_{i=1}^{n} b_i \cdot g_i(t) = Q_{blow} \cdot c_{circ} + Q_{spray} \cdot c_{circ} + Q_{vapor} \cdot c_{circ}(t) + Q_{others} \cdot c_{circ}(t). \quad (3)$$

Considering that

$$M = c \cdot V_0,\; V_0 = Q \cdot T \text{ and } q_i = \frac{Q_i}{Q_{circ}}, \quad (4)$$

where T - is the circulation period, we write:

$$\frac{dc_{circ}}{dt} = \frac{1}{T}\left[q_{make-up}(t) \cdot c_{make-up}(t) - (q_{spray}(t) + q_{blow}(t)) \cdot c_{circ}(t)\right], \quad (5)$$

where q - are flows expressed in fractions of a unit of the cooling water flow rate (Q).

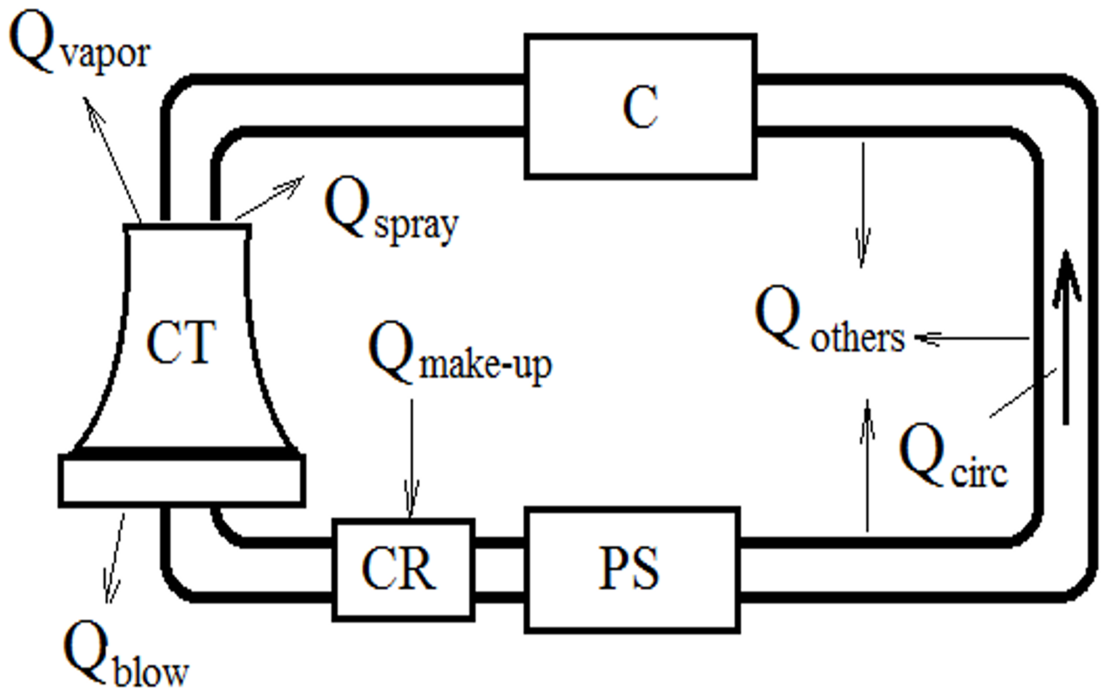

Fig. 2. Scheme of the circulating cooling system. CT - cooling towers; CR – make-up water receiving chamber; PS – pumping station; C – condensators; $Q_{make-up}$; Q_{circ}, Q_{vapor}, Q_{spray}, Q_{blow}, Q_{other} – flows: circ – circulating water; vapor – evaporation; spray – spray carried; blow – blowdown; others – other losses (for technological needs, at treatment facilities, for filtration).¶

By marking:

$$p(t) = \frac{1}{T}(q_{spray}(t) + q_{blow}(t)) \text{ та } r(t) = \frac{1}{T}(q_{make-up}(t) \cdot c_{make-up}(t)), \quad (6)$$

Let's write the differential equation of the water exchange process:

$$\frac{dc_{circ}}{dt} + p(t) \cdot c_{circ} = r(t). \quad (7)$$

The solution to equation (7) has the form [5]:

$$c_{circ}(t) = \frac{1}{\exp(\int p(t)dt)} \cdot (\int r(t) \cdot \exp(\int p(t)dt)dt + C) . \qquad (8)$$

The constant C in (8) is chosen from the initial conditions by introducing the concentration coefficient (k) in the form [1]:

$$k(t) = \frac{c_{circ}(t)}{c_{make-up}(t)} . \qquad (9)$$

Then, taking into account (9), we write the initial conditions in the form:

$$c_{circ}(0) = k(0) \cdot c_{make-up}(0) . \qquad (10)$$

According to the authors, condition (10) is the most general, taking into account arbitrary (physically significant) initial values of the concentration coefficient ($k(0) < 1$, $k(0) > 1$, $k(0) = 1$). Taking into account (9), and also taking into account that for our case $q_{vapor} = const1,\ q_{spray} = const2,\ q_{blow} = const3$, we obtain the expression for the integration constant

$$C = (k(0) - k_\infty) \cdot c_{circ}(0) , \qquad (11)$$

where

$$\frac{q_{vapor} + q_{spray} + q_{blow}}{q_{spray} + q_{blow}} = k_\infty \qquad (12)$$

and k_∞ - is called the limiting concentration coefficient [1]. From (8), taking into account (11), we write the expressions for the concentration of soluble salts in CCS water, which has the form:

$$c_{circ}(t) = k_\infty \cdot c_{make-up} + (k(0) - k_\infty) \cdot c_{make-up} \cdot \exp(-\frac{q_{spray} + q_{blow}}{T} \cdot t) . \qquad (13)$$

From (12) and (13), the dynamics of the concentration coefficient for constant water flows of the CCS will be as follows:

$$k(t) = k_\infty + (k(0) - k_\infty) \cdot \exp(-\frac{q_{spray} + q_{blow}}{T} \cdot t) . \qquad (14)$$

From (14) it is clear that the expression for calculating the external flows (q_{spray} + q_{blow}) in linearized form will be as follows:

$$\ln\left(\frac{k(0) - k_\infty}{k(n) - k_\infty}\right) = \left(q_{spray} + q_{blow}\right) \cdot n , \qquad (15)$$

where t/T is the number of turnover cycles (the number of discrete water exchanges in our laboratory experiments). It can be seen from (15) that the angle of

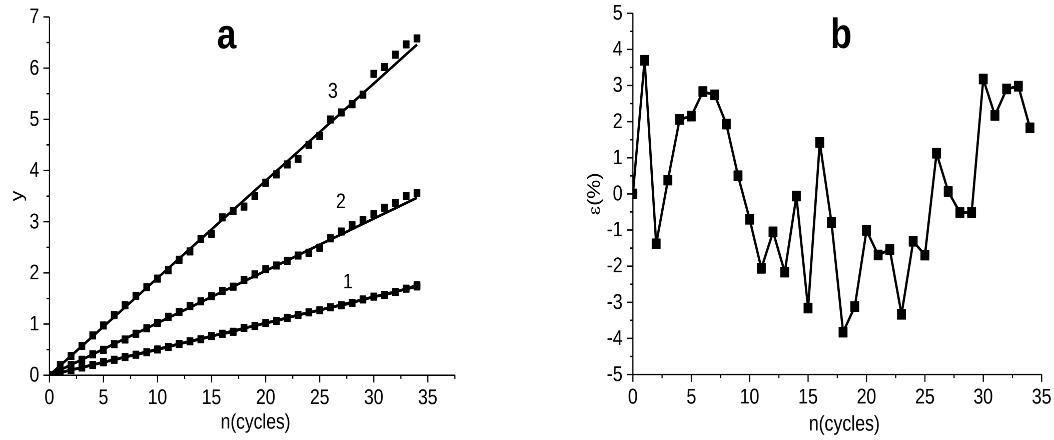

Fig. 3. Linearized form of dependence (14) in the form of (15) for experimental determination of output water flows (spray carried and blowdown) for their different values: 1 – 5%; 2 – 10%; 3 – 20% (a) and the largest relative error for the experiment with external flows of 20% (b).

inclination depending $\ln\left(\frac{k(0)-k_\infty}{k(n)-k_\infty}\right)$(in Fig. 3 marked as "y") on n will be equal to the value of the output water flows (spray carried and blowdown).

Based on conductometric measurements with an accuracy not exceeding ±4%, a model of the dynamics of soluble salts in CCS water was experimentally verified and a formula was proposed for determining the output water flows (spray carried and blowdown) under the condition of stationarity of water exchange flows and stationarity of the circulation flow.

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HUMAN RESOURCE MANAGEMENT IN THE CONTEXT OF GREENING THE CONSTRUCTION INDUSTRY

Daria Halias
Mariupol State University
galiasdasha@gmail.com

In the current context of economic transformation and the growing importance of environmental safety, the construction industry is increasingly oriented toward the principles of sustainable development. One of the key areas of this process is "green" construction — an approach aimed at reducing negative environmental impact through the use of energy-efficient, environmentally friendly materials, lowering carbon emissions, and conserving resources. However, the implementation of such practices requires not only technical modernization but also the adaptation of organizational management, particularly in human resource management.

The greening of enterprise activities necessitates updating HR policies, as the success of “green” initiatives directly depends on the level of environmental awareness, motivation, and engagement of personnel. During the transition to sustainable practices, effective HR management must combine traditional management tools with new approaches focused on ecological values. This approach has already been termed Green Human Resource Management (Green HRM) — a concept that integrates the environmental component into all HR functions: from recruitment to performance evaluation, training, motivation, and the development of corporate culture.

A study conducted by Tsymbaliuk S.O. and Kovtun O.A. [1] confirms that over 95% of respondents support the implementation of environmental practices in HR processes. Among the most effective tools were eco-trainings, inclusion of environmental requirements in job descriptions, and incentivizing employees for ecological initiatives. At the same time, only about 18% of organizations systematically implement such measures.

Currently, Ukraine’s construction industry faces an acute labor shortage. According to a 2023 survey of developers [2], the lack of qualified workers in some companies reaches 50%. The most in-demand specialists remain concrete workers, rebar installers, and electricians. The reasons for this situation include both demographic factors and the consequences of war, such as mobilization and migration.

To successfully integrate “green” practices into the operations of construction companies, HR departments must adapt their strategies. This includes developing professional training programs with an environmental focus, cooperation with relevant educational institutions, revising employee evaluation systems to include environmental KPIs, and fostering an ecologically-oriented corporate culture. Moreover, internal communication should be enhanced to make environmental responsibility a part of each employee’s daily routine.

In this context, human resource management becomes not just an administrative function, but a strategic tool to support innovation, increase the company's competitiveness, and ensure the sustainable development of the construction industry. Importantly, the successful implementation of "green" practices contributes not only to improving the organization's image but also to increasing its efficiency and social responsibility in practice.

Below is a chart illustrating the growth in the number of green construction projects in Ukraine over recent years (Fig. 1).

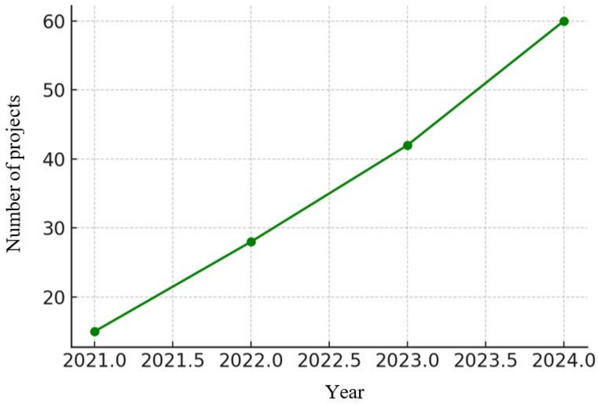

Fig. 1 Growth in the number of green construction projects

Another important component of Green HRM is the environmental education and development of employees. Organizations should foster their employees' environmental competence, which includes knowledge about the environmental impact of construction activities, skills in resource optimization, and motivation to adhere to sustainability principles. According to the Deloitte (2023) study, companies that implement systematic eco-training show 23% higher employee engagement.

Moreover, in the context of global warming, climate change, and new environmental standards (such as LEED and BREEAM certifications [5]), HR professionals need to integrate these requirements into workforce planning processes. The implementation of green standards should encompass all stages of the employee life cycle in the company — from recruitment to offboarding. This includes developing an environmentally oriented employer brand to attract motivated candidates, as well as creating evaluation systems.

Table 1

Main directions of green HRM in construction

Green HRM area	Description	Expected result
Green Recruitment	Considering environmental values when selecting candidates	Increased employee engagement in green initiatives
Eco-Training	Training employees on sustainable development principles	Formation of environmental competence
Eco-Friendly Behavior Incentives	Introducing bonuses for ecological initiatives	Reduction of resource consumption

Digitalization of HR	Transition to electronic documents and communication	Reduced CO_2 emissions, resource savings
Environmental KPI Evaluation	Inclusion of environmental indicators in employee performance evaluation	Increased employee accountability

Another promising area is the digitalization of HR processes, which helps reduce paper use, automate routine operations, optimize communication processes, and lower the organization's carbon footprint. In the construction sector, this is particularly relevant in areas such as occupational safety control, maintaining digital safety logs, and e-learning formats.

To systematize the data, a summary table of the main directions of Green HRM in construction is provided below (Table 1).

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EXPERIENCE OF UKRAINIAN CITIES IN DIVERSIFYING ENERGY RISKS

Hamotskyi Roman Olegovych, Kryvomaz Tetiana Ivanaina

Kyiv National University of Construction and Architecture,

roman.gamotskii@gmail.com, kryvomaz.ti@knuba.edu.ua

The unified energy system of Ukraine was built as a centralized structure with large nodal power plants and an electric energy transmission system with high-voltage lines. In wartime, such a configuration turned out to be vulnerable to targeted enemy attacks on the energy system, since it is practically impossible to ensure the protection of large power plants. The first wave of attacks in 2022 focused on the transmission system, then focus shifted to the conventional power plants. The power outages are substantial, particularly given that the electricity demand has already decreased by 20% from prewar levels due to reduced economic activity and the loss of territory to occupation. Approximately 35% of the total capacity has been partially or completely destroyed and the same amount is located in the currently occupied territories, thus Ukraine had lost near 70% of the electricity production capacity that was operational before the war [1]. The damaged energy generation capacity in Ukraine needs to be restored as much as possible, and also need to increase import capacity, and establish new generation capacities.

The energy sector and utilities are being transformed to meet the challenges of energy security in wartime. In the face of constant threats of an aggressor's strikes on Ukraine's energy system, it is necessary to decentralize generation so that the network continues to operate even if main lines and centralized power supply systems are damaged. At different stages, a number of scenarios for the development of the unified energy system of Ukraine were developed. Several diversification strategies can be used to ensure the reliability and sustainability of energy supply, taking into account the diversity of energy supplies, on-site generation, energy storage, and demand management. Local energy production with the possibility of storage in batteries allows for optimal use of own resources and minimizes dependence on external suppliers. To do this, a distributed generation system must meet a number of technical, economic, and organizational requirements. Flexibility is the basis for the development of future power systems.

The implementation of municipal energy plans (MEPs) in local communities help build community resilience against climate change by increasing energy independence, enhancing energy efficiency, and reinforcing social and economic stability. Ukrainian cities that have participated in the Pro Green Deal for Smart Cities programe and implemented MEPs have seen reductions of up to 28% in the number of megawatt-hours (MWh) consumed [2]. This illustrates the importance of strategic planning and energy investment to achieving energy consumption reductions in various Ukrainian cities.

In the Zhytomyr community, a large-scale building retrofit project funded by the European Investment Bank (EIB) led to a 40% reduction in heating costs for residents. Such measures not only decrease greenhouse gas emissions but also increase ability of communities to withstand extreme weather events. Zhytomyr's energy security is based on own resources, modernization of heating networks, efficient equipment produces green energy, circular economy principes and moving away from natural gas. Zhytomyr city administration was the first in Ukraine to announce plans to achieve 100% use of renewable energy in the municipal sector. Via extensive work on the modernization of heating networks, heat loss has been reduced by 5-6 times compared to many other cities in Ukraine. A decade ago, Zhytomyr consumed about 100 million m^3 of natural gas per year, but in 2022, this figure decreased to 51 million m^3. Further substitution of gas will allow reducing its consumption by 90% by 2030, and in 2050 - to completely abandon fossil fuels for heating the municipal sector. The city managed to reduce gas consumption by 50% thanks to switch to using its own raw materials - biomass, in particular, wood chips and other woodworking waste. The use of biomass will allow replacing up to 6.4 million m^3 of natural gas per year. At the same time, the city will reduce emissions by about 13 thousand tons of CO_2 each year, and electricity consumption will decrease to 8050 MWh per year.

The Dolyna community has received a grant from the Northern Environmental Finance Corporation (NEFCO) to modernize its district heating system, which has resulted in a 30% reduction in energy consumption [2]. This project aims to develop a decentralized intelligent energy system adapted to local conditions and community needs in the city of Dolyna, Ivano-Frankivsk region. The proposed project to create a cellular energy network (CEN) meets the tasks of modernizing the energy sector of Ukraine by implementing the concept of "smart grids". Its goal is to modernize the energy networks of territorial communities, increase their reliability, efficiency and social well-being of local residents. The project aims to address the geographical, political, economic, social, technical, legal and environmental requirements for new and smart local energy systems and their role in the energy transition. Such a comprehensive approach provides for increasing the stability of the energy supply system of the territorial community of Ukraine and the possibility of increasing the efficiency of the use of existing and new distributed generating units and energy storage through the creation of CEN. The implementation of this project will not only contribute to the social well-being of local residents, but will also provide an opportunity to study and replicate the developed conceptual solutions throughout Ukraine. In the Ivano–Frankivsk region, the community reduced energy consumption by 30% through RES integration and energy infrastructure modernisation. This not only increased energy independence but also strengthened the economics of community and social resilience. A similar approach was implemented in the Lviv region, where a cooperative initiative to build a wind power plant provided the community with energy and created new jobs.

In the Vinnytsia community, the "Energy-Efficient Homes" program included a series of workshops and public meetings that engaged more than 500 residents in discussions about energy-saving practices and the benefits of renewable energy. This initiative increased the transparency and accountability of local authorities and fostered environmental awareness and support from residents. Such educational programs and information campaigns can motivate citizens to actively participate in implementing energy strategies, stimulating environmentally responsible behaviours.

Such initiatives can serve as catalysts for entrepreneurship development and the creation of new business opportunities in the region. Close cooperation among different stakeholders, such as local authorities, energy companies, civil society organizations and investors, is vital to preparing a comprehensive approach to addressing local energy challenges. The key trend is a growing interest in integrating renewable energy sources into MEPs, whereas a significant barrier is the lack of access to financing for small-scale energy projects.

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RECYCLING OF BUILDING MATERIALS DURING THE RECONSTRUCTION OF DAMAGED FACILITIES WITHIN THE LIMITS OF "GREEN" RECONSTRUCTION AS A RESPONSE TO THE CHALLENGES OF WAR

Kashchenko Tetyana, Hyzhko Anna

Kyiv National University of Civil Engineering and Architecture,
kashchenko.to@knuba.edu.ua, *artannagyzhko@gmail.com*

The full-scale war in Ukraine has caused unprecedented destruction of infrastructure, including residential, administrative and industrial facilities. Estimates suggest that the cost of destruction exceeds $ 100 billion , and the amount of construction waste has reached over 10–12 million tons . In this context, recycling of construction materials is becoming particularly relevant as a key element of the country’s “green” recovery[1]. According to the Kyiv School of Economics, in the first year and a half of the war alone, total losses in the housing sector exceeded $58 billion[1]. This scale of destruction has generated enormous amounts of construction waste that needs to be effectively disposed of or reused to reduce the environmental burden and ensure sustainable recovery.

In this context, recycling of building materials is considered one of the key approaches to implementing “green” renovation. This approach is in line with the principles of the circular economy, according to which building materials, instead of ending up in landfills, are returned to the construction cycle as secondary raw materials [2]. This not only reduces the need for new resource extraction, but also contributes to the reduction of greenhouse gas emissions, energy consumption and the volume of construction waste.

The issue of environmentally friendly disposal of construction waste is becoming particularly relevant due to the limited landfill space and the need for rapid and cost-effective restoration of damaged facilities. Many cities are already implementing pilot projects to recycle debris from destroyed buildings into rubble that can be used for road construction, foundations, or temporary shelters [3]. This practice has already proven effective in European countries that have faced the consequences of military conflicts or natural disasters.

Recycling of construction materials is the process of reusing construction waste generated during the dismantling or reconstruction of structures. This process is of utmost importance for Ukraine in the context of large-scale infrastructure reconstruction after armed aggression. That is why the concept of "green" reconstruction should be based not only on the principles of energy efficiency, but also on the integration of construction waste recycling and disposal systems.

The most common types of building materials suitable for recycling include concrete, brick, wood, metals and glass. For example, concrete fragments, after being cleaned of reinforcement, can be crushed and reused as crushed stone for road works or foundations [4]. Metal elements (rebar, beams, pipes) can be melted down and further processed, while wood can be used as fuel or in the construction of temporary structures [5].

At the level of European standards, EU member states strive to achieve a recycling rate of construction waste of over 70% [9]. In Ukraine, according to experts, the recycling rate still remains significantly lower, although recently there has been a gradual increase in the number of initiatives in this direction.

In Ukraine, work is underway to develop practical recycling cases . As of 2024, several successful initiatives for recycling construction materials are operating in Ukraine. In particular, mobile crushing plants have been created in the Kyiv region to process the debris of damaged buildings, which are used to restore local roads [7]. Construction waste sorting points have been established in the Lviv and Chernihiv regions, allowing the separation of fractions suitable for reuse [3].

In addition, Ukraine has received international support in developing recycling infrastructure. In particular, the joint Ukrainian-German initiative BauCycle is being implemented , which introduces technologies for separating and sorting construction waste to obtain reusable materials [8]. Online platforms such as “Povtorno” are also emerging, allowing the exchange of construction resources between communities, contractors, and architects [4].

Recycling construction materials can significantly reduce waste, reduce the need for new natural resource extraction, and reduce the carbon footprint of construction [9]. For example, converting concrete into crushed stone requires significantly less energy than mining and transporting new material. According to preliminary estimates, the reuse of construction waste can reduce reconstruction costs by up to 20% compared to new construction [1].

It is also important to note that the development of the recycling industry creates new jobs, stimulates innovation, and allows communities to independently solve the problem of post-war reconstruction without excessive dependence on imported resources [9].

Thus, recycling of building materials in the context of Ukraine's reconstruction is not only environmentally appropriate, but also economically beneficial. Its implementation makes it possible not only to reduce the burden on the environment, but also to form a modern, innovative model of reconstruction taking into account European standards of sustainable development.

Technological aspects and challenges:

The process of recycling construction materials involves several stages: dismantling, transportation, sorting, crushing, cleaning and certification for reuse. The biggest technological problem is the low quality or mixed origin of construction waste, especially after military operations, where there are remnants of combustible materials, toxic elements or fragments of ammunition [9].

Another challenge is the lack of a single state standard or regulation regulating the use of recycled materials in capital construction. This significantly hinders the widespread implementation of such technologies, especially at the level of state reconstruction projects [7].

Recycling of construction materials is a key element of Ukraine's "green" recovery strategy in the context of post-war reconstruction. It allows not only to reduce the burden on the environment and save natural resources, but also to ensure the economic feasibility of reconstruction, involve local communities in the process, create new jobs, and reduce construction costs.

recycling practices requires the introduction of regulatory regulations, the development of infrastructure for the collection and sorting of construction waste, as well as the active involvement of foreign experience and innovative technologies. Against the backdrop of environmental challenges caused by the war, the recycling of construction waste becomes not only a technical task, but also a moral responsibility to future generations.

The integration of circular economy principles into the construction industry opens up new opportunities for sustainable development, increasing energy efficiency, and rebuilding Ukraine as a state that cares about the environment, safety, and quality of life of its citizens.

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PROSPECTS FOR REDUCING OF CO_2 EMISSIONS IN PORTLAND CEMENT PRODUCTION

Vadym Gonchar[1], Maryna Kochevykh [2], Olha Honchar[2], Dmytro Anopko[2]

[1]ARTIDEK LLC, vadimus-p@ukr.net

[2]Kyiv National University of Construction and Architecture, gonchar.oa@knuba.edu.ua

It would not be an exaggeration to call Portland cement the material that has shaped today's construction paradigm and determines the direction of the construction development for the next 15-25 years, at least. It is one of the leaders among materials that do not occur in the nature and that humanity produces artificially to meet its own needs. As of 2024, the total global production of Portland cement exceeded 4.1 billion tons, and showed a growing trend [1, 2].

A characteristic feature of Portland cement production is a significant CO_2 emission: depending on the raw materials and the technology used, CO_2 emission is placed between 0.657…0.822 tons per ton of Portland cement produced [3, 4, 5]. Taking into account the above-mentioned annual production volumes, it can be calculated that the annual CO_2 emission of the cement industry reaches 2.7…3.4 billion tons, which takes a significant 6.5…10% of the total annual anthropogenic carbon dioxide emission, that are estimated at 40…53 billion tons [6, 7, 8]. The data presented clearly demonstrate the urgent need to reduce the carbon footprint of the cement industry as a prerequisite for the green transition.

One of the important features of Portland cement production is the presence of two sources of carbon dioxide emissions. About 40...50% of the total amount is generated by fuel combustion, another 50...60% is released during the heating of carbonate raw materials [9, 10]. Therefore, emission reduction strategies can be divided into groups depending on the source of CO_2 emissions considered as an object.

The transition to modern energy-efficient technologies has already largely taken place. Replacing the wet process with a dry one, substituting of the ball mills with the vertical rotary mills, implementation of the pre-calciners, cyclone decarbonizers, and optimizing the length of furnaces have already led to a significant reduction in CO_2 emissions due to more economical fuel use [11].

Use of carbon-free or carbon-neutral fuels. Portland cement production traditionally consumes carbon-containing fuels. Switching to hydrogen, which does not produce CO_2 when burned, could potentially reduce emissions by the same 40% mentioned above. As an alternative to expensive and hazardous hydrogen, carbon-neutral fuels derived from biomass can be considered, all of the carbon in which has already been captured from the atmosphere, therefore, returning it back will not increase CO_2 levels in the air [12].

The use of oxygen (OxyFuel process), or enrichment of air with oxygen, also allows reducing CO_2 emissions by increasing the efficiency of fuel combustion and obtaining a high-potential heat carrier, which leads to reduced fuel consumption [13].

Utilization of low-potential heat and reduction of heat consumption is an obvious and potentially effective mechanism for reducing CO_2 emissions. The technological process of cement production is accompanied by the formation of a large amount of medium- and low-potential wasted heat, mainly in the form of gases with different temperatures, that are usually released out. It causes to losses of 30...40% of the generated thermal energy. Traditional heat exchange methods are ineffective for the utilization of that low-potential heat. However, the use of the modern heat pumps, in particular, the organic Rankine cycle, allows to increase the potential of the heat carrier for its reuse, or to convert heat into another form of energy, in particular, electrical [14, 15].

Transition to cements with reduced clinker content/clinkerless. This emission reduction strategy combines a whole group of diverse technologies. The first of them is the "dilution" technology. It involves reducing CO_2 emissions by decreasing of the content of Portland cement/clinker in cement via adding of the active or inert additives (pozzolans, ash, ground limestone). This solution seems obvious and can be implemented without significant changes in existing technological chains; therefore, it is being implemented most actively among others. EU Regulation No. 305 provides for a full transition to mixed cements by 2030 [16]. However, it should be noted that reducing specific CO_2 emissions per ton of finished cement by decreasing of the clinker content in cement does not affect to the CO_2 emission in the production process itself. That is, this strategy looks like rather an administrative activity than a technological solution. This also includes the use of alternative sources of calcium silicates/aluminates (metallurgical slags) to replace clinker: CO_2 emission for these materials have already occurred, but it was happened before, during their formation. That should be taken into account in calculations.

From a technological and materials science point of view, technologies aimed at reducing the calcium content in clinker (belite cements) are more interesting, as is the use of completely calcium-free binder systems (alkali alumina-silicate binders, geo-cement), the implementation of which will lead to a real reduction in CO_2 emission during the decarbonization of raw materials via reducing the carbonate content there.

The use of concrete as a CO_2 absorber is based on the concept that, from the point of view of thermodynamics, it is possible for CO_2 to interact with the products of hydration and hardening of Portland cement, up to the complete carbonization of all available CaO, without significant deterioration (and sometimes even with improvement) of the properties of concrete [17…19]. Theoretically, this approach allows to "return" to the cement stone all the CO_2 that was contained in the carbonate raw materials - and this, as is known, is up to 50% of the total CO_2 emission during cement production [9, 10].

Some of the above technologies are combined by a concept called **CCUS**: Carbon Capturing, Utilization and Storage, aimed at reducing the carbon load on the atmosphere through the effective capture and utilization of CO_2. A clear example of the implementation of this concept is the **HERCCULES** project, which is currently being implemented by a group of companies from Europe and Ukraine with funding from the European Union [20].

This project involves the reconstruction of two cement plants in Europe by:

• converting the pre-calciner to the OxyFuel oxy-combustion process, which will allow obtaining a concentrated CO_2 stream at the outlet;

• installing a compression and purification unit at the outlet of the pre-calciner. It is more efficient one than traditionally used liquid sorbent-based absorbers for capturing and refining most of the CO_2;

• switching to modern solid sorbents characterized with an improved regeneration ability to capture residual CO_2.

Thanks to the above measures, it is planned to ensure the efficiency of CO_2 capture at the level of 95…98% and to obtain liquid purified CO_2 with a purity of not less than 99.9%, which will allow it to be used as a liquid product.

The remains of unsold CO_2 will be used:

• for the manufacture of concrete goods by accelerated hardening under conditions of CO_2 saturation in carbonization chambers;

• for carbonization of crushed concrete with the subsequent use of carbonized product as an aggregate in the manufacture of ready-mixed concrete.

The totality of the above measures should lead to a significant reduction in CO_2 emissions into the atmosphere. Provided that biomass-based fuel will be partially used, and the resulting cement will be fully used for the manufacture of carbonized concrete containing carbonized aggregates, it is expected to obtain a negative emission value, which will be an impressive -150 kg per ton of clinker produced.

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ENERGY-EFFICIENT VENTILATION OF RESIDENTIAL BUILDINGS WITH CO_2-BASED CONTROL

Horbunov Bohdan Tarasovych

[1]*Kyiv National University of Construction and Architecture, ppp@knuba.edu.ua*

[2]*Private Entrepreneur "Bohdan Tarasovych Horbunov", horbunovbt@gmail.com*

INTRODUCTION

Modern construction is increasingly focused on the creation of energy-efficient buildings. In designing such houses, architects and engineers aim for maximum airtightness of the building envelope to minimize heat loss and maintain a stable indoor climate with minimal energy consumption. High-quality insulation materials, airtight windows, and doors are used to achieve impressive energy efficiency metrics.

However, in the pursuit of airtightness, one of the most important aspects is often overlooked — ventilation. In such airtight homes, uncontrolled air entry (through cracks, gaps, or open windows) is virtually absent. Without proper ventilation, indoor air quality deteriorates: CO_2 levels, humidity, and harmful substances increase, negatively affecting both the residents' health and the building itself. Therefore, controlled ventilation systems with heat recovery and CO_2-level regulation are becoming an integral part of a truly efficient, healthy, and comfortable home.

ENERGY-EFFICIENT HOUSE

An energy-efficient house consumes minimal energy for heating, cooling, and ventilation while providing a comfortable environment for its occupants. The key principles of energy efficiency are:

- Thermal insulation: Walls, roofs, and floors must be well insulated to reduce heat loss.
- Airtight construction: The building must be sealed without gaps or drafts that could let heat escape.
- Energy-saving technologies: Use of high-quality windows, energy-efficient lighting and appliances, and renewable energy systems (e.g., solar panels, heat pumps).
- Ventilation: An essential component that ensures indoor air quality with minimal energy loss. CO_2-based ventilation systems not only save energy but also support a healthy indoor climate.

CO_2-BASED CONTROL

A ventilation system that automatically regulates airflow based on CO_2 levels significantly reduces energy consumption. CO_2 is a reliable indicator of indoor air quality as its concentration correlates with the number of people and their activity level.

When CO_2 levels rise, it signals insufficient fresh air, prompting the system to increase ventilation. Conversely, lower CO_2 levels suggest fewer people or lower activity, allowing the system to reduce airflow, thus saving energy. This approach ensures comfort while optimizing energy usage, especially in residential settings where people are often inactive or absent for periods of time.

HEAT RECOVERY

A crucial element of energy-efficient ventilation is heat recovery — a process where the system captures the heat from exhaust air to pre-warm incoming fresh air. This greatly reduces heating costs.

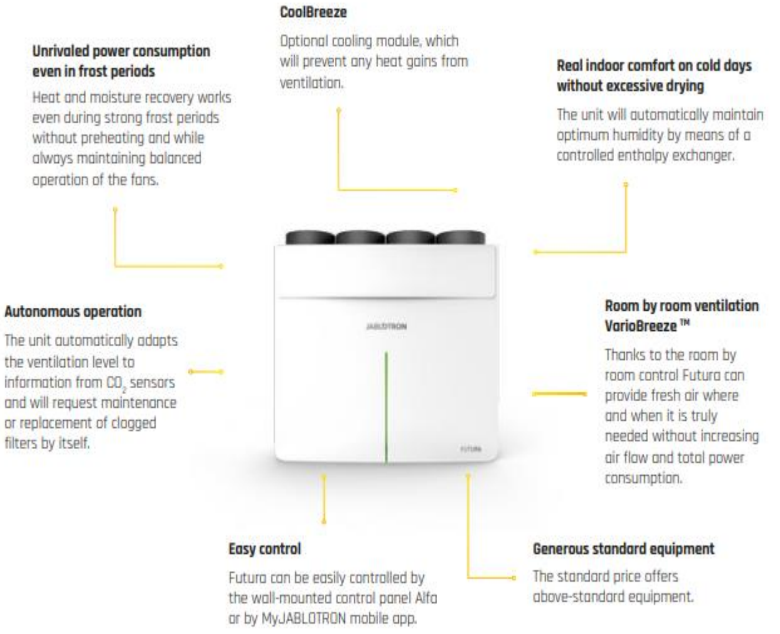
In the case of Jablotron Futura, heat recovery is achieved using a special heat exchanger that transfers heat from exhaust to incoming air, helping to retain indoor warmth even in cold weather.

Advantages of heat recovery:

- Lower heating costs: No need to fully heat fresh air from scratch.
- Comfortable indoor temperature: Maintains stable indoor climate, especially in winter.
- Environmental benefits: Reduces CO_2 emissions by lowering energy demand.

JABLOTRON FUTURA SYSTEM

Jablotron Futura is an innovative energy-efficient ventilation solution that integrates various technologies to reduce energy use while maintaining comfort.



Pic 1.Jablotron Futura installation diagram and description

The system automatically adjusts airflow based on CO_2 levels, avoiding unnecessary energy expenditure. It also features heat recovery to save on heating and cooling costs. All settings can be controlled via a user-friendly remote interface, making it an ideal and convenient solution for modern homes.

Jablotron Futura operates on a modular basis, allowing customization for specific room needs. It is equipped with sensors to monitor air quality and provide real-time data on indoor climate conditions.

PRACTICAL EFFICIENCY

Installing CO_2-controlled ventilation systems can significantly reduce energy consumption in residential buildings. Studies suggest that such systems can lower ventilation energy use by 20–30% compared to conventional systems that do not consider CO_2 levels.

In typical homes where occupants are not always present, CO_2-based regulation ensures fresh air only when needed, conserving energy while maintaining optimal humidity and temperature.

These systems are especially effective in large residential complexes or multi-apartment buildings where occupancy varies by time of day or season.

CONCLUSIONS

Implementing CO_2-controlled ventilation systems is a key step towards reducing energy use in residential buildings. The Jablotron Futura system exemplifies effective application of this technology, significantly lowering electricity costs, improving air quality, and ensuring a comfortable indoor environment.

Such systems are not only energy-efficient but also enhance residents' health by maintaining optimal CO_2 levels. Given growing demands for energy efficiency and environmental responsibility, CO_2-regulated ventilation is a crucial element for the future of residential construction.

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ENVIRONMENTAL RISKS IN THE TRANSPORT OF THE OIL AND GAS COMPLEX RAW MATERIALS AND PRODUCTS

Danylo Danylenko, Olena Kotovenko, Olena Miroshnychenko
Kyiv National University of Construction and Architecture,
ddanilenko81@gmail.com, kotovenko_ea@ukr.net, elenamiroshka@ukr.net

The oil and gas industry is one of the most important not only within the economy fuel and energy complex, but also in the economy functioning as a whole. Currently, due to military operations on the territory of Ukraine, the problem emergency risks in the entire oil and gas industry operation, especially oil pipelines, has become much more acute.

The armed aggression has affected the entire industry operations, resulting in negative GDP growth of 15% for production companies. As a result of the hostilities, the situation in the industry has deteriorated significantly, with gas production and transmission systems damaged.

At the same time, the world is increasingly paying attention to solving environmental problems that can be caused by nature itself (natural factors) or be of anthropogenic nature, with the latter factor gaining a higher status.

Ukraine's oil and gas industry is a complex system consisting of three subsystems (sub-sectors): oil production, transportation and refining. Oil production and transportation are powerful sources of pollution.

According to experts [1,2], the most environmentally hazardous and destructive pollution is associated with accidental spills of oil products and associated formation water during well drilling and the deposits opening with abnormally high reservoir pressure. The maritime transportation of oil products causes great damage to the ecological system.

Ukraine's oil pipeline network plays an important role in ensuring Ukraine's energy security. Special attention should be paid to ensuring these complex technical systems safe operation.

The most dangerous systems components are leaks of oil pipeline contents. Oil fractions are increased fire and explosion hazard source. Most accidents on oil pipelines occur as a result of wear and tear (more than 1/3 of oil pipelines have been in operation for more than 30 years) and internal corrosion. Statistics show that the specific frequency all types ruptures has increased from 0.131 to 0.247 cases per km per year. The average is 0.168 cases per year. The highest failures frequency is typical for oil gathering networks of fields.

Ground disturbance occurs during drilling of production wells and at the stage of field development. Accidents on pipelines (oil pipelines) primarily lead to soil contamination, with changes in their chemical composition, properties and structure. Soils are considered to be contaminated with oil and oil products if these substances concentration increases to a level that disrupts the ecological balance in the soil system, changes the morphological and physical and chemical soil horizons characteristics, changes the water and physical soils properties, disrupts the ratio between individual soil organic fractions matter, and reduces productivity.

The consequences of oil seepage in soils are as follows:

1) Changes in the chemical soil composition, changes in soil properties and structure. First of all, this affects the humus horizon - the carbon amount in it increases dramatically, but at the same time, the soil quality as a nutrient substrate for plants deteriorates. At the same time, hydrophobic oil particles interfere with the plant roots hydration, which leads to physiological changes in the entire plant.

2) Changes in the soil humus composition, which initially occur in the soil lipid and acidic components.

3) Sharp disruption soil microbiocenosis, inhibition photosynthesis in plant organisms, which primarily affects the development of soil algae.

The most promising method soil decontamination is the oil oxidation and oil products by soil microorganisms. There are two ways to clean up soils with the help of microorganisms: first, by activating the metabolic activity soil microflora through agrotechnical methods that contribute to changes in the physical and chemical the environment conditions; second, by introducing specially selected oil-oxidizing microorganisms into contaminated soil.

The main causes oil pipeline accidents accompanied by oil and oil product leaks are as follows:

- Mechanical oil pipelines destruction and related structures as a result internal pressure drops, external forces, metal corrosion and sudden temperature changes;
- Malfunctions pumping station equipment, both main and auxiliary;
- Malfunctions in the control systems of pipelines and pumping stations;
- Malfunctions in security systems;
- Violation pipelines welds and connecting flanges [3].

Therefore, today it is necessary to develop methods and tools for diagnosing and monitoring the technical main pipelines for oil and oil products condition. It would also be useful to define generalized requirements for assessment criteria that would be applicable without technical limitations. It should also be borne in mind that accidents on oil pipelines can lead to contamination of large areas.

Ensuring the trouble-free operation of pipeline systems is achieved through various approaches to assessing the corrosion and mechanical defects of pipe metal, the combination of which with the risk and safety assessment methodology will undoubtedly reduce the risk of accidents on main pipelines. Extending the service life and ensuring reliable performance of pipelines operating in modern conditions requires the development of a comprehensive method for assessing and forecasting their safe operation.

Therefore, the priority tasks for improving the environmental and technological safety Ukrainian the oil and gas complex are as follows:

- Improving the environmental monitoring system of oil and gas facilities, from fields and pipelines to gas and oil storage and production facilities, based on observations changes in the chemical composition the atmosphere and soil, their spectral and physical parameters

- Development a methodology for assessing the impact scale of destruction main pipelines and the size leaks on the formation pollution areas
- Development an automatic system for diagnostics and forecasting of the pipelines condition
- Development scientific foundations and continuous environmental audit organization at oil and gas transport infrastructure facilities.

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RECLAMATION OF MINING AND CHEMICAL ENTERPRISE TERRITORIES FOR GREEN CONSTRUCTION AND RENEWABLE ENERGY PURPOSES

Vladyslav Dzhumelia, Elvira Dzhumelia, Orest Kochan

Lviv Polytechnic National University, elvira.a.dzhumelia@lpnu.ua

Introduction. As a result of the long-term activity (1956-1996) of SE “Rozdil mining and chemical enterprise “Sirka”” various wastes were formed on its territory, which are sources of ecological danger [1, 2], in particular:

- lump sulfur – 700 m^3;
- flotation tailings – 85 million tons;
- sediments of recycled water – 1.29 million m^3;
- phosphogypsum – 3 million tons;
- oil tars (illegally imported from Hungary in 2004) – 17 thousand tons;
- solid household waste – 560,000 m^3.

After the closure of industrial operations, the enterprise’s territory was transformed into a complex technogenic landscape characterised by environmental instability. The absence of a systematic approach to post-operational reclamation and the maintenance of waste accumulation facilities exacerbates the risks of long-term environmental pollution. At the same time, modern approaches to spatial planning, green construction, and the implementation of circular economy concepts enable a rethinking of the future functional use of such areas.

In this regard, there is growing interest in the utilisation of such degraded sites for green and renewable projects, particularly the establishment of phytoremediation buffer zones, recreational landscapes, renewable energy facilities (solar and wind power plants), and nature-based wetland systems. The implementation of such approaches is especially relevant in the context of limited availability of free land resources and the need to comply with environmental standards in line with European post-industrial land management practices [3].

The aim of this study is to assess the environmental condition of the former mining and chemical enterprise site for the further development of a comprehensive concept for its reuse, considering the principles of environmental safety, sustainable development, and the integration of green infrastructure and renewable energy.

Results and Discussion. The results of the environmental analysis of the former mining and chemical enterprise territories indicate the presence of significant and persistent sources of anthropogenic pollution, which require continuous monitoring and specialized environmental protection approaches for reclamation. In the aquatic environments, exceedances of the maximum permissible concentrations of indicators such as sulfates, chlorides, and ammonium nitrogen have been recorded, indicating the ongoing impact of residual technological and household waste. Signs of soil degradation have also been detected, caused by acid drainage formed as a result of the oxidation of sulfur-containing compounds. Given the complex technogenic nature of the pollution, there is a real threat of secondary environmental contamination in the absence of waste containment and isolation systems [4-6].

For the environmentally safe and feasible reuse of the territory, a comprehensive approach has been proposed, combining nature-oriented solutions with the implementation of renewable energy technologies. This approach is structured into three main directions:

1. Green Buffer Zones and Phytoremediation. First and foremost, the creation of buffer landscape elements in the form of shelterbelts, green plantings, and bio-isolation corridors is advisable. These will act as natural barriers between the residual pollution sources and adjacent territories. The use of plants with a high capacity for phytoremediation (e.g., willows, poplars, miscanthus) ensures the gradual reduction of heavy metal content, residual sulfur compounds, and nitrogenous forms in the soil. This approach will also foster the formation of new ecosystems and the stabilization of the local microclimate.

2. Hydrological Management and Purification. Given the presence of flooded quarries, technogenic lakes, and unorganized surface runoff, particular attention should be paid to the systematic management of hydrological processes. It is proposed to establish drainage systems with elements of natural filtration, which utilize bioremediation mechanisms based on sludge platforms and wetlands. Additionally, the technogenic water bodies should be rethought – they can be transformed into bioengineering reservoirs with selective isolation of bottom sediments and the use of hydrophytes for natural water purification.

3. Placement of Renewable Energy Facilities. One of the promising directions for the reutilization of degraded territories is the implementation of renewable energy projects. Specifically, areas that are unsuitable for agriculture or residential development can be utilized for the installation of ground-mounted solar power plants (SPPs). At the same time, lakes formed in the locations of flooded quarries could serve as platforms for floating solar power plants, which would also help reduce water evaporation. Additionally, the potential for using open spaces for the installation of wind power plants (WPPs) should be highlighted, which requires further wind energy zoning and assessment of the region's microclimatic characteristics [7].

Regardless of the chosen trajectory of use, a key safety condition is the implementation of a continuous environmental monitoring system. This system should include the monitoring of water quality, soil condition, atmospheric air, noise levels, as well as the dynamics of changes in phytotoxicity and radiation background. Monitoring should be viewed not only as a control tool but also as the basis for decision-making in waste management, land planning, and ecosystem reconstruction.

The proposed approach to reclamation and further use of the territory not only reduces the environmental burden but also ensures its integration into modern models of green construction and circular economy.

Conclusions. The territory of the former Rozdil Mining and Chemical Enterprise “Sirka” holds significant potential for transformation into an ecologically balanced zone within the framework of modern green construction concepts. By integrating phytoremediation techniques, hydrological management, and the implementation of renewable energy solutions, it is possible to repurpose hazardous industrial landscapes into functional spaces that maintain a minimal environmental footprint. This approach not only addresses the immediate risks associated with contaminated and degraded areas but also provides a sustainable model for the development of industrial sites in line with principles of circular economy and sustainable development. Furthermore, the successful transformation of this site could serve as a benchmark for the ecological restoration of similar abandoned or contaminated sites across Ukraine, contributing to national efforts in environmental rehabilitation and green infrastructure development.

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GREEN BUILDING AS A KEY TO ENVIRONMENTAL SAFETY IN THE CITIES OF UKRAINE

***Diachenko Khristina*[1]*, Lytvynenko Oleksandr*[2]**
[1,2]Kyiv National University of Civil Engineering and Architecture
kristidyachenko07@gmail.com

1. Relevance

Due to global climate change and the need to reduce the negative impact of the construction industry on the environment, green construction is becoming a priority area for urban development in Ukraine. Today, urban development accounts for a significant share of CO_2 emissions and consumption of natural resources. In recent years, Ukraine has made significant steps towards the introduction of environmental technologies in construction, but the level of green construction still lags significantly behind European standards.

2. Definition and basic principles of green building

Green building is an integrated approach to the design, construction and operation of buildings, aimed at minimizing the negative impact on the environment. Its main principles include:

• Energy efficiency – reducing energy consumption due to modern insulation methods, the use of renewable energy sources and innovative energy saving technologies.

• Use of environmentally friendly materials – the use of natural, safe for health and recycled building materials.

• Optimization of water use – introduction of systems for collecting and reusing rainwater and wastewater to reduce water consumption.

• Landscaping of urban areas – creation of green roofs, vertical landscaping of facades, as well as the use of natural ventilation mechanisms to improve the microclimate of buildings.

This approach contributes to reducing the environmental burden of cities, increasing living comfort and efficient use of natural resources [1].

Fig 1. Green roof [1]

3. The main environmental challenges of Ukrainian cities and the role of green building

The main environmental threats faced by Ukrainian cities are:

• Air pollution – most of the emissions come from residential heating and industrial enterprises using outdated technologies.

• High energy consumption – according to the International Energy Agency (IEA), buildings in Ukraine consume 2-3 times more energy per unit area than in EU countries.

• Reduction of green spaces – urban development displaces natural ecosystems, which worsens air quality and contributes to the greenhouse effect.

• Construction waste – in 2022, more than 20 million tons of construction waste were generated in Ukraine, a significant part of which is not recycled.

The use of green building principles allows minimizing the impact of these factors by integrating energy-efficient and environmentally friendly solutions into urban development [3].

4. International experience and problems of ecological cities in the world

Green cities have become an important component of the global strategy for sustainable development. However, even in countries where green initiatives are actively developing, there are certain problems. Including:

1. Low level of implementation in practice. In many developed countries, such as the United States, Germany and the United Kingdom, despite the developed legislative and financial framework, there are difficulties in implementing the principles of green construction due to the high cost of investment, especially for private developers.

2. Conflicts of interest between environmental and economic goals. In some cities (for example, in the USA and China), there is a contradiction between the need to reduce CO_2 emissions and the need for economic growth, which leads to delays in the implementation of "green" projects.

3. Lack of available finances. While green building is becoming an important part of international policies, many countries, especially in South America and Asia, still face a lack of resources to fully implement these initiatives. This includes both limited funding and high costs for environmentally friendly technologies.

4. Social inequality and accessibility for the general population. In many cities, where environmental initiatives are implemented mainly in wealthier areas, there is often a problem of social inequality in access to environmentally friendly housing and infrastructure.

Given these challenges, it can be argued that the successful development of green cities requires an integrated approach that includes not only technological and financial innovations, but also social inclusion and interaction at all levels – from local communities to governments [2, 5].

5. Key Green Building Technologies and Their Impact on Environmental Safety

Modern green building technologies are aimed at reducing resource consumption, reusing materials and creating a comfortable microclimate. The main environmental solutions are shown in Table 1.

Table 1

The main technologies of green building and their impact on environmental safety

Technology	Principle of operation	Environmental effect
Green roofs and walls	Use of vegetation on buildings	Improving air quality, lowering temperatures in cities (heat island effect)
Energy-efficient facades	Use of thermal insulation materials	Reducing heat loss, reducing energy consumption
Water collection and reuse systems	Use of rainwater for technical needs	Reducing the consumption of drinking water, reducing the load on the city sewerage system
Renewable energies	Solar panels, wind turbines, geothermal pumps	Reducing dependence on traditional energy carriers, reducing emissions CO_2

Recycling of building materials	Use of Recycled Materials in Construction	Reducing waste, reducing the consumption of natural resources

6. Green Building Certification

There are various certification systems for green buildings in the world: LEED (USA), BREEAM (Great Britain), DGNB (Germany) and others. Certification in accordance with international standards is also being developed in Ukraine. For example, the Astarta Organic Business Centre in Kyiv received a BREEAM certificate, confirming compliance with the principles of sustainable construction [4].

Fig 2. House model [4]

7. Ukrainian context: problems and prospects

Despite the prospects, the spread of green construction in Ukraine is hampered by:

1. Lack of an effective legislative framework.
2. High cost of implementing environmental technologies.
3. Insufficient support from the state and municipalities.
4. Low awareness of developers and consumers about the benefits of green buildings.

To overcome these problems, it is necessary:

• Implement economic incentives for developers (tax benefits, grants, government support programs).

• Strengthen legislative regulation in the field of energy efficiency and construction waste processing.

• Promote environmental certification among developers

8. Conclusions

Green building is an important tool for ensuring the environmental safety of Ukrainian cities. Its implementation helps to improve the quality of life of the population, reduce energy consumption and reduce the negative impact of the construction sector on the environment. For the effective implementation of green technologies, state support, the development of financial mechanisms to stimulate and raise public awareness of the benefits of green construction are necessary.

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LEGAL FRAMEWORK FOR OVERCOMING THE CONSEQUENCES OF HOSTILITIES USING GREEN BUILDING METHODS

Vladyslav Yegorov
Kyiv National University of Construction and Architecture,
egorov.1977@email.ua

It is important to note that the priority for Ukraine's recovery is believed to be compliance with the values and standards of the "green economy." Thus, on April 22, 2022, the National Council for the Restoration of Ukraine from the Consequences of the War was established [7]. At the same time, the need for "green recovery" was also declared in a unified position by Ukrainian public associations.

Researchers emphasize that Russia's invasion of Ukraine has created economic preconditions for accelerating the implementation of the European Green Deal in various areas, including agriculture. The objective of this agreement is to transform Europe into a climate-neutral space by 2050, when a fundamentally new model of agricultural production based on sustainable organic and carbon farming practices is expected to emerge. According to the researchers, under such conditions, the least developed countries, as well as developing ones, will hypothetically increase the production and export of their own agricultural products. It is important to note that one of the fundamentals of the agreement is the abandonment of inefficient production. Instead, there should be industries where waste from one production should become a raw material for another.

Thus, according to the researchers, the "green" model of post-war economic recovery in Ukraine should also be based on the creation of high-tech industries that will be competitive in domestic and foreign markets. Several principles are noted on which such a recovery model should be based. Among these principles, attention is drawn to the following: integration of environmental and climate policy into all sectors; the country's recovery should serve the needs of Ukrainians and contribute to Ukraine's sustainable development; development of a green economy; setting environmental standards at all levels; commitment to European methods of environmental planning for Ukraine's recovery; and increasing the role of local government, transparency and involvement of the public and communities in the decision-making process; effective functioning and use of targeted/donor funds for post-war recovery and development of the “green” economy [10, p.345,347].

At the same time, some researchers see compliance with the standards and values of the green economy, and thus ensuring the implementation of green construction as a basis for overcoming the consequences of the numerous destructions caused by the war, as possible through a number of legal acts and agreements. Among them are, first of all, the UN Charter, the Universal Declaration of Human Rights (1948), the Covenant on Civil and Political Rights (1976), the Declaration of the Stockholm Conference on the Environment (1972), the Convention on Environmental Impact Assessment in a Transboundary Environment (1981), the Convention on Biological Diversity (1992) and other international acts and agreements. The general legal framework may include the Laws of Ukraine “On State Assistance to Business Entities”, “On Public-Private Partnerships”, “On Industrial Parks”, partially the Law of Ukraine “On the Improvement of Settlements” (2005), Articles 1-4 and Section VIII of the Commercial Code of Ukraine on the establishment of various special economic regimes. All of the above regulations, agreements, laws and the Code enshrine mechanisms of state assistance, support, and stimulation of certain types and types of economic activity [8, p.81; 5].

According to the researchers, at this stage, there is a need to develop a comprehensive program and algorithm of actions for environmental assessment and restoration of agricultural land. Depending on the degree and nature of the contamination, land restoration measures may include mechanical tillage, soil improvement by fertilization, or cleaning with sorbents. More complex reclamation methods are also possible, involving the dismantling of fortifications and the transfer of fertile soil to the disturbed areas. Some areas, in particular those close to the contact line, where a wide range of munitions were used (and continue to be used) contain an increased level of contamination with substances, debris, and explosive objects, the cleanup of which will require a long period of demining and cleanup. Consequently, there is a need to conserve such sites, which is a rather complicated problem from a legal and economic point of view. This difficulty, according to researchers, is compounded by the fact that most agricultural land contaminated by military operations is now privately owned. At the same time, the legislation does not contain an effective mechanism for land conservation, especially when such actions involve the need to seize land from the owner to withdraw it from use. Therefore, it is necessary to legislatively regulate the issue of land conservation, as well as to identify sources of compensation to owners of contaminated land [2, p.46].

According to researchers, the legal problems of restoring damage from the consequences of hostilities include the availability of methods for compensating for damage from the consequences of military emergencies. This problem is proposed to be solved at the legislative level, by developing and adopting an independent methodology for assessing damage from the consequences of military emergencies or by amending existing government decisions, which contain, in particular, inconsistencies with later legislation, in particular, some articles of the Forest Code of Ukraine (29.03.2006), which provides for the division of forests by environmental and socio-economic significance into protective forests, recreational and health, nature protection, scientific, historical and cultural purposes and exploitation. [3,p.185].

Researchers draw attention to the fact that Ukrainian legislation contains tools for the post-war restoration (reproduction) of natural resources. Among them, attention is drawn to the processes of conservation and reclamation [1, p.179]. These processes include technical assessment of the territory affected by hostilities in order to determine the scope of work, types of work and resource requirements; removal of remnants of hostilities, mines and explosive devices from the affected territories; cleaning the territory from debris, destruction and other materials. It also includes the restoration and reconstruction of infrastructure; soil and landscape restoration, which includes the restoration of soil and vegetation cover and the organization of a drainage system. Cleanup can also be carried out by removing and disposing of the contaminated fertile soil layer, washing the soil [6, p.157-158].

The next natural step, according to the researchers, is the need to reforest, alkalize degraded and man-made contaminated lands, create flora, forestry, and wildlife. This list of actions is defined as a mandatory component of post-war restorat ion. At the same time, in addition to the need to develop national programs to restore the environment and its natural resources, it is also important to join European and international environmental programs. Among these programs is the European LIFE program, which was adopted in June 2022. This program is defined as an EU funding instrument for environmental and climate activities. It can provide Ukraine with financial revenues to accelerate the implementation of the tasks of ecological restoration of the territories of Ukraine and ensure environmental and resource security [1, p.185].

At the same time, the program stipulates that, subject to participation, the state of Ukraine and/or Ukrainian legal entities must make operational and membership contributions. The operational contribution is calculated as the ratio of the gross domestic product (GDP) of Ukraine at market prices to the GDP of the European Union at market prices. The market prices to be applied are determined by the Commission's special services on the basis of the most recent statistical data available for budget calculations in the year preceding the year in which the annual contribution is to be paid. If the contribution is not made, Ukraine may be notified of the suspension of this agreement. The agreement states that Ukraine's participation in this program is also subject to constant monitoring by the European Commission. Separate rules on the use of EU funds are set out in a separate annex to the agreement, these rules are aimed at financial control and anti-fraud. It`s also important to emphasize that in recent years, as a result of hostilities, Ukraine's GDP has significantly declined, which has significantly changed its ratio to public debt (to which the European Union pays special attention) [4].

These circumstances affect the adjustment of Ukraine's contributions to the program.

The annexes to the agreement provide for the possibility for representatives of the European Commission and the European Anti-Fraud Office (OLAF) to obtain access to all information, premises, works and documents of an individual/legal entity and third parties receiving funding from the European Union in accordance with paragraphs 1, 2 of Article 1, and paragraphs 1-13 of Article 2 of Annex 2 to the agreement on sound financial management. Article 3 of this annex provides for the reimbursement of claims (if any) from the European Union by the government of Ukraine. And the judicial review of disputes is provided for in paragraphs 2.3 and 3 of Article 3 of the Annex to this agreement. Article 4 of the Annex separately regulates the provision and exchange of information and documentation on the use of funds related to the conclusion of contracts and agreements provided for the implementation of this program[9].

In summary, many researchers believe that in the long term only a “green economy” can be the basis for ensuring the continuous development of states based on more efficient resource and energy consumption, reducing harmful environmental impact and developing a socially integrated society. The implementation of such plans in Ukraine, in the context of post-war reconstruction, will depend on solving a number of interrelated financial and, above all, legal problems (contradictions), the solution of which will significantly revitalize the attraction of financial resources to the process of overcoming a number of environmental problems and the ukrainian lands reclamation.

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DEVELOPMENT OF ECOLOGICAL TRANSPORT AND GREEN BUILDING IN URBAN PLANNING

Zyhun Alina [1], Nikolaienko Dmytro [2], Pleshynets Artem [3]
[1,2,3] *National University "Yuri Kondratyuk Poltava Polytechnic",*
alinazygun@gmail.com, [2] dmitriynikolayenko3185@gmail.com, [3] artem121197333@gmail.com

The challenges of the 21st century arise at the global level, affecting social processes, climate and nature at many levels of human existence, which directly affect the state and well-being of a person. Climate change, depletion of natural resources, urbanization pressure, military escalation and challenges of sustainable urban development require revisions in the approach to the formation of strategic programs for the development of urban planning. The latest aspects and methods of approaches in the integration of urban development and urbanization are the development of environmentally balanced transport systems and the introduction of "green" technologies in urban design. The introduction of ecological transport and environmentally efficient architecture should become the latest tools for the formation of sustainable development of the urban environment in Ukraine.

The concept of sustainable development proposed in the "Brundtland Report" provides a system for meeting the needs of the population without threatening future generations [1]. In the context of urban planning and the urban environment, this concept applies such aspects as environmental, economic and social aspects of the population's life. At the same time, green technologies that are introduced in urban spaces of cities, buildings and structures are considered as a priority-neutral approach to climate and microclimate formation in cities, which contributes to a comfortable life.

Cities in which environmentally friendly transport systems are introduced, review the current state of the entire electrification of the city with appropriate measures for repairs and restoration of electrical substations. Such systems are introduced with the aim of decarbonizing city mobility, urban public transport and installing facilities for servicing electric cars, which, in turn, allows to reduce the level of greenhouse gas emissions and exhaust gases, and reduce the level of noise pollution in the urban environment. At the same time, institutional instability and fragmented planning limit the scale of their implementation.

Green building embodies the concept and the latest approaches. The main criteria that are observed and envisaged at the design stage of buildings and structures are energy efficiency and the use of renewable energy sources. The result is the achievement of the maximum level of energy efficiency and resource conservation after the commissioning of buildings with the assignment of the appropriate energy conservation class. Compliance with ergonomics when designing water, electricity and ventilation systems allows you to reduce the carbon footprint of building materials, which, in turn, minimizes the negative impact on the environment after commissioning.

The implementation of the principles of Transit-Oriented Development (TOD) provides definitions and mechanisms for interaction between environmentally friendly transport and green construction, which ensures the integration of the city with an increase in the quality of life, reduction of energy consumption and preservation of the natural environment by reducing the consumption of natural resources [2]. The integration of the urban environment is based on the compact development of medium and small cities, in particular, these are buildings with service provision, office and business centers. The use of green technologies contributes to improved human perception of the environment. One of the advantages is the equalization of economic potential between communities. Accordingly, this concept creates a holistic structure of the system of sustainable development of urban spaces, the integration of spatial planning with a reduction in energy consumption.

Modern certification in Ukraine requires a thorough review of assessment methods and approaches to the examination of the latest technologies that are being introduced in the country and used in modern building projects. Green construction, in turn, necessarily goes through inspection systems and quality certification systems, in particular BREEAM, LEED, DGNB and WELL. These standards cover verification of compliance with European standards, such criteria as energy efficiency of buildings, the impact of microclimate on the environment and human space, water and electricity-saving technologies, comfort and environmental assessment of building materials, etc. For example, in Germany, new real estate projects undergo mandatory Passivhaus certification of the required criteria when buildings are put into operation. In Ukraine, such approaches are just beginning to develop.

Given the need to modernize urban space in the context of post-war reconstruction, Ukraine has a unique opportunity to implement the principles of green construction and reach a new level of urban urbanization. It is advisable to introduce TOD principles at regional levels and stimulate sustainable construction along with these aspects. Include them in the master plans of cities that need to be updated, develop a map of transport decarbonization and the current state of urban pollution, create a legislative framework for assessing and criteria for the impact of construction on the environment. Strategies and programs for comprehensive community and post-war reconstruction are being actively implemented in Ukraine with the participation of European communities and investment banks. In particular, comprehensive measures developed and approved at the regional level are in Poltava region, in the territory of Myrhorod district [3]. The general plan includes the regulation of priorities taking into account the opinion of the local population, protection of the environment and natural resources, spatial planning and land use, protection of cultural heritage, development of transport and engineering infrastructure [3]. At the beginning of the full-scale invasion, bicycle infrastructure became a key aspect of mobility and a support for critical infrastructure workers in the absence of public transport, which became a guarantee for the provision of humanitarian, medical and professional assistance. This challenge contributed to the creation of the Myrhorod Bicycle Infrastructure Development Program until 2027, which is included in the Comprehensive Recovery Program.

The experience of European countries demonstrates the realized possibilities of an integrated urban environment, where ecological transport and energy-efficient architecture interact with many criteria of sustainable development. For example, in Copenhagen, 60% of the population uses bicycles. This trend of bicycle infrastructure exists due to the organization of urban space by the authorities and initiatives of the local population, compliance with a large number of criteria for the organization and integration of urbanism between cities and small communities, where a large number of enterprises are based, where jobs for the local population exist within walking distance [4]. In November 2020, the Vancouver City Council approved the Climate Emergency Action Plan (CEAP) - a five-year strategy containing six main directions and 19 specific actions. The main goal of the plan is to reduce carbon emissions by 50% by 2030 [5].

A comprehensive approach to implementing the development of ecological transport and green construction at the state level in the formation of sustainable development with integration into the urban planning policy of Ukraine will contribute to the development of the population's life at a completely new level. Decarbonization, noise reduction, resource economy and ergonomics will become a guarantor of environmental safety, which will contribute to the harmonious development of man in a society where it is important to involve inter-sectoral cooperation, state bodies, communities and developers with scientific institutions.

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THE IMPORTANCE OF RECREATIONAL RESOURCES FOR LOCAL COMMUNITIES

***Mariia Ilina*[1]**

[1]*Institute of demography and life quality issues of the National Academy of Sciences of Ukraine, maria_ilina@ukr.net*

Recreational resources in bordering areas make a special impact on the development of local communities, since touristic views attract visitors who add to municipal budgets and energize inhabitants' everyday lives. In the case of natural areas' designation, recreation, tourism and leisure activities astonishingly assist to protect the environment and conserve wildlife species.

The comprehensive approach is to study the recreational activities carried on transboundary or frontier natural reserves comparatively. This study concerns the cases of the East Carpathian Biosphere Reserve, situated on the three-border edge of Poland, the Slovak Republic, and Ukraine, and of the Iguazu Falls, located on the border of Argentine and Brazil. The descriptive approach is applied to depict the spatial status and routes of the locations, and key economic and financial indicators of the nature reserves are analyzed.

The East Carpathian Biosphere Reserve is a transboundary-protected area that was designated as an area having worldwide importance in accordance with the UNESCO Program on Man and the Biosphere. The Biosphere Reserve's area is 2,13 sq km, including 1,09 sq km in Poland, 408 sq km in the Slovak Republic, and 0,59 sq km in Ukraine. The reserve was originally established as a Polish–Slovak transboundary reserve in 1992. In 1998, it was extended due to the inclusion of the Ukrainian part. Thus, the East Carpathian Biosphere Reserve became the first trilateral biosphere reserve globally [1].

It consists of the three national parks and the three landscape (nature) parks in the three neighboring countries (Fig 1):

- In Poland: Bieszczady National Park (*Bieszczadzki Park Narodowy*) and the two neighboring landscape parks – Cisna-Wetlina (*Ciśniańsko-Wetliński Park Krajobrazowy*) and San Valley (*Park Krajobrazowy Doliny Sanu*);

- In Slovakia: Poloniny National Park (*Národný Park Poloniny*) and the around areas;

- In Ukraine: Uzh National Nature Park (*Natsionalnyi Pryrodnyi Park Uzhanskyi*) in Zakarpattia region, and Nadsianskyi Regional Landscape Park (*Regionalnyi Landshaftnyi Park Nadsianskyi*) in Lviv region [2].

UNESCO declared the Iguazu Falls as a World Heritage Site in 1984, and reaffirmed their exceptional universal value in 2013 [3]. The two parts of the Iguazu Falls Site lie on the opposite banks of the Iguazu River. The Iguazu Falls consists of the two national parks in two neighboring countries (Fig 2):

- In Brazil: the Iguazu National Park (*Parque Nacional do Iguaçu*) in Foz de Iguazu city,

- In Argentina: the Iguazu National Park (*Parque Nacional Iguazú*) in Puerto Iguazu city.

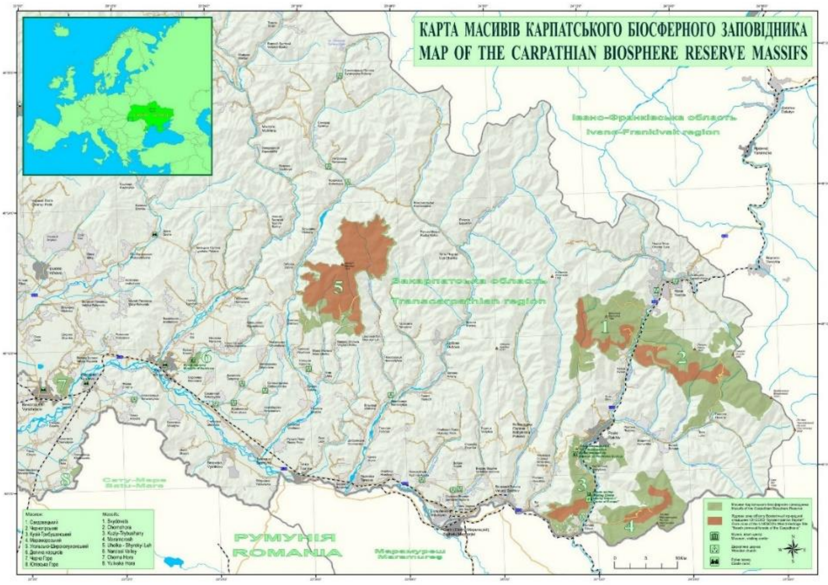

Fig 1. Carpathian Biosphere Reserve [2]

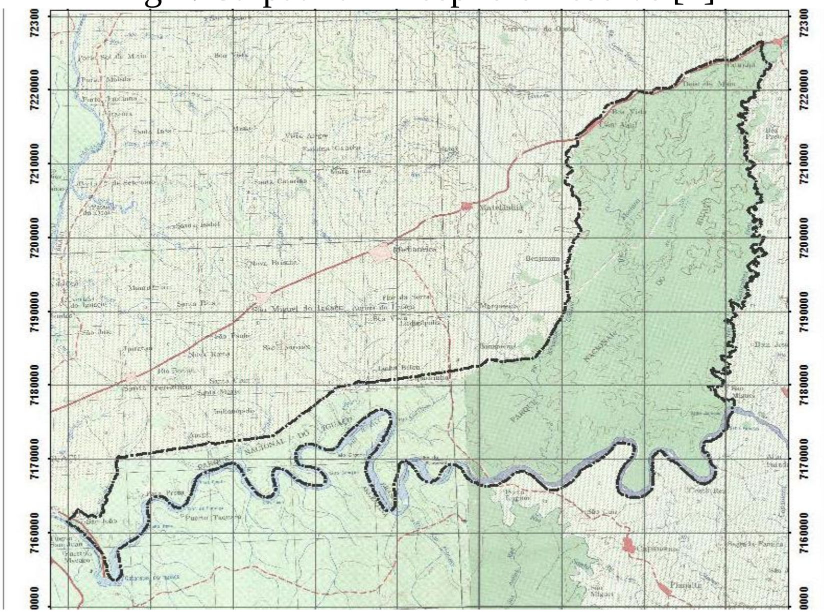

Fig 2. Iguacu Falls natural reserves [3]

The site has an area of 2,53 sq km – 0,68 sq km on the Argentine side and 1,85 sq km on the Brazilian side. Both Argentina and Brazil declared the National Parks almost at the same time – Argentina in 1934 and Brazil in 1939. In 1981, Brazil expanded the Park’s area and established new boundaries. The park is part of the proposed Trinational Biodiversity Corridor, which seeks to establish forested connections between conservation areas in Brazil, Paraguay, and Argentina. Even more, to the southeast of the park, it borders the Urugua-í Provincial Park that was created in 1990 and has an area of 84 hectares. The main viewpoint of the National

Parks is the Iguazú Falls. Guided tours, site viewing, boat riding, hiking and bird-watching routes near the falls, and scenic helicopter flights are the principal activities and attractions of the Falls [4]. The Falls attract over 1.5 million tourists annually, both foreign and domestic, and is the third largest tourist destination in Brazil [5].

The study reveals certain differences and similarities in how tourism and leisure go in the East Carpathian Biosphere Reserve and the Iguazu National Park, and the industry's impact on local economies has been assessed and specified. It proves the idea that large transboundary and bordering natural parks and reserves impact significantly on local economies and make great impulse for the development of frontier communities. The location of a natural park or reserve within a community's area is the substantial economic and social advantage, since tourism and leisure activities generate more revenues for local budgets. Moreover, the study provides extra and indirect evidence for earlier considerations that bordering communities usually have better opportunities for development compared to inner provinces.

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ON THE USE OF ALTERNATIVE GAS IN UKRAINE'S ENERGY SECTOR

Antipov Yevhen[1], Franchuk Yuriy[1], Klapchenko Vasyl[2], Kuznetsova Irina[2]

[1]National University of Life and Environmental Sciences of Ukraine,
term_chair@nubip.edu.ua, franchuk196405@gmail.com
[2]Kyiv National University of Construction and Architecture,
klapchenko.vi@knuba.edu.ua, kuznetsova.io@knuba.edu.ua

Ukraine is following the course of the European Union countries, aimed at gradually reducing dependence on fossil energy sources from 96% to 75% and increasing the share of renewable sources from 4% to 25%. In its Energy Strategy [1], it intends to achieve this result through the development of renewable energy sources and the modernisation of energy transmission systems. An important component of the Strategy is the use of biogases (e.g. biomethane) obtained from the biomass of household, industrial and agricultural waste and hydrogen extracted in nature or obtained artificially. Today, Ukraine's potential for biogas production is, according to the Strategy, 21.8 billion m^3/year. First of all, this will affect the cleanliness of the environment, reduce greenhouse gas emissions and ensure decentralization of energy generation, which is very important. But the economic effect for Ukraine seems even more important.

European countries plan to reduce greenhouse gas emissions to zero and become a climate-neutral continent by 2050. To this end, the EU plans to increase biogas production from 4.2 billion m^3/year in 2023 to 35 billion m^3/year in 2030 and to 90-125 billion m^3/year in 2050. At the same time, Ukraine can take up to 20% of the European biomethane market, produce more than 20 billion m^3/year of biomethane and attract up to 40 billion euros of investment in this industry. The state receives jobs, foreign exchange earnings from the sale of biomethane and significant revenues to the country's budget.

Within Ukraine, existing infrastructure should be used to deliver biogas to consumers. Ukraine has extensive gas transportation and distribution systems. This significantly simplifies the delivery of biogas to consumers; it can be downloaded into the existing gas network, saving significant funds on the development and modernization of individual systems. The existing gas networks of Ukraine are designed to supply consumers with more than 100 billion m^3 of gas.

State regulation should stimulate producers of all types of artificial and alternative gases so that they aim to supply the produced gas to the gas transportation system for financial gain. Thus, the Law of Ukraine "On the Natural Gas Market" [2] allows the supply of biomethane provided that it "in its physical and technical characteristics complies with the regulatory and legal acts on natural gas." Then, for all market participants in the provision of these services, the main question will arise - gas production technologies and technological regulations for transportation must be agreed upon. The quality of biogases must be acceptable for the safe operation of gas equipment, including for the use of these gases as motor fuel.

The current documents, in general, do not contradict each other and generally determine the quality of gas fuel transported by networks [3-5]. For this purpose, we present a comparative Table 1.

Table 1

Comparison of gas quality requirements in different regulatory documents

№	Indicator	Codes of GTS, GDS	Technical regulations (project)	DSTU EN 16726:2019
1	Relative density	no requirement	min 0.555 max 0.700 (0.750)	min 0.555 max 0.700

2	Methane content, mol.%	min 90	no requirement	no requirement
3	Ethane content, mol.%	max 7	same	same
4	Propane content, mol.%	max 3	same	same
5	Butane content, mol.%	max 2	same	same
6	Pentane content, mol.%	max 1	same	same
7	Nitrogen content, mol.%	max 5	same	same
8	Carbon content mol.%	max 2	max 2.5 or 6.0 for GDS	max 2.5 or 4.0
9	Oxygen content, mol %	max 0.2 GTS	max 0.2	max 0.001
		max 1.0 GDS	max 1.0	max 1.0
10	Hydrogen content, mol %	no requirement	max 0.5 або 5	no requirement
11	Higher combustion heat (25°C / 20°C) - minimum	36.20 MJ/m^3 (10.06 kW·h/m^3)	no requirement	As for the calorific value, the requirement is partially defined in EN 437:2018.
	- maximum	38.30 MJ/m^3 (10.64 kW·h/m^3)		
12	Lower combustion heat (25°C/ 20°C) - minimum	32.66 MJ/m^3 (9.07 kW·h/m^3)	no requirement	
	- maximum	34.54 MJ/m^3 (9.59 kW·h/m^3)		
13	Wobbe number, kW·h/m^3	no requirement	min 13.4 max 16.1	There is no requirement for the Wobbe number
14	Methane number	no requirement	no requirement	min 65
15	Dew point (°C) at a pressure of 3.92 MPa	does not exceed minus 8°C	does not exceed minus 8°C	does not exceed minus 8°C at pressure up to 7 MPa
16	Dew point (°C) at a gas temperature not lower than 0 °C	does not exceed minus 0°C	does not exceed minus 0°C	does not exceed minus 2°C

Hydrogen may be a promising component from an environmental point of view that can be used to replace fossil methane. It is obtained both artificially (by splitting water into hydrogen and oxygen) and extracted from natural sources. Artificial production of hydrogen is a complex process that is accompanied by greenhouse gas emissions. Identifying large natural reserves could be a breakthrough in clean energy technology. New research suggests that there may be huge reserves of natural hydrogen in mountain ranges that remain untapped.

In many countries of the world, regulatory documents define permissible limits of hydrogen in mixtures with natural gas. In Ukraine, the content of hydrogen in networks has not been regulated as an indicator for a long time. For the first time, such information appeared in the draft Technical Regulations of 2024 [4]. The use of hydrogen was considered in works [5-8] (Table 2).

Table 2

Maximum permissible concentration of hydrogen in gas networks

Country	Netherlands	Germany	France	Spain	Austria	Switzerland
H_2, % vol	12	10	6	5	4	4
Country	Italy	Sweden	Belgium	Great Britain	Japan	Ukraine
H_2, % vol	3	0.5	0.1	0.1	0	Undefined

The conducted analytical and experimental studies determine the range of restrictions on the hydrogen content in gas networks from 7 to 19% (in mole fractions). The restrictive conditions in the composition of a multicomponent gas mixture, taking into account the numerical values of the regulatory requirements for the main gas indicators, can be determined using the corresponding formulas [6, 7]. In particular, the most stringent restriction (7%) is introduced by a decrease in the combustion heat of the gas mixture [5].

Requirements for gas quality when used in internal combustion engines differ somewhat from the requirements of the Code of GTS [5] (Table 3).

Table 3

Basic requirements for gas quality for internal combustion engines

№	Indicator	Value
1	Lower specific heat of combustion, MJ/m^3, not less	31.8
2	Relative density (compared to air)	0.55-0.70
3	Calculated octane number (by motor method), not less	105
4	Hydrogen sulfide concentration, g/m^3, not more	0.02
5	Mercaptan sulfur concentration, g/m^3, not more	0.036
6	Weight of mechanical impurities in 1 m^3, not more	1.0
7	Total volume fraction of non-combustible components, %, not more	7.0
8	Volume fraction of oxygen, %, not more	1.0
9	Water vapor concentration, mg/m^3, not more	9.0

It is expected that by the end of 2030, about 25% of public transport in large cities of Ukraine will operate on electric motors, hydrogen fuel or biogas. And by 2033, it is planned to increase the amount of such public transport to 50% [2]. This will definitely bring Ukraine closer to European environmental standards.

The technology of generating electricity from natural gas is simple and well-developed. More active use of gas compared to coal allows not only to simplify the technology, but also to reduce logistics costs and improve the environment. The development of electricity generation from natural gas can solve the problem of balancing the power system in emergency situations. In particular, the disintegration of energy generation sources reduces the risk of the power system being disabled during military operations.

The use of combined energy is promising: "natural gas plus hydrogen" and "natural gas plus biomethane". These technologies are being actively implemented in European countries. Biomethane can be used as fuel for motor vehicles and local production of electrical energy.

The Ukrainian gas transportation system can be considered as the basis for the development of decentralized balancing gas generation of electricity. Such a branched, maneuverable system will allow working in conditions of energy shortage and its surplus, it will ensure the storage of excess energy with subsequent use during peak consumption hours.

Despite the overall positive effect of using hydrogen and biomethane, there is still a wide field for detailed studies of the influence of such gas mixtures on the transport properties of networks, throttling processes at gas distribution points, and the stability of materials in gas networks and gas equipment.

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SUSTAINABLE PRODUCT DESIGN AS AN IMPORTANT CRITERION FOR USING RECYCLED MATERIALS IN PVC PROFILES TO IMPROVE ENVIRONMENTAL IMPACT.

Kozhevnikov Sergii[1], Bereznitska Yuliia[2]

[1]Kyiv National University of Construction and Architecture, slondie7@gmail.com

In today's environment of growing polyvinyl chloride (PVC) waste, finding effective environmental solutions in the construction industry is of particular importance. PVC profiles, which are widely used in window and door systems, have a long life cycle, but once they reach the end of their useful life, they create a significant environmental burden. Although PVC recycling technologies are already being implemented, the effectiveness of their application largely depends on the initial approach to product design.

The concept of sustainable design involves developing products with a view to subsequent disassembly, recycling, and minimizing harmful environmental impact. However, in actual practice, these principles are often ignored due to technological or economic barriers. That is why it is extremely important to study the role of sustainable design in creating conditions for effective recycling of PVC profiles. This allows not only to reduce the amount of waste but also to make recycling more cost-effective and environmentally friendly.

In the context of the transition to a circular economy and the tightening of environmental legislation in Ukraine and the EU, developing new approaches to product design with a view to its further recycling is a strategically important task.

For a deeper understanding of the concept of sustainable product design as a factor that directly affects the formation of environmental principles, we should first consider the concept of sustainable development in general and its basic principles and trends.

Sustainable development is the concept of a harmonious combination of economic growth, social welfare and environmental protection, taking into account the needs of both present and future generations. It was officially formulated in 1987 in the Bruntland Report “Our Common Future”. In the global context, the UN Sustainable Development Goals (SDGs), adopted in 2015, are the basis for sustainable development. They cover 17 key areas, including poverty eradication, clean energy, responsible consumption, climate change and biodiversity conservation.

In the European Union, sustainable development is the foundation of policy. It is being implemented through the European Green Deal, which envisages the transition to a climate-neutral economy by 2050, the development of a circular economy, organic agriculture, digital transformation, and a just social transition. [1]

Thus, in Europe and the world, sustainable development has become not only an ethical norm, but also a strategic policy direction that shapes the future of humanity and the planet. Among the basic principles of the global concept of sustainable development, we are interested in the area of circular economy, responsible consumption, and environmental safety.

Now let's move on to the question of how product design can affect the overall environmental burden, what factors it affects, and what consequences it can cause. Let's analyze the concept of sustainable product design.

Sustainable Product Design is a design methodology that does not harm the environment. It is an approach to product development that takes into account **environmental, social, and economic** aspects at all stages of the product life cycle, from material selection to disposal. It takes into account the impact on nature and human health throughout the product's life cycle. Thus, the realization concerns resource-saving production processes, a long service life or time of use, and, most importantly for us, a reliable recycling concept.

Let's look at the example of plastic window profiles, which are made primarily of PVC. Figure 1 shows two sample window profile systems that are made and designed according to different product design principles. Profile system 1, shown on the left, does not contain recycled PVC (recyclate) and is designed and extruded* using virgin PVC. In contrast, the profile system on the right is more modern and has been designed and extruded in accordance with modern sustainable product design principles and contains recycled PVC (recycled). In the European Union, there are no strict regulations on the minimum or maximum content of recycled PVC (recycled content) in window profiles. However, there are industry initiatives and environmental standards that encourage manufacturers to increase the share of recycled content in their products.

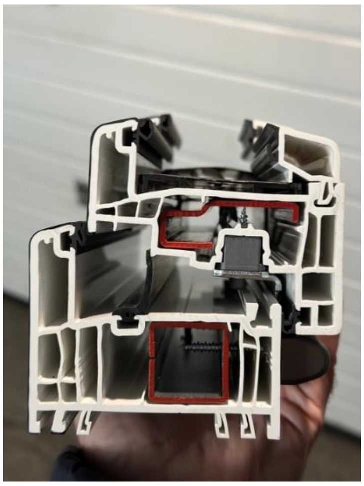
Although there is no mandatory minimum percentage of recycled content in the legislation, many manufacturers are voluntarily implementing its use. For example, GEALAN uses 40% to 60% recycled PVC in its LINAER line of window profiles. Technologically, it is possible to produce window profiles from 100% recycled PVC and some manufacturers of profile systems have already started producing such systems. [6]

The European VinylPlus® initiative brings together more than 200 PVC product manufacturers who voluntarily commit to reducing their carbon footprint and ensuring full recycling of the material. The Recovinyl program, part of this initiative, contributed to the recycling of more than 810,000 tons of used PVC in 2022, with a target of 900,000 tons by 2026. [4]

Although European legislation does not set specific limits for the content of recycled PVC in window profiles, industry initiatives and environmental standards encourage manufacturers to increase the use of recycled content. This contributes to the development of a circular economy and reduces the environmental impact of window system production. [3]

If sustainable design is considered in the context of the use of PVC profiles for their subsequent successful recycling, the following important factors should be noted. Correctly designed PVC profiles in the concept of sustainable design should:

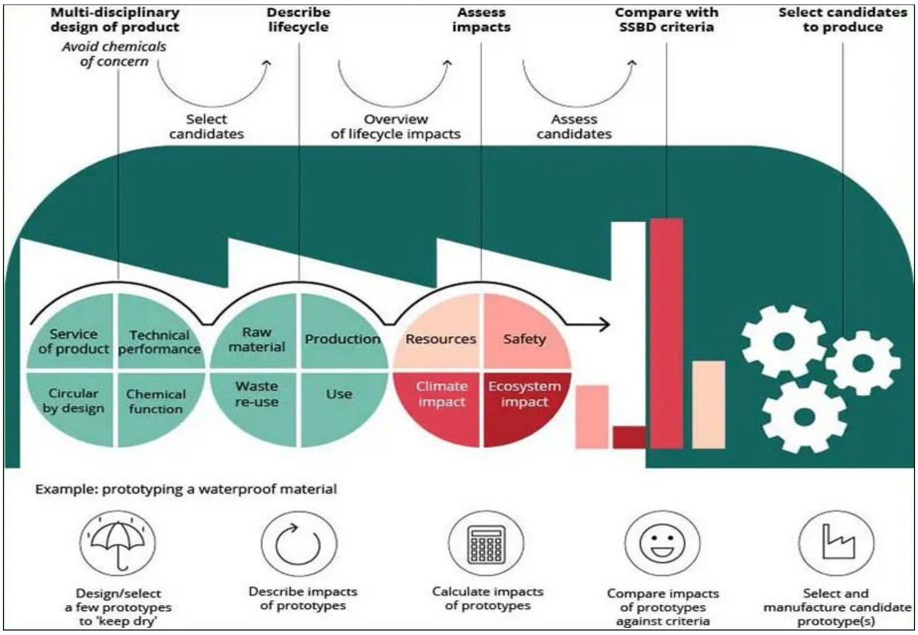
- can be easily disassembled for sorting materials,
- contain recycled PVC without loss of quality,
- have less toxic additives or heavy metal substitutes,
- are compatible with existing recycling systems of various types and methods.



1. PVC profile without the addition of recycled PVC (recycling)

2. PVC profile using recycled PVC (recycling)

Fig. 1. Examples of profile window systems



This approach should support the circular economy and help the construction industry reduce its environmental impact.

Implementing and properly designing for recycling has an impact on the development of materials and products because it is where the foundation for resource-saving products and processes is laid. Taking into account the entire product life cycle, future recycling scenarios need to be considered at the design stage. According to EPPA, this is a big issue for plastic windows. Windows in use today will only return to the cycle in 30-40 years. Because the return periods are too long, no one knows if and how the requirements might change during this time."[2]

* Polyvinyl chloride (PVC) profile extrusion Polymer extrusion is a method of forming products or semi-finished products of unlimited length by forcing polymer melt through a forming head (die) with channels of the required profile.

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ENVIRONMENTALLY ORIENTED APPROACH TO MANAGING THE DEVELOPMENT OF THE CONSTRUCTION COMPLEX

Zhukova O.G., Korduba I.B., Trush I.G.

Kyiv National University of Civil Engineering and Architecture

The constant global deterioration of the environment dictates the need to use only those innovations in the construction sector that can improve the quality of life of citizens without harming the biosphere. The purpose of this study is to develop a construction management system that guarantees a comfortable and safe existence of people in harmony with nature.

The crisis in the construction industry, which is reflected, in particular, in the uncertainty of current regulations, the lack of adequate control by government agencies over the construction process (for example, the transition to self-regulatory organizations has led to a situation where "every man for himself"), the desire for profit to the detriment of the high quality of the construction project, as well as many other negative processes, requires a fundamental rethinking of the existing construction management system and the definition of new development goals. In the context of environmental degradation, the development of the construction industry as the basis for the formation of the human environment should take into account the significant increase in environmental requirements for construction facilities and technologies for their construction. Therefore, only those innovations that can ensure the required level of environmental quality should be implemented and developed.

The ecological paradigm of construction sector development, known as Green Building, is gaining momentum in the world. Green building focuses on solving the problems of the quality component of the construction of facilities by applying advanced environmental technologies in urban planning, design, construction, use and liquidation of buildings, covering all stages of the life cycle of buildings and structures.

The use of such technologies helps to reduce the negative impact of the construction industry on the environment and human health. The introduction of green technologies reduces air and water pollution, saves natural resources, improves the comfort and safety of indoor spaces, and leads to better health of residents and employees, as well as increases their work efficiency.

Among the economic benefits that manifest themselves at the stage of operation of green buildings are the following:

- reduction of energy costs (power consumption, water consumption, heat supply, etc.);
- increase in the attractiveness of the facility for consumers and tenants;
- improvement of the image of a construction company focused on the construction of ecological housing;
- reduction of costs for medical care of employees and their insurance;
- reduction of fines for violation of environmental safety standards in the construction of facilities;
- spread of environmental technologies will lead to an increase in their use.

Energy efficiency, as a cornerstone of green building, aims to minimize the costs of both maintaining the functioning of buildings and manufacturing building materials. In addition, modern, energy-efficient structures and buildings are generally designed using environmentally friendly materials that are not only safe for the health of residents but also provide for the possibility of further processing and multiple reuse.

The Green Building Certification System is used to professionally evaluate a construction project in terms of implementing green technologies and determine its appropriate quality. The certification process is based on a rating system, where the final result is based on the total number of points scored according to the established criteria. These criteria cover various aspects of green technologies, including landscape design, use of renewable energy sources, use of energy-efficient materials and structures, improved thermal insulation and ventilation of buildings, and other important characteristics.

The objects subject to management are developers, design and contracting companies, as well as individuals engaged in individual housing construction. It is these entities that make decisions regarding the technical and technological side of construction projects and can be held fully responsible for non-compliance with standards and damage to the ecosystem.

Management impacts are tools aimed at achieving management goals. These include the issuance of regulations at the regional level that set minimum technical requirements for facilities, contributing to a more rational use of resources. Another tool for promoting environmentally oriented construction is the development of a system of “incentives and penalties.” This involves penalties for developers, design and contracting organizations for non-compliance of the constructed facility with the established technical and environmental standards, as well as a bonus system in the form of preferential taxation, energy payment benefits until the energy-saving technologies are paid off, subsidies and grants, and simplification of the procedure for registering land for construction (provided that the project meets the established requirements).

The task of management is to prevent the destruction of the construction sector system, society, and ecosystems through innovative progress based on an ecological approach to the implementation of construction projects.

According to the established mechanism, the management system represented by the state structures for control and supervision in the construction industry determines technical and environmental standards for participants in the construction process (construction companies). A system of sanctions and incentives for contractors should be envisaged to ensure the best possible compliance with the established standards.

The managed system (construction organizations) has an impact on the ecosystem in the course of its activities. At the same time, the management system should assess the impact of planned and implemented construction projects on the environment and, depending on the state and changes in the ecosystem, adjust management impacts on construction organizations. In other words, it provides for strict control over construction production processes by authorized bodies with an assessment of the environmental impact of the processes taking place and, if necessary, adjustments to construction projects.

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GREEN CONSTRUCTION AND TECHNOLOGICAL INNOVATIONS: TRENDS AND PROSPECTS

Koturanova Tetyana, Koturanova Irina
NNI "Pridniprovsk State Academy of Civil Engineering and Architecture" UDNT
t.v.koturanova@ust.edu.ua

Today, green construction and innovation are gaining increasing momentum. Sustainable development in the construction sector is becoming increasingly important in the context of growing environmental pressure. Green construction is a set of design, architectural, and engineering solutions that minimize the negative impact on the environment at all stages of a building's life cycle [1].

Modern technologies are developing rapidly, and this trend does not bypass the construction sphere. In recent years, it has been observed how innovations are transforming the construction industry, making it more efficient, safer, and environmentally sustainable.

The goal of green construction is to reduce the consumption of resources (energy, water, materials) and the emission of harmful substances by using environmentally safe technologies and materials. Architectural design is focused on energy saving, a comfortable environment, and preserving the natural balance.

Innovative Environmental Technologies and Materials Include:

- The use of renewable energy sources (solar panels, wind turbines, hydro systems).
- The use of natural and recycled building materials (wood, stone, clay, cork, plant-based adhesives). Today, green buildings are spreading all over the world. They are built from environmentally clean materials of natural origin, free from toxic substances. The number of such buildings is increasing every year.
- Recycling and waste disposal technologies — not a novelty, but a necessity for preserving natural resources and eliminating waste. Many materials can be recycled and reused. This field has been developing recently due to the shortage of some resources.
- The implementation of energy-efficient heating, ventilation, water supply, and sewage systems.

The Design of Sustainable Architectural Objects Takes into Account:

- Minimal interference with the natural landscape.
- Greenery on façades and rooftops has become a trend today — it not only decorates buildings but also adds more greenery.
- Integration of green zones into the urban environment.
- Creation of buildings with low energy consumption.

For example, buildings with zero energy consumption and carbon neutrality are designed to produce as much energy as they consume, and sometimes even more. In construction, this is achieved through the use of energy-efficient green technologies and renewable energy sources that fully cover the building's energy needs.

One example of such an object is the office building of the Sustainable Energy Foundation in the USA with an area of 1,394 sq.m., which generates more than 130% of the energy it requires. Compared to similar buildings, it consumes 75% less energy [3].

In Economic and Social Aspects, Green Buildings Contribute to:

- Reducing operating costs.
- Improving air quality and microclimate.
- Raising the standard of living and health of the urban population.
- Developing the green economy and construction innovations.

Today, energy efficiency is a key success factor, meaning that green buildings that help significantly reduce energy consumption are considered successful. The most effective strategies for decarbonizing buildings are passive design principles (using renewable energy sources and effective thermal insulation) and energy-efficient equipment.

It is also important to use eco-materials in construction — durable and low-maintenance materials; and to follow the circular economy approach.

For example, smart glass — glass that changes transparency to regulate the amount of light and heat entering a room. This glass helps maintain a stable temperature inside: in summer it protects from heat, eliminating the need for air conditioning, and in winter it lets in more sunlight, allowing savings on heating [2].

Or low-carbon concrete, consisting of 80% coal ash without compromising its characteristics. Prototypes of concrete beams made with this type of concrete meet technical and environmental standards. This solution reduces the use of traditional Portland cement and enables the effective use of millions of tons of ash accumulating at coal-fired power plants [3].

As for the Development Prospects of Green Technologies their implementation is becoming a global trend. Increasing public awareness, regulatory support, and technological progress contribute to the scaling of green construction as a sustainable model for the development of cities of the future.

Future technologies are already changing the construction market today, offering solutions that increase the efficiency, safety, and environmental friendliness of processes. Drone technologies, 3D printing, smart materials, modular construction, green technologies, and artificial intelligence — this is only the beginning of the path toward fully digital and automated construction processes.

Innovations continue to evolve, and soon we may witness even more radical changes in architecture and urban planning.

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ECONOMIC EFFICIENCY OF GREEN CONSTRUCTION IN UKRAINE

Andrii Kocherhan[1], Tetiana Tkachenko[2]

[12]Kyiv National University of Construction and Architecture

The modern construction sector of Ukraine requires the implementation of solutions that allow for cost optimization and increased market competitiveness. The main goal of this study asserts that green construction ensures economic efficiency through reduced operational costs, lower energy consumption, and the attraction of investments in high-tech industries. The introduction of environmental technologies creates a favorable environment for the development of innovations that can ensure sustainable economic growth of the country.

Economic instability, rising energy prices, and increasing energy efficiency requirements necessitate the transition to new construction technologies. Green construction serves as a powerful tool for resource conservation, as reduced energy consumption and cost optimization help to decrease the financial burden both for property owners and for the state budget. At the same time, the implementation of such technologies stimulates the development of related industries and creates new jobs. [1]

To analyze the economic efficiency of green construction, the following methods are proposed:

Economic Modeling: NPV and ROI for the evaluation of green technologies

Economic modeling helps assess the financial feasibility of implementing green technologies in construction, specifically:

• Net Present Value (NPV):

• Calculated as the difference between the present value of cash flows (revenues) from the investment and the initial costs.

• If NPV > 0, the investment is profitable; if NPV < 0 – economically unfeasible.

• In construction, NPV is used to evaluate the effectiveness of implementing energy-efficient materials, renewable energy sources (solar panels, heat pumps), technologies for reducing water consumption, etc.

• Return on Investment (ROI) Analysis:

• ROI = (Net Profit / Investment Cost) × 100%

• Measures the efficiency of the invested funds and determines how quickly they will pay off.

• For example, if solar panel installation costs $50,000 and saves $10,000 per year, ROI = (10,000 / 50,000) × 100% = 20% annually.

• Used to compare traditional and ecological solutions based on financial indicators.

NPV and ROI allow for making informed investment decisions, forecasting economic benefits, and evaluating the feasibility of long-term projects in green construction.

Показник	Index	Unit	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Первісні інвестиції	Initial investments	$	-650 000										
Операційний грошовий потік	Cash Flows from operating activities	$	116 116	136 300	135 993	135 687	135 382	112 564	112 311	112 058	111 806	111 555	
Чистий грошовий потік	Net Cash Flows	$	-533 884	136 300	135 993	135 687	135 382	112 564	112 311	112 058	111 806	111 555	
Сукупний грошовий потік	Cumulative Cash Flows	$	-533 884	-397 584	-261 591	-125 904	9 478	122 042	234 353	346 412	458 218	569 773	
Ставка дисконтування	Discount rate	%											3,8%
Чиста теперішня вартість	Net Present Value (NPV)	$											379 398
Внутрішня ставка доходності	Internal Rate of Return (IRR)	%											18,7%
Строк окупності	Payback period	years											4,9

Drawing 1. Economic modeling results using green construction [2]

SWOT analysis helps assess the internal and external factors influencing the application of ecological solutions:

• Strengths:

• Reduction in operational costs (energy, water, heating).

• Increased market value of buildings.

• Compliance with international environmental standards (LEED, BREEAM).

• Improved quality of life for residents (healthy microclimate, clean air).

• Weaknesses:

• High initial investment cost.

• Need for specialists and new technologies.

• Longer payback period compared to traditional technologies.

• Opportunities:

• Government support programs and subsidies for ecological technologies.

• Growing demand for certified “green” buildings.

• Development of new materials and technologies that reduce CO_2 emissions.

• Potential to attract international investment in the green construction sector.

• Threats:

• Price volatility of eco-materials and equipment.

• Strict regulatory requirements and possible fines for non-compliance.

• Conservatism in the construction industry and low awareness of green technology benefits.

SWOT analysis helps develop strategies to minimize risks and effectively utilize opportunities for implementing green technologies.

Financial Modeling: Economic Development Scenarios Considering Energy Consumption and Investment:

• Financial modeling enables forecasting the economic impact of implementing ecological technologies based on various factors.

Main components of financial modeling:

• Current cost analysis: Evaluation of energy, water, heating, and building maintenance costs.

• Scenario planning:

• Optimistic scenario: Active implementation of ecological technologies → cost reduction → fast payback.

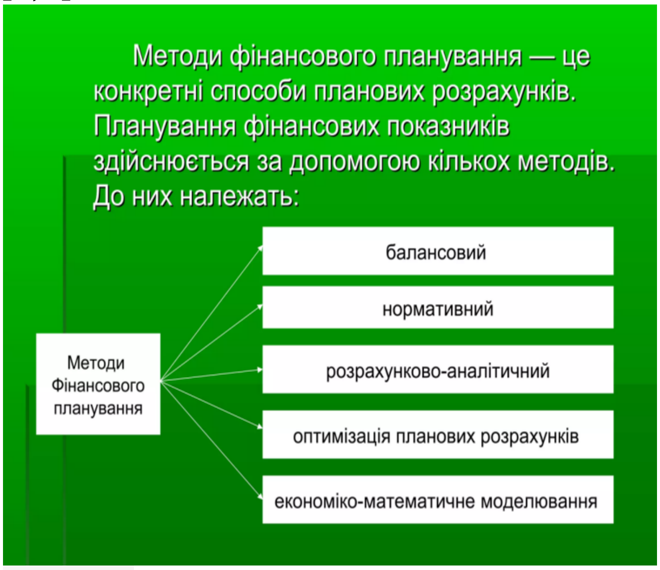
• Baseline scenario: Partial implementation → moderate savings.

• Pessimistic scenario: No changes → high resource costs → risks for investors.

• Investment risk assessment: Analysis of changes in material costs, electricity and water supply tariffs.

• Payback forecasting: Calculation of return periods based on reduced operational costs and government subsidies.

Financial modeling helps construction companies, investors, and government agencies evaluate the effectiveness of ecological solutions, make long-term strategies, and minimize risks. [3;4]



Drawing. 2. Financial planning methods [6]

Hypothetically, with effective integration of green technologies in construction, operational costs could be reduced by 25–35% over the next decade. Previous research indicates high potential for investment in this field, contributing to the development of related industries and the creation of high-tech jobs. Modeling of economic indicators shows that even with moderate investments, the implementation of green construction can yield significant economic benefits, forming a foundation for stable growth. [5]

Thus, the economic efficiency of green construction opens new prospects for the modernization of Ukraine's construction sector, reducing costs and stimulating innovative development.

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WAYS OF EFFECTIVE USE OF MINERAL WASTE FORMED DURING THE DESTRUCTION OF BUILDINGS AND STRUCTURES

Pushkarova Kateryna [1]***, Kochevykh Maryna*** [2]***,***
Honchar Olha [3]***, Hlumakov Ilya*** [4]
Kyiv National University of Construction and Architecture
pushkarova.kk@knuba.edu.ua[1], *kochevykh.mo@knuba.edu.ua*[2],
gonchar.oa@knuba.edu.ua[3], *hlumakov.io-2024@knuba.edu.ua*[4]

The amount of infrastructure destruction in Ukraine as a result of the Russian invasion exceeds 100 billion USD, and the largest share of destruction falls on industrial and civil construction facilities [1]. As a result of the large-scale destruction of infrastructure during the war, Ukraine faced an acute problem of recycling and using construction waste, the volume of which is approximately 10...12 million tons and is constantly increasing [2]. Also, one of the negative consequences of the war was a significant deterioration in the state of the environment and living conditions of the population.

Demolition waste differs from construction and demolition waste in that it is mixed in the rubble with substances that cannot be reused and therefore requires very careful sorting by hand or mechanical means. After sorting, materials that can be reused are determined, among which the largest share is made up of mineral components – concrete, ceramic bricks and glass.

Therefore, an important task is to develop effective ways to recycle and reuse such construction waste, which allows solving the problems of rebuilding the destroyed infrastructure and housing stock of Ukraine. According to [3], the management of demolition waste is a set of organizational and technical measures and works (operations) carried out to ensure environmentally safe collection, transportation, sorting, storage, processing, utilization, removal, neutralization and disposal of such waste.

The volume of concrete rubble among the products of destruction of buildings and structures is about 50%. According to the Law of Ukraine on Waste Management [4], destroyed concrete can be used as a raw material for the production of coarse and fine aggregates for concrete (class up to C20/25), as well as crushed stone-sand mixtures for the arrangement of base layers and road surface without the use of binders; the arrangement of highway embankments; as materials for backfilling (relief restoration, filling of mining operations (voids), reclamation of waste mining sites, other landscape works), as well as a secondary material resource for the production of Portland cement clinker.

Broken brick can be used as a raw material for the production of coarse and fine aggregates, as well as crushed stone-sand mixtures for the arrangement of base layers and road surface coverings, aggregate for gabions, as a material for the arrangement of a drainage cushion in wetlands, and a material for strengthening dirt and forest roads [5].

It is worth noting the possibility of obtaining recycled aggregate from the products of concrete and ceramic brick destruction. The general production process for obtaining recycled aggregate consists of the following stages: selection of a suitable source material, assessment of its suitability, collection of waste and its transportation to a processing point, crushing (using hydraulic hammers, crushers), screening of aggregate to identify unwanted residues, fractionation using sieves. In the case of using mobile units for processing (crushing and sorting) broken concrete at the place of waste generation, it is possible to exclude the transportation process, as well as long-term storage with the use of useful land.

The use of recycled aggregate in the composition of concrete opens up prospects for the creation of new construction projects while reducing the consumption of raw materials and energy. Thus, when obtaining aggregate from concrete, fuel consumption is 8 times lower than when it is extracted in natural conditions, its cost is approximately 5 times lower, and the cost of concrete on secondary aggregate is reduced by 25% [6].

But it should be noted that recycled aggregate is heterogeneous in composition and properties, depending on the type of concrete products from which it is obtained and the method of their processing. This is what determines the possibility of using only 75% of construction debris after dismantling the building [7]. It has been shown that the strength of concrete on secondary aggregate is 20% lower than the strength of its analogue on natural aggregates. The possibility of increasing strength can be achieved by increasing the cement consumption (up to 10%). But even in this case, the production of concrete on crushed stone is two times cheaper than the production of concrete on natural aggregates [8].

It has been established that the products of crushing spent concrete contain 20% of aggregate grains of fraction 20...40 mm and 40...50% of fraction 5...20 mm in their mass, crushed stone has a developed surface, is characterized by increased water absorption (up to 10%), which leads to an increase in water consumption for the production of concrete mix. But to solve this problem, a superplasticizer is usually used, as well as pre-treatment of the aggregate with water repellents.

The peculiarities of the properties and heterogeneity of aggregate from concrete prevent its widespread use in structural concrete (the highest replacement level is set at 50%), but allow it to be used in non-responsible structures and decorative concrete. When using aggregate of small fractions (more than 30%), a deterioration in the operational properties of concrete is noted [7].

The ways to obtain high-quality concrete based on recycled aggregate (for example, for the restoration of the residential segment, the strength class of concrete should be C20/25) are as follows. Various methods of removing the solution from the surface of the crushed products (mechanical, chemical, thermal), as well as the selection of the recipe for new concrete using new generation superplasticizers, microfillers (to reduce shrinkage), and finally, limiting the amount of recycled aggregate in the concrete composition. It is important to establish the properties of old concrete for a preliminary assessment of the quality of recycled aggregate, which guarantees the production of durable concrete with the necessary properties.

To prepare broken ceramic for use, the starting material is cleaned of unnecessary inclusions, then using a hydraulic hammer or perforator, large fractions of the material (up to 300 mm) are obtained, the next stage of grinding is carried out using a jaw crusher. Using special sieves, the brick crumb is divided into fractions: large – from 40 to 100 mm, medium – from 20 to 40 mm and small – less than 20 mm. A feature of the grinding product is a rather rough surface, and the open porosity corresponds to the porosity of the starting material [7].

Fractionated broken brick is used as an aggregate for concrete instead of a part of the more expensive granite aggregate (5-25%). It is also possible to use finely ground brick powder as part of cement mixtures, which allows saving up to 20% of clinker when using M400 cement. Broken brick can also be used as a fine and coarse aggregate in lightweight concrete, but a feature of this aggregate is the presence of a porous granular structure, which contributes to increased water absorption [8]. Coarse fractions of broken brick can be used in landscape design as the basis for garden paths – due to its bright color, broken brick is used to decorate building facades, create flower beds, alpine slides, and also when forming gabions for zoning the landscape.

International experience in construction waste management in each country has its own characteristics, but some general approaches and best practices can be identified. For example, according to German standards (DIN 4226-100), the composition and possibilities of using different types of regenerated aggregates in concrete are provided. Depending on the predicted conditions of use of concrete, concrete regenerated coarse aggregate (90%) and sand from it (10%), which have fractions larger than 2 mm and are characterized by a maximum water absorption of 10 wt.%, can be used in an amount of less than 45% of the total volume of aggregates in the composition of concrete operating under conditions of carbonization processes, and less than 35% when obtaining concretes of increased frost resistance.

One of the effective ways to use regenerated aggregates is to create gabion structures, which are divided into fortification (mobile and permanent defense systems), engineering (for regulatory and coastal protection structures) and decorative (in landscape design as retaining walls in places of elevation changes, to prevent deformation of slopes and terracing and zoning of the area, making fences, etc.) by functional criteria.

Gabion is a spatial mesh box-shaped structure consisting of a metal or polymer mesh (or geotextile) and can be filled with artificial stone (recycled aggregate), which must be resistant to moisture and weathering. The advantage of such a structure is its flexibility and ability to filter water, which allows you to reduce hydrostatic pressure and consolidate the soil. Such structures do not require a special foundation (such as concrete) and can be built at any time of the year without the use of specialized equipment. Not only recycled concrete rubble, but also brick chips can be used as fillers for technical gabions, ensuring the strength and reliability of the structure (usually the fraction size is 1.3 of the frame cell size). For military gabions, the filler must be sufficiently heavy and waterproof, the size of the filler does not matter, since it is held inside the mesh box by a dense membrane. For decorative gabions, ceramic brick fractions of 4…10 mm are most often used, smaller fractions – 2…4 mm and less than 2 mm can be used in landscape design.

Glass is a difficult-to-recycle product. Compared to concrete and ceramic brick recycling, glass recycling is a more complex process, the main stages of which include several stages of crushing and sorting to obtain a product of the required quality, sometimes a remelting process is necessary.

The most effective direction is the use of recycled glass in concrete [9]. There are many studies on the use of glass cullet as a pozzolanic additive. To obtain a high-quality recycling product, cullet is subjected to several stages of crushing and sorting by fractions and color. The most popular product is glass powder (fractions (0...50 μm, 0...100 μm, 0...180 μm). Such material can exhibit binding properties and participate in the synthesis of cement-based artificial stone, but when used, an uncontrolled reaction of the interaction of cement alkalis with silica may occur, which causes internal corrosion of concrete and affects the loss of strength over time.

The studies also show the possibility of using glass as a filler and fine aggregate in the case of controlling the alkali-silicate reaction. Thus, when replacing 60% of the coarse aggregate with secondary glass, the compressive strength of concrete increases from 17.3 to 26.8 MPa at the age of 28 days compared to the control analogue.

To reduce the impact of such a reaction, cements with a low alkali content should be used, the total amount of glass in the concrete composition should be limited, and fine-grained siliceous materials, such as microsilica and metakaolin, should be additionally added. The nature of the specified reaction, as well as the processes of hardening and strength gain, is also influenced by the color of the glass aggregate, which depends on the addition of various impurities to the composition of the original glass.

Given the current situation in Ukraine, the presence of large volumes of destroyed industrial and civil construction sites, it is extremely necessary not only to use traditional approaches to the utilization of crushed mineral substances, but also to search for new energy-saving technologies for their comprehensive utilization and processing, relying on new achievements in the field of ecology, building materials science, and civil engineering.

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THE ROLE OF PLANTS IN IMPROVING THE EFFICIENCY OF RAIN GARDENS: A SYNTHESIS OF RESEARCH AND RECOMMENDATIONS

Kravchenko Maryna[1], Shcherbak Andrii[1]
kravchenko.mv@knuba.edu.ua, *andron.vr@gmail.com*
[1]Kyiv National University of Construction and Architecture

The intensive development of urban areas is accompanied by a significant increase in the proportion of surfaces that cannot pass water into the soil, which significantly changes the hydrological balance of the urban environment. Impermeable coatings limit the infiltration of rainwater, contributing to the formation of surface runoff with increased volumes and velocity [1]. In such conditions, rainwater mostly enters centralised sewerage networks, which creates a threat of overloading hydraulic structures during heavy rains and provokes local flooding, pollution of river systems, as well as a decrease in the quality of water resources and access to them [2]. In addition, local surface runoff is a significant source of pollution, causing degradation of aquatic ecosystems [3].

In response to these challenges, environmentally sound stormwater management strategies based on the principles of sustainable development are gradually being implemented in urban planning [4]. One of the key areas is the use of solutions combined into the concept of green infrastructure – a system of nature-based engineering elements, such as rain gardens, biofiltration zones, high permeability pavements, green pavements, etc. [5].

Among the elements of this infrastructure, a special place is occupied by rain gardens – structures that reproduce the water-regulating functions of the natural landscape. They not only reduce the hydraulic load on the drainage network, but also improve the quality of runoff by serving as effective biofilters [6]. The main functional elements of such systems are a soil substrate with planted plants, infiltration and drainage layers, as well as auxiliary materials for regulating filtration processes [7].

Plants that make up the top layer of rain gardens perform various ecological and aesthetic functions. Thanks to their ability to phytoremediation, plants contribute to stormwater treatment by reducing the concentration of nutrients, heavy metals, suspended particles and organic compounds. In addition to improving water quality, they have a significant impact on the hydrological efficiency of systems: they protect the substrate from siltation, help reduce runoff volume through transpiration and evaporation, reduce erosion processes and modify water flow paths. Additionally, green spaces in rain gardens play an important role in shaping a favourable urban environment – they improve the aesthetic characteristics of the space, create habitats for pollinators and small fauna, and contribute to improving air quality [8].

Vegetation is involved in regulating the water regime of the soil by improving the structural characteristics of the substrate. According to the results of studies [9], the presence of plants increases the filtration capacity of the soil environment, in particular by increasing porosity and water permeability. Although part of the rainwater can be retained in plant tissues, the main retention mechanism is evaporation through the process of evapotranspiration (*ET*). The infiltration efficiency in systems with vegetation has been found to be superior to that in non-vegetated variants, both in field conditions and in laboratory models using columns [3]. Thus, the available empirical data indicate a positive impact of plants on the infiltration process in rain gardens, although the need for further research, in particular on the differences between plant species, remains relevant.

In addition to its hydrological role, vegetation in rain gardens contributes to stormwater treatment through processes such as phytodegradation, phytoextraction and rhizosphere interactions [10]. Phytodegradation, or phytotransformation, involves metabolic processes in plants that allow the decomposition of complex organic pollutants, such as polycyclic aromatic hydrocarbons, using special enzymes.

This process reduces the toxicity of contaminants by converting them into less harmful compounds that promote plant growth. Phytoextraction involves the absorption of pollutants from the soil by plants and their transfer to plant tissues. Phytoevaporation involves the transport of volatile organic compounds and toxic inorganic elements with their subsequent release into the atmosphere through plant leaves. All these mechanisms increase the effectiveness of rain gardens as elements of nature-based stormwater management in urban areas.

Plants show considerable variability in morphophysiological characteristics, such as the type of root system, water consumption, resistance to pollutants and efficiency in self-purification processes. These differences are mainly due to the species or functional affiliation of the plants. For example, herbaceous species are able to effectively retain suspended solids in stormwater due to their dense leaf cover, which serves as a physical barrier [11]. Trees have a high transpiration capacity, which can significantly reduce the volume of water in the system. In addition, in combination with low-growing vegetation, woody vegetation helps to improve the water-holding properties of the soil [12]. Roots play a key role in stabilising the soil structure, promote particle aggregation and macroporosity formation, which enhances the infiltration properties of the system [13].

An assessment of the impact of morphological characteristics and plant species on the functional efficiency of rain gardens is shown in Table 1.

Table 1

Evaluation of the influence of morphological characteristics and plant species on the efficiency of rain gardens

The functional role of the rain garden structure	**Morphological characteristics of plants**	**Explanation**
Hydrological efficiency	Thick roots	A higher value of hydraulic conductivity is observed in rain gardens planted with trees, as opposed to shrubs, sedges and grass species. Thick roots contribute to the formation of large macropores that increase infiltration in the rain garden system
Nitrogen removal	Root length and mass, plant growth rate	Differences are observed between species with certain morphological characteristics of plants, but not between specific types (lawn grass, grass, sedge, shrubs). Interactions between plant species and the soil environment (substrate) are possible
Phosphorus removal	No effect of specific plant characteristics	The effect of plants is considered negligible

Metal removal	No effect of specific plant characteristics	The impact of plants is considered to be negligible
Removal of pathogens	Characteristics related to the hydrological permeability of the soil, its composition and the functioning of the rhizosphere microbial community	1. Direct impact of plant species on the rhizosphere (competition, predation, antimicrobial root exudates). 2. Indirect influence of plants on the infiltration rate. One study confirms that shrubs are more effective.

Therefore, careful selection of vegetation species is a key factor in determining the efficiency and success of rain garden designs. The choice of plants for these systems should be based on characteristics such as the ability to adapt to specific climatic conditions, resistance to periodic flooding, efficiency in filtering pollution, and the ability to maintain a stable ecosystem on a long-term basis. Taking these parameters into account ensures not only the functionality of the system, but also its resilience to environmental changes. General recommended vegetation characteristics for rain gardens that include these important aspects are shown in Fig. 1.

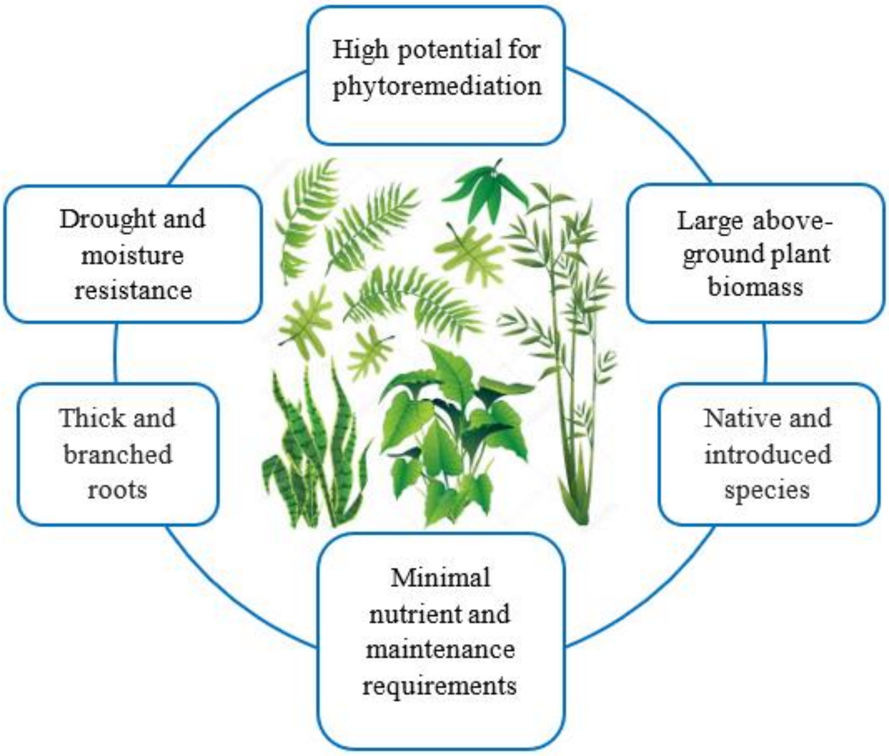

Fig. 1. Recommended vegetation characteristics for rain garden designs

Research on rain gardens offers considerable potential for improving their functional performance, in particular through recent advances in microbiota and phytoremediation. Further experimental research focusing on the role of plants should include both field studies of real, full-scale systems and laboratory setups, such as filtration columns. The latter have certain limitations, such as edge effects and non-normalised root density, but also offer important advantages, such as the ability to repeat experiments and control experimental parameters. In addition, it is important to expand the geographical and climatic coverage of rain garden plant systems research, as results obtained in one climate may not be applicable to other regions with different climatic conditions. This will allow for more universal recommendations for the design of such systems in different parts of the world.

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CALCULATION OF THE EFFECTIVE DIAMETER OF COLLECTING DRAINAGE PIPELINES

Oleksandr Kravchuk[1], Andriy Kravchuk[2]

Kyiv National University of Construction and Architecture

[1]kravchuk.oa2@knuba.edu.ua, [2]kravchuk.am@knuba.edu.ua

Drainage systems are increasingly used in agriculture for growing various types of plants [1]. One of the key components of the considered systems is the collecting drainage pipelines, which ensure the required (effective) intensity of water removal from the land plot, a necessary condition for creating a technologically prescribed moisture regime in the soil [2].

As is known, the minimum permissible technological drainage rate per unit area of land depends on the type of agricultural product being grown, the moisture regime in the soil, and can be determined by the following equation [3]:

$$q_{\min} = \left(\frac{dQ}{dx}\right)_{\min} = q_m E = 116\varepsilon E\,, \tag{1}$$

where q_m (l/(s·ha)) is the drainage runoff modulus; ε (m/day) is the intensity of infiltration feeding; $\boldsymbol{E}$ (m) is the distance between drainage pipes.

In many studies [4, 5] it has been shown that the movement of liquid in collecting perforated drainage pipelines is usually described by a system of differential equations, which consists of the equation of fluid motion with variable flow rate (2) and the modified filtration equation (3):

$$\frac{dh}{dx} + \frac{2}{g}V\frac{dV}{dx} + \frac{\lambda_{col}}{2gD}V^2 = 0 \tag{2}$$

$$q = \frac{dQ}{dx} = \frac{d(V\Omega)}{dx} = \frac{k_f(H-h)}{\overline{F}} = k_f\frac{z}{\overline{F}}, \tag{3}$$

where H is the depth of immersion of the pipeline axis from the groundwater level; h is the piezometric head in the pipe; $z=H–h$ is a pressure drop varying along the length, under the influence of which liquid flows from the environment into the pipeline; Q, V, D, Ω is accordingly, the flow rate, average velocity, diameter, and cross-sectional area of the flow at a distance x from the beginning of the pipe; $\overline{F}$ is dimensionless drainage resistance (its determination represents a separate filtration problem [6]); k_f is the filtration coefficient of soil around the pipe; λ_{dis} is the hydraulic friction factor of the distribution drainage pipeline; *g* is the acceleration of gravity.

For further analysis, it is necessary to use new dimensionless variables:

$$\overline{V} = \frac{V}{\sqrt{gz_{fin}}}, \quad \overline{x} = \frac{k_f x}{\Omega \overline{F}} \sqrt{\frac{z_{fin}}{g}}, \quad \overline{z} = \frac{z}{z_{fin}}. \tag{4}$$

It is also necessary to introduce the concept of effective structural characteristics of collecting drainage pipelines. By this, we mean the parameters of the drainage pipeline that will ensure the delivery of the minimum permissible flow rate into the drain. For the purpose of their analytical determination, it is necessary to express with new dimensionless variables (4) the minimum permissible variation in the relative velocity of a portion of the fluid flow (1) that can be delivered to the collector per unit of its relative length:

$$\overline{q}_{\min} = \left(\frac{d\overline{Q}}{d\overline{x}}\right)_{\min} = \left(\frac{d\overline{V}}{d\overline{x}}\right)_{\min} = \overline{z}_{in.ef}, \tag{5}$$

where $\overline{Q} = \frac{Q}{\Omega\sqrt{gz_{fin}}} = \overline{V}$ is the relative flow rate of the fluid, which numerically equals the relative velocity in an arbitrary cross-section of the drain; $\overline{z}_{in.ef}$ is the minimum allowable (effective) value of the relative head difference in the initial cross-section of the pipe, which ensures the required intensity of groundwater level reduction.

Certainly, when designing drainage systems on agricultural plots, the length of the drains, the material, and the filtration characteristics of the soil and the walls of the drainage pipes are known. Thus, as a result of the calculations, the effective diameter of the drainage pipes D_{ef} and the distance between the drains *E* are typically determined.

As a result of solving the system of equations (2), (3), and neglecting the second term in equation (2) due to its negligible impact [7], the minimum permissible (effective) value of the relative head loss in the initial cross-section of the pipe ($\overline{z}_{in.ef}$), which ensures the delivery of the required water flow into the drain, can be determined by the following equation:

$$\overline{z}_{in.ef} = \frac{1}{\left[1 + \frac{1}{4A_{ef}\overline{V}_{fin.\infty}}\right]^3}. \tag{6}$$

From this, the effective value of the generalized parameter A_{ef} will be:

$$A_{ef} = \frac{1}{4\bar{V}_{fin.\infty}}\left(\frac{1}{\sqrt[3]{\bar{z}_{in.ef}}} - 1\right). \qquad (7)$$

In the presented equations, the parameter $\bar{V}_{fin.\infty}$ represents the relative velocity of the fluid flow in the final cross-section of a pipeline of infinite length. It can also be interpreted as the relative velocity in the final cross-section of a pipeline of finite length, but with an infinitely large filtration capacity of its side walls. This parameter is recommended to be calculated using the equation:

$$\bar{V}_{fin.\infty} = \sqrt[3]{\frac{3}{2\zeta_{l_{col}} A_{ef}}} = \sqrt[3]{\frac{12k_f}{\lambda_{col}\pi D\bar{F}}\sqrt{\frac{z_{in.ef}}{g}}}, \qquad (8)$$

where $\zeta_{l_{col}} = \lambda_{col}\frac{l}{D}$ is the resistance coefficient of the collecting drainage pipeline.

From (7), the effective diameter of the collector drainage pipeline (D_{ef}, m) will be:

$$D_{ef} = \sqrt[5]{\frac{2\lambda_{col}k_f^2 z_{fin} l^3}{3g\pi^2\bar{F}^2\left(\sqrt[3]{\frac{k_f z_{fin}}{q_m \bar{F} E}} - 1\right)^3}}. \qquad (10)$$

The obtained calculation formula for determining the effective diameter of collecting drainage pipelines is quite simple and convenient to use. It will be useful when designing real drainage systems.

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CARTOGRAPHIC MODELING OF THE ECOLOGICAL STATE OF THE SUMYA REGION USING GIS

Inessa Krasovska[1], Elizaveta Grebenyuk[2]

[1]National Aerospace University "Kharkiv Aviation Institute" (NAU "KhAI"), i.krasovska@khai.edu

[2]National Aerospace University "Kharkiv Aviation Institute" (NAU "KhAI"), y.v.grebenyuk@student.khai.edu

Modern environmental monitoring poses a challenge due to the war in Ukraine. Especially in regions where there are active hostilities, which are borderline and subject to frequent shelling. One of these regions is Sumy. A comparison of the environmental indicators of Sumy region for 2021 and 2023 based on two environmental passports showed that most of the changes in 2023 are related to the military situation, which reduced the industrial and transport load; optimization of nature use; climate fluctuations (temperature, precipitation); increased environmental control at individual enterprises [1]. Unfortunately, at the moment, an environmental passport for 2024 has not yet been formed. But due to the war, we have a powerful factor of environmental pollution in the form of explosives (Explos.) (table 1) [2].

Table 1

Environmental pollution due to explosives

Weapon type	Air pollution	Soil pollution	Water resource pollution
FPV-drones	Emissions of CO_2 (~0.25 kg/drone), NO_x, PM2.5 particles from internal combustion engines	Oil spills, traces of heavy metals from batteries (Li, Ni, Cd), up to 10 mg/kg contamination	Ingress of electrolytes from batteries (fluorine, lithium content - 5–50 mg/l)
UAV «Shahed»	In case of explosion – up to 200 g of CO, NO_2, SO_2; 15 g of formaldehyde; dust and soot (up to 300 mg/m³)	Unburned fuel residues, heavy metals from electronics (Pb, Cu, Hg), up to 100 mg/kg	Ingress of unburned fuel and soluble toxins into water bodies – up to 40 mg/l

KABs	Emissions of smoke, NO_x, sulfur dioxide and carbon dioxide - up to 3000 mg/m³ during an explosion	TNT or hexane content in the soil - up to 50 g/kg; contamination with lead, cadmium, ammonium compounds	BP residues in water - up to 0.2 mg/l of TNT, pH changes, heavy metal contamination (Cu, Zn, Pb)
Artillery	Emissions of lead, nitrogen dioxide, carbon monoxide (up to 1 kg per large-caliber shot)	Soil contamination with debris, metals, nitrate compounds (up to 80 mg/kg), BP residues	Flushing from positions – nitrates, oil products entering the water – up to 30 mg/l

Open source environmental monitoring websites were analyzed (table 2).

Table 2

Open source GIS platforms for environmental monitoring

📌 Platform	🔍 What it tracks	🌐 Hyperlink
Sentinel Hub (EO Browser)	Vegetation, fires, water, indices (NDVI, NBR, etc.)	https://apps.sentinel-hub.com/eo-browser
Global Forest Watch	Deforestation, fires, ecosystem degradation	https://www.globalforestwatch.org/
NASA FIRMS	Real-time fires (MODIS, VIIRS satellites)	https://firms.modaps.eosdis.nasa.gov/
AirVisual (IQAir)	Real-time air pollution by city	https://www.iqair.com/
Earth Nullschool	Wind flows, dust storms, CO_2, CH_4 concentration	https://earth.nullschool.net/
MarineTraffic + Copernicus Ocean	Seawater status, currents, pollution	https://marine.copernicus.eu/
Map of Garbage (Ukraine)	Illegal landfill detection	https://map.sche ne.org.ua/
EcoCity (Ukraine)	Air pollution (PM, NO_2, CO) in Ukrainian cities	https://eco-city.org.ua/
Google Earth Engine	Powerful analytics of land surface changes, GIS analysis	https://earthengine.google.com/
UNEP Live	UN data on global environmental processes	https://uneplive.unep.org/
Cukr.	Explosion data in Sumy region by month with distribution by territorial communities	https://cukr.city/city/2025/obstrily-berezen-2/

For cartographic modeling of the assessment of the current ecological state of the region, data on air pollution, fires and explosions in the Sumy region were informative for analysis. For example, in March there were 6927 explosions according to the Sumy Regional State Administration. The ecological state is also affected by industry.

Fig. 1. Cartographic model of the division of Sumy region into deoccupied territories (pink) and combat zones (red)

Fig. 2. Cartographic model of the location of industry and air pollution measurement stations in the city of Sumy

The use of geographic information systems makes it possible to simultaneously show different factors and indicators of environmental pollution in one territory. The first stage of forming a cartographic model of the ecological state of the Sumy region was the creation of a territorial spatial model, where the deoccupied territories are highlighted in pink, and the combat zone in red as of April 2025 (fig. 1.) [3]. The next step was to create a point layer of industry and air pollution measurement stations in the city of Sumy (fig. 2). The use of geographic information systems allows you to create attribute databases in which it is possible to update air pollution information from stations, make changes to emissions in industry, add new ones and mark inactive ones.

Data from Global Forest Watch allows us to update information about fires in the Sumy region and create a vector layer (fig. 3) [4].

The ecological map of Sumy region as of April 2025 based on open source data is presented in figure 5.

An electronic ecological map allows for spatial analysis of environmental pollutants, including soils and hydrographic objects, to assess the ecological state of individual territories (where a large amount of explosives have been released), identifies the need for additional monitoring facilities, helps determine locations for contact methods of pollution assessment, allows for adding new data and constantly updating information.

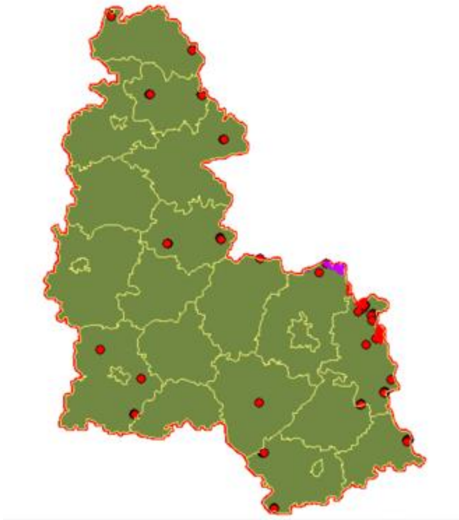

Fig. 3. Cartographic model of fires in Sumy region as of 04/21/2025.

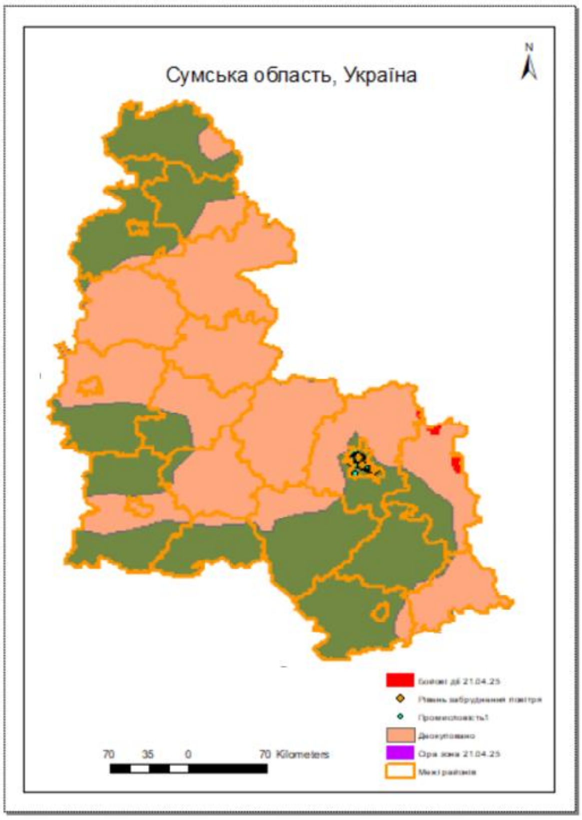

Fig. 4. Map of the environmental situation of Sumy region as of April 2025

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NEW TRENDS IN THE CONSTRUCTION INDUSTRY OF UKRAINE

Kryvomaz Tetiana Ivanaina

Kyiv National University of Construction and Architecture,

kryvomaz.ti@knuba.edu.ua

Construction sector is waiting for the new Urban Planning Code of Ukraine (Code), work on which began in June 2023. In April 2025, the working group will present a detailed concept and, after discussing it, will proceed to the direct writing of the draft law, which is planned to be completed by the end of the year. This Code should replace the draft law on reforming the sphere of urban planning No. 5655, which lobbied the interests of development and central authorities, which contradicted decentralization, public participation and the principle of rebuilding "better than before". Experts believe that over 30 years, construction legislation has turned into a set of inconsistent instructions that do not provide a holistic and balanced system. Will the new Code be able to solve the pressing problems of the construction industry and really establish new rules of the game for urban planning?

The Code is a framework legislation for systematizing and harmonizing individual laws and by-laws to eliminate gaps and correct errors. It is positioned as a set of mechanisms for balancing relations in the construction sector so that trust can be established in the industry between the state, local authorities, business, specialists and local communities. A bottom-up approach was used to develop the concept of the Code, which is why representatives of associations, unions, communities and guilds representing the urban development market were involved: archaeologists, geologists, land managers, urban planners, architects, builders, developers, monument conservators, restorers. The working group also included members of the relevant committee of the Verkhovna Rada of Ukraine, people's deputies, representatives of Ministries and other central government bodies, industry experts and representatives of the public sector and local governments. In total, 300 people worked on the development of the Code on an ongoing basis. In addition, experts from 11 countries of the world (European countries, Britain, the USA and Israel) joined the discussion, who spoke about their urban planning system, regulatory documentation and rules.

The developers of the Code concept identify five main subjects of interaction in the field of urban planning: residents, specialists, local governments, construction and development companies, as well as state authorities. It is planned that each of these subjects will be able to exercise their influence, rights, obligations and the opportunity to join the development of a new Ukraine thanks to the new Code. It is hoped that every citizen of Ukraine will be able to directly participate in changes in their city and will soon feel an improvement in the quality of the built environment. The most significant changes that the Code will bring: flexibility of urban planning documentation, ensuring the responsibility of specialists, protection and reduction of investment risks, completion of decentralization in the field of urban planning and implementation of the best European principles.

The Code identifies four stages of urban development: spatial planning, design, construction and operation of real estate. In addition, complex aspects of redevelopment, reconstruction and restoration are considered. The current legislation in each of these areas is multiple and complex, therefore, existing problems were clearly identified and proposals were made to resolve them with reference to a list of relevant regulatory legal acts. The Code covers the areas of construction, design, operation, restoration, land management, spatial planning, housing policy, state construction control. Aspects of price regulation, financing and insurance, public procurement, construction and copyright law were considered. The social and humanitarian sphere, monument protection activities, archeology, landscaping and advertising, professional certification, education and science were also not left out of consideration. The Code takes into account transport, ecology, energy efficiency, compensatory mechanisms, civil protection and digitalization.

Global urban planning trends are also focused on digitalization, including the increased use of artificial intelligence (AI) to address economic, social, environmental, and governance challenges [2]. Responsible algorithmic urban planning can contribute to smart and sustainable development, but the implementation of AI requires interaction and collaboration between key stakeholders in urban decision-making. Privacy, bias, and inequality remain complex issues that require careful rethinking to best minimize these risks when implementing AI technologies for urban planning. AI has been and can continue to be used in a number of urban planning tasks to solve complex urban development problems and meet the needs and priorities of local communities. AI has great potential to improve the overall experience of safety, comfort of living, and sustainability of cities and their residents in an intelligent way. New perspectives are opening up not only in the combination of different algorithms and AI applications, such as AI and the Internet of Things, but also in the combination of human experience and AI for urban planning. At the same time, it is necessary to be aware of the shortcomings of AI and find ways to address them.

It is important to start developing and implementing strategies for the responsible implementation of AI in planning now. AI can help systematize community vision, plan development, standards, policies, public investments, incentives and development [2]. Urban planning needs to identify how AI can be used to automate any of these tasks. At the same time, it is necessary to establish a prompt and transparent collection of data generated by planning work to set up AI analysis support for better data-based and evidence-based decision-making to achieve sustainable outcomes.

Big data is an integral element for the effective use of AI in urban planning. Real-world applications of AI in urban planning are already underway, paving the way from early adopters to broader adoption of AI by local governments. Achieving broader adoption of AI for urban planning requires collaboration and partnership between key stakeholders. The convergence of AI and human intelligence is crucial for adequately addressing urbanization challenges and achieving smart and sustainable development. With its expanded capabilities, AI will become one of the main tools for achieving smart and sustainable urban development.

The main trends for Ukraine's construction industry in 2025 are similar to the challenges of the previous year:

1) an increase of up to 25-40% in production costs due to rising prices for energy and building materials in various segments of the construction market;

2) a shortage of labor, both low-skilled and highly skilled specialists and engineers;

3) power outages due to missile strikes on energy infrastructure;

4) payment delays when working with government orders, which requires the contractor to have significant working capital;

5) a slowdown of up to 33% in the dynamics of infrastructure construction due to problems with state financing of the protection of energy facilities [1].

Currently, the construction market of Ukraine has more potential than financial capabilities, and at the same time, active construction, repair and reconstruction have continued throughout the war. There is hope that thanks to the new Code, digitalization and investments, Ukraine will become the most comfortable country in Europe after the war.

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GUARANTEE OF SUCCESS IN GREEN BUILDING – THE SUSTAINABLE DEVELOPMENT OF CONSTRUCTION MACHINE INDUSTRY (CAUSAL AND EFFECTIVE CORRELATIONS IN THE LIGHT OF THE SINGULARITY OF THE IDEOLOGY OF REGIONAL INDUSTRIAL POLICY)

Kudria Yaroslav Valeriyovuch

Dolishniy Institute of Regional Research of the National Academy of the Sciences of Ukraine, swiss.inc.com@gmail.com

In the conditions of dynamic economic development, the solution of the development issues of not only the production of building materials is gaining more and more to the attention and importance every day. This also applies to construction industry as one of the leading types of industrial activity for the economy of Ukraine and a component of heavy machine industry.

At the same time, all of the above are irreplaceable, integral components of the construction industry and the machine industry. Therefore, the current state, progressive approaches, one of the best forms, the methods and prospects for the development of construction industry, and therefore the construction industry in general and machine industry in particular, are today being actively discussed by shareholders of construction corporations and machine industry (or engineering) enterprises, entrepreneurs of all forms of ownership, in scientific institutions and representatives of various levels of government.

Further dynamic development, qualitative improvement of the efficiency of the domestic construction industry into the areas of development of construction machine industry and production of construction materials, level of comfort and level of quality of residential and industrial buildings, environmental standards of the construction materials, minimization of the technological, the operational and environmental risks in the construction industry, methodical and systematic increase in the general indicator values of energy efficiency and resource saving, military and civil infrastructure universality, besides production of construction materials and defense stability of the material assets (as is known, fixed capital – buildings, mechanisms etc.) are possible provided that various modern tools and means are used, capable of the ensuring sustainable development of construction machine industry at the regional level of the country, for the comprehensive and rational development of Ukrainian machine industry.

A construction machine industry, in essence, is a set of interconnected and interacting industrial productions, otherwise as known in practice, manufacturers of construction machinery products that are integrated into the machine industry.

Obviously, the sustainable development of construction machine industry in the region is a type of progressive development that focuses on ensuring the modernization of construction machinery production, and therefore construction materials at the mesolevel of country’s economy over time by reducing energy, resource and labor intensity, the duration of technological processes and a cycles of industrial production (construction), the integration of production processes, service maintenance of construction materials production and next improving its quality, environmental and social safety.

The modernization of construction machinery production is the main result of increasing the efficiency of designed management systems, functioning and development of construction machinery manufacturers.

So, it follows that we are not only talking about searching for opportunities and innovative changes in the technological characteristics of industrial products (i.e. the construction machine and building materials), but also about conducting much more thorough specification, detailing of the very quintessence, as well as the content of the development process of construction machine industries into accordance with the modern neo-industrial paradigm of industrial policy.

By the way, these events are important steps in organizing the formation of a fairly predictable policy of safety and quality of building materials. The use of systemic approach allows not only to identify shortcomings in the development process of construction machine industries, but also to develop much functional effective mechanisms for preventing the potential crises in the building materials market. It can also be considered as guarantees of trust in the primary real estate market and the construction regulation system.

From historical facts it is known that construction machine industry is one of the largest in terms of volume and competitiveness of its market segments. In the world, the spatial localization of construction machinery production is due to the influence of a significant number of the differential determinants, the basic of which is always the cheapest possible labor force. Orientation to it determines systematic structural shifts in the location of construction machinery production and not only in their territorial location, but also for machine industry in general.

At the same time, another no less important factor influencing the location of construction machinery production is the level of development of scientific and technological progress. The value of the level determines structural shifts in domestic and global construction machine industry. A trends and also tendencies caused by scientific and technological progress have led to increase in the share of labor in the cost of industrial products. Therefore, the existing economic and social situation of geographical areas with cheap labor has become somewhat better, compared to those with a resource base.

The dynamic development of information technologies and systems leads to the presence of a complication of technological processes, cycles of industrial and the production of construction machinery. This fact practically prompted the division of the latter into producers of mass, highly qualified high-tech industrial products. According to the pages of [1; 2, p. 18; 5, p. 34–35], this subjective fact stimulated the transfer of mass production of the construction machine industry, which continues to our days, as they do not require large expenditures of highly qualified labor, as well as the lack of formation and preservation of the need to ensure the sustainable development of highly qualified and full cycle production of construction machine industry.

In turn, globalization and internationalization, specialization of the country stimulate the deepening and strengthening of ties of the production cooperation between world's construction machine industries. The emergence of this trend is due to the advantages of increasing the scale of construction machine industry.

A dynamic development of information technologies and systems together with the sustainable development of the domestic machine industry sector of the regions, including construction machine industry, which, in the author's opinion, are no less important and critical, constantly form the machine industry sector of the world economy with the highest level of potential for the implementation of technological, in particular the environmental (or so-called "green") innovations, in the industrial activities and construction. The latter in modern conditions are decisive for achieving a high socio-economic standard of living.

The Ukrainian, domestic construction machine industry in terms of its level of participation into the process development of the Ukrainian economy system, unfortunately, currently lags behind world dynamics. Despite a last, undoubtedly and in fact, at all times, the branch machine industry, in particular construction (the author's assumption), is a necessary foundation for ensuring the sustainable development of not only domestic industry, but also the national economy [5, p. 10–15]. It is expected that from the words of a columns of [5, pp. 10–15], which are characterized by the sufficient level of production and resource potential and human capital.

Thus, the results of the economic research conducted in [1–5] showed that machine industry, in particular domestic construction, is characterized by a wide and extensive network of the inter-sectoral relations. This may be due to the fact that machine industry:

- firstly, provide the world economy and country at all levels with industrial products for intermediate and final consumption;
- secondly, the closeness of a networks inter-sectoral relations, the wide and extensive nature, and their networks nature are quite the good reasons for at least positioning machine industry as the base, systemic sector of the real economy of the region with high values of multiplicative and synergistic effects of influence on the national and global economy and its subjects;
- thirdly, the effects and volume of the efficiency, the consequences of their sustainable development may well encourage the solution of applied problems of increasing labor productivity and wages, the levels of material, technical base and scientific, technological progress and technological singularity.

A priori refusal of the production and the use of material assets that do not meet the progressive modern conditions for the formation of market relations are unable to ensure an increase in the competitiveness of industrial products and it a basic typical postulates of building, and modernizing the system of sustainable development of machine industry at all levels of the economy.

Without no one exaggeration, increase the competitiveness of construction machine industry, accordingly quality of the production of building materials, their environmental standards, minimizing the level of technological, operational and environmental risks in the construction industry, the systematic increase into the values of energy efficiency and resource saving indicators, safety and quality of buildings, residential infrastructure facilities etc. are a number of strategically important challenges for modern Ukraine, as well as systemic strategic tasks for domestic machine industry.

Fulfilling the tasks set by increasing the added value of machine industry in the real economy of the regions and the efficiency of industrial infrastructure with the involvement of highly qualified labor in combination to administrative and economic measures will ensure the systematic sustainable development of industry in the regions (all this also applies directly to construction).

So, one of the measures that has a high functional potential and, due to its effectiveness, accessibility and efficiency of use, requires special attention is the implementation of a policy of sustainable industrial development in the regions (by main types of industrial activity) on the principles of reproduction with the subsequent mandatory application of mechanisms adequate to market situations.

By the way, this is due to the fact that the use of this type of development policy in conjunction with corresponding models of mechanisms can stimulate an increase in the level of rationalization of structure and, as one of the desired, the most expected consequences – the effective use of the material assets in the production process and an increase in the level of innovative activity.

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DETERMINING THE OPTIMAL LAYOUT OF A YARD HOUSEHOLD SEWER NETWORK

Kushka Oleksandr Mykolayovych, Nechypor Oksana Mykhailivna, Hizha Olena Oleksandrivna, Kotenko Maryna Ivanivna
Kyiv National University of Construction and Architecture,
kushka.om@knuba.edu.ua, nechypor.om@knuba.edu.ua, gizha.oo@knuba.edu.ua, kotenko_mi-2023@knuba.edu.ua

Despite the fact that centralized water supply systems for buildings and, consequently, yard sewer networks have existed for more than a hundred years, there are still issues related to their design that require modern reconsideration from a scientific perspective. One of these issues is the search for the optimal layout of yard networks during the development of new areas or the reconstruction of old ones.

At first glance, the task of designing the layout for yard sewer networks may seem trivial. However, even minor errors and deviations from the most optimal variant can result in significant financial costs when multiplied by the total area of residential development and the number of populated areas.

Therefore, let us examine the issue of routing household yard sewer networks in more detail. According to official technical literature, particularly the national construction standards [1], points 1.1 and 1.2 of the Code of Practice "Sewerage. External Networks and Structures" [1] state that the standards apply to the design of "systems and schemes" of wastewater disposal in populated areas, as well as the reconstruction of networks. Furthermore, point 5.4 [1] states: "Technological schemes must ensure the cost-effectiveness and efficiency of the networks throughout their projected service life."

The most specific guideline regarding sewer network layout is found in section 8.1 "Placement and Conditions of Laying Sewer Networks," particularly in point 8.1.1, which states: "The placement of the sewer network must correspond to the conceptual scheme of the sewerage system of the populated area."

That is all. The regulations do not contain parameters that must be taken into account to ensure the economic viability and efficiency of networks over their projected service life. Nor do they provide criteria or methodologies by which one could evaluate the optimality of a layout or determine which of the possible pipe routing schemes is the best.

To solve the problem of determining the optimal routing of sewer networks, approaches such as dynamic programming [3], iterative mathematical optimization [4], and mathematical modelling with the ability to adjust initial, sometimes interdependent, parameters—such as initial geodetic elevations of pipes, slopes, volumes of earthwork, etc.—have been proposed [5]. These studies are not the only ones dedicated to finding optimal layouts for sewer networks, but they all share a key feature: the use of computer applications based on appropriate mathematical models.

However, the aforementioned scientific works address citywide sewer networks, not yard pipelines. Therefore, the proposed methods are too complex and thus unsuitable for the design of neighborhood household sewer systems. Nevertheless, the key variables that affect the cost-effectiveness of the designed network are the same for both citywide and yard-level sewer systems. However, for the latter, a simpler express method is required to evaluate the efficiency of the layout—one that considers two key components of an economical network: optimal scheme and optimal calculation.

In practical design, the second component is not always given due attention. This is likely because designing specific sections of a gravity-flow network requires considering factors such as flow velocity (not less than 0.7 m/s), pipe slope (not less than 0.008), and pipe filling ratio (H/D)—the ratio of water depth in the pipe to pipe diameter—which can vary from 0.3 to 0.7.

We addressed this second component by using the "Canalization" application. This software calculates the design values for specific sections of the sewer network using the method described in DBN point 8.2.1 [1], while the flow rates for individual sections are determined using Table A.5 [2].

Screenshots of selected application windows are presented in the figure.

As a result of the calculation, we obtain optimal values for all technological and construction-related parameters: slope, filling, velocity, pipe burial depth, elevations, and so on.

According to sources [3, 4, 5], the construction cost of individual sections of the sewer network consists of the cost of pipes, manholes, and earthworks. It is known that two parameters influence the operational costs of a sewer network: the pipe diameter and the burial depth.

The diameter of yard household sewer networks must not be less than 150 mm (160 mm) [point 8.3.1, 1], and larger diameters are unlikely for most residential blocks (for 550 apartments, the design slope equals the minimum at a flow velocity of 0.81 m/s; for 1000 apartments, the slope is 0.0222, and the velocity is 1.35 m/s). Thus, the next standard diameter of 200 mm is rarely used.

The volume of earthwork does not change when increasing the pipe diameter from 160 to 200 mm. Therefore, the influence of pipe diameter on the optimization of layout can be neglected.

Consequently, a dimensionless parameter for determining the optimal layout of the yard sewer network will be as follows:

$$YSN = \frac{l(h_{mt} + N \cdot h_{mw})}{S};$$

Where:

YSN – dimensionless parameter; l – length of the calculated direction, from the reference building to the municipal sewer manhole, m; h_{mt} – average depth of pipe laying along the calculated direction, m; h_{mw} – average depth of sewer manholes along the calculated direction, m; N – number of sewer manholes along the calculated direction, units; S – area of the sewered block, m².

A lower value indicates a better (more optimal) network.

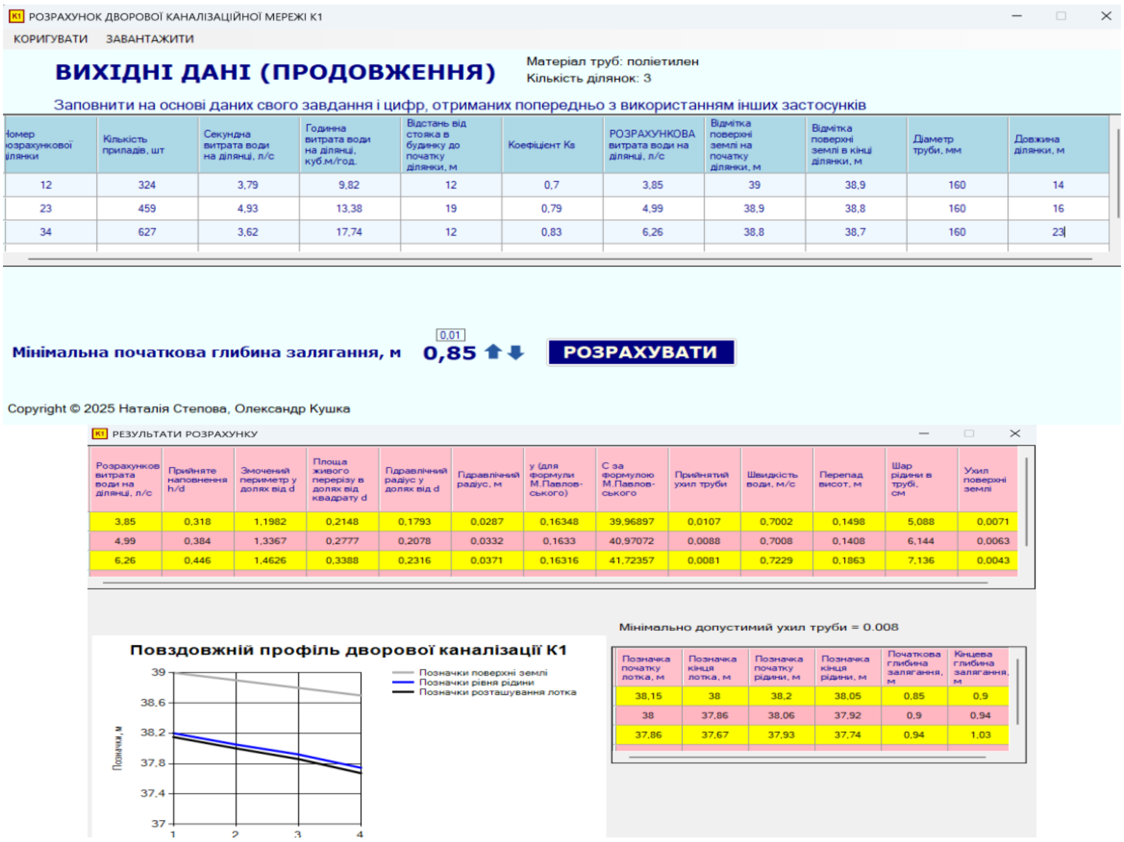

Fig.1. Screenshots of individual application windows for calculating a yard sewer network

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PASSIVE COMPONENTS FOR REDUCING ENVIRONMENTAL IMPACTS OF BUILDINGS:ANALYSIS OF AN EXPERIMENTAL GREEN ROOF

Liubov Lepska

Kyiv National University of Construction and Architecture, lepska.la@knuba.edu.ua

With the aim of pursuing a better environmental efficiency in human activities that would result in a more sustainable utilization of resources, the building sector plays a relevant role, being responsible for approximately 40% of both release of pollutants in the atmosphere [1, 2] and energy consumption for air-conditioning purposes [3, 4, 5]. In this perspective various strategies have been implemented [6, 7, 8, 9], and more effort in promoting actions and finding new approaches to reduce the environmental impacts related to the building sector has been put in the last few years [10, 11, 12, 13].

Specifically, the reduction of the energy consumption [8], along with the decrease of greenhouse gases emissions [14], represent the two most important aspects to which more attention has been paid.

When trying to reduce buildings' environmental impacts associated to climatization purposes two main categories of components can be considered, the technical plants and the building envelope, which are linked by a mutual synergistic relationship. In more detail, an impact reduction related to the technical plants consists in the use of more efficient active systems, which however entail an energy consumption, while as for the building envelope, passive systems (no energy consuming) can be used. Such passive components allow to obtain a reduction of both the building's energy consumption (as well as a reduction of the size and the utilization time of the technical plants) and the whole environmental impact of the building.

Among passive solutions, green roofs have been gaining more attention lately [15, 16], not only because of their capacity to reduce the building's energy needs for air conditioning [17, 18], but also due to their ability of having a positive impact on the outdoor urban surroundings. In fact, various environmental benefits have been related to the use of green roofs, including reducing air pollution [19, 20], improving the management of runoff water [21, 22], mitigating noise [23], increasing the urban biodiversity [24] and alleviating the urban heat island (UHI) effects [25, 26]. Furthemore, they have been demonstrated to positively affect the indoor comfort levels of buildings [27].

Although the subject of green roofs has been dealt with extensively from many different points of view, both analytically and experimentally, some limitations, on which further improvements can be made, have been evidenced: particularly, the role of the substrate in the whole environmental impact of this component, the effective analysis related to the cost of the disposal operations, and the current status of database of parameters required to model the radiative heat exchanges occurring in vegetation layer of these components. Moreover, in the opinion of the authors of the present paper, despite the wide diffusion of such technologies in urban contexts, the lack of an extensive knowledge of the environmental impact of the different life cycle phases of a green roof, and therefore of its overall environmental impact, seems to still exist.

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HYDROPOWER AS A GREEN ENERGY COMPONENT

Olena Kotovenko, Olena Miroshnychenko[1], Svitlana Lytovchenko[2]

Kyiv National University of Civil Engineering and Architecture,

kotovenko_ea@ukr.net, . *elenamiroshka@ukr.net*

PrJSC "Ukrhydroenergo", *drazena2012@gmail.com*

Hydropower is a traditional, time-tested, renewable electricity source and one of the most widespread and reliable energy sources supply in the modern world.

For example, in Ukraine, the installed global hydropower capacity in 2020 was more than 1300 GW, i.e. it provided about 20% total electricity generation [1]. Hydropower is also an effective complement to other electricity sources, primarily solar and wind, due to its high regulatory capabilities and is the most efficient electricity generation technology (96%).

Electricity generation through the renewable hydropower resources use is one of the most important environmentally friendly and resource-saving technologies that allow us to protect the environment from pollution by waste from alternative (traditional) sources of electricity. For example, to obtain 2650 million kW of electricity, which is produced by all hydroelectric power plants in the world, it would be necessary to burn 1 billion tons conventional fossil fuels at thermal power plants annually, which would lead to very serious negative consequences for the environment and, accordingly, to an increase in morbidity, health deterioration and premature death thousands of people. Therefore, from the environmental point of view, human life and health preservation, the energy produced by hydroelectric power plants is clean.

It is the hydroelectric power plants with complex purpose large reservoirs and their cascades, performing the tasks of rivers flow regulating, that form water management complexes. They include energy, municipal, industrial, agricultural water supply, irrigation, water transport, fisheries, recreation, ensuring human needs in energy, water, food, recreation, etc. through the environmentally friendly renewable natural resources use. They also provide the natural and social environment protection from floods, guaranteeing socio-ecological discharges from reservoirs in low-water years, which plays an important role in environmental protection, because the floods and droughts consequences can be catastrophic.

At the same time, hydropower can negatively affect the environment, especially river and riverine ecosystems, and can cause significant and often irreversible damage to rivers, biodiversity, etc. [2,3].

That is, the main hydropower disadvantages can be identified as:

1. Environmental destruction: increased erosion under the dam, changes in riverbeds, impact on animals and plants, etc. However, these negative consequences are predictable and can be reduced due to the reservoir effect.

2. The need to build dams, resettle the population from flooded areas, large investments in infrastructure.

3. In areas with large fluctuations in water levels during the rainy season, electricity generation is small or may even be lacking in the dry season.

4. The layer of fertile alluvial soil decreases downstream.

In addition, there are also some potential disadvantages of these technologies. One of them is that large-scale projects can significantly affect the environment. When implementing such projects, it is necessary to take into account the need to ensure sustainability and climate resilience; aging facilities and related investment needs; the need to adapt operation and maintenance to power systems modern requirements; outdated market structures and business models.

Hydroelectric power plants and hydro-accumulating electric power plants play an exceptional role in integrated power systems, covering the load schedule peak part, and district heating plants also cover the schedule failure part, performing the emergency function and load reserves, ensuring reliable power supply to the population, utilities, etc., preventing their shutdown in emergency situations and the associated negative consequences for the environment.

Thus, the main advantages of hydropower are:

1) cleanliness: water energy is a renewable energy source, practically not polluted;

2) low operating cost and high efficiency;

3) electricity supply on demand;

4) inexhaustible and renewable;

5) flood control;

6) provision of irrigation water;

7) river navigation improvement;

8) The associated projects also improve transportation, energy supply and the area economy, especially for the tourism and aquaculture development.

The Renewable Energy Institute (Japan), based on an analysis of the current state of renewable energy and its forecast for future development, concluded that hydropower is a vital part of the global energy transition.[4]

Hydropower produces clean energy, and this is one of the most obvious advantages using it. Hydropower does not pollute the air, which leads to a reduction in carbon dioxide emissions. It is also completely renewable, since the water does not disappear anywhere, but is constantly returned in the form of precipitation.

Hydropower is low-cost, the costs associated with hydropower are the most competitive in the renewable energy sector. It is an affordable alternative to other energy sources, providing low-cost electricity and sustainability its production. Construction costs can even be reduced by using existing structures such as bridges, tunnels and dams. Hydropower uses domestic water resources, which achieves price stability and eliminates market fluctuations. In addition, it allows countries to produce their own energy, reducing their dependence on international fuel sources.

Hydropower is a highly reliable source of energy. Unlike solar and wind power, which can be erratic and weather-dependent, hydropower is consistent and predictable, making it a valuable source for stabilizing power systems.

Traditional hydropower facilities can quickly go from zero to full capacity. This ability to instantly generate electricity into the grid provides much-needed backup power during major outages or power outages. Water can be stored in reservoirs, allowing electricity production to be adjusted to meet demand, leaving room for other renewable energy sources to expand.

One of the greatest hydropower advantages is that it provides support for other energy sources, creating a foundation for the further implementation and green energy expansion.

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NOISE PROTECTION OF ELECTRICAL GENERATORS BY USING A NOISE PROTECTION BOX

Maksymenko Artem, Klimova Iryna

[1] *Kyiv National University of Construction and Architecture,*

mksmnkart@gmail.com

One of the most common types of acoustic pollution is noise from engineering equipment. Such noise sources surround a person in almost all areas of his life, including during work [2]. In terms of work, noise sources that affect a person can be divided by location into internal and external.

Internal noise sources are generated within the workplace and production process. Internal noise sources include: ventilation and air conditioning equipment (fan coils, indoor air conditioner units), household engineering equipment (electric kettles, refrigerator compressors, noise from computer equipment) and noise from specialized technological equipment (machine tools, hand power tools, production lines).

External sources generate noise outside the workplace and are located outside the building that employees are in. Such sources include external elements of ventilation and air conditioning systems, generator equipment, noise from loading and unloading operations, and noise from the operation of neighboring industrial buildings.

The actual problem of recent years in Ukraine is the use of electric generators, which are sources of external noise.

This work evaluates the noise level generated during the operation of an electric generator and evaluates the reduction of noise levels using an individual noise protection box.

The work is based on conducting full-scale acoustic measurements of an electric generator located under an office building (at a distance of 7 m from the facade) before using acoustic solutions (noise protection box) and after its installation. As a source of noise, an ordinary gasoline generator was chosen, and not an inverter generator, because the inverter generator changes the number of revolutions, depending on the load, which does not allow us to talk about a constant noise level and introduces the concept of minimum and maximum level. A conventional gasoline generator operates at the same revolutions and produces the same noise level.

Table 1

Sound pressure levels from the electric generator at a distance of 5 m

Frequency, Hz	31,5	63	125	250	500	1000	2000	4000	L_{Aeq}
Sound pressure level at a distance of 5 m	81,9	77,7	71,8	70,4	68,6	68,7	64,7	59,7	73

Below are the results of field measurements of the operation of the electric generator without the use of acoustic measures at a distance of 5 meters from the equipment.

The measurement results are presented in the form of sound pressure levels *L*, dB, in octave bands with geometric mean frequencies of 31.5; 63; 125; 250; 500; 1000; 2000; 4000 Hz [3]. The results are also presented in the form of equivalent sound pressure level $L_{A\,eq}$, dBA.

In order to reduce the noise level from the operation of the electric generator, a noise protection box was designed and implemented [4]. The scheme is presented on Fig. 1.

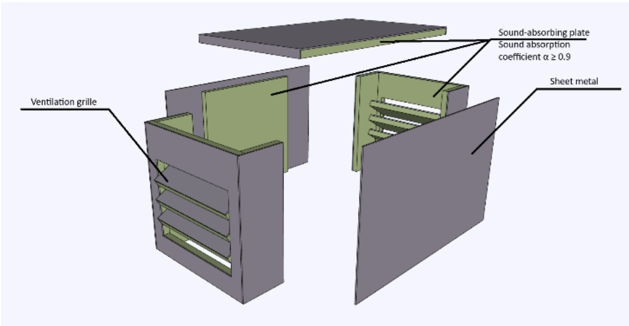

Fig. 1 Scheme of the installation of the noise protection box

Fig. 2 Manufactured noise protection box

Below are the results of field acoustic measurements after using the acoustic solution.

Table 2

Sound pressure levels from the electric generator at a distance of 5 m using a noise protection box

Frequency, Hz	31,5	63	125	250	500	1000	2000	4000	$L_{Aекв}$
Sound pressure level at a distance of 5 m	78,6	76,9	68,8	64,7	52,1	49,4	46,3	43,3	59

Fig. 3 presents a comparative graph of noise levels in octave bands with geometric mean frequencies.

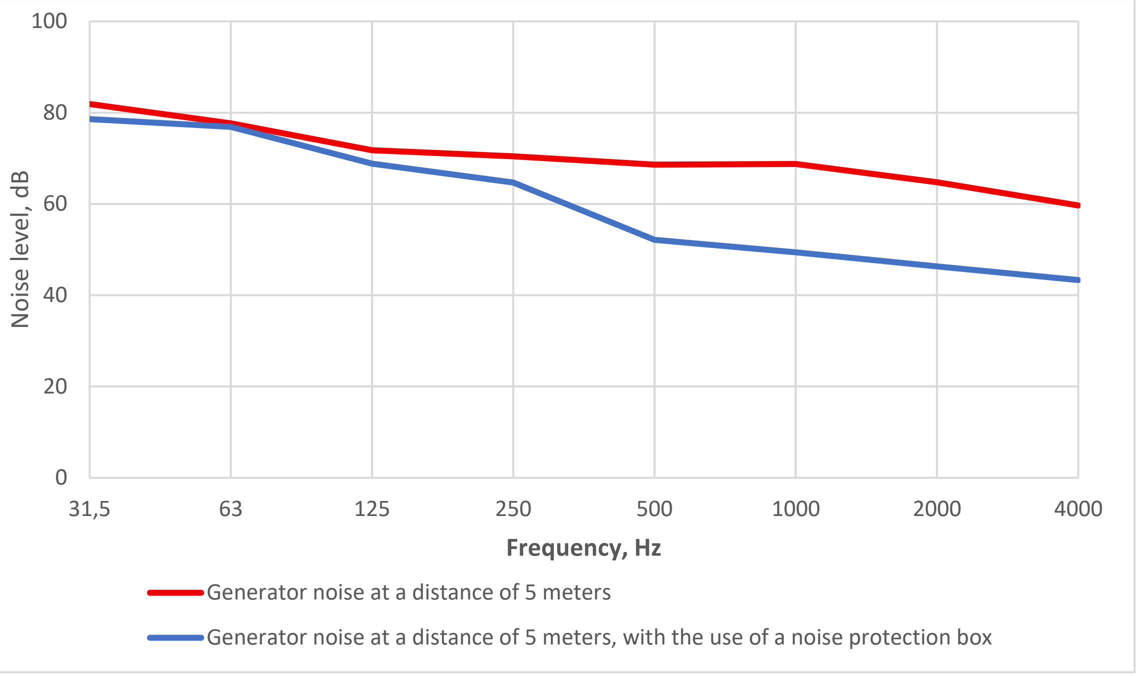

Fig. 3 Comparison of noise levels in octave bands with geometric average frequencies

According to the results of field measurements, the use of this individual noise protection box reduces the level of acoustic pollution at a distance of 5 meters by 14 dBA ($L_{A\ eq}$). And after analyzing the results in octave bands with geometric mean frequencies, we can note high efficiency in the frequency range from 250 Hz to 4000 Hz.

The implementation of such solutions is quite effective in terms of reducing the level of acoustic pollution and its negative impact on humans. But we should not forget about acoustic solutions that can be implemented at the design stage of buildings of various types. Such solutions include [1]:

- Volumetric planning decisions. Relocation of engineering equipment to locations where its impact on workers will be minimized or absent altogether;
- Architectural solutions. Provision of separate rooms for noisy equipment that does not operate in stationary mode;
- Choosing less noisy engineering equipment;
- Determination of predicted noise levels by calculation methods or mathematical modeling methods at the design stage;

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THE ROLE OF WOOD AND WOOD WASTE IN GREEN CONSTRUCTION IN THE CONTEXT OF CLIMATE CHANGE MITIGATION AND CIRCULAR ECONOMY

Mykola Maksymiv
Ukrainian National Forestry University
maksymiv.mi@nltu.lviv.ua

Green construction is becoming increasingly popular and prioritized around the world, attracting the attention of a wide range of stakeholders, from scientists to decision makers. This necessitates the search for effective solutions in the construction industry to ensure comfortable living conditions while taking into account environmental protection requirements and reducing greenhouse gas emissions as the main factor of anthropogenic climate change.

Compared to traditional materials, green building materials have a lower carbon footprint and can save energy during manufacturing and transportation. They have the potential to improve indoor air quality, reduce waste, and conserve natural resources. Such materials include wood [3].

The European Union Commission has adopted a number of regulations directly or indirectly related to green building as a means of achieving the EU's climate and energy goals by 2050 and the goals of the European Green Deal, which requires investment in sustainable projects and activities. Regulation (EU) 2023/2486 of June 27, 2023 on Delegated Environmental Powers (in particular the amendments to the Delegated Disclosure Regulation) introduced the construction sector, in particular building construction, renovation, demolition and dismantling, into the classification system for sustainable economic activities (“EU taxonomy”) among nine sectors and economic activities. It is emphasized that the construction sector requires energy efficiency measures.

Green construction is especially important given the need for post-war reconstruction in Ukraine. Russian aggression has caused huge losses, with some sectors - buildings and infrastructure - being particularly hard hit [7]; intensive destruction of buildings and structures continues. The reconstruction and rehabilitation needs are highest in the housing sector (almost USD 84 billion, or 16 %

of the total long-term needs). Housing is one of the sectors most affected by the Russian invasion of Ukraine: 13% of the total housing stock was damaged or destroyed, affecting more than 2.5 million households [5]. After the war, construction capacity will increase and will require new, environmentally friendly materials to meet the requirements of a low-carbon, circular economy.

Ukraine's woodworking industry is capable of providing a significant portion of the building materials for reconstruction. Given the goals of the Green Deal and Ukraine's achievement of the decarbonization of the construction sector, wood construction projects will be of interest to EU funding. Obstacles to this include legal restrictions on the use of wood in high-rise buildings. State policy, a dialogue between the forest industry and the public on the perception of wood as a green resource is the key to success in the field of wooden construction [2].

The construction industry accounts for a significant share of the world's resource consumption and waste generation, so implementing circular economy principles is paramount to achieving a more sustainable future. Through innovative practices such as reuse, recycling, and sustainable design, the circular economy can help reduce waste, conserve resources, and create a more sustainable built environment [3]. Circular economy practices contribute to making the construction sector more material efficient and less carbon intensive. This will require quantification by modeling climate change mitigation processes along the entire value chain of a product or material [6].

A large number of different materials are used in the construction process, such as cement, reinforcement steel, bricks, flat glass, glass wool, and sawn wood.

All of these materials, except for sawn wood, a primary biomaterial product, are composed of different blends and different proportions, which affects their role and contribution to the circular economy. Construction wood is one of the forest products that are eagerly utilized worldwide for construction needs. Among the reasons for the popularity of wood as a building material is its biological origin, i.e. it is a renewable resource, in contrast to building materials made from non-renewable fossil resources,the use of which cannot be considered sustainable.

Wood and wood waste are becoming increasingly popular in construction due to their special physical, chemical, mechanical and other properties. Softwood lumber is important for construction due to its mechanical properties, availability, processability, and affordability. The cost of softwood lumber construction materials is influenced by the type of use, the type of trees from which they are made, production volumes, and so on. About 38.1 % of the wood used in the world is used for construction [6]. About two-thirds is sawn timber and the rest is wood-based panels. While softwoods are used for construction, hardwoods are mainly used for energy production.

When considering wood as a building material, a purely circular approach is seen as practicing cascade utilization. Cascade use can be well understood as part of a circular economy approach due to its objective and integration of R strategies. An initially high quality wood product is successively downstreamed to lower stages of production during its life cycle. Wood products are rarely processed for identical uses, and the purpose of the product changes with each stage of the life cycle. The production stage covers the processes of manufacturing new wood products; production waste, such as sawdust, is also used to make new products (pellets). Under these conditions, new approaches to the reuse, repurposing, recycling and recovery of wood-based building materials are required.

In addition to sawn timber, other building materials include chipboard, fibreboard and oriented strand board (OSB). Waste from sawn timber production is used to make wood-based panels, which is a real example of cascade utilization. According to the concept of reuse, wooden boards and by-products of production are used in building structures in other ways, for example, by repurposing them for facade cladding, flooring, and other construction works [6]. A potential untapped wood reserve is production and consumption waste, the so-called used wood, such as wood from the demolition and dismantling of buildings (wall elements and roof frames) [4].

According to the Law of Ukraine "On Waste Management", business entities engaged in the construction/demolition of buildings and engineering structures must ensure separate collection of construction and demolition waste, its accounting and transfer to waste management entities for treatment. Construction / demolition waste that is not hazardous is prepared for reuse, recycling, or other recovery, including backfilling [1]. This is especially true for building materials and wood products, as their use as secondary materials helps prevent excessive deforestation for construction purposes.

Waste wood is suitable for reuse, for example, as an additive to composite products. Wood-plastic product is used to make acoustic panels, garden furniture, indoor-use bricks or playground surfaces, and cement-wood composites such as wood-fiber-cement boards. In addition to being repurposed, wood products can be reused at the recycling phase. A theoretical recycling factor of about 25 % exists for buildings with wood as a load-bearing structure. About 21 % of recovered wood can be used to manufacture fiberboard and OSB. Including waste wood from engineering wood fractions, around 44 % of the total quantity of wood recovered can even be used to produce particle boards, as the requirements are less demanding, particularly in terms of toxicity and absence of pollution [6].

The suitability of wood waste as a structurally significant component can be determined using non-destructive testing methods. Some EU countries restrict direct use by classifying waste. Waste wood, as mentioned above, is used for the production of chipboard and fiberboard. The mechanical properties are not a concern, as the product goes to another quality stage where it is finally chopped and further processed. Sometimes up to a quarter of the required raw materials can be obtained from wood waste. The recovery of wood products accounts for about 51.6 % of global wood use. In practice, this value refers to the primary use, not the final disposal of wood products, most of which must eventually be thermally treated in a similar way to cascade utilization. About 62.5 % of the total wood used in the EU is thermally utilized for energy production [6].

The Forest Stewardship Council (FSC) initiated a discussion of the role of wood in the green reconstruction of Ukraine with representatives of the authorities, government agencies, and NGOs [2]. The discussion emphasized the need to develop clear indicators for the green recovery of the construction industry, introduce New European Bauhaus (NEB) principles to deepen cooperation with European partners and attract long-term investment in Ukraine's economy. It is important to create a life cycle assessment system for materials, develop modular construction using wood, and encourage the use of certified materials. As noted above, wooden house building is hampered by established stereotypes about wooden houses as short-lived and fire hazardous.

To overcome such stereotypes, it is important to popularize the training of specialists in the field of modern wood construction. In this sense, joining the NEB Academy (New European Bauhaus Academy, NEBA) Alliance, established in the EU in 2024, may be useful. The aim of the Alliance is to develop high-quality training courses related to the built environment. The project “Rebuilding a Better Ukraine through the New European Bauhaus (NEB) Academy” aims to promote the sustainable functioning of the NEBA hub in Ukraine as part of the NEB Academy Alliance, using its experience and resources. The project “NEBA (New European Bauhaus Academy) HUB in Ukraine” was prepared, presented by an international group of PhD students and Students with the participation of the author of the thesis at the University of Sustainable Development Eberswalde, Germany as part of the Project Development and Management course in 2025.

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MODELING THE IMPACT OF GEOMETRIC SHAPE CHANGES ON THE LEVEL OF TRANSMISSION HEAT LOSS OF ENERGY EFFICIENT GREEN BUILDINGS

Martynov Viacheslav[1], Martyniuk Oleh[2], Stadniichuk Denys[3], Poliak Yurii[4].

[1.2.3.4.]Kyiv National University of Civil Engineering and Architecture

In a world facing climate change and energy crises, energy efficiency in buildings is becoming one of the key areas of sustainable development. Ukraine, which is experiencing energy challenges due to war and needs to rebuild its infrastructure, has a particular need for "green" building projects. Energy efficiency modeling allows you to optimize costs, reduce environmental impact and ensure long-term resource savings.

Energy challenges that arise in Ukraine are a high dependence on imported energy sources (gas, coal). Destroyed infrastructure due to the war - the need to restore it taking into account energy efficiency. Increasing utility tariffs - encourages energy conservation.

Green building designers are faced with the task of quickly determining building parameters to form a certain level of building energy consumption

One of the ways to increase energy efficiency is to use an efficient building form, which will help reduce heat loss through the building's enclosing structure.


Fig. 1. Green buildings of various geometric shapes

A green building designer needs a quick way to determine the level of heat loss reduction when changing the geometric shape of a building.

Objective: To propose a way to quickly determine the level of transmission costs when changing the geometric shape of a green building.

Main part. In the conducted studies [1] it was determined that the transmission heat losses are influenced by factors related to the geometric parameters of buildings. One of them is the geometric shape of the building.

The study was conducted and the compactness of various geometric shapes of buildings was determined. The conversion factors K_{112} of the change in transmission heat losses under the condition of changing the geometric shape of the building were determined.

Transmission heat losses Qtr after changing the shape are determined by the formula:

$$Q_{tr} = Q_{tr\ ext}\ K_{112} \quad (1)$$

where:

Q_{tr} – transmission heat loss of the building after changing the geometric shape;

$Q_{tr\ ext}$ – existing transmission heat loss of the building before changing the geometric shape;

K_{112} – coefficient of change in transmission heat loss when changing the geometric shape during design.

$$K_{112} = \Lambda_{nov} / \Lambda_{isn} \quad (2)$$

where:

Λ_{nov} – the compactness coefficient of the geometric shape of the building after the transformation;

Λ_{isn} – the existing compactness coefficient of the geometric shape of the building before the transformation.

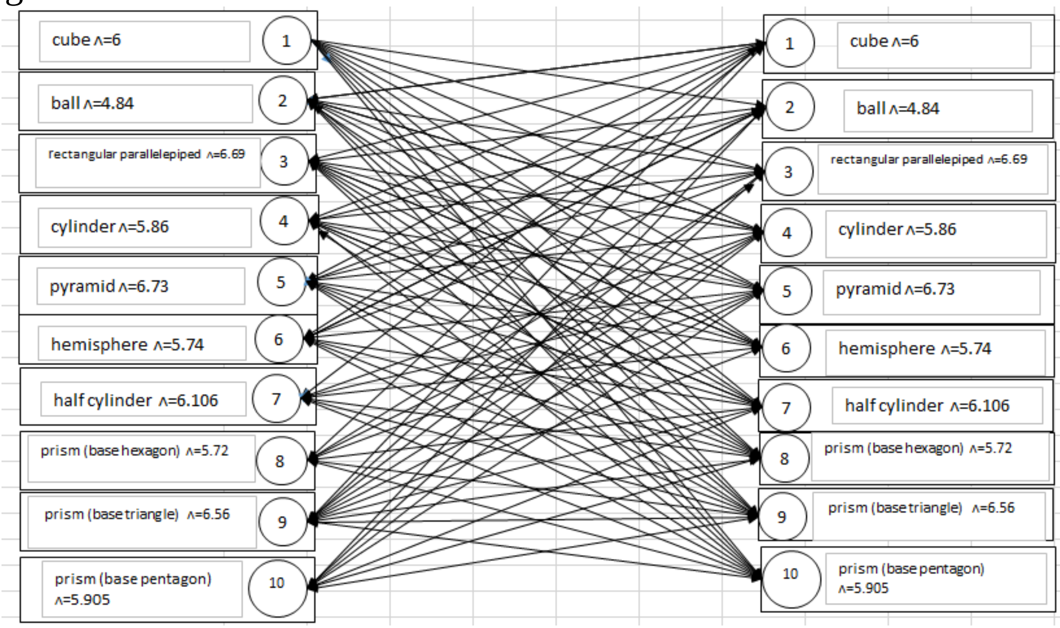

Fig. 2. Possible options for transforming the geometric shape of green buildings

The coefficients K_{112} of the change in the transmission costs of buildings are summarized in the table in Fig. 3.

		1	2	3	4	5	6	7	8	9	10
		cube ʌ=6	ball ʌ=4.84	rectangular parallelepiped ʌ=6.69	cylinder ʌ=5.86	pyramid ʌ=6.73	hemisphere ʌ=5.74	half cylinder ʌ=6.106	prism (base hexagon) ʌ=5.72	prism (base triangle) ʌ=6.56	prism (base pentagon) ʌ=5.905
			1,240	0,886	0,980	0,892	0,957	0,917	0,950	0,915	1,016
1	cube ʌ=6		0,807	1,120	1,023	1,120	1,045	1,017	1,048	1,093	0,984
		0,807		0,723	0,826	0,719	0,843	0,792	0,846	0,730	0,819
2	ball ʌ=4.84	1,240		1,380	1,210	1,390	1,190	1,261	1,180	1,370	1,220
	rectangular parallelepiped	1,120	1,120		1,142	0,994	1,165	1,100	1,170	1,020	1,136
3	ʌ=6.69	0,886	0,893		0,876	1,006	0,858	0,909	0,855	0,980	0,880
		1,023	1,210	0,880		0,870	1,020	0,960	1,025	0,890	0,990
4	cylinder ʌ=5.86	0,980	0,826	1,136		1,149	0,980	1,042	0,976	1,124	1,010
		1,120	1,390	1,010	1,148		1,172	1,100	1,180	1,025	1,139
5	pyramid ʌ=6.73	0,892	0,719	0,990	0,871		0,853	0,909	0,847	0,976	0,878
		1,045	1,190	0,858	0,980	0,850		0,940	1,003	0,875	0,972
6	hemisphere ʌ=5.74	0,957	0,840	1,166	1,020	1,176		1,064	0,997	1,143	1,029
		1,017	1,261	0,912	1,041	0,907	1,064		1,067	0,930	1,034
7	half cylinder ʌ=6.106	0,917	0,793	1,096	0,961	1,103	0,940		0,937	1,075	0,967
		1,048	1,180	0,855	0,976	0,850	0,997	0,936		0,873	0,968
8	prism (base hexagon) ʌ=5.72	0,950	0,847	1,170	1,025	1,176	1,003	1,068		1,146	1,033
		1,093	0,738	0,980	1,190	1,031	1,142	1,073	1,146		1,100
9	prism (base triangle) ʌ=6.56	0,915	1,355	1,020	0,840	0,970	0,876	0,932	0,873		0,909
	prism (base pentagon)	0,984	1,220	0,880	1,010	0,878	1,029	0,967	1,033	0,909	
10	ʌ=5.905	1,016	0,820	1,136	0,990	1,139	0,972	1,034	0,968	1,100	

Fig. 3. Table of conversion coefficients K_{112} of transmission heat losses when changing the geometric shape of the building

Conclusion. The study was conducted, a method was proposed for quickly determining the change in the level of transmission costs when changing the geometric shape, and increasing energy efficiency by using a rational geometric shape of a green building. The K_{112} weighting factors were determined to determine the level of conversion of transmission heat losses when changing the geometric shape. The results of the study can be used by designers and students when developing projects for energy-efficient green buildings.

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USING SISAL FIBER IN THE INSTALLATION OF GREEN ROOFS

Kateryna Matviichuk [1]***, Tatyana Tkachenko*** [2]

[1,2]*Kyiv National University of Constructions and Architecture*

Environmental live constructions (green roofs, flower beds, horizontal landscaping) is a new way to improve comfortable condition for coexistence with wildlife and create comfortable conditions to improve the quality of the environment.

Due the human factor, industrialization has been actively taking place for decades, which has had a significant negative impact on the state of the environment. The main dangerous impact factor is the release of harmful gases that accumulate in atmosphere and form a greenhouse effect, which entails negative consequences.

Increasing the area of green spaces significantly improves not only the state of environment, but also the overall state of the planet's ecosystem.

It is important to make green structures completely safe, and with minimal damage to the plants in these structures, which will perform the functions of landscaping the area and purifying the a.

The green roof structure consists of a concrete building structure, a root barrier layer, drainage mat, a geotextile filter, soil, and vegetation (Fig.1). Each component ensures optimal plant growth and functional.

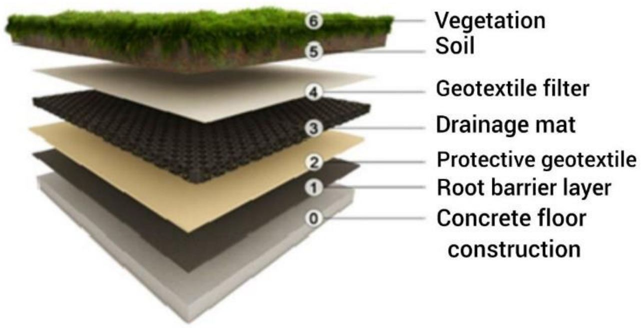

Fig 1. Green roof construction [1]

Purpose of green structures:

- Thermal insulation and energy officiency
- Reducing heat islands in urban environments
- Rainwater absorption
- Optimization of air quality
- Noise insulation
- Optimizing biodiversity in urban environments
- Psychologically comfortable architecture

Disadvantages:

- Additional weight on structures
- High cost of material
- High complexity of repair in case of emergency roof condition
- Climatic restrictions
- Harmful effects on vegetation

Ensuring a reduction in the number of deficiencies is possible by changing the technology for installing green structures, which will increase the efficiency and accessibility of green building technologies in urban environments. Replacing the root barrier layer from synthetic materials used in the structure with organic ones[2].

Root barriers are created to prevent the spread of roots. Regulates the direction of root growth and prevents structural destruction. Made in plastic[5]. Over time, there is a risk of microplastic particles getting into the roots, which provokes stress reactions in plants, a negative impact on microorganisms in the soil, and a change in soil pH.

The average weight per square meter of root barrier is 2 kilograms.

Sisal is a natural coarse fiber obtained from the leaves of the agave sisal or henekena of the genus Agave·. Fiber composition: cellulose (55-65%), lignin (10-20%), hemicellulose (10-15%), pectin (2-4%) [3].

Advantages of sisal fiber:

- Sisal is a natural material that is biodegradable, making it environmentally friendly..
- Sisal fiber has high tensile strength, which allows it to withstand significant loads..
- Sisal is moisture resistant, which is necessary for use in the soil.
- The material allows air to pass through, which promotes healthy plant growth.
- Sisal does not accumulate static electricity, which reduces the risk of dust or other particles accumulating.

The average weight of a square meter of sisal fiber is 800 grams.

In comparative characteristics, sisal fiber has a lower weight, which provides less load on the roof. The environmental friendliness of the fiber and its biodegradability will provide: optimal conditions for plant growth and development, regulation of the direction of root growth, ventilation and drainage[4]. The affordability of sisal fiber is much cheaper than root barriers.

Table 1

Price comparison characteristics [5,6]

Cost	Material	
	Sisal	Root barier
Prise per ton	350$	5713$
Price per kilogram	0,35$	5,71$

Thus, sisal fiber is a cost-effective and environmentally friendly alternative to root barriers. Its natural origin and low cost make the material available for wide application. Sisal fiber has high strength and durability, which allows it to be effectively used to protect soil from erosion and contain plant root systems. Thus, sisal fiber is a competitive alternative in terms of efficiency and cost.

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INNOVATIVE HYBRID SOLAR COLLECTOR FOR HEAT AND POWER SUPPLY

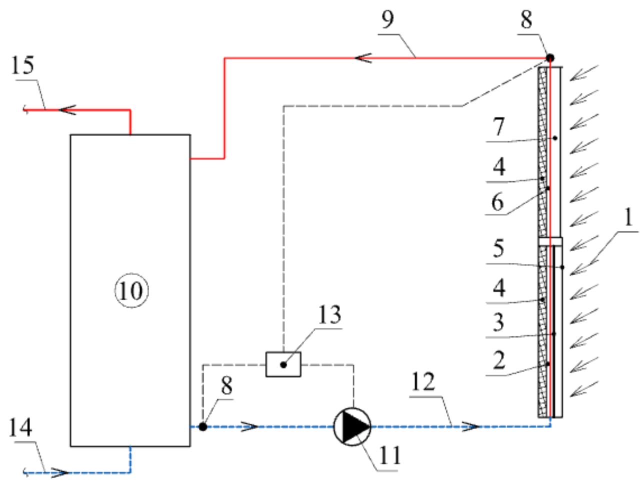
Stepan Mysak, Stepan Shapoval
National University "Lviv Polytechnic"
stepan.y.mysak@lpnu.ua, stepan.p.shapoval@lpnu.ua

According to alarming forecasts of the United Nations, the deterioration of the ecological situation on the planet has necessitated the development of a comprehensive action plan [1] for implementing sustainable development principles. In this context, the ratification of the Paris Agreement [2] became one of the key steps. Projections show that if current greenhouse gas emission levels persist over the next 20 years, Earth's temperature may increase by 1.5°C. This requires urgent measures to reduce global greenhouse gas emissions [3]. To achieve the set goals, an analysis of the European Union's energy sector policy was conducted [4], resulting in the implementation of the European Green Deal, oriented toward a sustainable development strategy [1]. Within this initiative, a number of regulatory documents aimed at reducing greenhouse gas emissions have been developed and enacted, such as [5,6,7]. An important role is also played by the promotion of renewable energy sources, which is established, for example, in EU Directive 2018/2001 "On promoting the use of energy from renewable sources." Additionally, the European Commission approved an energy conservation plan [8]. To accomplish these tasks, it is necessary to reduce the use of traditional energy sources that operate on fossil fuels. This encourages more active involvement of renewable and non-traditional sources, such as vibration energy [9] or solar energy. This requires developing new technologies [10] and improving existing solar energy supply systems [11], applying modern technologies. One of the key directions is the development [12] and improvement of devices that allow efficient use of solar energy for simultaneous production of thermal and electrical energy through the application of hybrid solar collectors. The problem of optimizing solar energy use is creating modern constructive and technological solutions that will ensure maximum effective absorption of solar radiation and its conversion into thermal and electrical energy with minimal losses. This includes combining photovoltaic panels and thermal collectors into a single integrated system, optimizing heat exchange processes, and increasing insulation levels through improving structural elements and applying innovative materials. After all, hybrid systems have their drawbacks. In particular, almost 90% of solar radiation is absorbed by the surface of photovoltaic panels, and only 15% of the absorbed energy is converted into electrical energy, while almost 10% is converted into thermal energy . In this context, it is proposed to combine thermal and electrical components in hybrid systems, adding concentrators that can significantly increase heat exchange efficiency . The implementation of such solutions will contribute to reducing dependence on fossil fuels, cutting greenhouse gas emissions, and supporting sustainable development. To reduce the impact of these drawbacks and increase the efficiency of the photovoltaic-thermal collector, the authors proposed conducting computer modeling of a system equipped with such a solar collector.

The article analyzes the functioning of a hybrid energy supply system (HESS), which includes a hybrid thermal photovoltaic solar collector (HTPSC). The schematic diagram of this system is shown in Fig. 1.

The aim is to analyze the functioning of a hybrid solar collector in heat supply systems, as well as to identify parameters that significantly affect its thermal and electrical efficiency. This is necessary to achieve maximum thermal and electrical efficiency of the equipment under given operating conditions.

According to Fig. 1, the hybrid energy supply system with a hybrid thermal photovoltaic collector (HESS with HTPSC) consists of two main blocks: a hybrid thermal photovoltaic collector, which includes a photovoltaic part 2 and a thermal part 6, and a thermal accumulator (TA) 10. These blocks are connected by pipelines for heated 9 and cooled water 12, which serves as the heat transfer fluid in this system. The circulation of the heat transfer fluid occurs thanks to pump 11, which ensures the transfer of absorbed thermal energy from the solar radiation source 1 to the TA, from where water is then supplied to end consumers. The operation of the circulation is controlled by control unit 13 based on information received from thermal sensors 8. To reduce heat losses and increase the efficiency of the HTPSC, the design includes a thermal insulator 4 and solar radiation concentrators 7. The installation generates electrical energy using photovoltaic cells 3, which receive solar radiation through the transparent cover 5.



Legend:

1 – solar radiation source; 2 – thermal photovoltaic part of HTPSC; 3 – photovoltaic cells; 4 – thermal insulator; 5 – protective transparent cover; 6 – thermal part of HTPSC; 7 – solar radiation concentrators; 8 – thermal sensors; 9, 12 – pipelines for heated and cooled heat transfer fluid; 10 – thermal accumulator (TA); 11 – circulation pump; 13 – control unit; 14, 15 – pipelines for cooled and heated heat transfer fluid in the consumer system

Fig.1 Hybrid energy supply system

Experimental studies of the solar system were conducted at an ambient air temperature of 15°C. The HTPSC plane was oriented perpendicular to the direction of the sun's rays. Parameter values were recorded every 5 minutes. During each experiment, the mass flow rate of the heat transfer fluid in the installation remained constant.

Experiments on the HES with HTPSC were conducted under constant azimuthal deviation angle of the normal to the HTPSC from the local meridian α = 50° and tilt angle of the HTPSC to the horizon β = 50° (Fig. 2 – Fig. 7), as well as for α = 50° and solar radiation intensity in its plane I_t = 500 W/m² (Fig. 8 – Fig. 13).

The thermal efficiency of the HTPSC ηHTPSC, depending on the solar radiation intensity in its plane I_t [W/m²], is shown in Fig. 2.

According to Fig. 2, for a specific mass flow rate of the heat carrier G, which is 0.015 kg/(m²·s), with an increase in the intensity of solar radiation in the HTPSC plane I_t, its thermal efficiency ηHTPSC decreases nonlinearly: threefold from 2.42 at I_t = 100 W/m² to 0.81 at I_t = 500 W/m², and by an additional 22% to 0.63 at I_t = 900 W/m², reducing by a total factor of 3.8.

In Fig. 3, a graphical dependence of the thermal efficiency of HTPSC ηHTPSC on the mass flow rate of the heat carrier G [kg/s] is presented.

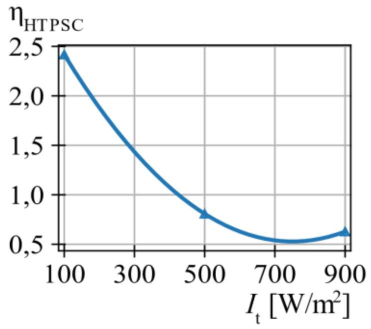


Fig. 2. Dependence of the thermal efficiency of HTPSC η_{HTPSC} on the intensity of solar radiation in its plane I_T by α = 50˚, β = 50˚, G = 0,015 kg/m² s

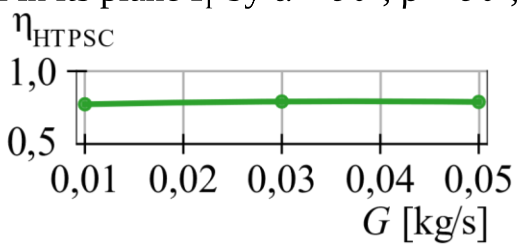


Fig. 3. Dependency of the thermal efficiency of HTPSC ηHTPSC as a function of the mass flow rate of the heat transfer fluid G, at α = 50°, β = 50°, and I_t = 500 W/m².

From Fig. 3, it follows that at a solar radiation intensity in the HTPSC plane of I_t = 500 W/m², its thermal efficiency ηHTPSC is almost independent of the mass flow rate of the heat carrier G in the system and ranges from 0.79 to 0.81.

Fig. 4 shows the variation in the thermal efficiency of the HES with HTPSC ηHES with HTPSC, depending on the solar radiation intensity in the HTPSC plane I_t [W/m²].

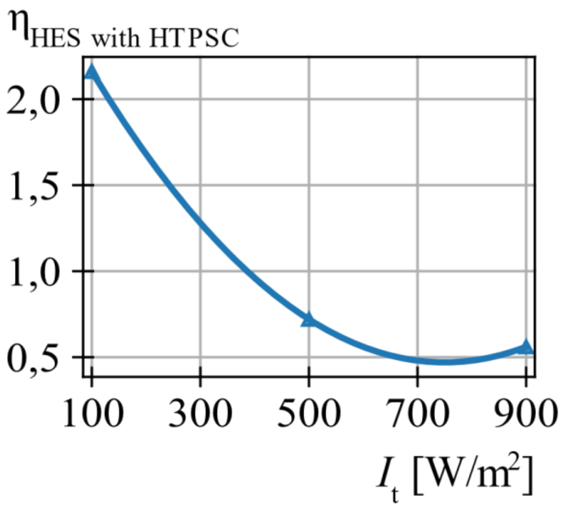


Fig. 4. Dependency of the thermal efficiency of the HES with HTPSC ηHES with HTPSC as a function of the solar radiation intensity in the HTPSC plane I_t, at α = 50°, β = 50°, and G = 0.015 kg/(m²·s).

From Fig. 4, it follows that for a specific mass flow rate of the heat carrie G, which is 0.015 kg/(m²·s), with an increase in the solar radiation intensity in the HTPSC plane I_t, the thermal efficiency of the HES with HTPSC ηHES with HTPSC decreases nonlinearly: threefold from 2.12 at I_t = 100 W/m² to 0.71 at I_t = 500 W/m², and by an additional 22% to 0.55 at I_t = 900 W/m², decreasing by a total factor of 3.8.

The graphical dependence of the thermal efficiency of the HES with HTPSC ηHES with HTPSC on the mass flow rate of the heat carrier G [kg/s], is shown in Fig. 5.

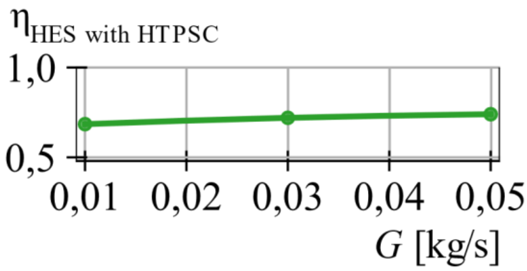


Fig. 5. Dependence of the thermal efficiency of the HES with HTPSC ηHES with HTPSC on the mass flow rate of the heat carrier G at α = 50°, β = 50°, and I_t = 500 W/m².

According to Fig. 5, at a solar radiation intensity in the HTPSC plane of I_t = 500 W/m², the thermal efficiency of the HES with HTPSC ηHES with HTPSC slightly increases from 0.67 at G = 0.005 kg/(m²·s) to 0.71 at G = 0.015 kg/(m²·s) and to 0.73 at G = 0.025 kg/(m²·s), increasing by a total of 9%.

Thus, for an azimuthal deviation angle of the normal to the HTPSC from the local meridian α = 50° and a tilt angle of the HTPSC to the horizon β = 50°, at a solar radiation intensity in its plane I_t = 500 W/m², the change in the mass flow rate of the heat carrier G from 0.01 kg/s to 0.05 kg/s has little effect on the thermal and electrical characteristics of the HTPSC. However, at G = 0.03 kg/s, an increase in I_t from 100 W/m² to 500 W/m² reduces ηHTPSC and ηHES with HTPSC threefold, from 2.42 to 0.81 and from 2.12 to 0.71, respectively. An increase in I_t from 500 W/m² to 900 W/m² further decreases ηHTPSC and ηHES with HTPSC by 22%, to 0.63 and 0.55, respectively. Conversely, the electrical efficiency of HTPSC ηFE increases by 8.6% when I_t changes from 100 W/m² to 900 W/m².

For α = 50° and I_t = 500 W/m², at β = 50°, the thermal efficiency ηHTPSC and the electrical efficiency ηFE of HTPSC are almost independent of the variation in the mass flow rate of the heat carrier G from 0.01 kg/s to 0.05 kg/s, while ηHES with HTPSC increases by 9%, from 0.67 to 0.73.

For G = 0.03 kg/s, when β increases from 10° to 50°, the thermal efficiencies ηHTPSC and ηHES with HTPSC decrease by 15%, from 0.95 to 0.81 and from 0.83 to 0.71, respectively, and remain almost unchanged when β increases further to 90°. The variation in the tilt angle of the HTPSC to the horizon β from 10° to 90° has almost no effect on the electrical efficiency of the HTPSC photovoltaic cells ηFE, reducing it by only 1%.

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STUDY OF OIL HYDROCARBON REMOVAL PROCESSES IN FILTRATION LAYERS OF RAIN GARDENS

Kravchenko Maryna[1], Tkachenko Tetiana[1], Mileikovskyi Viktor [1]
kravchenko.mv@knuba.edu.ua, tkachenko.tm@knuba.edu.ua, mileikovskyi.vo@knuba.edu.ua
[1]Kyiv National University of Construction and Architecture

Increasing urban populations, expanding urban areas, and increasing land development density play a key role in the deterioration of water resources, affecting both their quantity and quality in urbanised water basins [1].

The study of urban stormwater quality began in the mid-20th century, and the authors of [2] were among the first to draw attention to this problem. Later studies have focused on traditional pollutants such as total suspended solids, chemical or biochemical oxygen demand, metals, pathogens, and nutrients. Modern scientific work often confirms previous results on the main pollutants of urban stormwater and provides data on new substances such as pesticides, microplastics, as well as organic pollutants (OPs) such as polycyclic aromatic hydrocarbons, phthalates, alkylphenols, petroleum hydrocarbons (PHs), which are ubiquitous in urban stormwater [3]. The most common representatives of organic pollutants are diesel fuel (DF) and used engine oil (UEO), as the main source of energy worldwide.

Due to the harmful effects of OPs on aquatic ecosystems and humans, including a combination of genotoxicity, bioaccumulation and resistance to degradation, stormwater treatment is becoming increasingly important in the field of urban stormwater management [4]. Solving this problem requires modern research and development on innovative and effective stormwater quality management technologies that can prevent further transport and spread of pollutants into the environment, where they bioaccumulate in food chains.

Over the past decades, urban stormwater management paradigms have gained popularity that focus on controlling stormwater directly at the source rather than rapid drainage. One of the practices often used in these cases is rain gardens, which are implemented in residential areas for local stormwater management and contribute to slowing the rate of peak runoff, reducing its volume, recharging groundwater through infiltration, and removing pollutants from water before it reaches local streams [5].

To investigate the effectiveness of rain garden structures in removing petroleum hydrocarbons from stormwater runoff, a laboratory experiment was conducted over a period of six months (22 weeks) in the laboratory for monitoring environmental parameters of the Department of Environmental Protection Technologies and Labour Safety of the Kyiv National University of Construction and Architecture (Ukraine).

For the experimental studies, cylindrical columns (Fig. 1) were used, made of polyvinyl chloride materials, 100 mm in diameter, 900 mm in height and 2 mm in wall thickness, in order to create an economical and compact installation with dimensions that minimised the wall (edge) effect and dispersion in the columns. In the vertical cross-section of the filtration columns, the filter media were placed in the following sequence (from top to bottom): 330 mm of soil, 330 mm of sand and 200 mm of gravel. Plants with a well-developed fibrous root system, including a representative of the widespread Ukrainian species *Physocarpus opulifolius ‘Diabolo’*, were planted in the upper part of the soil layer.

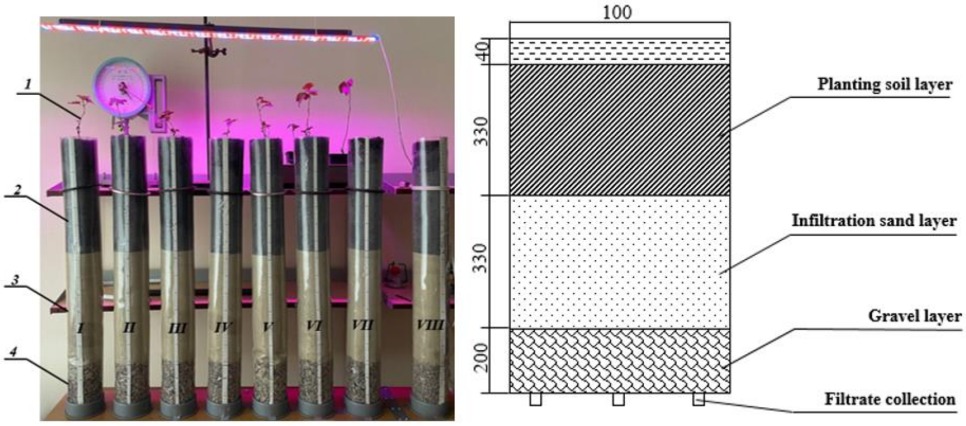

Fig. 1. Experimental columns and their schematic diagram:
1 – *Physocarpus opulifolia Diabolo*; 2 – soil layer; 3 – sand layer; 4 – gravel layer

The experimental methodology consisted of modelling the process of oil hydrocarbon filtration through laboratory columns with and without *Physocarpus opulifolius ‘Diabolo’* plants (columns I-VI). Watering was carried out every three days for 22 weeks, adding pollutants (DF or UEO) followed by tap water. The filtration efficiency and plant condition were assessed by visual observations, morphometric measurements and analysis of filtrate samples by the RP-HPLC method, conducted at the Institute of High-Molecular Weight Chemistry of the National Academy of Sciences of Ukraine.

The results of RP-HPLC showed a complete absence of characteristic UEO and DF components in the filtrates of all experimental columns. However, an intense chromatographic peak with a retention time of 4.22 min was observed in each sample. The UV-visible spectrum of this peak does not coincide with any of the components of the model PHs, indicating the presence of a foreign compound.

This peak is likely to correspond to a metabolite released by the root system of *Physocarpus opulifolia ‘Diabolo’* into the soil environment, which requires further research to study the biological mechanisms of remediation. It should also be borne in mind that at 240 and 290 nm, there is a possible effect of UVB on other UV-active compounds, in particular fulvic and humic acids, present in the organic fraction of the soil. Given that the sandy loam fertile soil used had a high content of organic matter, humic components could be simultaneously extracted into the filtrate and detected in the corresponding zones of the chromatogram.

Based on the spectral characteristics, retention time and peak areas, it can be assumed that the detected substance is a hydrophilic compound with a low molecular weight containing a carbonyl or carboxyl functional group conjugated to a double bond.

Thus, based on the results of chromatographic analysis of leachates after 62 exposure cycles over 154 days (22 weeks), it was found that none of the samples contained DF or UEO residues. This indicates the complete removal of model PHs within the selected experimental parameters, including the characteristics of the filtration medium, pollutant dosage and storm water, and therefore the removal efficiency was 100%.

In addition, the experiment analysed the soil media in which the accumulation and transformation of pollutants occurred. As can be seen from the study results, up to 95% of model pollutants are retained in the surface layer of the soil medium for planting plants mainly due to sorption processes. During the experiment, it was found that the DF and UEO components introduced into the filtration layer underwent biochemical transformation, which is confirmed by changes in the UV-visible spectra. In particular, oxidation processes probably led to the formation of oxygen-containing functional groups - hydroxyl, carbonyl, epoxy, carboxyl, as well as a reduction in the carbon skeleton of molecules. At the same time, an increase in the retention time of the newly formed substances in the chromatographic column was observed compared to the original components, indicating a decrease in polarity and an increase in molecular weight. In general, the increase in the size of hydrocarbon molecules leads to an increase in their hydrophobicity, electrochemical stability, sorption capacity and stability in the soil environment.

During the experimental study, a change in the hydraulic conductivity k (mm/h) over time was detected, especially for the experimental columns that were subjected to UEO irrigation (Table 1). This indicates the clogging of the experimental rain gardens, which was manifested in the delay of water infiltration inside the columns.

Table 1

The average value of hydraulic conductivity k (mm/h) of the experimental columns after 10 and 22 weeks of their operation under different conditions

Number of Experimental Columns (Presence of Vegetation/Type of Model PHs)	Value of *k* after 10 Weeks, mm/h	Percentage of Decrease in *k* after 10 Weeks, %	Value of *k* after 22 Weeks, mm/h	Percentage of Decrease in *k* after 22 Weeks, %
I and II (with vegetation/UEO)	137	26	47	75

III and IV (with vegetation/without irrigation with PHs)	180	27	157	15.1
V and VI (with vegetation/DF)	163	12	112	40
VII (without vegetation/UEO)	124	33	42	78
VIII (without vegetation/DF)	158	15	98	47

The value of hydraulic conductivity for all experimental columns at the beginning of the experiment was 185 mm/h. After 10 weeks of research (20 irrigation cycles), the *k* value decreased by 26 and 12% for columns I, II and V, VI with vegetation (UEO and DF irrigation). For columns VII and VIII without vegetation, the decrease in *k* was 33 and 15%, respectively. As can be seen from the results in Table 1, the hydraulic conductivity decreases with time for all configurations of the experimental columns (with and without vegetation).

At the end of the experiment (22 weeks and 62 irrigation cycles), the k value decreased significantly for columns I, II and VII, which were injected with UEO, in contrast to columns V, VI and VIII, which were injected with DF. Moreover, the percentage of *k* reduction depending on the presence of plants did not differ significantly, since at this stage the development of the outer part of the plant and its root system was already inhibited.

The results obtained can be explained by the ability of UEO, unlike DF, to change the hydrophilic properties of the air-dispersed soil medium to hydrophobic ones. UEO contains alkyl sulfonates, which can change the interfacial properties of the soil. When water penetrates the oil-filled soil pores, it does not wet the mineral particles and does not displace the oil, as is required by physical laws. Thus, water infiltration through UEO adsorbed on hydrophobic mineral surfaces is slower, which leads to a decrease in the hydraulic performance of the system as a whole.

The change in hydraulic conductivity of experimental columns III and IV, which were planted with vegetation and were not subjected to watering with any of the model PHs, but only with tap water, should be separately justified. This allows us to draw a conclusion and compare it with the results available in the literature regarding the change in the hydrological parameters of the system during its operation in the absence of the pollutant factor. As can be seen from the results presented in Table 5, the percentage of reduction in k for columns III and IV after 10 and 22 weeks was 2.7 and 15.1%, respectively. That is, the modelled flow in the columns showed a slight decrease in k values at the end of the experiment, which correlates with the results obtained in studies [6]. Rain garden systems «clog up» over time and the hydraulic conductivity decreases by an average of 3.6 times during 72 weeks of testing due to the top layer. Authors [6] studied an infiltration basin built on sandy loam soils. They found that hydraulic conductivity increased from 20% to 40% (of its original value) after replacing the top 5 cm of soil. Removal of 15 cm of soil was required to restore the hydraulic conductivity of the system to its original value (68%).

To preserve the hydraulic conductivity of rain gardens operating under conditions of high concentrations of UEO, it is recommended to periodically remove and replace the top layer of the soil medium (5-10 cm), where pollutants mainly accumulate. A decrease in infiltration rate and prolonged saturation with water after precipitation (>48 hours) are signs of saturation of the medium and the need for technical intervention. Such regeneration of the layer allows to restore the infiltration capacity of the rain garden, reduce the volume of overflow and extend the effective life of the system.

To maintain the structure of the medium and prevent its compaction, it is recommended to use plants with a well-developed root system that form macropores, promote aeration, and activate hydrocarbon biodegradation. At the same time, it is advisable to design a rain garden with separate maintenance areas - with and without vegetation, which simplifies maintenance. Optimising the composition of the filtration medium by adding adsorbents (biochar, activated carbon, ash) also helps to increase the long-term hydraulic stability of the structure.

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SECONDARY ENERGY RESOURCES IN THE ENERGY SECTOR OF UKRAINE

***Anna Moskvitina*[1]*, Bondarenko Victoria* [1]**
[1] *Kyiv National University of Construction and Architecture,*
moskvitina.as@knuba.edu.ua, bondarenko_vo-2022@knuba.edu.ua

The energy sector of any country is a crucial factor in the progress of its economy, as well as the level of well-being of its citizens under certain circumstances, and either an impetus or a brake on its development.

The annual energy consumption in the world is about 14 billion tonnes of energy equivalent. These are mainly resources of organic origin - coal, oil, natural gas - 82%, nuclear power - 7%, hydropower - 3%, firewood - 7% and renewable energy - 1%. However, the level of economic development of any country is now determined not by the amount of fuel and energy resources (FER) produced or consumed, but by the efficiency of their use - the energy intensity of GDP, the specific consumption of FER per unit of output. These indicators are much lower in those countries where effective economic and legal mechanisms for stimulating energy saving have been created, on the basis of which the market for energy-saving technologies and equipment, demand and provision of energy saving services has emerged [1].

A new criterion for assessing the economic development of countries that has emerged in recent decades is the share of energy produced from non-conventional and renewable sources. In highly developed economies, it ranges from 0.7% (UK) to 64.5% (Iceland) and has clear upward trends in the future.

Ukraine is an energy deficit country, as it does not cover its energy consumption needs. Such a structure of FER is economically unreasonable, makes Ukraine's economy dependent on oil and gas exporting countries and threatens its energy and national security.

However, experts' calculations show that Ukraine's own reserves of traditional fuel and energy resources will be exhausted in 40-60 years at the current rate of field exploitation (except for coal). In this regard, the implementation of energy saving policy is a matter of energy security of the state and ensuring the future of the national economy. According to the Institute of General Energy of the National Academy of Sciences of Ukraine, Ukraine's energy saving potential is estimated at 42-48%. According to experts, the main FER savings can be achieved in industry - 38%, in the utilities sector - almost 30%, and in the fuel and energy sector - 17%. It is important to note that the cost of extracting or purchasing fossil fuels is 2-2.5 times higher than the cost of saving 1 tonne of fuel equivalent through energy saving [2].

Analysing the structure of industrial production, own resource base and projected volumes of FER consumption, it can be concluded that the future of Ukraine's economy and the state as a whole depends primarily on the ability to create an effective system of encouraging the improvement of efficiency of use and reduction of FER consumption, introduction of favourable lending conditions for energy saving measures and increase of peat, various types of gas, and renewable energy.

The use of cogeneration in public utilities and industry, at compressor stations, improvement of heat supply systems, introduction of energy-saving lighting devices and other measures will increase the efficiency of traditional fuel use by 30-35% [3].

Develop an analysis of the operation of fuel equipment at enterprises and the feasibility of reorienting certain power plants, metallurgical and machine-building enterprises, as well as manufacturers of construction materials to use other energy sources instead of natural gas, studying the real possibilities and economic and environmental consequences of this transition. Based on the analysis, develop a state programme 'Reorientation of individual power plants, metallurgical and machine-building enterprises, as well as producers of construction materials to use other energy sources instead of natural gas'.

Energy conservation is classified as a new source of energy that is cheaper than many other traditional and non-traditional sources. There are three areas: utilization measures (use of "energy waste" - secondary energy resources (SER)), energy modernization (reduction of waste without changing the fundamental principles of technologies and techniques) and intensive energy conservation and energy efficiency (measures that realize an extremely high energy conservation effect, achieved by changing the fundamental principles of technologies). In Ukraine, the use of renewable energy sources is relevant because the cost and capital expenditures for the production of thermal energy from thermal waste are 3-4 times lower than at a CHP or boiler house.

As of 2018, the total annual output of renewable energy sources in Ukraine is estimated at 26.18 million tons. At the same time, combustible SER account for 38.5% of the total SER output, thermal SER - 58.0%, and overpressure SER - about 3.5% [4].

If we assess the current state and prospects of SER use in Ukraine, the levels of SER utilization of different types differ significantly. Secondary energy resources of overpressure are used in Ukraine to a very limited extent. The reasons for this are: lack of heat recovery equipment, its short service life and low level of maintenance; lack of heat consumers near the source of SER generation, which makes it impossible to install heat recovery equipment; limited locations for equipment installation; mismatch of modes of generation and consumption of thermal SER; lack of optimal schemes for the use of SER within a single energy technology system of enterprises or industrial units; insufficient number of developments for emergency situations.

The utilization rate of combustible SER is very high and reaches 86.9%. For thermal SER, this figure is much lower. In the case of high-potential SER, it is 71.7%. Until recently, utilization of low-potential SER was considered economically inefficient, although the output of these SER reaches half of the total output of all SER. At present, the development of low-potential SER utilization requires special attention. According to forecasts, the output of combustible SER will increase by 43% by 2030, and that of high-potential thermal SER - by 45% [5].

At present, the main areas of work on the use of SER are related to the utilization of combustible (we are talking about the development of scientific foundations for efficient technologies for the combustion of wood mass, primary and secondary agricultural waste, solid household waste and the creation of appropriate equipment) and thermal SER. For high-potential thermal SER, research is related to the utilization of thermal waste from industrial furnaces for various purposes, as well as gas turbine and gas piston engines. For low-potential thermal SER, research is being conducted on the use of heat emissions from boiler units, industrial furnaces, as well as heat from various ventilation emissions, domestic and industrial wastewater, and mine water [6].

The study of the state and prospects of the use of secondary energy resources is one of the important areas of analysis of possible fuel and energy savings in the country, as well as ensuring environmental standards.

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HEAT ACCUMULATION FROM COGENERATION UNITS

***Anna Moskvitina*[1], *Vyacheslav Melnychenko* [1].**

[1] *Kyiv National University of Construction and Architecture,*

moskvitina.as@knuba.edu.ua, melnychenko_vm-2022@knuba.edu.ua

The benefits of using cogeneration systems to supply energy to facilities are multifaceted: in terms of cost-effectiveness (including by reducing energy transmission costs, as the power generating equipment is installed in close proximity to the consumer), reliability (by reducing the vulnerability of the energy infrastructure in case of unforeseen failures) and heat recovery (by expanding the range of degrees of use of primary and secondary energy resources).

Combining cogeneration and absorption cooling units for combined production of electricity, heat and cold (trigeneration) seems to be advantageous in terms of energy saving. The use of cogeneration is particularly suitable for partial or complete conversion of an enterprise or housing stock from district heating to local cogeneration systems.

It is also advisable to convert energy types (heat to electricity and vice versa) using additional storage devices (to smooth out the uneven use of heat and electricity throughout the day), which rationally solve the problem of transferring excess electricity to the grid during periods of heat production interruption and ensure distribution.

Efficient and reliable operation of power generating enterprises is one of the most important criteria for ensuring a high level of economic well-being of society. The domestic infrastructure of industrial enterprises and housing and communal facilities usually involves a centralised procedure for obtaining energy. At the same time, the existing unified energy systems (electric and thermal) have the following disadvantages:

- significant losses in energy transmission through long and extensive networks;
- lack of reserve electric and thermal power;
- low efficiency and reliability of outdated equipment.

Currently, in the new economic environment of transition to socially oriented market relations and relatively high inflation, it is not possible to use centralised funds to replenish the resources that have been used up and require replacement of generating capacities. The construction of small thermal power plants (mini-CHPs) and the modernisation of existing mini-CHPs using cogeneration principles is one of the most promising ways to develop the country's energy sector [1].

Cogeneration is the thermodynamic production of two or more forms of useful energy (mechanical, electrical and thermal) from a single primary energy source (fossil fuels or unconventional types). If a significant portion of the fuel energy is not used in the traditional separate production of electricity (at power plants) and heat (in boiler houses), the total fuel consumption can be significantly reduced by using cogeneration plants that provide simultaneous joint production of electricity and heat.

Cogeneration processes can be used as a new technology in energy consumption in the projected area (as well as at an industrial or municipal facility), which provides significant economic benefits and increases the reliability of energy supply. When operating traditional (steam, gas) power plants, due to the technological features of the energy generation process, a large amount of heat is lost and released into the atmosphere through steam condensers, cooling towers and other cooling devices (heat exchangers).

Conventional power plants that produce only electricity use fuel less efficiently than cogeneration plants. The latter allow simultaneous production of both heat and electricity, which significantly increases the fuel utilization rate.

However, there is a problem: in the summer, when heating is not needed, the thermal energy of cogeneration plants is hardly used. This leads to significant heat losses. To avoid such losses, it is proposed to use heat storage systems that can accumulate heat during the warm period for further use in winter. One of the most effective solutions is to store heat in soil accumulators. For this purpose, special systems of heat exchangers are used, submerged in the ground, where heat is accumulated. Soil and water contained in it have a high heat capacity, which allows storing large amounts of thermal energy [2].

An important part of this system is heat pumps, which are used to extract the stored heat and transfer it to the heating network in winter. They work in such a way that they maintain a constant temperature in the heating system, which is especially important for ensuring comfort during the cold season. Heat pumps extract heat from the ground, where it accumulates in summer, and transfer it to the heating system, maintaining the required temperature of the heat carrier [3].

The system's operation scheme is as follows: first, in the summer, the heat is accumulated, during which the soil temperature gradually increases. Analyzing the experimental data, it can be concluded that the temperature accumulates and rises until the 180th day, reaching its maximum value. After that, the discharge phase begins, when the heat pumps extract heat, and the temperature in the soil gradually decreases. This is important for even heat distribution and maintaining the heating system during the cold season [4].

In addition, minimizing heat loss is important to increase system efficiency. Insulation of the top layer of the soil accumulator can reduce losses to 0.6% of the total amount of accumulated heat. This significantly improves the overall efficiency of the system, as even small heat losses can significantly reduce performance during the heating season [5].

One of the main advantages of the proposed technology is that it doubles the amount of heat that can be produced by cogeneration units without increasing fuel and energy consumption. That is, more heat can be produced for the same cost, which makes such a system particularly attractive for countries with a long heating season, such as Ukraine. And also when using cogeneration units during summer power outages in residential complexes with individual boilers.

The system is efficient from both an economic and environmental point of view, as it does not require the use of additional natural resources and has no negative impact on the climate.

Thus, an integrated system consisting of a cogeneration unit with heat storage in the summer and its use in the heating season using a heat pump is a promising solution for improving the operation of municipal thermal power plants. It helps to increase fuel efficiency, reduce heat losses and ensure a more stable heat supply in winter. In the context of rising energy prices and problems with power outages, such systems are becoming increasingly relevant and cost-effective.

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FEATURES OF THE USE OF HEAT PUMPS IN COMBINED HEAT SYSTEMS

Moskvitina Anna[1], Okhrysko Vadym[1], Kostiuk Pavlo[1].

[1]Київський національний університет будівництва і архітектури,
moskvitina.as@knuba.edu.ua, okhrysko_vv-2022@knuba.edu.ua , kostiuk_pl-2022@knuba.edu.ua

The Energy Strategy of Ukraine until 2030 plans to reduce energy imports and increase the share of coal and nuclear power. Heat supply will be developed through heat pumps. By 2030, it is expected to produce 180 million Gcal of heat. The share of nuclear power plants will remain at 52%. Heat pumps (HPs) use the temperature difference between a low-potential heat source and a receiver [1]. Their coefficient is always greater than 1 (usually 2-4), which does not contradict the laws of thermodynamics. They effectively concentrate energy from the environment. The world experience has long since mastered the use of heat pump units in heat supply systems, including combining them with thermal power plants, defining it as a thermodynamic heating method. Heat pumps with a conversion coefficient of $\varepsilon = 2$ are inferior to traditional heat generators with an efficiency of more than 70% in terms of fuel consumption. The only advantage of the heat source is that there is no need to supply solid or liquid fuel. By increasing the conversion efficiency of heat pumps and reducing electricity consumption, their efficiency is significantly higher than traditional heating systems for residential and industrial buildings. Heat pumps provide an effective solution for heating both urban and remote facilities (farms, cottages, etc.). They are economical, environmentally friendly, safe and reliable. The advantages of heat pumps are their environmental friendliness, i.e. the absence of harmful emissions, and flexibility, as they are suitable for any heating system and also operate as a refrigeration machine in summer [2].

Heaters provide efficient heat supply to facilities located far from utilities. They are cost-effective, environmentally friendly, safe, reliable, quiet and suitable for various systems. Heat pumps are widely used in many countries, including the US (30% of homes) and Sweden (350,000 homes). Subsidies, installation certification, and the growth of new construction are important factors in the market growth. In Finland, HPs have become popular, especially for heating houses using heat from the ground or lakes. The main challenges in the HPs industry are training and maintaining high product quality. In Ukraine, development is constrained by the low cost of energy, although in the current environment, the use of HPs is becoming promising for improving the environmental situation and saving fuel. Ukraine has the potential for heat pump development, including scientific, technical and manufacturing capabilities. Although some residential projects have already been implemented in the country, their scale is limited. Laws and programmes should be adopted to support environmentally friendly heating systems. This includes government support, tax breaks and credits, and the introduction of new technologies in the southern regions. There are already some projects in Ukraine to use heat pumps in cottages and apartment buildings, but these are isolated cases that do not cover the municipal heat sector. To develop this area, it is necessary to adopt legislation, including the creation of targeted programmes, such as ‘Environmentally Friendly Heat Supply’, that support the introduction of heat pumps through investments, tax breaks and loans [3].

At the same time, due to the sharp rise in natural gas prices and government regulations that stimulate interest in electricity as a heat source, the demand for integrating heat pumps into existing building heating systems has been growing. Typically, air-to-water heat pump installations are of interest because they are less costly and complex.

When integrating a heat pump into an existing heat supply system, the problem of selecting its capacity arises. Therefore, it is necessary to determine the optimal heat pump capacity for existing heat supply systems in private houses [4].

According to existing standards, specific heat losses in low-rise residential buildings in the southern region should not exceed 80 W/m². The temperature of the heat carrier in systems with gas boilers at a temperature of -18 °C in Odesa is 80-60 °C. However, in single-stage air-to-water heat pumps, the maximum temperature of the heat transfer medium does not exceed 60 °C, which makes it difficult to ensure the standard indoor temperatures. The minimum outdoor air temperature at which the heat carrier at 60 °C is able to provide comfort in the room is about 0 °C, while the heat source power does not exceed 55% of the maximum. This means that there is no need to install a heat pump of the same capacity as a gas boiler.

The efficiency of the heat pump is determined by the coefficient of performance (COP), which depends on the outdoor air temperature and the temperature of the heat transfer medium. The lower the outdoor temperature and the higher the temperature of the heat carrier, the lower the COP value. At current gas and electricity prices, a COP below 2 results in a higher cost of heat from a heat pump compared to a gas boiler. For most heat pumps, the COP above 2 is observed at outdoor temperatures above -5 °C. In Odesa over the past 10 years, the average number of days with temperatures below -5 °C is only 14 days per year [5].

The cost of a heat pump is significantly higher than the cost of a gas boiler, so it is important to correctly determine its capacity when developing a combined heat and power system. The boiler capacity can be calculated based on the maximum load on the heating and hot water system. And for an air heat pump, it is necessary to take into account the mode of operation and efficiency in this mode. More sophisticated heat pumps (two-stage) can provide a temperature regime of 80-60 °C, but their cost is 1.5-2 times higher. Having analyzed the feasibility studies of three variants of heat supply systems for a private house in Odesa with an area of 300 m² and 5 people: a gas boiler, a gas boiler with a single-stage heat pump, and a heat pump that provides a temperature regime of 80-60 °C, taking into account the calculation of heat losses and water consumption in accordance with existing standards, the following conclusions can be drawn:

1.Single-stage air-to-water heat pumps can only be used effectively in combination with a gas boiler.

2.The efficiency of air-to-water heat pumps is observed at outdoor temperatures above -5...0 °C.

3.The use of more complex heat pump designs that can provide temperature conditions of 80-60 °C leads to a significant increase in capital costs with insignificant savings.

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GLOBAL EXPERIENCE IN CONSTRUCTION WASTE UTILIZATION

Negoda N.V., Zhukova O.G., Bestiuk V.I, Panko P.M.
Kyiv National University of Construction and Architecture

The construction industry is one of the most influential factors of anthropogenic impact on nature. Construction rightfully occupies an important place among environmental pollutants, generating waste, residues of construction materials, as well as a significant amount of solid waste in the form of soils to be developed.

As the scale of investment and construction activities in Ukraine's major cities has increased, the need for vacant land plots for development has rapidly increased. One possible solution to the land shortage is to dismantle old structures that are not in use and occupy large areas. The analysis shows that there are a large number of buildings on the territory of industrial zones and military facilities that need to be reconstructed or demolished to free up land.

The anthropogenic impact of construction is multifaceted and manifests itself at every stage of construction work - from the extraction of raw materials and the manufacture of building materials to the processing of construction waste during the demolition of buildings and structures. In other words, the environment is affected by both the construction process and the products it produces.

Recycling construction waste can significantly save money on collection, transportation, and other necessary processes. Building waste, such as concrete and bricks, does not require transportation. Almost always, after a building is dismantled, a new facility is built in its place, and this requires a lot of crushed stone for the foundation. Recycling construction waste instead of crushed stone allows you to get crushed bricks and concrete that are formed during the dismantling of an old building.

In addition, the domestic market is seeing an increase in investment in the construction of various facilities, including wholesale stores, supermarkets, office and shopping centers, warehouses, and production workshops for new companies. Quite often, the restoration of old buildings is financially viable, while in other cases they are almost completely dismantled for the sake of new construction. Given the strength of old buildings and their foundations, it is quite difficult to demolish such objects. The dismantling process generates a significant amount of construction waste that needs to be disposed of.

The source of construction waste is the materials that appear during the construction of new buildings. The analysis of new buildings of large construction organizations showed that during the construction of a 100-apartment building, an average of 15...20 tons of solid waste, which is based on broken bricks, remnants of hardened concrete and mortar, shredded drywall, shortage of expanded clay concrete wall blocks, cellular concrete, foam and mineral wool.

Another source is waste from the construction materials industry. The most common of these are screenings from crushed stone quarries, glass cullet, bricks that were found to be defective, defective reinforced concrete structures, used plaster molds from ceramic factories, and so on.

Construction waste also includes solid materials generated during road repairs. While some of the old asphalt is reused, crushed concrete from the roadway is usually taken to landfills. All construction waste contains the following substances: concrete and reinforced concrete, brick, metal, soil, sand with clay, sanitary ceramics, wood, glass, drywall, plastic, and asphalt. Experts estimate that 52% of construction waste is concrete and reinforced concrete by weight, 32% is stone wall materials (bricks, wall blocks, foam and aerated concrete), 8% is asphalt and mortar waste, 4% is metal waste, 2% is wood and plastic waste, 1% is ceramic products (sanitary ware, ceramic tiles), and 1% is drywall, glass, and other waste.

In addition to reducing transportation and loading costs, you eliminate the need to pay for the storage of construction waste in landfills, as it is recycled directly on site.

Undoubtedly, construction waste cannot compete with full-fledged building materials, but due to its low cost, materials such as old asphalt, broken glass, bricks, reinforced concrete structures and plastic products can be used to erect new buildings after processing.

Reinforced concrete left over from the dismantling of buildings is often used for foundations or to fill holes and voids. To recycle reinforced concrete, special hydraulic equipment is used, such as hydraulic hammers or shears. They crush or grind large fragments. After that, the reinforced concrete is fed into a crusher, where it is sorted into the required fractions.

Construction waste, such as asphalt, is often used to create roadways. It is subjected to heat treatment at high temperatures, which causes the resinous components to melt. If the asphalt loses the required viscosity or other important parameters, special additives are added to it to strengthen and “concrete” it.

The equipment used to process construction waste can be different: stationary, mobile or self-propelled. There are different types of equipment, including crushing and sorting equipment. The type of equipment chosen depends on the volume of recyclable materials produced and their final quality.

Stationary equipment is characterized by high productivity. Sorted and collected waste first enters the system. A magnet is placed inside the system to extract metal elements from the total mass. Then the loaded raw materials are shredded. The final product obtained by the stationary equipment is ready-mix concrete, which is used in road construction.

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FEASIBILITY AND ADVANTAGES OF USING A HEAT RECUPERATOR IN VENTILATION SYSTEMS OF INDIVIDUAL RESIDENTIAL BUILDINGS

Novak Yevheniya Volodymyrivna

Chernivtsi National University, e.novak@chnu.edu.ua

In modern conditions, when the issue of energy conservation and increasing energy efficiency is becoming increasingly important, it is particularly crucial to implement innovative technologies that allow reducing energy resource costs while improving comfort and quality of life. One of these solutions is the use of heat recuperators, which are becoming popular not only in industrial or commercial buildings but also in individual residential homes. The high cost of energy, the need to reduce the environmental impact, and the continuously growing requirements for energy-efficient buildings stimulate the search for new, effective solutions for heat retention and ensuring a constant supply of fresh air without significant costs.

Heat recuperators use the principle of heat exchange between outgoing and incoming air, which allows significantly reducing heating and cooling costs while maintaining a stable temperature inside the premises. These systems are an important element for achieving energy efficiency in buildings, as they help maintain the temperature in rooms at an optimal level, reducing the need for energy consumption for heating or air conditioning. This is particularly important in conditions where the energy situation in the country is becoming more complex and energy prices are rising, forcing homeowners to look for opportunities to reduce heating costs.

Moreover, the implementation of such technologies meets modern environmental requirements. Reducing energy consumption not only helps reduce energy costs but also has a positive impact on the environment by decreasing greenhouse gas emissions. Considering the growing interest in energy conservation and ecological technologies, the use of heat recuperators is becoming an important step towards sustainable development and preserving natural resources.

Working Principle of a Heat Recuperator

Heat recuperators operate on the principle of heat exchange between outgoing and incoming air. The cooled or heated air that is expelled through the ventilation system transfers its heat to the cold air entering from outside. This allows significantly reducing energy costs for heating or cooling the room, as the air entering the building is already at an optimal temperature. Such a system enables the use of heat that would otherwise be wasted.[1].

Advantages of Using a Heat Recuperator

The main advantage of using a heat recuperator is energy conservation. The system reduces heating and cooling costs by decreasing the need for constant heating or cooling of the air entering the house. This is not only economically important but also contributes to achieving energy efficiency in buildings. Additionally, heat recuperators improve the comfort in rooms by providing a constant flow of fresh air that already has a comfortable temperature.

Another advantage is the improvement of indoor air quality. Thanks to filters used in ventilation systems with recuperation, not only are the necessary temperature characteristics provided, but also clean air is delivered into the building. This is especially important for people with allergies or asthma, as the system effectively purifies the air from dust, allergens, and other harmful particles.

Environmental Benefits

Heat recuperators are not only economical but also ecological. They help reduce energy consumption, which in turn reduces CO_2 emissions and other greenhouse gases, an important aspect in the fight against global warming. Using such systems in residential buildings significantly reduces the load on the energy system and contributes to the conservation of natural resources.[2].

Implementation of a Heat Recuperator in Individual Residential Buildings

Installing a heat recuperator in an individual residential house is advantageous from a technical point of view, as the system can easily be integrated into existing ventilation systems. It also requires minimal maintenance costs, making it economically feasible. Moreover, a heat recuperator can be used in conjunction with other energy-saving systems, such as solar panels or heat pumps, which allows achieving even greater efficiency.

Using heat recuperators in individual residential buildings is an effective way to reduce energy costs, maintain a comfortable temperature, and improve air quality. Thanks to its ability to reduce heat loss and purify the air, heat recuperators help reduce the load on heating and air conditioning systems, which saves energy resources and lowers energy consumption costs.

An important aspect is also the ecological benefit of using heat recuperators, as they reduce the amount of harmful substances emitted into the atmosphere and contribute to maintaining a healthy atmosphere in the house. Furthermore, the proper choice and installation of heat recuperators can significantly improve the indoor microclimate, which is essential for the health of the inhabitants.

Therefore, heat recuperators are a reliable and cost-effective solution for improving energy efficiency, enhancing the quality of life, and ensuring sustainable development. Given these advantages, heat recuperators should become an integral part of modern energy-saving technologies in individual residential buildings.[3].

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MODELING THE TEMPERATURE REGIME OF A BRICK WALL WHEN INSULATED WITH FOAM GLASS (with dew point analys)

Roman Norkin

Cherkasy state technological university,

roman.com.ukr@gmail.com

Energy efficiency is one of the key priorities of modern construction. In the context of increasing energy costs, environmental challenges and requirements for living comfort, the right choice of insulation and its rational placement are crucial for the durability and efficiency of building structures [1]. One of the promising thermal insulation materials is foam glass, which deserves a detailed analysis in terms of its properties, advantages, disadvantages and application possibilities. In this study, we modelled the thermal regime of a 510 mm thick brick wall using various foam glass insulation configurations, with a focus on dew point behaviour under internal and external insulation scenarios. This work investigates the technologies of applying foam glass as a modern thermal insulation material in building structures, considering its physical and technical properties, installation methods, and efficiency under real-life conditions.

Foam glass is a thermal insulation material produced by sintering cullet with the addition of gas generators. The result is a light, porous, but fairly dense material with a glass-like structure. It is available in the form of plates, blocks and granules.

The main properties of foam glass are:

- Non-flammability – the material does not support combustion at all, which is critically important for fire safety.
- Non-toxicity – does not emit harmful substances either under normal conditions or when heated.
- Resistance to microorganisms and rodents.
- Durability – service life of over 50 years.
- Vapor permeability – provides a barrier to moisture penetration.
- High thermal insulation capacity – effectively retains heat.
- High water resistance, which is confirmed by experiment: after 10 days of soaking in tinted water, the paint remained only on the surface, without penetrating inside.

Among the main disadvantages are: mechanical fragility and high cost.

One of the most important advantages of foam glass is its safe dew point. Foam glass retains its effectiveness even when the dew point is located inside the material [2]. Due to its low vapor permeability, the material does not allow moisture to penetrate into the structure, preventing the formation of condensate, fungus and corrosion of metal elements.

Let's consider two main methods of thermal insulation of structures using foam glass. External insulation is the most energy-efficient option, in which the dew point is shifted to the insulation, which helps to maintain a dry and warm state of the load-bearing wall. Internal insulation is advisable in cases where external thermal insulation is technically impossible or prohibited, in particular during the reconstruction of cultural heritage sites.

Technological solutions for external foam glass insulation include the use of an auxiliary supporting frame for block installation, dowel fixation, and blocks with enhanced surface adhesion for better bonding with finishing layers. The technology of external insulation involves the following sequential steps: facade preparation, installation of foam glass plates on an adhesive base, surface reinforcement, finishing. External insulation with foam glass is advisable to use in new construction, reconstruction of facades, in conditions of high humidity and temperature fluctuations, on objects with increased requirements for fire resistance, environmental friendliness and durability of thermal insulation.

Internal insulation revealed the issue of thermal bridges, particularly at junctions with structural elements. This problem is addressed by maintaining a continuous insulation layer and minimising mechanical fasteners that penetrate the insulation barrier. The technology of internal insulation consists of preparing the wall surface, applying waterproofing, adhesive installation of foam glass plates, reinforcement and finishing. The areas of appropriate application of internal insulation with foam glass are: foundations, basements and cellars, historical buildings and roof insulation.

Particular attention should be paid to modeling the temperature regime and analyzing the dew point. As part of our study, we simulated the position of the dew point in a 510 mm thick brick wall with 50 mm thick foam glass insulation. The results show that without insulation, the dew point falls inside the wall and leads to a high probability of condensation. With external insulation, the dew point shifts towards the insulation, and with internal insulation, it shifts into the thickness of the foam glass, leaving the brick wall dry. This confirms the effectiveness of such insulation with the correct selection of thickness and installation quality.

So, we can conclude that foam glass is a highly efficient, environmentally friendly and durable insulation. It is advisable to use it for both external and internal insulation. The effectiveness of insulation depends on the correct modeling of the temperature regime and taking into account the position of the dew point.

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SUSTAINABLE SETTLEMENTS AS A MODEL FOR UKRAINE'S POST-WAR SPATIAL DEVELOPMENT

Pantiukhina Oleksandra

Pryazovskyi State Technical University,

pantiukhina_o_y@pstu.edu

Today, Ukraine is experiencing one of the most challenging periods in its history. The full-scale war has caused not only a deep humanitarian crisis and the loss of human lives, but also the widespread destruction of residential, transport, and critical infrastructure, environmental degradation, large-scale population displacement, and the breakdown of social structures and local communities. Yet, this extremely difficult period presents a unique opportunity — not only for the physical reconstruction of the country, but also for rethinking the principles of spatial development and the model of human interaction with the environment.

Reconstruction must not be a mere return to the previous state, but rather a qualitative transformation of the environment in which future generations will live. In this context, the concept of sustainable settlements, implemented on the basis of green building principles, becomes crucial. This approach involves not only engineering and technical solutions focused on energy efficiency, the use of local and renewable resources, reduction of the carbon footprint, and integration of natural systems, but also the formation of socially cohesive, environmentally conscious, and economically resilient communities.

The ideas of sustainable living have deep historical roots. As early as the beginning of the 20th century, the German Lebensreform movement advocated a return to a natural way of life — including vegetarianism, ecological farming, and minimalism. In the 1970s and 1980s, during a wave of global environmental awareness, interest in living in harmony with nature intensified. In 1978, Professor George Ramsey first introduced the term "ecovillage" to describe small, self-sufficient communities. A landmark moment came with the publication of the study Ecovillages and Sustainable Communities [5] and the first ecovillage conference held in Findhorn, Scotland — now home to one of the world's largest ecovillages.

Ecovillages and intentional communities (those founded on shared values) share a common goal: to create environments where people live in harmony with nature and interact within a framework of economic self-sufficiency. These communities also foster social cohesion and are guided by sustainable development principles, including the use of renewable energy, closed-loop resource cycles, and sustainable building practices. According to Dawson's classification [1], the key characteristics of ecovillages include: private initiatives based on shared values; independence from centralized resource systems; ecological lifestyles with minimal waste; and functioning as platforms for experimenting with and teaching sustainable practices.

Since the early 2000s, the term "sustainable settlements" has replaced the term "ecovillage" in international terminology [4,7]. This shift is linked to the expansion of the concept of sustainable development, where the main focus is on integrating ecological, social, and economic aspects into broader spatial strategies — from small communities to entire cities. Sustainable settlements aim to create conditions that ensure long-term resilience and adaptability to changing social, economic, and environmental conditions.

The European Green Deal [3] emphasizes that "citizens are and must remain the driving force of the transition to sustainable development," underlining the importance of civic participation in the transition to sustainability. This involves not only top-down political initiatives but also active citizen involvement in planning and decision-making processes. Such participation ensures fairness in access to resources and includes the voices of diverse social groups in decision-making. At the same time, a just transition to a sustainable society also involves the consideration of:

- Distributive justice (who has access to resources),

- Procedural justice (who has a voice in decision-making),

- Intergenerational responsibility (what kind of planet we will leave for future generations).

A sustainable settlement is a locality (city, village, or neighborhood) designed with long-term ecological, social, and economic needs in mind. Its operation is based on balanced resource use, waste and harmful emissions minimization, high energy efficiency, integration of natural components into spatial structure, and ensuring a comfortable environment for all social groups. Green building principles [9] play an essential role in the development of such settlements, promoting energy-efficient technologies, environmentally safe materials, rational water use, and the stimulation of local economic development. Together, these factors contribute to creating a viable environment with minimal negative environmental impact and high potential for sustainable development.

One of the promising models for the development of sustainable settlements is the concept of self-sufficient environments [2], which is especially relevant in the context of post-war territorial reconstruction. A self-sufficient environment involves the formation of autonomous ecosystems capable of meeting all basic needs—energy, water, food, and efficient waste management—without critical dependence on external infrastructure. The foundation of such systems lies in the use of renewable energy sources, closed-loop water supply systems, local agricultural production, and bio-based technologies that ensure ecological balance. Implementing these approaches contributes to enhancing the ecological and social resilience of territories, reducing their vulnerability to crisis situations, and creating conditions for long-term sustainable development.

Despite variations in scale, cultural, and natural-climatic features, most sustainable settlements serve as "living laboratories," within which innovative practices in green building, circular economy, and climate-neutral lifestyles [5] are tested, and these practices could also be applied in Ukraine.

Examples of successful sustainable settlements that could serve as models for the reconstruction of Ukrainian communities include:

- The Farm (Tennessee, USA) — One of the oldest eco-communities in North America (since 1971), operating on the principles of nonviolence, vegetarianism, and collective management. Its infrastructure includes a permaculture education center, a birthing center, a school, a publishing house, and an NGO focused on international development.

- Crystal Waters Eco Village (Queensland, Australia) — The world's first settlement built according to permaculture principles. Of its 640 hectares, only 20% is developed for housing, while the remaining area is used for forests, agroecological, and recreational projects. The settlement is actively involved in environmental education and hosts tourists.

- EcoVillage Ithaca (New York, USA) — An example of an ecological settlement with a low carbon footprint (about 30% of the average in the USA), combining passive architectural solutions, local farming, and cohesive social structures.

- Findhorn Ecovillage (Scotland) — The largest eco-community in the UK, recognized by the UN Habitat Best Practice program. It operates on the "20-minute city" model, where the basic needs of residents are met within walking distance. The architecture is based on principles of energy efficiency and the use of natural materials.
- Eco Truly Park (Peru) — An eco-community founded on a combination of spiritual-artistic and ecological principles. The settlement actively promotes organic farming on degraded soils, functions as an arts and tourism center, and organizes international volunteer programs.

This model is highly relevant for Ukraine. It opens up opportunities for ecologically and socially oriented reconstruction of the destroyed territories [8], taking into account the need to preserve natural resources, restore local ecosystems, and create new approaches to spatial planning. This approach aligns with international sustainable development principles [9] and ensures long-term ecological, social, and economic stability at the local level.

Sustainable eco-villages can serve as innovative platforms for implementing the principles of "green" reconstruction. Their implementation will contribute not only to the physical recovery of damaged areas but also to the rehabilitation of the social fabric through the active involvement of internally displaced persons, veterans, and local residents in the collective creation of the environment. The application of bioclimatic architectural solutions, water conservation systems, and zero-waste production, the development of green infrastructure, and the introduction of governance models based on collective decision-making principles create a foundation for long-term, sustainable, and inclusive development. At the same time, this promotes economic localization, the development of small-scale production and crafts, and reduces dependence on imports and centralization.

Key advantages of implementing sustainable eco-village models in Ukraine:

- Economic efficiency — reducing housing and infrastructure operation costs through energy-efficient and autonomous solutions.
- Adaptability to contemporary challenges — resilience to climate change, energy crises, and migration processes.
- Enhancing social cohesion — creating public spaces that promote interaction, cooperation, and solidarity among residents.
- Strengthening international image — positioning Ukraine as an example of innovative and environmentally-oriented approaches to post-war reconstruction.

Thus, Ukraine's post-war reconstruction has the potential to be not just a technical, but also a civilizational project. Sustainable settlements in the concept of green building are not only a response to contemporary challenges, but also a way to ensure a dignified, safe, and ecological future for future generations. By combining international experience, innovative technologies, and community participation, Ukraine can become an example for the world of how new quality of life can emerge from the ruins.

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ASSESSING THE BEARING CAPACITY OF SOLAR PANELS AS WAY OF IMPROVING THE ENERGY EFFICIENCY OF BUILDINGS

Vladyslav Nastoyashchiy, Viktor Pashynskyi, Mykola Pashynskyi

Central Ukrainian National Technical University, vanast52 @ukr.net

The growing shortage of energy resources encourages more active implementation of energy-efficient technologies, in particular "green" energy in construction. One of the promising solutions is the installation of solar panels on the roofs of low-rise buildings to partially or fully provide them with electrical energy. Usually the orientation of the panels and their angles of inclination to the horizon are determined by the roof design. The only available installation scheme makes it necessary to assess their ability to withstand climate loads in different regions of Ukraine, as well as to develop recommendations on the maximum panel sizes that can be safely installed.

Solar panels made of monocrystalline or polycrystalline silicon are used to power low-rise buildings. Despite the variety of sizes and electrical parameters, they all have a similar design: photovoltaic cells are placed between two layers of tempered glass [1, 2].

Analysis of the solar panels range presented on the Ukrainian market shows a significant variety of models available in online stores. According to some trading platforms [3, 4], most panels used in the installation of solar power plants have a width of 65–130 cm, and a length of 99 to 239 cm. Smaller models, indicated in the source [4], are usually intended for powering small autonomous devices, such as street lamps, traffic lights or road information boards.

Solar panels that are mounted on a metal frame can be considered as slabs supported along the contour and subjected to bending moment. To determine the load-bearing capacity, loads taken from the following sources were taken into account:

The dead weight of the panels is calculated in accordance with the technical specifications given in the manufacturers' documentation [3, 4], as well as on official Internet resources.

Climatic loads – in accordance with the norms of STATE BUILDING STANDARDS [5], that must include:

1) snow load;
2) wind pressure;
3) ice load in combination with wind.

The calculation of the internal forces and deflections was carried out on the basis of tables of coefficients [6], which take into account the ratio of the length to the width of the panel. The smallest forces occur in square panels. If the length of the panel exceeds its width by more than twice, the panel should be considered as a beam on two hinged supports with a span equal to the width of the panel.

The strength and deformation assessment of solar panels was carried out based on general principles of material strength and calculation methods for plate structures [6]. The mechanical characteristics of glass were taken from [7].

Currently, the regulatory standards of Ukraine and reference materials lack specific instructions for designing solar panels, which necessitates the creation of a simple engineering methodology for determining their load-bearing capacity, taking into account the requirements for strength and rigidity.

The following information was taken into account as initial data and calculation assumptions:

The solar panels are mounted on metal frames that are installed parallel to the surface of the pitched roof. Taking into account the possibility of their placement on mansard-type roofs, the calculations of the bearing capacity of the panels uses angles of inclination to the horizon within the range of 15°…75°.

Analysis of typical panels according to [3, 4] showed that the length to width ratio varies within 1.4…2.0, and the width of the panels is 65…130 cm.

According to data [7], it is assumed that the calculated resistance of tempered glass is $R = 35$ MPa, and the modulus of elasticity is $E = 70$ GPa.

The loads on solar panels mounted on the roofs were calculated as follows:

The characteristic value of the load from the panel's own weight according to [3, 4] is 98…125 Pa. Given the small spread of these values, taking into account the reliability coefficient γ_{fmp} = 1.1 according to [10], for further calculations the following was adopted:

• operational design load: p_e = 125 Pa,

• limit design load value: p_m = 138 Pa.

Climate loads determined for the city of Kropyvnytskyi according to STATE BUILDING STANDARDS [5], taking into account design features and a service life of 100 years, are given in the table 1:

Table 1

Climate loads for the city of Kropyvnytskyi

Load type	Characteristic value	Reliability coefficients
Snow weight	S_0 = 1230 Pa,	γ_{fms} = 1,14, γ_{fes} = 0,49
Maximum wind pressure	W_0 = 410 Pa	γ_{fmw} = 1,14, γ_{few} = 0,21
Wind pressure during icing	W_B = 210 Pa,	γ_{fmwg} = 1,16
Ice wall thickness	b = 22 mm,	γ_{fmg} = 1,16.

Since the solar panel consists of two layers of tempered glass, between which photovoltaic cells are placed, its design can be approximately represented as two plates that work on bending independently of each other and subjected to a half of the load each. In this case, a uniformly distributed load is taken into account, which acts perpendicular to the plane of the panel, inclined at an angle α to the horizon.

Two combinations of loads that meet the requirements of STATE BUILDING STANDARDS [5] are considered. The calculation of plates hinged along the contour is performed using the coefficients given in [6] and other sources.

As a result of the research, working formulae were obtained for calculating loads, checking strength and stiffness, as well as determining the permissible span according to the criteria of strength and stiffness of solar panels installed on the roofs of low-rise buildings at different angles to the horizon. It is shown that in the conditions of Kropyvnytskyi city, calculaions should always be performed for a combination of loads from the panel's own weight, snow weight and wind pressure. Stiffness calculations at small angles should be performed for the same combination of loads, and at angles over 42°, the ice-wind load becomes decisive.

The permissible span (smaller size) of a solar panel increases with increasing angle of inclination to the horizon and with approaching the ratio of the panel side dimensions to 1:1. For panels with tempered glass thickness of 3 mm, the span is 0.68…1.36 m. In all calculation cases in the conditions of Kropyvnytskyi city, the stiffness condition is decisive.

The economic effect is that, according to [3, 4], installing 7 m^2 of solar panels on a pitched roof provides a power of about 1 kW for the energy supply of the house.

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PROPOSALS REGARDING THE PROCEDURE FOR ASSIGNING HEAT TRANSFER RESISTANCE OF ENCLOSING STRUCTURES.

Viktor Pashynskyi, Mykola Pashynskyi, Vladyslav Nastoyashchiy,
Central Ukrainian National Technical University, Kropyvnytskyi, Ukraine.
pva.kntu@gmail.com

One of the most important indicators of enclosing structures, on which heat consumption for heating and energy savings depend, is heat transfer resistance. The requirements for heat transfer resistance are established in STATE BUILDING STANDARDS DBN V.2.6-31:2021 [1] depending on the type of enclosure and the building's belonging to one of the two temperature zones of Ukraine. In [2] it is shown that the choice of heat transfer resistance, limited to only two temperature zones, leads to a large territorial spread of the values of annual heat loss through the enclosure and encourages the differentiation of heat transfer resistance depending on the climatic conditions of the territory. The methodology set out below for determining the required heat transfer resistance of enclosing structures is based on the results of previously performed studies, as a result of which:

- a probabilistic model was developed to represent the temperature of atmospheric air in the form of a quasi-stationary random process and statistical characteristics of air temperature were obtained for more than 400 observation points in Ukraine [3];

- a methodology for administrative-territorial zoning of climatic load and impact parameters has been developed, according to which a regional design value of each parameter is established for each administrative region of Ukraine [4];
- it has been established that when designing enclosing structures according to the STATE BUILDING STANDARDS [1], heat losses through them have a significant spread even within the same temperature zone [2];
- a significant increase in heat losses through enclosures with increasing altitude above sea level and the need for a corresponding increase in heat transfer resistance have been identified, and the values of geographical altitude coefficients that take this phenomenon into account have been established [5];
- a methodology for determining the required heat transfer resistance of enclosing structures and the number of degree-days of the heating period, taking into account permissible heat losses, has been developed, and administrative-territorial zoning of Ukraine by the number of degree-days has been performed [6]. The results obtained allow us to propose the sequence set out below for determining the required heat transfer resistance of enclosing structures.

The results obtained allow us to propose the following sequence for determining the required heat transfer resistance of enclosing structures.

1. Depending on the purpose of the building and the type of enclosing structure, establish the permissible value of annual heat loss through 1 m^2 Q_0 in megacalories.

2. Establish the building's belonging to a certain administrative region of Ukraine and, using the table or map from work [6], shown in Figure 1, determine the number of degree days of the heating period G_{20} at an indoor air temperature of +20°C.

3. Using table B.2 of in STATE BUILDING STANDARDS [1], determine the calculated value of the indoor air temperature in the room.

4. Using the formula from [6], calculate the value of the required heat transfer resistance of the enclosure

$$R_0 = \frac{\left[1 + 0,034 \times \left(\theta_{IN} - 20\right)\right] \times G_{20} + 57,1 \times \left(\theta_{in} - 20\right)}{48,5 \times Q_0} \qquad (1)$$

5. When designing for mountainous conditions with an altitude above sea level of more than 400 m, correct the obtained value of the required heat transfer resistance by multiplying it by the geographical altitude coefficient from work [5], equal to:

at H ≤ 400 m; at H > 400 m (2)

6. According to the instructions, formulas and reference data of State Standard of Ukraine [7], select the insulation thickness that, together with other structural layers of the enclosure, provides the established value of heat transfer resistance (1).

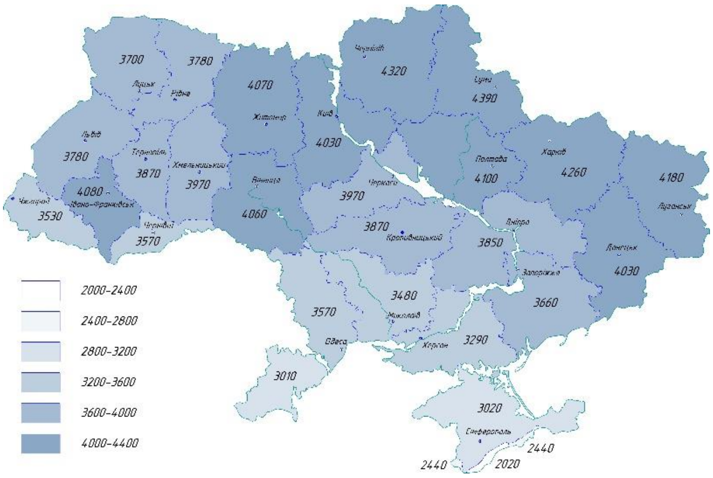

Figure 1. Territorial zoning of Ukraine by the number of degree days of the G20 heating period.

The effectiveness of the developed method for determining the required heat transfer resistance is analyzed on the example of designing walls of civil buildings. When designing according to STATE BUILDING STANDARDS [1], the minimum required values of the heat transfer resistance of walls in different regions of Ukraine differ by only 14%, and the differences in heat losses through these walls in different regions reach 89%. When designing according to the proposed method, the values of the required heat transfer resistance of walls in different regions of Ukraine may differ by 2.2 times, and the differences in heat losses do not exceed 20%.

Thus, the proposed method provides differentiation of the required heat transfer resistance and equalization of heat losses through enclosing structures in the territory of Ukraine.

The unsolved issue remains the standardization of permissible heat losses through enclosures. This problem is planned to be solved on the basis of regulatory documents [8, 9], by distributing the heating costs specified in them between the enclosing structures.

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DIVERSIFICATION OF ENERGY SOURCES AS A KEY ASPECT TO DEVELOP ENERGY SECURITY OF UKRAINE

Vitaliy Ploskiy[1], Oleksiy Zabarylo[2], Yulia Korotkykh[3], Pavlo Zabarylo[4]
[1]*Kyiv National University of Construction and Architecture, ploskyi.vo@knuba.edu.ua*
[2]*Kyiv National University of Construction and Architecture, zabarylo.ov@knuba.edu.ua*
[3]*Kyiv National University of Construction and Architecture, korotkykh.iua@knuba.edu.ua*
[4]*Kyiv National University of Construction and Architecture, zabarylo_po-2023@knuba.edu.ua*

Energy independence is a priority for the development of both the Ukrainian economy and the country as a whole, but at the same time, national security challenges threaten plans for the gradual implementation of relevant initiatives. The energy sector is one of the key sectors of the national economy, and uninterrupted and efficient energy supply has a direct impact on economic growth. Ukraine's economy, despite shifts in the right direction, still feels highly dependent on energy imports, not to mention the problems of excessive environmental pollution due to the use of outdated production equipment, so implementing new, diversified energy system is becoming more and more crucial task.

Energy diversification means using different energy sources, suppliers and routes to reduce dependence on a single resource or supplier. A country that diversifies its energy mix insulates itself from energy disruptions and strengthens its energy security. The following aspects are among the undoubted advantages of a diversified energy system:

- *Political independence:* Dividing energy needs among different suppliers allows the importing country to reduce its dependence on a single supplier and strengthen its independence in global politics.
- *Economic growth:* Energy diversification promotes economic growth. Obtaining energy from multiple sources and suppliers insulates an importing country from energy disruptions when one source or supplier is unable or unwilling to meet demand.
- *Environmental protection:* The development of renewable resources, such as solar and wind power, reduces the threat of energy shortages. Investments in renewable energy also stimulate innovation and employment growth.

Key component for an energy diversification nowadays is an active use of alternative energy sources. As an example of an implementation of such approach, the European Union was systematically switching to renewable energy sources and diversifying its natural gas suppliers for decades to reduce future dependence on a single importer in the event of a disruption or political conflict and increase the region's energy security. Full-scale invasion in 2022 only strengthen Europe’s priorities on energy security and diversification. As for more actual initiatives, on February 2023 the European Commission published the “Green Deal Industrial Plan”, aimed at increasing the long-term competitiveness of European industry with net-zero emissions and facilitating the transition to climate neutrality; as part of this strategy, on May 2024, the Critical Raw Materials Act (CRMA) was passed, aiming to increase the resilience of the supply chains of critical minerals in the EU and reduce dependence on third countries for critical raw materials needed for the green transition[1]. For instance, in January-June 2024, wind turbines and solar panels became the main source of energy in Europe for the first time, overtaking traditional energy sources (gas, coal, and oil). According to experts from the Ember climate think tank, their share is 50%, taking into account other renewable energy sources such as hydropower. Countries' strategies to achieve their climate goals and comply with legislation by 2030 will determine the role of conventional and clean energy technologies in Europe. Experts predict that the total energy consumption in the EU will remain relatively unchanged over the next three decades. The International

Energy Agency (IEA) estimates that by 2040, electricity demand in the EU will increase by 12-26%.

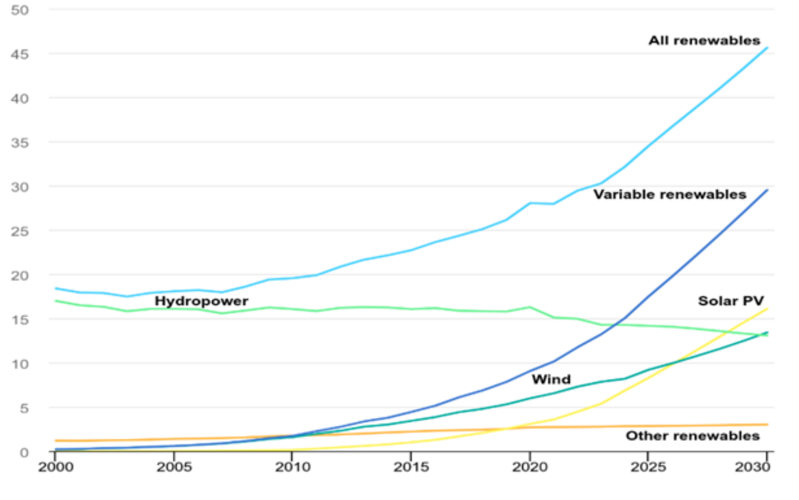

Fig 1. Share of renewable electricity generation in EU, 2000-2030[2]

Before full-scale invasion the most important aspect of alternative energy sources was its purity and environmental friendliness - unlike thermal power plants, solar, wind, and hydroelectric power plants produce almost no greenhouse gas emissions. But in current times, against the backdrop of the refusal to imported energy carriers using renewable energy sources is vital alternative to fossil fuels, as it can cover large part of energy consumption and has great potential for development. It is crucial for Ukraine to increase investment in the large-scale deployment of decentralized renewable energy sources, given that around 40% of its energy infrastructure has been damaged by the fighting and the trend is unlikely to abate in the near future. The Kyiv School of Economics estimates direct losses in the electricity sector as a result of Russian attacks at USD 56.2 billion[3]. The economic potential for the development of renewable energy sources in Ukraine remains quite significant - large areas of undeveloped territories, geographical and natural diversity create very favorable conditions for further diversification of the structure of energy generation sources[4].

Diversification in the energy sector of Ukraine should be carried out in accordance with European standards, principles, and norms, taking into account the close interrelationships between the diversification of natural energy resources, their supply routes, etc. and the level of energy security of the country [5]. The current war has affected significantly both the energy security of the European Union and its policies in this area with the loss of traditional energy supply. In response to these challenges, the EU has developed ambitious initiatives “RePowerEU” and “Fit for 55”, aimed at accelerating the energy transition and reducing dependence on fossil fuels, and Ukraine, by integrating into the EU energy system, can become an important supplier of “green” energy and contribute to the diversification of energy supply sources for the EU[6].

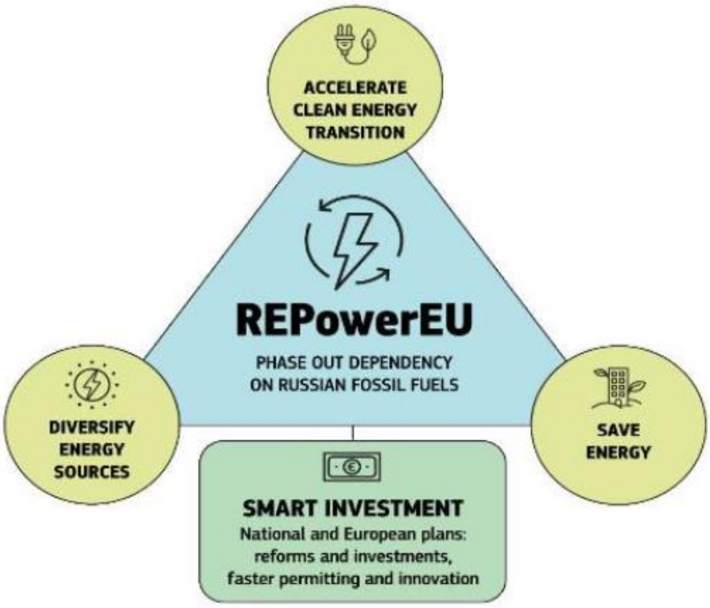

Fig 2. REPowerEU plan summarizing

The most promising for development in Ukraine are the following types of renewable energy: solar energy, wind energy, small river energy, geothermal energy and biomass energy[7]. Effective diversification of resources and ways of obtaining them in the energy sector will help it reach a qualitatively higher level of functioning and, accordingly, reduce energy risks, increase profitability, etc.

Ukraine has the promising potential of renewable energy sources, having vast territories with different conditions, despite the fact that full-scale invasion creates big challenges on the path to energy transformation. Nevertheless, it is advised to use develop alternative energy sector in order to diversify our country's power production and strengthen energy security and independence, which is more and more crucial for our benefit for the last few years. Such approach will provide an availing alternative to imported fossil fuels, which coincides with current government policies and eurointegrational process.

Table 1

SWOT-analysis of alternative energy sources implementation in Ukraine

Strengths: - Rich natural resources - Growing interest in green energy - Qualified specialists	**Opportunities:** - European integration - Growth of the global market - Improving energy security
Weaknesses: - Limited financing - Old infrastructure - Regulatory barriers	**Threats:** - Political and military instability - Competition with traditional energy sources

	- Climate change

It is also worth noting the trend in recent months of using the infrastructure of gas storage facilities, previously used to store imported natural gas from Russian fields to accumulate biomethane. In synergy with the recent researches, such as American startup Quino Energy on the transformation of oil reservoirs into a cluster of flow batteries, this direction looks more than promising[8] and using existing equipment adapted to the new realities will help reduce costs and promote the development of this area of green energy, which in turn will only strengthen the course towards energy diversification. But in order to increase effectiveness, there is a need for further research to improve the management process of energy generation sources. The following steps should be considered for the gradual introduction of a diversified energy supply system:

- Establish a legal framework for energy policy that attracts investment, rewards entrepreneurship and innovation, and limits inefficiency and waste.
- Enter into partnerships with the private sector to identify and develop alternative energy sources.
- Work with experts to determine the best mix of available domestic and foreign energy sources.
- Work with the international community to introduce and enforce environmental standards related to energy exploration and production.
- Develop set of recommendations, in particular with the involvement of the latest information technologies.

Key element of promoting the development of the green energy sector is an implementation of an appropriate energy generation sources rational distribution model with implementation of the latest information technologies. Already existing tools, such as Multilayer Perceptron(MLP), are used in energy sectors to solve different tasks such as creating a model of energy consumption, prediction of energy needs in different conditions and optimization of energy system overall, but it needs some adjustments and further researches to be effectively used for diversified systems with large dependency on alternative energy sources.[9]

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PROJECT OF CONSTRUCTION OF A HOUSE FOR CHILDREN WITH SPECIAL EDUCATIONAL NEEDS: INCLUSIVE EDUCATION

Romanenko Oleksandr

... autism is all-encompassing: it defines every event,
every feeling, every thought and every aspect of existence
J. Sinclair

There are more than 100 thousand children with autism in Ukraine, although according to official data, there are only 3 thousand of them. Strengths in children with autism, visual perception and mechanical memory, attention to detail. Autism Spectrum Disorders (ASD) is a condition that results from impaired brain development.

Studies of inclusive, correctional pedagogy were carried out (V. Bondar [1], L. Vygotsky, I. Eremenko, A. Luria, V. Sinev [2], N. Baykina, B. Sermeev, Kobernik G.M. [3], N. Stadnenko and others). Autistic context (B. Rimland, L. Kanner, E. Bleiler, G. Asperger, N. Shubertiy, D. Chaban, Ya. Vikhlyaev, K. Ostrovskaya, T. Skrypnik, V. Tarasun, D. Shulzhenko, E. Schopler, B. Mesibov [4], K. Kosinski [5], T. Skrypnyk [6], J. Ayres [7], etc.

According to the definition of V. M. Sinev, correctional education is "the education of personality qualities by means of cognitive, labor, aesthetic activity, which allows it to adapt to the social environment." Forming the cognitive activity of children with autism should, first of all, focus their attention on what they can perform.

Children with autism can and should develop productively and fully learn, be educated, obedient and diligent. Only it is necessary to help uncover their resources, creating first the foundation of their development [6, p. 8]

Autism is not a sentence. Without exaggeration, we can say that autistic people can live an absolutely happy and full life. Even among the very famous, outstanding and brilliant personalities there are people with autism.

For example, Albert Einstein had difficulty making contact with other people. He did not study well at school, experienced difficulties in expressing opinions. The future scientist at one time could not find work, because he did not like to communicate with people and could not tolerate touch.

Mozart, like many autistic people, was characterized by a lack of facial expressions. There were stereotypical hand and foot movements. The musician had a super-sensitive hearing, too sharp and loud sounds caused pain. Mozart often changed his mood. But this did not prevent him from becoming an outstanding composer.

Historical evidence suggests that Charles Darwin was autistic. He rarely met people, loved to be alone. He maintained contact with others through writing. He collected various items. But all this did not prevent him from becoming a brilliant person and creating an evolutionary doctrine, which some still adhere to.

Thomas Jefferson, former president of the United States, lived with autism. He was not adapted to social contacts, he barely managed to communicate with people, performed poorly in front of an audience, for him it was difficult. He was annoyed by loud noises.

Sir Anthony Hopkins - British actor, composer and artist, Oscar winner. He has Asperger's syndrome, has difficulties in establishing new relationships, poorly perceives changes and, on the contrary, obsessively admires different areas.

Hopkins himself believes that his illness helps him in his work - he has an ideal memory, can remember 7 pages of the script. But he recalls that any talent must be worked on.

The famous film director, one of the largest and most influential directors in the history of cinema, Stanley Kubrick suffered from autistic disorder. He had Asperger's syndrome. On the set, he often behaved rudely, fixated on trifles.

Well-known activist Greta Thunberg said that she has Asperger's syndrome, so her behavior may differ from the generally accepted one. But this is her superpower, which gives her perseverance and perseverance.

Dan Aykroyd is an American-Canadian actor, comedian, musician, director and businessman, nominee for the Academy Award and Emmi Award. In early childhood, the doctor diagnosed him with moderate Asperger's syndrome. He often said that Asperger's Syndrome was perfect for the movie Ghostbusters because he was obsessed with ghosts and law enforcement. This is not surprising, because

Asperger's syndrome can cause a person to focus on a limited number of interests. [6].

Numerous studies (Akalin, S., Sucuoglu B., 2015; Corps P., 2008; Stronge J.H., Tucker P.D., 2004; Wong H.K., Wong R.T., 2009, 2014) proved that a carefully thought out and specially organized resource room influences the formation of personal and social qualities of children with special educational needs in general and the content, form and productivity of their educational activities in particular

It is a resource room, a separate, specially equipped room for children with special educational needs, where training takes place according to an individual development plan, accompanied by a correctional teacher, a defectologist teacher, and psychological and physical adaptation of children with disabilities. Its main purpose is to create a comfortable space for organizing the learning process for children with special educational needs based on the use of person-oriented teaching methods.

Given the potential of autistic children, we offer an example of a house as the basis of a future project/modernization using the latest technologies. Gifted child autistic school number 321, "future famous architect" chose this architectural model six years ago, (fig.. 1, 2) and today will like this house as a favorite object of research.

An inclusive educational environment as a planned and organized physical space in which children should safely move around during individual classes is the presence of a favorable social and emotional climate, the creation of conditions for children to work together, and assistance.

As a result of the creative cooperation of parents, teachers of defectologists and children of autistic people, the ability to be non-standard, to be creative in solving any problems and to transfer supra-situational activity, which is a mechanism for overcoming external and internal obstacles and restrictions, to other situations of their life. Especially important is the appearance of parents' awareness and mobilization of internal resources and readiness for purposeful active actions that will contribute to self-realization.

Physical confidence of a child with autism contributes to the regulation of his emotional state, and this, in turn, makes it possible to successfully contact with other people

J. Ayres

Figure 1

When parents are able to manifest themselves in a bright and diverse way, creatively pick up the actions of the child, feel that it is worth doing for its development at one time or another. The importance of parents in the successful development of a child with peculiarities of psychophysical development remains extremely important.

Self-esteem, self-control and self-confidence are based on the sensations of one's body as a certain skillful sensorimotor whole.
J. Ayres

Figure 2

Consequently, the priorities of the development of inclusive education are the formation of meaningful and organizational features of an inclusive educational environment in educational institutions, the introduction of modern technological support for the implementation of an inclusive approach, the constant updating of the interior, it is necessary to have in all school resource rooms, and this is more than 12 thousand institutions of general secondary education of Ukraine, new modernized houses.

Lack of clarity, certainty, a certain structure negatively affects the organization of the educational environment, causing chaos, unproductiveness, which leads to a waste of time, misunderstanding, disappointment and a decrease in the authority of the teacher (Stronge J.H.).

"The ability to create," said academician V.O.Engelhard, "is the highest gift that human nature has awarded on the infinitely long path of its evolutionary development."

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ESTIMATION OF WASTE GENERATION FROM DESTRUCTION

Ihor Satin [1], Olena Koltyk [2], Olena Panchenko [1]

[1] Kyiv National University of Civil Engineering and Architecture, State Enterprise "Scientific Research and Design and Technological Institute of Urban Economy", satin@nikti.org.ua

[2] Ukraine Support Team (UST), hi@rethink.com.ua

[3] State Enterprise "Scientific Research and Design and Technological Institute of Urban Economy", panchenko@nikti.org.ua

As of the beginning of 2022, there were approximately 8 million residential buildings in Ukraine with a total living area of 892.1 million sq. m. Starting from February 24, 2022, due to hostilities, residential and public buildings, structures and other construction sites have been destroyed and damaged throughout the territory of Ukraine. The greatest destruction and damage was suffered by residential and public buildings in Donetsk, Kharkiv, Luhansk and Kyiv regions, and during 2022, significant damage and destruction was also suffered by buildings in Mykolaiv region. According to World Bank estimates, the RDNA3 report as of December 2023 indicates that among all damaged housing units, more than one quarter (547,010 housing units) were completely destroyed, the other two quarters are partially damaged, including: 882,528 thousand of housing units have minor damage (up to 10%), and 679,382 housing units have moderate damage (damage 10–40%). 230,315 individual residential buildings and 67,206 dormitory rooms were also damaged.

The World Bank estimates total housing damage at $55.9 billion. The most damage was to apartment buildings. Apartments in apartment buildings continue to account for the largest share of both damaged units and damage costs, both at 86 percent.

In Ukraine, in order to organize and carry out a complex of works to eliminate the consequences of destruction during martial law and during the reconstruction period, the management of waste generated in connection with damage (destruction) of buildings and structures, objects of unfinished construction, improvement objects as a result of hostilities, terrorist acts, sabotage or carrying out work to eliminate their consequences is carried out by the "Procedure for handling waste generated in connection with damage (destruction) of buildings and structures as a result of hostilities, terrorist acts, sabotage or carrying out work to eliminate their consequences", approved by the Resolution of the Cabinet of Ministers of Ukraine dated September 27, 2022 No. 1073 (hereinafter referred to as the Procedure).

However, the Procedure does not contain an algorithm for determining the preliminary volume of waste from destruction, which complicates planning decisions regarding the management of this type of waste, and also significantly burdens local governments in the event of destruction.

The assessment of the volume of waste generated from demolition is carried out mainly visually or by the volume of the truck body. Thus, there is a need to develop methodological recommendations for a preliminary assessment of the volume of waste generated from demolition using accumulated domestic and international experience.

Methodological recommendations for assessing the volume of waste generated as a result of damage and destruction of buildings and structures were developed with the support of the United States Agency for International Development (USAID) "Building Public Trust (UCBI)".

Generation Ratio Calculation Method (GRC – “generation rate calculation”) is a common approach used to estimate the amount of construction and demolition waste (hereinafter referred to as C&DW) [1-3]. This method can be implemented during construction, reconstruction, and dismantling both at the regional and project levels. The principle of this methodology is to obtain the level of waste generation for a certain unit of activity (for example, kg/sq.m and cubic meters. m/sq.m). Several methods have been introduced in this principle using alternative parameters in previous studies, such as per capita multiplier, extrapolation of financial value and area-based calculation. The amount of waste generated is calculated using a waste generation index, such as the waste generation ratio obtained through statistical analysis based on the gross floor area (GFA). floor area) [1-3].

In Japan, which suffers from regular natural disasters, a methodology for estimating the volume of waste generated from natural disasters is also used. The methodology takes into account the type of building, the main structural elements, the presence of fire during the destruction and allows for the estimation of the volume of waste generated from natural disasters in general and by main components - concrete, brick, plastic, glass, drywall, etc.

Thus, the methods used in the world to determine the volume of construction waste after the dismantling of a building or its destruction, as a rule, use specific indicators of the formation of individual materials or waste per unit area of the destroyed building.

At the same time, it should be noted that specific indicators obtained in other countries of the world cannot be applied in Ukraine for a number of reasons: location in different climatic zones, which affects the parameters of enclosing and supporting structures; different construction methods and different building materials.

In Ukraine, the accounting of demolition waste is currently carried out based on the actual volumes removed and it is not always possible to obtain high-quality statistical information on the amount of waste generated. As a rule, the volumes of actually removed demolition waste are smaller than the real indicators. The following factors lead to a decrease in the volumes of demolition waste recorded by territorial communities in Ukraine: a) a long period between the demolition and the dismantling work (from several months to years), during which some materials were removed by local residents or the military for their own needs; b) some of the demolished buildings suffered fires, and in some cases the demolition waste was recorded as construction waste; c) dismantling work was carried out on part of the building (quite often dismantling work in manor buildings was not applied to the foundations) [5].

Thus, to calculate specific indicators in Ukraine, it is advisable to use data from construction projects. Using the experience of different countries to assess the volume of waste generation from demolition, it is necessary to determine specific indicators per unit area - the waste generation rate. At the same time, the main indicators for determining the estimated amount of waste from demolition are volume (cubic meters) and/or mass (tons). The generation rate is determined for residential buildings of estate development and apartment buildings, buildings of general secondary education institutions, preschool education and healthcare institutions.

According to the Procedure, demolition waste consists of two components – main and associated components [4]. The main components include parts (fragments, debris) of building structures, fillings of door and window blocks, engineering networks, sanitary appliances, etc. The associated components include materials, objects that were inside or near the building at the time of damage (destruction) or during its dismantling, in particular equipment, personal belongings, household items (furniture, household appliances), organic substances, etc. Thus, the rate of demolition waste generation is also calculated based on the main and associated components.

The costs of basic materials for building construction are based on typical projects from 1958 to 1991 and design and estimate documentation after 1991.

To calculate specific indicators, we use the following building areas: building area of the house and total building area. Building area is used to calculate specific indicators of manor buildings, as well as to determine specific indicators of asbestos-containing roofing materials in apartment buildings and other buildings. Total building area is used to calculate specific indicators of apartment buildings. The total area destruction is parts on general areas or general area house, which is to be dismantled.

Thus, the calculation of the mass of waste generation from destruction by main components (sum of all masses by individual components) in residential buildings is carried out according to the formula:

$$Mi = Fi * ai \quad (1)$$

where:

M_i – total mass of waste generation from destruction by main components at the i-th development object, t;

F_i – building area on the i-th object, sq. m;

a_i – the rate of waste generation from destruction by main components at the i-th object, t/ sq. m.

Let us compare the norms of waste generation from destruction, which were obtained in our study according to design indicators, with the specific indicators of construction waste or disaster waste generation, which were obtained by other methods or calculations. The results of the comparison are summarized in Table 1.

Table 1

Comparison of waste generation rates from the destruction of residential buildings with specific indicators obtained by other methods

House type	Total rate of waste generation from demolition, t/ sq.m.	Notes
Data obtained from project indicators		
Manor houses	2,126	By project indicators
Large-panel houses	2,196	By project indicators
9-storey monolithic-frame house	1,524	By project indicators
Data obtained by other methods		
Manor houses according to actual UNDP data for the Kyiv region	1,628	Actual figure. May be underestimated due to material selection prior to dismantling and fire
Mass of structures and materials according to typical designs of apartment buildings, per total area	2,614	Project reliable indicator

Comparison of the norms of waste generation from destruction (Table 1), which were obtained in our study according to design indicators, with the specific indicators of construction waste or disaster waste generation, which were obtained by other methods or calculations, showed the statistical relevance of the results obtained. The arithmetic mean value of the norm of waste generation from destruction according to design indicators is 2.415 t / sq.m.

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DETERMINATION OF SHADING COEFFICIENTS OF SUN PROTECTION FROM GREEN PLANTINGS

***Oleg Sergeychuk*[1]*, Yuriy Kozak*[1]**

[1]*Kyiv National University of Construction and Architecture*

ovsergeich@i.ua, kozakyuriy1@gmail.com

In the northern hemisphere of the Earth, maximum insolation occurs on the day of the summer solstice - June 22. However, due to the accumulation of heat by the Earth, maximum atmospheric temperatures are recorded at the end of July. The trajectories of the Sun's movement across the celestial sphere, equidistant from the day of the summer solstice, coincide. Therefore, an unregulated sun protection device that blocks the entry of sunlight into the room on August 22, when it is very hot, does not let the sun in on April 22, although at this time in many European countries, including Ukraine, it is still quite cool and insolation of the rooms is desirable. Green plantings that shed leaves in winter have an advantage over unregulated sun protection devices, since they let in sunlight in the cold season. Therefore, the use of green plantings as sun protection devices (green SPD) contributes to the creation of comfortable temperature conditions in buildings. Modern architecture of cities and individual buildings involves a variety of uses of green SPDs: individual trees, rows of trees near facades, plants on facades - overhangs, side ribs or green curtains.

When energy certification of buildings, it is necessary to take into account the impact of external shading on the energy consumption for heating and cooling of buildings. To do this, it is necessary to know the value of the shading reduction factor $F_{sh,O}$, which is the ratio of solar radiation incident on an irradiated surface shaded by sun protection to solar radiation on this surface without shading [1,2]:

$$F_{\mathrm{sh,O}} = \frac{I_{\mathrm{sol,ps,mean}}}{I_{\mathrm{sol,mean}}}, \qquad (1)$$

where $I_{sol,ps,mean}$ – average energy irradiance by solar radiation of the considering surface, shaded by external objects, W/m^2;

$I_{sol,ps,mean}$ – average energy irradiance by solar radiation of the same surface in the absence of shading, W/m^2.

This coefficient is different for heating and cooling periods.

Heating and cooling periods are determined differently by different methods. However, in a central heating system, the heating period is determined by a certain average daily outdoor temperature, below which the heating period begins. For example, in Ukraine this is a temperature of -8°C [3]. The cooling period is determined more complicatedly.

Because of the transparency of green spaces depends on the density of leaves in the direction of sunlight and the length of the ray path through the green mass, it is assumed that the transparency of green SPD f_i in the direction i corresponds to the exponential decay law and can be given as:

$$f_i = e^{-\mu d_i}, \qquad (2)$$

where μ is the optical density of the green SPD; d_i is the length of the path the beam has traveled through the green mass.

The optical density of the green SPD is determined by the formula:

$$\mu = \frac{\ln f_{\angle}}{d_{\angle}}, \qquad (3)$$

where $f_{\angle}$ is transparency of the green SPD, which is measured at a certain angle of incidence of sunlight, $d_{\angle}$ is the path length of this ray in the green mass.

The values of $f_{\angle}$ and $d_{\angle}$ are taken from studies [3-6].

To calculate the energy efficiency of the SPD, energy solar maps are proposed [7]. They are obtained by plotting 100 points on the solar map for a plane of the corresponding orientation, which are distributed over the map in accordance with the contribution of elementary sections of the sky to the energy illuminance of this plane under the condition of a completely open sky. Energy solar maps are constructed separately for periods of cooling and overheating for vertical planes of facades oriented along eight cardinal directions: N, N-E, E, S-N, S, S-W, W, N-W. The construction was carried out based on data [8] with real cloudiness of the sky for five cities: Kyiv (I architectural and construction climatic region), Zaporizhia (II region), Ivano-Frankivsk (IIIa region), Uzhhorod (IIIb region), Simferopol (IV region).

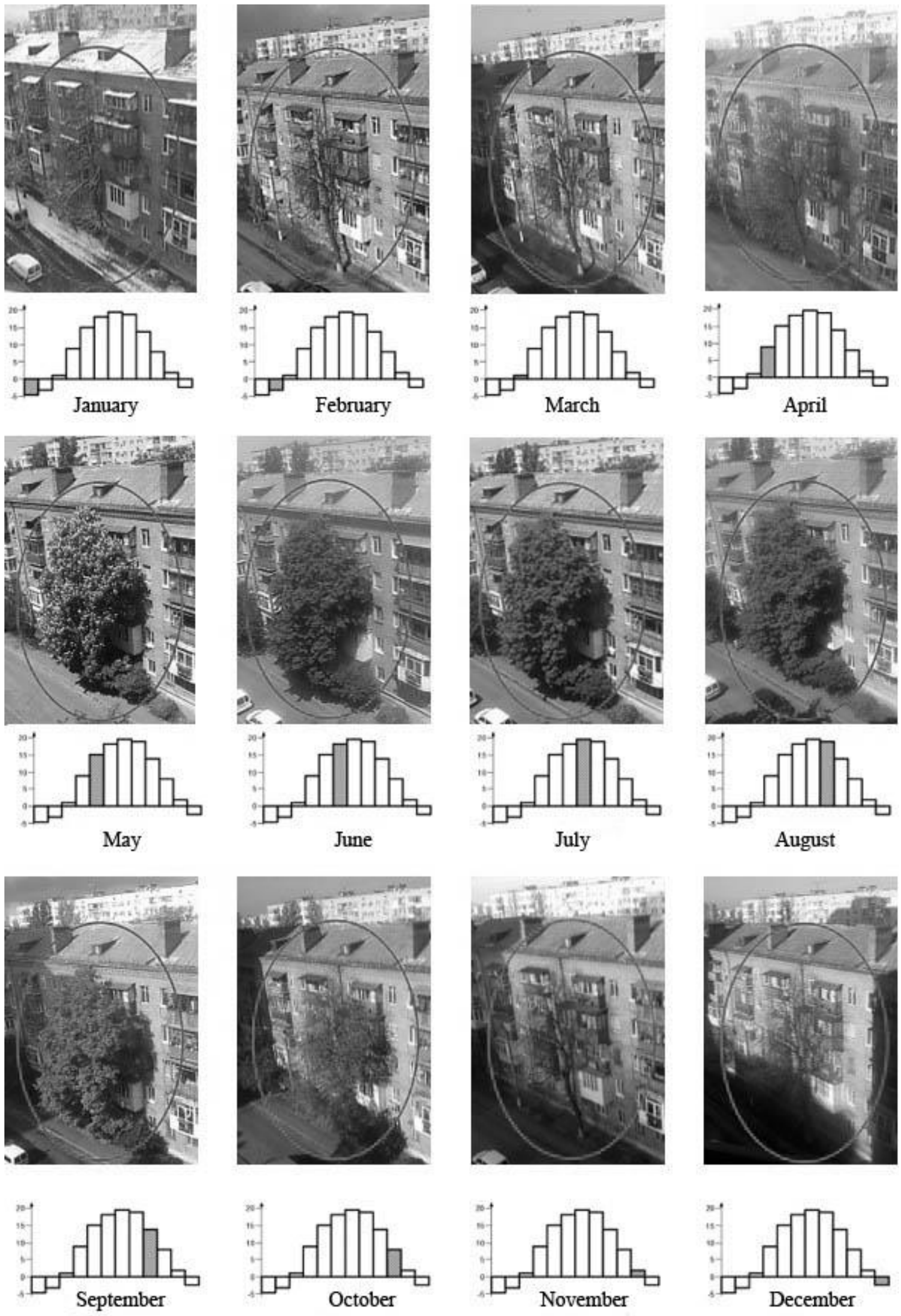

Fig. 1. **Blocking sunlight by chestnut throughout the year**

As is known, the solar radiation reaching the facade consists of direct, diffuse and reflected. When calculating the total radiation, a simplification is made that diffuse and reflected radiation reach the facade without reduction. This is identical to the assumption that shading reflects as much solar radiation as it absorbs [2]. Diffuse radiation in [8] already takes into account reflection from the ground. Therefore, the partial shading correction factor $F_{\text{sh,O}}$ can be determined by the formula:

$$F_{\text{sh,O}} = \frac{0{,}01 \cdot S \cdot P + D}{S + D}, \quad (4)$$

where S is the average monthly sum of direct solar radiation, MJ/m^2, determined by [8];

D – average monthly sum of scattered lunar radiation, MJ/m^2, determined according to [8];

P is the percentage of direct solar energy transmission of the SPD.

To determine P of an opaque SPD using an energy solar map, it is sufficient to construct a shadow mask of the SPD on it and count the number of N points that it shades. Then

$$P = 100 - N. \quad (5)$$

For green SPDs, formula (5) takes the form:

$$P = 100 - \sum_{i=1}^{N}(1 - f_i). \quad (6)$$

where i is the number of the point shaded by the SPD.

In [9], the determination of the reduction coefficients of external shading from tree rows, which are most often used in Ukraine for ordinary plantings in cities: poplar, horse chestnut, maple and spruce, is considered.

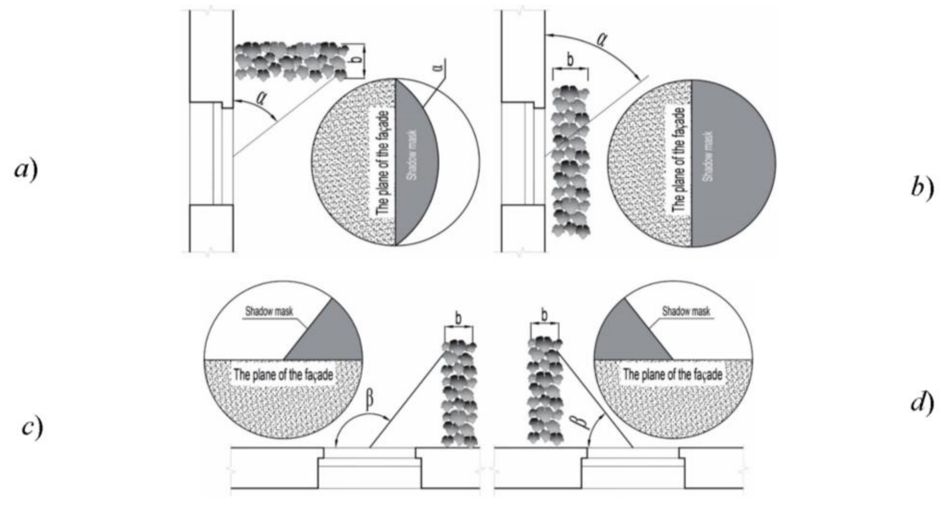

Fig. 2. **Schemes for determining the shading angles from green facade structures**
a – vertical angle α of overhang shading and thickness of green massif; b – vertical angle α of curtain shading and thickness of green massif; c – horizontal shading angle β of the right edge and thickness of green massif; d – horizontal shading angle β of the left edge and thickness of green massif

Today, the coefficients of external shading for green SPD in the form of overhangs, ribs and curtains have also been determined. They are shown on Fig.2.

The calculations assume a basic array thickness of *b* = 400 mm. The analysis of the influence of changing the thickness of the array on the values of partial shading coefficients was also carried out. The thicknesses of the green array from 200 mm to 1000 mm were studied. During the heating period, the partial correction coefficient of horizon shading for the overhang, curtain and ribs, when changing the thickness of the green array, changes slightly, which, of course, is explained by the fact that in the winter period there are no leaves on the plants. The situation is different in the summer cooling period. During this period, for example, for curtains with a thickness of *b* = 200 mm $F_{sh,O}$ decreases by almost 20%, and at *b* = 1000 mm it increases by the same amount.

Green spaces and structures made of them have recently been increasingly used in energy-efficient architecture. However, there are still no methods for determining their shading coefficients, which does not allow taking into account their impact on the energy performance of buildings when drawing up energy certificates. The conducted studies are aimed at correcting this situation.

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ENVIRONMENTALITY AS A PRIORITY OF THE GREEN COURSE OF DEVELOPMENT AND A GUIDELINE FOR THE IDENTITY POLICY

Stetsenko Svitlana
Kyiv National University of Construction and Architecture,
stecenko.sv@knuba.edu.ua

In the conditions of the Russian-Ukrainian war and postwar development, the formation of a political agenda regarding the priorities of Ukraine's social development acquires special importance. The subjects of development are the state and society as the bearer of relevant requests. In Ukrainian society, there are high demands for security and social welfare, which are correlated with the promotion of perspective priorities and effective management solutions. In the political and institutional context, "it is vital to ensure that the state can increase its capabilities in response to the growing needs of society... This requires new ways in which society can monitor and control the state and elites." [1]

The authors of this conclusion, laureates of the Nobel Prize in Economics for 2024. Daron Acemoglu and James Robinson emphasize that the usefulness of state intervention is measured not only economically, but also by political consequences, in particular, political and ecological ones. For scientific communities, bearers of different identities, and leaders of public opinion, the task of developing and arguing for the choice of reference points within the framework of the general imperative of development is actualized.

It is necessary to substantiate the logic of discourses about development in conditions of limited resources and to propose such narratives that can be adapted to the crisis phases of domestic and world political dynamics. It is about development in accordance with new challenges, in particular, a green development project, green construction, and at the same time about the formation of a new political identity as a positive identity of development, which forms the basis of the sociocultural sovereignty of Ukraine.

In the current realities, identity politics is the value and content dominant of the resource potential of Ukraine. A single system of meanings that consolidates the political nation for the sake of the future is imprinted in it: real power in the will; defend your own to the end; adaptability; innovativeness; environmental friendliness. For warring Ukraine, the geopolitical message of "peace through strength" that is present in the political rhetoric of the administration of D. Trump, means the withdrawal of the United States from world leadership and the destruction of the Euro-Atlantic strategic partnership. Balance and moderation between the victim and the aggressor is perceived as appeasement of the latter.

Warring Ukraine seeks a just peace, not a temporary truce. The new Ukrainian model of strategic asymmetry in warfare is being studied and integrated by the world's leading armies.

In wartime, identity politics focuses on the formation of identity, which records the change of cognitive attitudes and approaches to the perception and understanding of the change of eras. Ukrainian national identity has gone beyond the "narrow" topic of scientific identity studies and represents a powerful investment resource of intangible regenerative nature of social development. The question remains: how to convert the Ukrainian national identity not only into a representation of common values with politics and economy, but into a sustainable responsible partnership.

In this context, it is primarily about the imperative of development in the version of sustainable development. The complex character of this concept in the political and economic field is designed to solve the task of synthesis of social, economic and environmental problems. [2] It is about the combination of the "green" idea as the basis of the pan European value consensus, which is implicitly endowed with the quality of universality, with social and humanitarian components.

Ecological development programs take into account the key motivation: meeting the needs of current generations in conditions of limited resources without harming the opportunities of future generations. In warring Ukraine, environmentalism is actualized through the green course of development. The attractiveness of this approach lies in the implementation of clean technologies, in the bet on the use of renewable resources. At the same time, it is difficult to predict the environmental sustainability of development projects under the condition of dead land, which leaves behind an existential racist enemy. Elimination of ecocide caused by the enemy is a long process that requires significant resources.

Environmentalism in the Ukrainian national identity is marked by the archetypal symbolism of a "kind", "kind", fertile land, which returns the nation to its natural environment, contributes to the transmission of the experience of generations. Environmentalism as a value&fundamental feature of Ukrainian national identity is clearly emphasized in the narrative character of thousands years old traditions of Ukrainians' respect for nature, harmony with nature, and caring attitude towards it. The historical memory of Ukrainians as a component of identity politics, containing information, in particular, on the political and legal regulation of "man-society-nature" relations, is formed through specific chronicle stories from the time of Kyiv Rus and relevant narratives of the proto-Kyiv period.

Francis Fukuyama, a leading political scientist and professor of political science at Stanford University, rightly emphasizes that identity categories, which he considers universal, are the best way to explore and explain the origins of people's motivation for action. The scientist turns to Plato's "State" (Book Four), when Socrates and his students reflect on the principles of the human psyche, which serve as motivators for life. The initial conditions of the dialogue are as follows: thirsty people on the one hand, the presence of only polluted water as objective circumstances. In a situation of opposition, the "reasonable principle" wins - not to drink, although it resists and "acts contrary to the irrational craving principle." [3] With the further development of the dialogue, the participants managed to discover the third, spiritual principle - thymos, which means "spirit" in Greek.

This third valuable component of the human psyche operates independently of the first two - desire and reason, and is an expression of people's need for recognition of their significance, a positive assessment of their activities. The concept of "thymos" as a universal aspect of the human essence and the center of judgments about dignity is at the basis of the modern understanding of identity and forms the realm of identity politics, when the people, the nation, demand the recognition of their values and dignity.

Today, the issue of the relationship between the state and civilization, the ability of the state to accumulate and direct the resources accumulated in the space of cultural and civilizational interaction are brought into the focus of identity politics. It is important not to allow a departure from the traditional orientations of identity, not to resort to politicization, which the bearers of opposite value and worldview positions are trying to bring into the agreement of the party-political conjuncture.

Hybrid threats to identity politics from the racist aggressor state are not exhausted, which is not limited to the spread of fakes and manipulative innuendos, but generates all new narratives to the already existing ones about the historical unity of Ukrainians and Russians, about belonging to a single civilizational model, while using the religious factor that is sensitive to Ukrainian national identity.

In its genesis and consequences, the historical memory of Ukrainians holds the culminating peak of the sociopolitical demonstration of Ukrainian national identity: during the evolution of the Euromaidan into the Revolution of Dignity with the smell of blood during the execution of the Heavenly Hundred. Memorialization and commemoration of this historical event is an important component of identity politics. The formation of national commemorative practices, the strategy of building public ceremonials is a demonstration of the consolidation of the unity of Ukrainian society and the political nation. Through the institutionalized commemoration of the collective memory of the heroes, the actualization of events, images, and personalities of the past, not only the past, but also the present and the future are understood.

The priorities of the desired future, the green course of development are determined by the provision of resources, in particular, the possibilities of building up social capital, the effectiveness of which is determined by the motivation of citizens, the interrelationship of their life activities, the future of their children and grandchildren with the development prospects of the respective communities and the country. A new quality of Ukrainian national identity as a positive identity of development is formed on these basic principles.

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ON THE FORMATION THE STRUCTURE OF THE FIXED BIOCENOSIS IN BIOREACTORS AT WASTEWATER TREATMENT

Telyma Serhii Vasyliovych

Institute of Hydromechanics of NAS of Ukraine,sertelyma@gmail.com

The efficiency of organic pollution and nitrogen compounds removal in various bioreactors (aerotanks with additional loading with fixed biocenosis, flooded and trickle biofilters) is associated with the formation of a high concentration of biomass (biofilm) on their surface per unit volume of the bioreactor . Biofilm is a gel-like accumulation of microorganisms and other particles that are immersed in extracellular polymeric substances (EPS). Biofilm contains water but its main physical characteristic is in the solid phase. Although the liquid makes up the main part of the biofilm the solid particles are the main ones since they determine its reactive and structural qualities in the purification of wastewaters from various contaminants. The solid part of the biofilm has a complex heterogeneous multicomponent structure and consists of as a rule the heterotrophic and autotrophic microorganisms, inert biomass and extracellular polymeric substances EPS. Attempts to take into account the complex heterogeneous structure when modeling the processes occurring in biofilms are considered, for example, in works [1,4,5].

Thus, the results of comparative calculations of organic pollution removal using different biofilm models, namely, two-dimensional models (cellular automatism), one-dimensional nonlinear models according to the AQUASIM program and Mono models are considered and showed a good agreement of the calculation results obtained on different models with the numerical modeling data. In comparison with the numerical modeling data for flows it was 10–15%, and for concentrations at the reactor outlet - 4%, and in comparison for the two-dimensional model for flows - 4% and for concentrations at the reactor outlet - 9% [2,3] .

At the same time the question how the structure of the biofilm and external conditions, namely, the hydrodynamics of the flow around the outer surface of the biofilm which provides the biofilm with nutrients affects on mass transfer and the processes of their utilization in the biofilm was studied. For realization this complex mathematical model the well-known Navier-Stokes hydrodynamics equation and mass transfer using nonlinear reaction kinetics were used. At the same time an attempt was made to take into account in the models the non-planar (curvilinear) geometry of the biofilm surface using a correction factor A_e ,which reflects on the geometric structure of the biofilm and is greater than for a flat biofilm (A_e =1.0). For different geometric wavy forms of the biofilm surface the values of A_e are obtained which can vary within the limits of A_e =1.0-2.5.The greater irregularity and geometry of the biofilm structure the more peaks the biofilm has and the greater is value of A_e. It is also shown that the geometric shape affects on the known flow criteria Re , Se , Pe , Sh near the biofilm and some recommendations for their determination are proposed as well as results for valuation of the influence of surface irregularity on the formation of hydrodynamic conditions and on the processes occurring in the biofilm.

As a result of the analysis of existing theoretical investigations as well as the experimental studies we may conclude that when developing and using biofilm models it is sufficient to limit on considering and studying the biofilms with flat surface [3,4,6].

And the development of practical methods for calculating biological wastewater treatment by an fixed biocenosis (biofilm) may be based on the implementation of flat heterogeneous and homogeneous biofilm models . First models that are mainly were used for removing of the one substrate under stationary conditions of mass transfer had a uniform (homogeneous) structure in which the utilization of the substrate was implemented using simple linear reaction kinetics. Later such models were supplemented with the consideration of such important processes as decay, detachment which is especially advisable to consider with a significant thickness of the biofilm and with the long-term operating regimes of bioreactors [1,6,7] . At the same time that to determine the thickness of biofilm the following balance equation of growth, decay, adhesion and detachment is proposed to use [1,6]:

$$\frac{d\delta}{dt} = u_F(\delta) + u_{as} - u_{ds}, \qquad (1)$$

where $u_F(\delta)$- the rate of growth and decay inside the biofilm , u_{as}- the rate of adhesion, u_{ds}- the rate of detachment from the biofilm surface .

Based on the implementation of the general equation (1) for study the dynamics of the formation of the active thickness of the biofilm for the conditions of its homogeneous structure the following equations are proposed depending on the adopted growth kinetics. When removing organic contaminants by biofilm the following equation is most often used [1,2,7]:

$$\frac{d\delta}{dt} = \int_0^{\delta} \left(\frac{Y\mu_{\max} L}{K_{mL} + L} - b - b_S \right) dz. \qquad (2)$$

For the conditions of influence the inhibitory effect of other substances (the kinetics of the Haldaine equation) the following equation is proposed:

$$\frac{d\delta}{dt}=\int_0^{\delta}\left(\frac{Y_{\mu\max}L}{K_{mL}+L+\frac{L^2}{K_L}}-b-b_S\right)dz. \qquad (3)$$

For determination of the total thickness of the biofilm formed on the biofilter granules it is advisable to use the following equation:

$$\frac{d\delta}{dt}=\frac{Y\int_0^{\delta}\left(\frac{K\cdot L}{K_{mL}+L}X\right)4\pi(r_d+r_\delta)^2\,dr_\delta}{A_\delta X}-b\delta, \qquad (4)$$

$0\le r_\delta<\delta$, A_δ - the surface area of the granules, r_d, r_δ - the radii of the granules and biofilm respectively.

The following equation is proposed to determine the total thickness δ of the biofilm formed under the conditions of the nitrification process during the removal of ammonium nitrogen NH_4 in a trickling filter [6,8]:

$$\frac{d\delta}{dt}=\int_0^{\delta}\frac{\left(\mu\left(C_{NH_4}\right)X_1+\mu\left(C_{O_2}\right)X_2\right)-K_{d_1}X_1-K_{d_2}X_2}{\rho_e}dz, \qquad (5)$$

where ρ_e - the density of the biofilm .

In the case of combined extraction of organic pollutions and N compounds the following equation is proposed for determining the total active thickness of the biofilm on a spherical loading granule in a flooded filter [6,8]:

$$\frac{d\delta}{dt}=\frac{\int_0^{\delta}\left(Y_LK_L\gamma+Y_NK_N(1-\gamma)\right)4\pi(R+r_\delta)^2\,dr_\delta}{A_\delta}-\left[b_H\gamma+b_A(1-\gamma)\right]\delta, \quad (6)$$

$0<r_\delta\le\delta$, R - radius of the granule, r_δ - radius of the biofilm , A_δ - area of the granule, b_H, b_A - total rate of bacterial loss due to disintegration and fluid separation, Y, K, γ - known parameters of the model implementation.

In practical calculations for example under steady-state conditions and ignoring the boundary layer a simplified balance equation can be used to determine the biofilm thickness [6]:

$$\frac{YN}{X}-b_S\delta-u_{ds}=0, \qquad (7)$$

where - $\frac{YN}{X}$ biofilm growth, $b_S\delta=(b_{in}+b_{res})$ biofilm decay, b_{in}, b_{res} - respectively the coefficients of inactivation and endogenous respiration, u_{ds} - the rate of detachment from the biofilm surface .

For determination of speeds u_{ds} number of dependencies have been proposed. The most widespread dependency has the next form [3,4,8]:

$$u_{ds} = b_s\delta \ , \qquad (8)$$

which is widely used in the above models as well as a dependency of the form:

$$u_{ds} = K_d\delta^2 \ . \qquad (9)$$

So if we take into account a zero-order reaction when removing of the organic pollutions the values $N = w_L\delta$, $w_L = \dfrac{\mu_{\max} X}{Y}$ and the separation value according to (9) then on the base of solution (7) will be:

$$\delta = \frac{\mu_{\max} - b_s}{K_d}, \qquad (10)$$

When determining the flow value using Mono kinetics but without taking into account the boundary layer the separation velocity is also taken according to formula (9).

The formation of a stationary (constant) thickness of a biofilm occurs on significant time scales. If processes such as substrate diffusion and flow hydrodynamics occur within a few minutes achieving stationary conditions during the formation of the biofilm thickness requires at least several days and even weeks. At using the film models for the main processes occurring in the biofilm the some recommendations are proposed for determining the time to reach a stationary state. For example at a molecular diffusion coefficient $D_L = 8 \cdot 10^{-5}\ м^2/доба$ (for acetate), $\delta = 500$ μm the stationary state is reached after 4.5 min. Calculations have shown that the time to reach a stationary state for microorganisms in the middle of the biofilm will be from days to weeks [1-3].

Thus when calculating the thickness of a biofilm it is advisable to determine the time when the steady-state regime of operation is occurred in biofilm.

According to equation (6) biomass losses due to decay and detachment under conditions of competition between heterotrophic and autotrophic bacteria were considered and the influence of ammonium oxidation on the detachment processes with different organic loading were investigated.Some recommendations were proposed on the theoretical research modeling of the biofilm structure during the simultaneous removal of ammonium and organic pollutants at different concentrations in wastewaters. A mathematical model was adopted taking into account the decay and detachment processes and its features at wastewaters treatment under difficult conditions were noted. In particular it was shown that the hydrodynamics of the flow around the biofilm significantly affects on the detachment processes and the formation of stable operation of the biofilm .

An analysis of biofilm formation state shows that instead of complex models of heterogeneous biofilm which are based on taking into account complex processes at wastewaters treatment in bioreactors it is advisable to use a heterogeneous one-dimensional model in practical calculations and to use known approaches and principles used in the study of homogeneous biofilms. At this the proposed heterogeneous model divides the biofilm into a finite number of homogeneous layers and each of these layers is modeled as a homogeneous layer. The influence of biofilm heterogeneity is taken into account on the base of the properties of each layer. As a result of the studies of stratified biofilm taking into account the variable effective diffusion and density of the biofilm the main features that distinguish it from homogeneous biofilm were established . At the same time it was found that nutrients that limit growth penetrate deeper in stratified biofilm than in homogeneous. After correction the existing models of homogeneous biofilm and specific cleaning conditions the research results obtained in this way may be used in calculations of stratified biofilms . It is also shown that the results of research on the proposed models of stratified biofilms are in good agreement with experimental data [2,5,8].

In the future it is planned to conduct the researches to assess the possible impact on the formation of biofilm parameters the such factors and processes as temperature, pH (alkalinity), the presence of toxic and other substances. When developing mathematical models and engineering methods for calculating biofilm parameters an important questions are also the justification of the initial parameters (coefficients) that are included in the equations and dependencies during the practical realization.

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THE FIRST UKRAINIAN GREEN BUILDING STANDARDS

Tatiana Tkachenko*[1]*, Viktor Mileikovsky*[2]*,
[1]*Kyiv National University of Construction and Architecture,*
tkachenko.tm@knuba.edu.ua
[2]*Kyiv National University of Construction and Architecture,*
mileikovskyi.vo@knuba.edu.ua

Two significant events took place in Ukrainian green building this year:

- the first Ukrainian standard of voluntary certification SOU OEM 08.002.41.032:20XX "System for environmental certification and ecolabelling according to DSTU ISO 14024:2018 (ISO 14024:2018, IDT). Public buildings. Environmental criteria and method for life cycle assessment" [1];
- the World's first standard for the study of heat and mass transfer processes in green structures, DSTU XXXX-20XX "Environmental protection. Green structures. Method of testing thermotechnical and gas exchange characteristics of vegetation layers" [2].

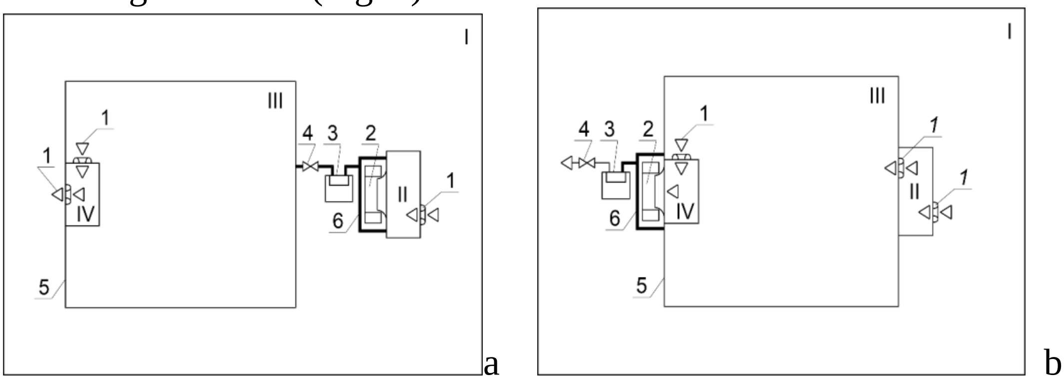
SOU OEM 08.002.41.032:20XX establishes requirements and criteria for rating the life cycle of public buildings in accordance with [3] at the stages of planning, designing construction and commissioning of a construction object.

The development of the standard takes into account international experience set out in the LEED, BREEAM, DGNB and other standards. Therefore, the life cycle assessment starts with construction management from the planning stage to commissioning and subsequent maintenance. Considerable attention is paid to innovations and ensuring their proper functioning.

A unique feature of the standard is that for the first time in the world, it assesses the integration of outdoor greening, external and internal building greenery into a project to address environmental, technical and social challenges. It is also the first to standardise the provision of opportunities not only for recreation but also for work in the natural environment. As practice shows, this increases productivity, physical and mental health. The standard also provides for an increase in the area of outdoor greening by creating slopes and pergolas, including false pergolas without human access. Given these possibilities, not only restorative landscaping is recommended, but also augmentative landscaping. This implies that the construction has a positive impact on the environment in terms of soil/substrate for plants and biodiversity. Considerable attention is also paid to ensuring plant care. These features were made possible by unique systematic research on the positive effects of green structures conducted at KNUBA.

The standard takes into account the experience of the russian-Ukrainian war. Unlike global standards, it is recommended not only to ensure the accessibility of the environment, but also to quickly deactivate all information signs, which is critical in the event of a sudden military or terrorist threat. Another unique feature is the provision of continuous life support for buildings in the event of possible interruptions in heat, electricity and water supply.

DSTU XXXX-20XX is the first in the world to standardise a method for studying heat and mass transfer in the plant layers of green structures. It covers more than 10 years of experience in experimental studies of thermal performance and gas exchange in plant layers. The standard defines methods for testing the heat transfer resistance and cooling effect of the plant layer on green surfaces, vertical and horizontal landscaping of buildings with ampelous plants, and gas exchange of plants in a gas exchange chamber (Fig. 1).



Legend:

a - installation of a gas exchange zone in the suction; *б* - installation of a gas exchange zone on the discharge side; *I* - the model air preparation zone; *II* - entrance zone; *III* - gas exchange zone; *IV* - output zone; *1* - air passage hole, which is recommended to be equipped with a collector; *2* - fan; *3* - flow meter; *4* - flow regulator; *5* - walls with average sealing requirements; *6* - sealed walls, ducts, air ducts, etc.

Figure 1. Examples of gas exchange chamber layout

For plant illumination, the standard establishes a special reduced photometric value – phytolux (phlx) – weighted by the typical spectrum of photosynthetic activity p(λ) of terrestrial plants (Fig. 2) so that under the solar spectrum (Fig. 3) phytolux is numerically equal to lux.

The study of the thermal resistance and cooling effect of the vegetative layer of green roofs is performed on the models in Fig. 4. The research method involves modelling the heat flux distribution in the soil or substrate layer using measured temperature fields avoiding living plants separation.

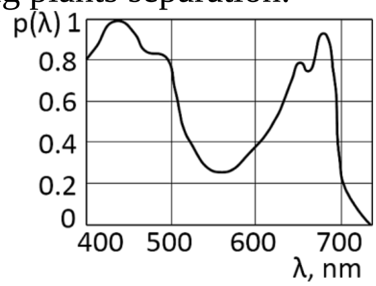


Fig. 2. Typical spectrum of photosynthetic activity p(λ) of terrestrial plants

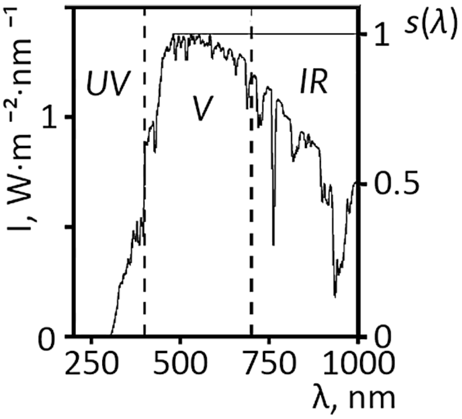
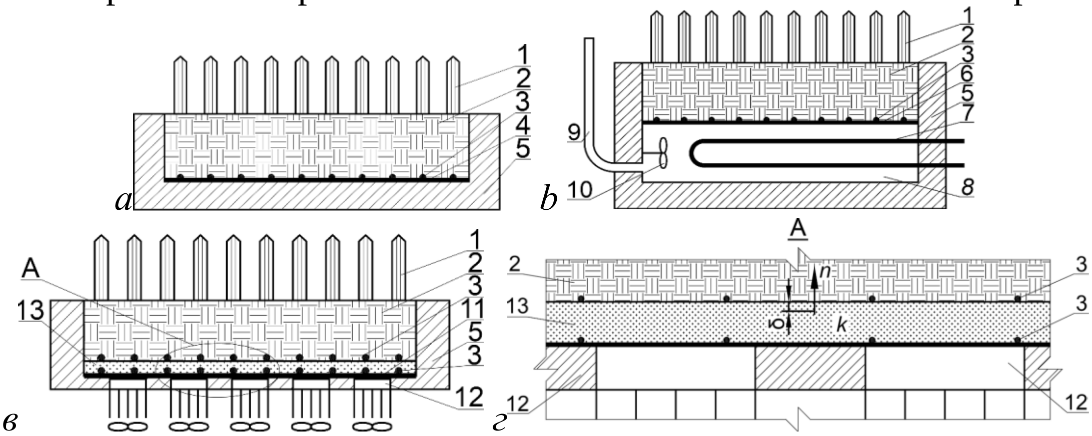


Fig. 3. Fragment of the graph of the standard spectral density of solar radiation at sea level

Methods for studying the heat transfer resistance of vertical and horizontal landscaping are much simpler and involve the direct formation of the required heat flow under the plant layer (Fig. 5).

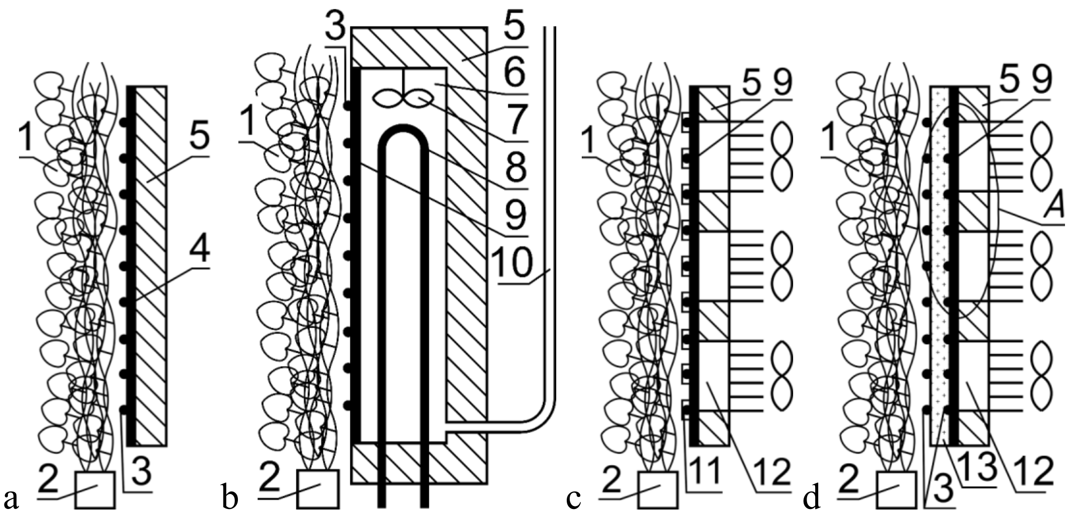
These two standards are the first specialised green construction standards in Ukraine. They are not just a copycat of other global standards, but take into account both global best practices adapted to Ukraine's conditions and our own developments.



Symbols:

а - with an electric heater or a heat exchange plate with a coil; *б* - with heat distribution by liquid or gas; *в* - with Peltier modules or other separate heat/cold sources; *г - calibrated layer or model of a homogeneous layer; 1* - vegetation layer; *2* - soil or substrate; *3* - temperature sensors; *4* - heater or plate with a channel for the coolant; *5* - insulation; *6* - heat-conducting plate; *7* - Heat exchanger or electric heat exchanger (smooth, finned, etc.); *8* - cavity with liquid or gas (air); *9* - Expansion tube or expansion tank connection (optional for gas filling); *10* - mixer

Figure 4. Diagrams of green roof models



Symbols:

а - with winding climbing plants on the heater; *б* - with a temperature calibrator; *в* - with Peltier modules; *г* - with Peltier modules and a calibrated layer; *1* - vegetation layer; *2* - Tray with soil; *3* - location of the temperature sensor; *4* - electric heater; *5* - thermal insulation; *6* - cavity with water or air or other liquid or gas; *7* - is a mixer; *8* - heat exchanger or heating element; *9* - heat distribution plate; *10* - Expansion tube or connection of the expanded tank; *11* - installation location of the temperature and heat flow sensor; *12* - Peltier module; 13 - Calibration layer according to Fig. 4

Figure 4. Diagrams of vertical and horizontal gardening models

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HEAT PUMPS AS A KEY COMPONENT IN ACHIEVING A GREEN BUILDING CERTIFICATION

Michael Ulanov

Institute of Engineering Thermophysics of the NAS of Ukraine, e3therm@gmail.com

The increasing impact of climate change and the rising frequency of natural anomalies necessitate innovative and effective strategies to a comfortable environment for people on Earth. With the expansion of industrial production and the construction sector, the importance of environmental comprehensive safety has reached a critical level. Adapting to these new conditions influences various aspects of human activity, but as individuals spend the majority of their time indoors, the environmental qualities of buildings are of paramount importance.

One approach to aligning construction projects with current realities is through their evaluation and certification, which aim to minimize environmental and climate impact while enhancing the and operational performance of buildings.

Certification not only reduces on the economy but also fosters the potential growth of the state's economic sector by incorporating energy-efficient solutions. The most widely recognized international systems include:

LEED – Leadership in Energy and Environmental Design is an international building certification system acknowledges exemplary and construction practices.

Established in 1998 by the American Green Building Council (USGBC) [1], the LEED standard has certified over 10,000 buildings, covering a total area of 608 million m² across 135 countries. It is founded on American ASHRAE standards.

In the LEED system, indicators are categorized into eight sections:

- Sustainable Sites (SS);
- Water Efficiency (WE);
- Energy and Atmosphere (EA);
- Materials and Resources (MR);
- Indoor Environmental Quality (IEQ);
- Innovation and Regional Priority (IRP);
- Location and Transportation (LT);
- Integrative Process (IP).

The rating of a project in the LEED green building assessment system is determined by the number of points earned during certification.

BREEAM – Building Research Establishment Environmental Assessment Method, an assessment standard established in 1990 by the British company BRE Global, incorporates advanced construction practices to minimize environmental impact and enhance the quality and operational characteristics of buildings [2].

Over 200,000 buildings have been certified, with 90% of the facilities located in the UK. The standard is based on European Union regulations.

Within the BREEAM framework, indicators are organized into ten sections:

- Management;
- Health and Wellbeing;
- Energy;
- Materials;
- Waste Management;
- Pollution;
- Innovation;
- Land Use;
- Transport;

- Water.

The BREEAM system example successful approach to environmental protection from human activities by accommodating the interests of all market participants without relying on international or local laws as punitive measures.

In BREEAM green building system, a rating is based on the number of points achieved during certification.

Certification of facilities according to green standards today not only reduces energy and material resource consumption but also enhances the project's appeal to investors and tenants. It serves as a crucial attribute of the facility, providing a competitive edge in selling or renting it out.

Compliance certification with green construction standards offers an independent evaluation of the construction facility while boosting the project's attractiveness. Overall, investors may anticipate a 5,9% increase in net operating income.

Factors enhancing the investment of green construction projects:

- rental rates increase by 2 – 16%;
- occupancy rates rise by 2 – 18 %;
- operating expenses decrease by 25 – 30% due to lower energy consumption;
- resale value increases by 5,8 – 35%;
- employee performance improves by 1% for LEED Certified and Silver levels, and by 1,5% for Gold and Platinum certifications
- attraction and retention of the most financially stable and long-term tenants.

Marketing advantages of the certified object:

- innovation and uniqueness of the offer;
- validation of the object’s quality, earning trust from the international community and tenants;
- appeal to tenants whose corporate culture emphasizes environmental responsibility, including prominent and prestigious global brands;
- certification results can serve as a foundation for an advertising campaign.

Meeting basic standards leads to a 2 – 3% increase in building costs compared to a standard structure, while attaining higher standards involves additional expenditures of 5 – 7,5%.

Each building possesses unique characteristics, necessitating tailored solutions to match its specific properties. Integrated heat pump systems enhance the environmental value of buildings while improving the working environment for tenants.

Consequently, the integration of these technologies contributes to the building's overall sustainability and enables:

- a LEED Gold or Platinum rating, contributing to 4 out of 8 LEED categories, and earning 18 ~ 35 LEED credits;
- achieving an Excellent or Outstanding BREEAM rating, contributing to 7 out of 10 BREEAM categories, and earning 29 ~ 50 BREEAM credits.

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EFFICIENCY OF VERTICAL CONSTRUCTION IN UKRAINE

Marina Umanets[1], Tatiana Tkachenko[2]

[1,2] *Kyiv National University of Civil Engineering and Architecture*

Vertical construction, which involves the erection of multi-storey buildings, is one of the key areas of development in modern urbanism. Growing urbanization, limited areas suitable for development and the need to optimize the use of urban resources make this use of energy resources. However, along with its

advantages, this approach also has a number of challenges: ensuring energy efficiency, minimizing environmental impact, creating a comfortable microclimate inside buildings.

In the context of global warming and the need for rational use of resources, vertical construction should combine technological innovations and environmental approaches in itself. One of the most promising methods of improving the efficiency of such buildings is the use of vertical gardening. Studies show that the use of plant facades can significantly reduce the temperature of the outer walls of buildings, reducing the load on air conditioning systems, and improves air quality in megacities. In particular, research results confirm that vertical landscaping helps to reduce the temperature of building surfaces by 10-14°C for the southern orientation of the facade, which, in turn, reduces the temperature of the internal air by 1°C. This effect can significantly reduce the cost of cooling buildings in summer and improve the overall level of comfort. [1]

Various scientific methods are used to assess the efficiency of vertical construction and the introduction of innovative technologies, such as vertical gardening. They include experimental studies, mathematical modeling, comparative analysis, and a systematic approach to energy efficiency assessment.

Experimental studies provide empirical data on the impact of various technologies on building parameters. The main aspects of experimental methods in vertical construction include:

- Measuring temperature characteristics - using thermal imaging analysis to determine heat loss through facades and the effectiveness of thermal insulation.
- Energy consumption monitoring - installation of sensors to analyze electricity consumption for cooling and heating in high-rise buildings with traditional and innovative facades.

• Humidity and comfort analysis - using sensors to monitor humidity levels and assess the indoor climate.

Figure 1. An example of thermal imaging analysis of a building facade [2]

To assess the efficiency of vertical construction, mathematical models are widely used to predict thermal processes and energy consumption of buildings.

• CFD modeling (Computational Fluid Dynamics) - used to analyze air flows around and inside the building, which allows for optimized ventilation and reduced energy consumption.

• Thermodynamic models - calculate changes in the temperature of building walls depending on weather conditions and the presence of greenery

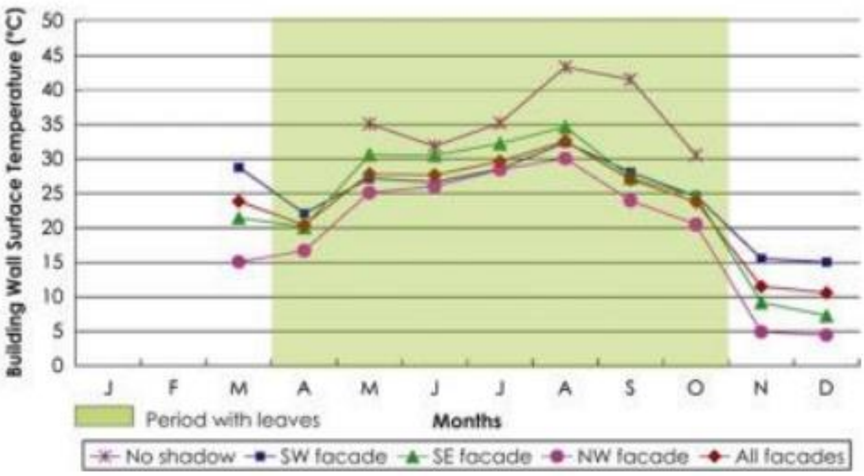

Figure 2. Graph of temperature changes in walls with vertical greening [3]

The method of comparative analysis allows us to assess the effectiveness of different approaches in vertical construction:

• Analyzing energy consumption in buildings of different heights - determining the difference in heating and cooling costs between high-rise buildings and low-rise buildings.

• Comparison of the effectiveness of traditional and innovative landscaping methods - for example, assessing the impact of living walls on reducing indoor temperatures

The research hypothesis assumes that the integration of vertical gardening into high-rise construction contributes to a significant improvement in the energy efficiency of buildings and the overall microclimate. The data confirm that the use of such technologies:

• Reduces air conditioning and heating costs by reducing the load on the power grid;

• Improves the environmental situation in cities by reducing the level of CO_2 in the air;

•Creates an additional thermal insulation layer that reduces temperature differences inside the premises. [4]

Thus, vertical construction is a necessary component of the future development of urbanism. However, for it to be effective, energy efficiency and environmental aspects must be taken into account. The use of vertical gardening technologies can significantly reduce energy consumption, improve the quality of life in cities, and improve climatic conditions. Further research in this area will help develop optimal solutions for different climatic zones. [5]

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PROJECT FOR THE ORGANIZATION OF THE “GREEN STOPS” SYSTEM IN LUTSK

Fedoniuk Vitalina Volodymyrivna[1], Fedoniuk Mykola Ananiyovych[1]
[1]Lutsk National Technical University, ecolutsk@gmail.com

Green public transport stop is an interesting environmental measure in the field of urban greening and adaptation of urban settlements to modern climate changes, which are accompanied by a significant increase in average and extreme air temperatures. Various projects of such stops provide for partial or complete and comprehensive greening of the roof of the stop, side walls and structures, and the surrounding area.

Regional manifestations of climate change in the North-Western region of Ukraine, in the zone of Volyn Polissya, to which the city of Lutsk belongs, are clearly expressed and are manifested in a steady increase in average monthly, annual and extreme air temperatures, which were analyzed in detail by Fedoniuk V.V., Merlenko I.M., Fedoniuk M.A., Lynyuk R.V., Kovalchuk N.S. [3; 4]. At the same time, in the city, under the influence of the urban heat island effect, such an increase in temperatures occurs especially intensively, it is most pronounced in central microdistricts, in areas of dense residential development as described in the work of Fedoniuk M.A., Fedoniuk V.V. [4]. Among other manifestations of climate change within the study area, we note a decrease in the total cloudiness of the sky, described in the works of Fedoniuk V.V., Husar O. N., Fedoniuk M.A. [6] and Fedoniuk V.V., Husar O.N., Fedoniuk M.A. [1]; changes in the precipitation regime, an increase in the number of cases of extreme daily amounts, which is studied in the works of Fedoniuk V.V., Ivantsiv V.V., Fedoniuk M.A., Ivantsiv O.V. [2] and Fedoniuk M.A., Fedoniuk V.V., Ivantsiv V.V. [5].

All of the above-mentioned changes in climatic parameters in urban environments (increased air temperatures, especially in the warm season, periods of extreme heat and extreme precipitation, decreased cloudiness of the sky) can create additional discomfort for residents who spend a long time in the open air, waiting for public transport. In such conditions, the concept of "green stops" is one of the effective methods of adapting to climate change and improving the ecological parameters of urban ecosystems.

"Green stops" of public transport are islands of reduction of extreme heat, wind, smog while residents are waiting for transport, they are also an aesthetically attractive element of small urban architecture and, due to their novelty for the cities of Ukraine, an interesting object of ecotourism.

To develop a project for the installation of "green stops" of public transport in the city of Lutsk, the concept of "traffic intensity of a public transport stop" was introduced, by which we understand the indicator of the number of people arriving and departing from a given stop within 1 hour. As a result of the assessment of such intensity, all public transport stops in the city were divided into three categories, presented in Table 1. It is obvious that the stops that fall into the first category (traffic intensity of more than 500 people/hour) are in the first place in need of landscaping. When comparing stops in this category, the following were also taken into account: a) the location of the stop within the city; b) the presence or absence of an existing landscaping system in the area adjacent to the stop.

Table 1

Classification of public transport stops in Lutsk by traffic intensity

№	Types of stops	Number of stops
1	Traffic over 500 people/hour	More than 10
2	Traffic 200 – 100 people/hour	More than 25
3	Traffic less than 100 people/hour	More than100

Taking into account all the above factors, as well as the fact that the arrangement of "green stops" is a costly project that cannot be large-scale at the initial stage, three public transport stops in Lutsk were selected as promising for the implementation of the concept: 1) "Dramteatr" stop; 2) "Zavokzalny rynok" stop (TC "Tam Tam"); 3) "Ploscha Geroiv Maidanu" stop. Green public transport stops help clean the air from carbon dioxide, particulate matter and other hazardous substances - pollutants in cities. These are zones within which city residents receive protection from heat, rain, wind and scorching direct sunlight. A well-planned drainage system of a green stop allows you to accumulate up to 90% of rainwater - both the surface with plants itself and the drainage system from the roof and on the sidewalk. The design of the stop can include a rainwater tank. This water can then be used to moisten the substrate used for plants. In the case of using succulents, green stops do not require additional watering.

Green stops make waiting for public transport in a big city much more comfortable, primarily due to the reduction in air temperature. Their design can be supplemented with built-in solar panels, which allow the project to be autonomous and energy-efficient

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“GREEN BUILDING”: METHODS AND STAGES OF ENERGY EFFICIENT CONSTRUCTION IMPLEMENTATION

Stanislav Fedorenko[1], Lesia Vasylenko[1].

[1]*Kyiv National University of Construction and Architecture*

Green building is a new (post-industrial) stage of development of the architectural and construction industry, which it began to move to at the turn of the XX and XXI centuries, and at the same time it is an important component of the concept of “sustainable development”. This transition is a manifestation of the deep processes of the world community's awareness of the role that human civilization in general and urbanized areas in particular play in destroying the sustainability of our planet's ecosystem. The concept of green building is aimed at preserving the ecosystem and the environment, as well as bringing benefits to people and society. Therefore, it takes into account the changing relationships between people, construction and the ecosystem. The goal is to leave behind a holistic world suitable for future generations [1, 2].

Expert data shows that buildings around the world consume about 40% of all primary energy, 67% of all electricity, 40% of all raw materials and 14% of all drinking water supplies, and produce 35% of all carbon dioxide emissions and almost half of all solid waste.

Expert data shows that buildings around the world consume about 40% of all primary energy, 67% of all electricity, 40% of all raw materials and 14% of all drinking water, and produce 35% of all carbon dioxide emissions and almost half of all solid waste. Green building basically means smart construction and, in particular, the efficient use of energy and resources and automated construction technology to increase comfort and functionality. Smart buildings offer comfortable, environmentally friendly high-tech environments for more productive living and working [2, 3].

Even though the "anthropogenic" theory of global warming has plenty of constructive critics, these figures are thought-provoking.

This awareness in Western companies has developed on the basis of more sophisticated strategic management structures that take into account significant nuances and a deeper understanding of corporate social responsibility. Developed construction markets, such as Europe and the United States, have also begun to develop new models of design, production, and management that have gradually come to be known as "green buildings." The European Green Deal aims to significantly raise environmental standards across the EU and reduce greenhouse gas emissions to zero by 2050. The rules on the overall energy efficiency of buildings should also be aligned with the European Green Deal, which aims to decarbonize the EU construction sector by 2050 [3].

The reform of the Energy Performance of Buildings Directive (EPBD), adopted as part of the Green Deal, stipulates, among other things, that residential buildings, in particular, should reduce energy consumption by an average of 16% by 2030 and by 20-22% by 2035 [3].

For a construction project to be called "green", certain standards and norms must be met at each of its stages. To adequately assess compliance with these principles in the implementation of real estate projects in the West, special market instruments have been developed - voluntary building certification systems, of which there are now several dozen in the world. A number of them are international systems that are used around the world, including in our country.

The annual growth rate of the green building industry abroad is 20-30%, and many consider the emphasis on environmental performance to be one of the main competitive advantages. Innovative construction methods, such as 3D printing and the use of steel, have reduced construction time and reduced the use of materials [4, 5].

Traditionally, there are two types of eco-friendly buildings:

1.Energy passive or zero-energy. Its main characteristic is that the energy required to maintain a healthy indoor climate is reduced to a minimum level. That is, it is practically energy-independent, not consuming energy and generating electricity from its own renewable resources.

2.Energy-active. It differs from the first type in that it produces more energy than it consumes. Such houses are equipped with generators with excessive power generation. Thus, this process can be converted into a means of payment by pumping electricity into the grid.

When it comes to building sustainable homes, climate plays an important role. This is because different climatic conditions lead to different building materials that are used in the construction process. 3D printing makes it possible to create complex structures quickly and efficiently. The use of steel in construction ensures the strength of the building and its ability to withstand different weather conditions. In practice, this means that green buildings are objectively more expensive than those built using traditional technologies. Therefore, in the United States, the price of houses in LEED-certified rural villas is on average 30% more expensive than conventional villas [5].

A good example of this is the trend of building entire eco-cities, where the environment, urban planning, development, communications and the way of life are in harmony with each other. Among the newest and largest urban planning projects are Masdar City in the United Arab Emirates, Houguang Lake near Wuhan in China, Songdo in South Korea, and others [6, 7].

In order for green design and energy-efficient construction to become the standard in Ukraine, government support and effective policies are needed. The government can incentivize sustainable building practices through tax breaks, grants, and rebates, making it more affordable and financially viable for developers and homeowners to invest in green building [7,8].

The Greening Ukraine's Reconstruction project has outlined a comprehensive roadmap for achieving sustainability in recovery efforts. This roadmap includes:

- Assessment and prioritization of damaged buildings and infrastructure.
- Integration of green building principles and environmentally friendly materials.
- Implementation of renewable energy systems.
- Community engagement and awareness campaigns.
- Capacity building and knowledge sharing.
- Evaluation and monitoring of sustainable development goals.

According to the roadmap, the project aims to create a replicable model for sustainable reconstruction projects in Ukraine and inspire other regions to adopt green reconstruction practices. The Recovery Plan for Ukraine is a comprehensive strategy that lays the foundation for the transformation of Ukraine's economy and infrastructure.

The diversity of environmental projects and trends in Ukraine is both good and bad. While the coverage, even if rather sporadic, of a wide range of issues is a plus, the inability to bring them together under a single umbrella in one coordinated strategy significantly undermines their effectiveness. This leads to the fact that some projects do not achieve the desired results. For example, the aforementioned EMBLAS project helps Ukraine understand and assess the scale of environmental problems in and around the Black Sea through an extensive research mechanism, but it lacks a full-fledged action plan to help reduce, let alone eliminate, pollution.

Another common problem with environmental initiatives in Ukraine is the lack of funding. Most projects are either funded through crowdfunding, so their impact is necessarily very limited, or they are funded by international donors such as the EU, UN or EBRD. In fact, initiatives can only be implemented within the framework of household ecology, i.e. focusing on waste sorting or battery recycling. But environmental problems of a national scale, such as the need to clean up the Dnipro riverbed from radioactive sludge or to combat pollution at heavy industry, can only be the subject of state policy, not the policy of subsidized NGOs.

With an emphasis on sustainable development, the plan aims to restore the country's affected regions and introduce green technologies and practices. By leveraging the financial support and expertise of international partners, Ukraine can accelerate its path to long-term sustainability.

In this context, it is important to emphasize that green building plays a key role in creating a safe and energy-efficient environment, which is an integral part of sustainable development.

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GREEN CONSTRUCTION FOR LANDSCAPE REVITALIZATION: URBAN MANAGEMENT RETHINKING

Fesenko Galyna Grygorivna
O.M. Beketov National University of Urban Economy,
Galyna.Fesenko@kname.edu.ua

Currently, cities are considered important locations for solving ecological problems and achieving sustainable development goals. In particular, the city should form such landscapes that make it impossible to harm the health (physical, mental, social) of the inhabitants. However, economic and spatial development, which in many cases and in many areas takes an uncontrolled and chaotic form, has caused significant threats to ecosystems and cityscapes, and often leads to their degradation. The tasks posed by urban landscape revitalization, therefore, take on a new local and global dimension. Moreover, this, in turn, raises the question of the optimal and effective way to achieve sustainability and prudent management, both of natural resources and the resources of the environment and the landscape of urban areas.

As is known, the notion of landscape is complicated by the overlapping of different structures and various features that are often opposing from the point of view of typology. The resulting landscape is characterized by multiplicity, variety, and structural and spatial discontinuity. Landscape science was developed as a way of understanding and interpreting the human being in its relation with nature, but now, the concept of landscape is also related to the social and cultural dynamics of the daily environment. In such an epistemological situation, a value-oriented approach should be used to address the physical, economic, and social requirements of the landscape revitalization projects.

There is an epistemological need to develop a methodology solution for the landscape evaluation of urban projects using the sustainability in project management. More broadly, it is important to highlight the potential of green building for revitalizing urban landscapes, as well as the convergence of environmental and urban planning strategies for urban development. Therefore, this paper aims to make a contribution to the rethinking of urban green space, based on current demands and environmental requirements for urban landscapes. It is based on green space management, but also urban nature and the biocultural diversity represented by it. It is about understanding the need to strengthen the relationships between urban people and urban nature.

The urban eco-sensitive planning has to guarantee the citizens' right to the city that fosters true ecologically just ways of being. An ecology perspective to urban revitalization involves principles and methodologies that move urban planning, strategies, and interventions to create the conditions for reformulating oppressive structures and cultivating lives worth living through caring urban paradigms – where cities allow citizens to care for ourselves, others, and the planet.Urban ecosensitive planning has to guarantee the citizens' right to the city that fosters true ecologically just ways of being. An ecology perspective to urban revitalization involves principles and methodologies that move urban planning, strategies, and interventions to create the conditions for reformulating oppressive structures and cultivating lives worth living through caring urban paradigms – where cities allow citizens to care for ourselves, others, and the planet.

The postmodern rethinking is updating urban interpretations about the level of interpenetration of the artificial and the natural. The role that current urbanization processes play in increasing pressure on nature and the planetary system prompts a fundamental revision of anthropocentric ways of planning, designing and developing eco-cities. The combination of "eco" and "city" may seem contradictory, since cities have become known as the complete antithesis of everything "ecological". The concept of an eco-city gets rid of the image of the city as a "concrete jungle", proposing an intelligent urban infrastructure (high level of greenery, extensive public transport network, use of renewable energy sources, etc.). An eco-city is designed to function in the most "natural way" [1].

Proponents of ecological urban management proceed from the idea that the development of a city-form must necessarily be in harmony with nature (with the biological structure of man and respect for biodiversity), as well as healthy (sustainable and safe). Urban design is conceived in radical opposition to the industrial design of cities, which was outlined in the categories of "domination and destruction" [2]. An ecological approach to urban management, urban design planning is based on the understanding of the city as a place of residence, and at the same time as part of the natural world – a dynamic ecosystem with a deep context. That is why ecological urban management outlines a strategy of "growing" nature as a garden, in contrast to the traditional "subjugation" of nature in the city.

The green construction must be recognized as a crucial element of the post-war recovery of Ukrainian cities. One of the most urgent problems in urban management is technological problems with finding opportunities to rebuild the destroyed object, and whether it is possible to apply green building technologies. Because of this, issues regarding the conceptual rethinking of architectural and spatial solutions, building production processes through the prism of modern requirements for energy saving and environmental friendliness become more acute [3].

The green construction must be recognized as a crucial element of the post-war recovery of Ukrainian cities. One of the most urgent problems in urban management is technological problems with finding opportunities to rebuild the destroyed object, and whether it is possible to apply green building technologies. Because of this, issues regarding the conceptual rethinking of architectural and spatial solutions, building production processes through the prism of modern requirements for energy saving and environmental friendliness become more acute [3]. In new construction, the greenest design strategies could be embraced: minimizing environmental impact while inspiring the community to think of the future as waste-, energy-, and water-positive. “Design, Build, Operate Green” seems to be more important now than ever before.

A green construction should be implemented with sustainable practices, or alterations carried out, so that they are a sustainable urban landscape. This includes using LEED (Leadership in Energy and Environmental Design) building practices [4]. The complexities involved in green building or revitalizing an urban landscape, combined with undertaking a sustainable design certification effort, can be daunting for someone unfamiliar with the process. The triple bottom line of environmental, economic, and social efficiency must be considered to achieve operational sustainability. The sustainable orientation of the green construction project must be represented in the processes, tools, and project actions throughout the entire life cycle. It is proposed to evaluate the level of implementation of the planning function in terms of maturity of project management, its ability to apply the necessary tools and methods to reduce uncertainty. It is argued that eco-sensitive urban planning makes project goals more specific and understandable to the project team. From a sustainability perspective, mature planning is seen as a basis for tracking actual progress, including on the Sustainable Development Goals. Moreover, the urban management for green building must take into account the values and needs of all stakeholders connected with the city area. The principal management tools can be the Management Plan and the integrated spatial planning system, based on an agreed Local Spatial Development Plan.

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GREEN CONSTRUCTION IN URBAN PLANNING MANAGEMENT: ECOFEMINIST VISIONS

Fesenko Tetiana Hrygorivna

[1]Kharkiv National University of Radio Electronics, tetiana.fesenko@nure.ua

Russia’s war of aggression against Ukraine has led to countless civilian casualties and the destruction of infrastructure, housing, and ecosystems. Immeasurable human suffering has become part of today's wartime. The war also breaks time into pieces, ripping human experience and creating a before and an after. At the same time, the idea of wartime incorporates the assumption that war is temporary and that wartime disrupts “normal” time, after which peacetime ensues. Therefore, the idea of wartime presupposes a concept of the future. In wartime thinking, the future is beyond war, when exceptional measures can be put to rest and regular life resumed. Despite Wartime hardships, Ukrainians are thinking about the future, particularly what the rebuilt cities should look like [1, 2]. Ideas are expressed about the environmental friendliness of the urban environment and the need to promote environmental conservation and restoration initiatives, even in wartime [3].

Ecofeminist theories can contribute significantly to the urbanist debate on revitalizing and post-war recovering Ukrainian cities. A feminist perspective on urbanism involves principles and methodologies that move urban planning cultures, processes, strategies, and interventions away from exclusionary practices towards the inclusion of everyone who inhabits and shapes the city [4]. In addition, feminist urbanism includes ideas from ecological feminism, which rethinks the in particular in the context of a critique of patriarchal domination, and includes caring for the earth and environmental protection [5].

The post-war reconstruction of Ukrainian cities should not be so much a return to “the way things were” as an opportunity to rethink and rebuild in a more ecologically and inclusively. The idea that disasters present opportunities to “build back” systems in a more resilient, sustainable, and inclusive manner way is promoted by global recovery programs. The United Nations Economic Commission for Europe (UNECE) has created the UN4UkrainianCities program to support national and local governments in Ukraine in developing conceptual master plans for cities to “build back better” [6]. The first concept master plan that has already been developed is for Kharkiv. As noted by UN4UkrainianCities, it not only envisions Kharkiv’s future but also serves as a hopeful blueprint for other Ukrainian cities [7].

Kharkiv got a vision of its future articulated by world-renowned urban planners. The conceptual vision of the Kharkiv masterplan represents a forward-looking vision for the city, spearheaded by Norman Foster and a global team of professionals in architecture, planning, and engineering. Norman Foster, a prominent architect who devotes much time to the study of cities and their future, leading the United Nations Forum of Mayors. He launched the UN Declaration for Sustainable and Integrative Architecture (San Marino Declaration 2022), which sets out the goal for every city to plan urban infrastructure and buildings in accordance with the principles for sustainable urban design. The first principle emphasizes "People-centrality" by fostering and supporting social responsibility and integrating diversity and equality through due consideration of the needs of individuals and households across all races, age groups, genders, cultures, abilities, and income levels. This declaration also provides for the principle of "Safety and health": providing safe and sustainable mobility and transport systems and ensuring accessible walking and meeting spaces, green areas and forests. It calls for the participation of local communities and stakeholders to ensure needs-responsiveness and continuously optimize infrastructure.

Among the team of professionals developing the masterplan for Kharkiv were Edward Glaeser, a professor at Harvard University, and Ian Goldin, a professor at the University of Oxford, who wrote part I of the Kharkiv masterplan, "Urban Rebirth: Economic Considerations for Reconstruction in Kharkiv and Ukraine". Nine Ukrainian experts ("Group of Kharkiv Architects", professionals in architecture, urban planning, and history) were involved in developing the Kharkiv Master Plan and provided local expertise [7]. They proposed "Guiding Principles for the New Kharkiv" (part II Kharkiv Masterplan) in cooperation with the Norman Foster Foundation. Notably, the Kharkiv experts were dominated by men, and only one woman had a voice as an expert, landscape architect Olga Kleitman. She was well known to Kharkiv residents thanks to her project of the Sarzhyn Yar water and landscape park, which was recognized as a good example of integrating nature into the urban environment. She accumulated ecological ideas through the group work of experts.

The urban planners, international and local, empowered by the mayor of Kharkiv to develop a post-war vision for the city, propose "ideal city forms" with an emphasis on functional zones and a modern transit network. The mayor of Kharkiv noted: "We are forming a new vision of the city – what it will look like after the war. We have set a goal to create an ideal city of the future – a city of dreams where you want to live. It should be an industrial and scientific centre, attractive for innovative enterprises and creative industries" [7]. As for involving city residents in the conceptual planning of post-war Kharkiv, the authors considered it sufficient to collect information through questionnaires. A questionnaire was composed of forty questions and divided into five categories: general, housing, neighborhood, transportation, and others. Once the content was agreed upon within the core team, the local administration adapted and shared the questionnaire with the city population through social media. More than 16350 responses were received (women made up the majority – 55.5%), and as stated in the masterplan, which was very helpful in better understanding the needs and positive qualities of the city while informing the approach to the masterplan. This city planning policy deprived citizens and gave them the role of passive recipients of a ready-made concept of a post-war vision of the city formulated by experts.

However, this positivist model of city planning making concept is subject to criticism. When it comes to more democratic ways of developing a vision of rebuilding a city, it is necessary to ensure a participatory management process open to all citizens and provide an opportunity to articulate alternative visions. Citizens should not be objects of city planning but rather subjects who set the agenda, participate in the collection and analysis of data, and control the use of the results, including deciding what green spaces to take or eco-sensitive directions to go. The bottom-up city management planning focused on the urban community's ability to develop radically new principles of city revitalisation with respect to the environmental needs of city residents.

In particular, urban planners are recommended to take into account the fact established by the UN that According to the United Nations, women and children are overwhelmingly more likely to die of indoor air pollution. Green buildings can play a significant role in facilitating various aspects of the built environment that impact women's lives. Green buildings prioritize indoor air quality, natural lighting, and the use of non-toxic materials. These features can enhance the health and well-being of all occupants, including women, who are more vulnerable to indoor air pollution. Additionally, well-designed green buildings can incorporate safety measures such as well-lit pathways, secure parking areas, and access control systems, creating a safer environment for all citizens.

The ecofeminism approach combines ecological and feminist principles to address the interconnections between the built environment and nature. It recognizes the significant impact that architecture and urban planning have on the environment and social structures. Ecofeminist architecture seeks to challenge and transform the dominant systems that contribute to environmental degradation. It emphasizes the need for more sustainable, equitable, and inclusive architectural practices, putting the well-being of people and the natural world first. It calls for participatory city planning to be open to all citizens regardless of gender, race, sexuality, age, etc [9, 10, 11]. Feminist epistemology argues that knowledge, data, and expertise are gendered and constructed to create privileged authorities and that women have experiences that should shape urban planning decisions. This, in turn, requires a shift in cognitive emphasis from technological determinism, when the city is seen as strongly organized, divided into functional zones, to socially and ecologically sensitive urban planning.

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RESTORATION OF BUILDINGS USING ALTERNATIVE ENERGY SOURCES FOR ENGINEERING SYSTEMS AND EQUIPMENT

Oksana Hryhorivna Dobrovolska[1], Olena Mykolaivna Fostashchenko[2]

[1]Zaporizhzhia National University, dogoks@gmail.com

[2]Zaporizhzhia National University, zdia2017@gmail.com

Green construction involves the use of energy-efficient technologies, renewable energy sources, environmentally friendly materials, and sustainable building methods. This approach minimizes the negative impact on the environment and ensures a high level of energy efficiency. In the context of post-war recovery, when there is an urgent need to rebuild destroyed infrastructure, the application of such principles is a vital step toward the creation of sustainable, eco-friendly, and energy-efficient facilities. Of particular importance is the integration of alternative energy sources – such as solar panels, wind turbines, and geothermal systems – into the engineering systems of restored buildings and infrastructure.

The aim of this research is to identify trends in the use of recycled construction waste and alternative energy sources in the process of restoring destroyed infrastructure. The object of the study is the non-residential and destroyed architectural infrastructure in Ukraine. The subject of the research is the process of creating public spaces through the reconstruction of buildings that have lost their functionality or have been destroyed.

To achieve the stated aim, the following objectives were set: to summarize the results of the analysis of scientific studies and regulatory legal acts governing the design, modernization, and restoration of non-residential and damaged buildings based on energy efficiency principles; to examine post-war reconstruction processes in Ukraine and other countries; to analyze both international and domestic experiences of reconstructing destroyed facilities and damaged infrastructure; to develop key stages for the reconstruction of non-residential buildings and destroyed urban areas; and to outline compositional and planning solutions for the energy-efficient reconstruction of urban environments.

The regulatory act governing building energy efficiency in Ukraine is the Law of Ukraine "On the Energy Efficiency of Buildings" [1]. This law sets out the requirements for the energy certification of buildings, defines the concept of nearly zero-energy buildings (nZEBs), and provides for the development of a Building Thermal Modernization Strategy for the period up to 2050.

In 2025, the Ministry for Communities and Territories Development of Ukraine approved the Requirements for Nearly Zero-Energy Buildings [2]. These requirements apply to the design, construction, and energy efficiency certification of buildings and stipulate the use of renewable energy sources, as well as the implementation of automation and energy consumption monitoring systems.

The Methodology [3] outlines approaches to local-level energy planning, including both technical and organizational projects aimed at enhancing the energy efficiency of infrastructure facilities.

Document [4] highlights the integration of energy efficiency principles into the reconstruction and modernization processes of buildings. It particularly emphasizes the need to develop a national professional development program for construction sector specialists.

In addition, the document points to the necessity of implementing building automation, monitoring, and control systems to achieve a high level of energy efficiency that complies with the requirements of the national standard [5].

The recovery of post-war territories requires not only the reconstruction of destroyed buildings but also the integration of modern approaches in construction practices. In particular, the experiences of countries such as Japan after World War II, Iraq following the Gulf War, and Ukraine demonstrate that rapid recovery is only possible through the implementation of innovative approaches to the use of construction materials and waste management.

In Japan, technologies for recycling construction waste were applied – specifically, methods for the secondary processing of building materials such as concrete and metal. This not only helped reduce reconstruction costs but also lowered environmental impact [6].

The German experience demonstrated that damaged buildings can serve as a valuable source of reusable materials – such as concrete, bricks, and metals – thus reducing the demand for new resources and minimizing the ecological footprint. Recycling construction waste in Germany was recognized as one of the key elements of the country's post-war recovery strategy, significantly reducing CO_2 emissions and conserving natural resources [7].

Following the 2020 explosion at the Port of Beirut, international actors – particularly France – proposed reconstruction plans that included infrastructure modernization and a shift toward renewable energy sources [8].

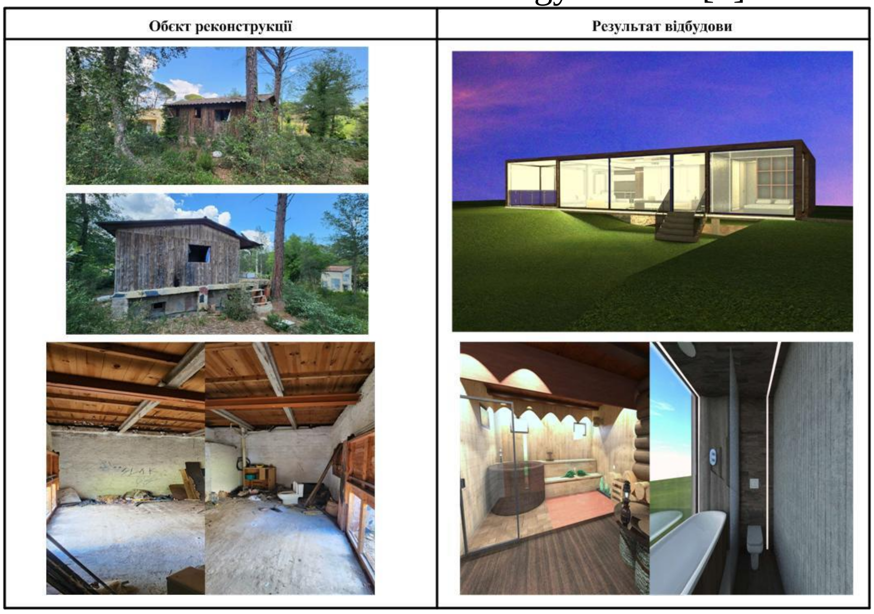

Figure 1. Renovation of a Non-Residential Facility

In Ukraine, as in many other countries, the lack of an efficient system for collecting and processing construction waste complicates the recovery process. However, drawing on the experiences of European nations, there is real potential to develop recycling infrastructure for construction materials. The reuse of old construction materials in new building projects is already being actively implemented at the local level – particularly in cities like Kyiv and Kharkiv – where damaged buildings are being used as a source of construction materials [9].

The stages of non-residential building reconstruction were developed using the example of a modernization project for a structure that previously belonged to the residential housing stock. The building has a rectangular floor plan measuring 14,000 × 7,000 mm. Figure 1 illustrates the changes that occurred during its reconstruction.

The second floor was dismantled, and the structural elements were removed for disposal. To reduce costs and give the building a distinctive character, it was decided to preserve the basement level as the foundation of the project. One of the rooms on this level was converted into a bathroom.

The exterior basement walls were clad with natural stone, including sandstone and river cobblestone. The wall thickness is 400 mm. To expand the usable space, soil backfilling was carried out, and a column structure was installed to support the new structural elements. The construction used monolithic panels made of M50-grade perlite concrete, 400 mm thick, which effectively provide thermal insulation.

As part of the renovation project, several options for heating engineering systems were analyzed, including:

a) a water-based underfloor heating system combined with an air-to-water heat pump;
b) a water-based underfloor heating system powered by an electric boiler;
c) a water-based underfloor heating system combined with a solid fuel boiler;
d) an electric underfloor heating system powered by a solar power station.

The results of the energy efficiency assessment of the considered systems are presented in Figure 2.

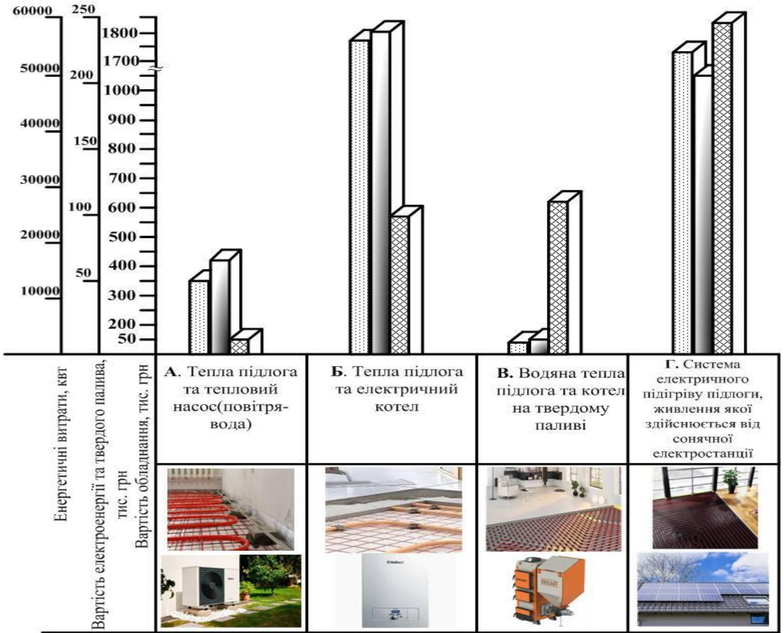

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Figure 2. Economic Indicators for Different Building Heating Options

The key criteria used to assess the feasibility of each heating option included energy consumption, as well as the total cost of equipment and operational expenses.

Among all the proposed solutions, Option D has the highest equipment cost. Moreover, during the winter season, the performance of the solar power station drops to 5–10% of its nominal capacity, which is insufficient to ensure the required level of heat supply.

Option B is characterized by significantly higher electricity consumption—four times greater compared to Option A.

When comparing Options A and C, it is evident that Option C has the lowest electricity usage. However, due to the need for continuous supply of solid fuel, the total energy costs for this option exceed those of Option A by a factor of 2.3.

Overall, calculations show that Option A has the lowest energy consumption. The installation costs for this system are offset within 5.5 heating seasons.

Compositional and spatial planning solutions play a key role in achieving energy efficiency in the reconstruction of urban environments. Optimizing building orientation, the spatial arrangement of structures and open spaces allows for efficient use of natural lighting, solar gain, and natural ventilation. Enhancing the thermal performance of building envelopes and implementing energy-saving engineering systems (particularly heat pumps) contributes significantly to reducing energy consumption.

Thus, rational planning solutions combined with innovative technologies form a technically sound foundation for the sustainable functioning of reconstructed urban areas.

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INFLUENCE OF OXYGEN MODE ON NITROGEN REMOVAL FROM WASTEWATER

Kharlamova Olga Vasylivna, Revyakina Natalia Yurievna
Institute of Hydromechanics of the National Academy of Sciences of Ukraine,
viddil.pgd@ukr.net

As is known, nitrogen extraction by biofilm occurs under aerobic conditions when sufficient oxygen is provided. For the growth and vital activity of microorganisms, it is necessary to ensure uninterrupted supply of oxygen and control its consumption to maintain the kinetics of reactions with a high rate of utilization of nitrogen compounds (N) under given conditions of the aerobic process. In the article, as a result of the analysis, some recommendations are proposed that allow substantiating the parameters of the oxygen mode in practical calculations. Thus, for the reactions, the most common case in practice is used, when N extraction in the biofilm is assumed to be a zero-order reaction and oxidation also occurs by a zero-order reaction. Thus, in this case, for the reactions we have the following equations (1) and (2) [1,2,4]:

$$R_N = w_N = \frac{\mu_{\max N} X_N}{Y_N}, \tag{1}$$

$$R_C = \alpha_1 R_N + \alpha_2 b_C X_N \quad . \tag{2}$$

As a result, the solution of the following equation regarding the oxygen concentration in the biofilm *C:*

$$D_C \frac{d^2C}{dz^2} - R_C = 0 \tag{3}$$

under boundary conditions: $-D_C \frac{dC}{dz} = K_C\left(C_e - C_\delta\right) = I_C$ at z=0,

$$\frac{dC}{dz} = 0 \quad \text{at} \quad z=\delta\,, \tag{4}$$

we obtain the following equation for determining the concentration C_δ in a zero-order reaction:

$$C_\delta = C_e - \frac{w_c \delta}{K_C}, \qquad (5)$$

and for the flow I_C according to equation (4):

$$I_C = w_c \delta, \qquad (6)$$

where $w_c = \alpha_1 R_N + \alpha_2 b_c X_N$. In this case, the oxygen consumption for the utilization (self-oxidation) of the dying biocenosis in the biofilm is taken into account by the parameter $\alpha_2 b_c X_N$.

In the general case, the value of the oxygen flow entering the biofilm is determined by equation (4). However, for a zero-order reaction, when the processes determined by the parameter b_c are not taken into account, i.e., when b_c=0, the flow I_C can be determined using the relation [1,3,4]:

$$\frac{I_N}{\gamma_N} = \frac{I_C}{\gamma_C} \qquad (7)$$

That is, to determine the flow I_C we have:

$$I_C = \frac{\gamma_C}{\gamma_N} I_N, \quad I_N = \frac{\gamma_N}{\gamma_C} I_C, \qquad (8)$$

where the stoichiometric coefficients for oxygen γ_C and nitrogen will be:

$\gamma_C = \frac{4{,}57 - Y_N}{Y_N}, \quad \gamma_N = \frac{1}{Y_N}, \quad Y_N \approx 0{,}22$.

and to determine the flows I_C and I_N we have:

$$I_C = (4{,}57 - Y_N) I_N, \quad I_N = \frac{I_C}{4{,}57 - Y_N}, \qquad (9)$$

then (at $b_c \approx 0$) the value α_1 will be:

$$\alpha_1 = (\alpha_N - Y_N), \quad \alpha_N = 4{,}57 \frac{гO_2}{гN} \qquad (10)$$

Since nitrogen extraction in a biofilm under aerobic conditions is controlled by oxygen penetration, the comparison of the processes of penetration of contaminants and oxygen into the biofilm is the most important result of kinetic studies in biofilms, which allows determining which of them will limit the process of substrate (nitrogen) utilization. Nitrogen can be present throughout the thickness of the biofilm, but cannot be extracted in the area where oxygen cannot penetrate, i.e. dissolved oxygen must be provided in sufficient quantity throughout the thickness of the biofilm. In this case, the rate (limiting) will be determined by the substrate that penetrates the biofilm to a smaller depth of penetration. A number of criteria have been substantiated and proposed for different reaction kinetics using stoichiometric coefficients. Thus, the following criteria are proposed under zero-order reaction kinetics [1,2]:

a) nitrogen is potentially limiting, but oxygen completely penetrates the biofilm

$$\frac{N_\delta}{C_\delta} > \frac{1}{\alpha_1}\frac{D_C}{D_N}, \qquad (11)$$

b) oxygen is potentially limited, but nitrogen completely penetrates the biofilm

$$\frac{N_\delta}{C_\delta} < \frac{1}{\alpha_1}\frac{D_C}{D_N} \qquad (12)$$

Comparison of the flux I_N and I_C values also allows us to determine which of the substrates limits the conversion processes within the biofilm. As an example, Table 1 shows the data on penetration $(\beta_N\delta)$ depths and fluxes I_N obtained in calculations for zero-order kinetics conditions.

Table 1

Calculations of the limiting component in nitrification [1]

Nitrogen	NH_4
D_N	$149\cdot10^{-6}$ m^2/day
Oxygen	O_2
D_C	$175\cdot10^{-6}$ m^2/day
α	$4{,}57\,\frac{гO_2}{гN}$
Y_N	$0{,}22\,\frac{гХПК}{гN}$
Equation (12)	$\frac{N_\delta}{C_\delta} > 0{,}27\,\frac{гN}{гO_2}$
Calculation at $C_\delta = 8\,\frac{мгO_2}{л}$	$2{,}2\,\frac{мгN}{л}$

Since the extraction of substrates in bioreactors with biofilm is limited by mass transfer, the substrate flow and the depth of penetration into the biofilm are a function of the substrate concentration on the biofilm surface, the reaction rate inside the biofilm and the diffusion mass transfer. In addition, the penetration of oxygen into the biofilm is only a few hundred microns. Therefore, it can be concluded that biofilms with increasing thickness are unsuitable for aerobic processes in them. In the general case, the most reasonable solution to this question, namely, which of the substrates is limiting, will be determined based on the ratio of the curves of changes in the concentrations of N and C constructed in the biofilm and the depth of their penetration into the biofilm. The change in the concentration of C in the biofilm can be obtained as a result of solving equation (3) under boundary conditions (4). To assess the effect of oxygen on nitrogen extraction, one can also use the results of studies presented in the special literature, in particular in [1,3]. They present theoretical and experimental studies with a high concentration of ammonium in the bioreactor wastewater (250,

$500\ \frac{мг\ N-NH_4^+}{л}$) during ammonium removal by a biofilm, taking into account the boundary layer and the influence of dissolved oxygen on the process of ammonium utilization. As a result of the analysis and evaluation of the results of these studies, the following was established:

a) as the main parameter in assessing the influence of oxygen, which controls the process of ammonium oxidation to nitrite, the relation was substantiated and proposed $O_2/N-NH_4$. Specific examples show that this parameter can be a better alternative for control during nitrification in the reactor compared to the oxygen concentration.

b) it is determined that throughout the biofilm area, oxygen is the main parameter that controls and limits the nitrification process in the biofilm and its amount depends on the ammonium flow entering the biofilm. If the value of this ratio at different points is from 0.05 to 0.1, then about 80% of the incoming ammonium is oxidized (converted) into nitrites.

c) the comparative analysis performed showed that the results of theoretical studies largely coincide with the experimental data. Since these results can be used in the development of engineering calculation methods in the future, the values of some of the main initial parameters that were adopted when conducting the specified comparative analysis are given below. Thus, as a result of the experiments conducted using the developed methodology, the average active thickness of the biofilm was determined to δ=102 μm with the following values of the main parameters: mass transfer coefficients through the liquid film of ammonium $K_N = 0{,}038\ год^{-1}$ and oxygen $K_C = \frac{K_N \delta}{D_C} \approx 0{,}55$; effective diffusion coefficient of oxygen in the biofilm $D_C = 0{,}85 D_{bO_2}$; $D_{bO_2} = 7{,}54 \cdot 10^{-6}\ м/год$, $D_N = 0{,}83 D_{b_N}$; $D_{b_N} = 7{,}04 \cdot 10^{-6}\ м/год$.

In the case of the presence of toxic and other substances in wastewater, the reaction rate can significantly decrease due to their inhibitory (braking) effect [1,3,4]. In [1], specific data are provided that allow us to assess the inhibitory effect of various metals and other substances on nitrification processes.

In order to obtain practical methods for calculating the processes and mechanisms that occur in various bioreactors during the removal of ammonium nitrogen N from wastewater, a general balance mathematical model of nitrogen N removal in a mixer bioreactor was considered as an example for the conditions for sufficient oxygen supply of nitrogen N removal processes, which has the following form:

$$W_P \frac{dN_e}{dt} = Q_e (N_0 - N_e) - F_{бn} I_N - R_e W_P, \qquad (13)$$

For practical calculations, if the extraction of nitrogen N occurs only by the biofilm, equation (13) can be significantly simplified to the form:

$$N_0 - N_e - F_{\delta n} T_e I_N = 0, \quad (14)$$

where $F_{\delta n} = \dfrac{F_{\delta l}}{W_e}$, $T_e = \dfrac{W_P}{Q_e}$, $I_N = K_N \left(N_e - N_\delta\right)$

Hence, with known (given) concentrations of N in the wastewater entering the bioreactor N_0 and in the treated wastewater N_e, the reaction T_e duration will be:

$$T_e = \frac{N_0 - N_e}{F_{\delta n} I_N}, \quad (15)$$

where $F_{\delta n}$ - specific surface area of the biofilm in the bioreactor.

Thus, the proposed approach to significantly simplifies practical calculations with a reduced number of input parameters.

In general, a method for calculating the removal of ammonium nitrogen by a biofilm has been proposed, which is based on the implementation of constructed and implemented mathematical biofilm models and is sufficiently substantiated and can be used in the development of relevant provisions and recommendations for assessing wastewater treatment in various bioreactors.

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GREEN CONSTRUCTION – MILITARY CHALLENGES AND CIVIL PROTECTION

***Viktoriia Khmelnyk*[1]*, Nesterenko Viacheslav*[2]**

[1,2]*Kyiv National University of Construction and Architecture*

khmelnyk_vi-2023@knuba.edu.ua

Under the current conditions of military conflicts and threats to national security, green construction is acquiring new functions related to the protection of the civilian population and infrastructure[**Ошибка! Источник ссылки не найден.**]. In times of war, construction ceases to be solely a tool for development — it becomes an element of defense capability, civilian protection, and adaptation to emergency challenges[2]. Green construction, traditionally associated with energy efficiency, ecology, and sustainable development, takes on a new role — ensuring safety in the face of military threats[1]. Camouflage becomes not only a means of preserving structures but also a factor in reducing casualties among personnel and civilians[**Ошибка! Источник ссылки не найден.**].

1. Camouflage of Construction Sites.

The use of natural materials and landscape solutions in green construction allows for effective camouflage of facilities from aerial reconnaissance and other surveillance methods[2]. For example, the use of green roofs, vertical landscaping, and adaptive facades helps reduce the visibility of structures in the infrared spectrum[1].

In the context of modern warfare, buildings become targets for precision weapons. Therefore, camouflage is not a luxury but a necessity[**Ошибка! Источник ссылки не найден.**]. This is especially true for structures located near combat zones or critical infrastructure[**Ошибка! Источник ссылки не найден.**].

Camouflage methods in green construction include the use of green roofs and vertical landscaping to reduce visual detection from the air, integration of structures into the natural landscape (such as utilizing hills, ravines, and wooded areas), eco-friendly camouflage coverings (made from natural materials or recycled waste), and the construction of buildings with adaptive facades that change color or texture depending on lighting conditions[2].

Digital camouflage: limiting digital footprints, maintaining radio silence, shielding thermal signals (infrared camouflage)[**Ошибка! Источник ссылки не найден.**].

Mobile camouflage: rapid concealment or alteration of the external appearance of structures[**Ошибка! Источник ссылки не найден.**].

Camouflage objectives: complicating the detection of an object from the air and space, imitating the natural environment or inconspicuous objects, protecting the object from deliberate strikes, ensuring the continuous operation of the object under combat conditions[**Ошибка! Источник ссылки не найден.**].

Examples of effective camouflage: Ukrainian defensive structures in the Joint Forces Operation (JFO) zone disguised as farmsteads, the use of nets with 3D elements to imitate trees or terrain irregularities[2], and fake positions made of wooden mock-ups of equipment or shelters to mislead the enemy.

Challenges and limitations: high requirements for camouflage materials (durability, invisibility across various spectra), the complexity of camouflage in urban environments, and the constant evolution of surveillance tools (thermal imagers, spectral sensors)[2].

2. Shelters in Green Building Projects.

The integration of shelters into building structures is a necessary requirement in frontline areas[**Ошибка! Источник ссылки не найден.**]. Green building makes it possible to create not only energy-efficient but also safe structures with shelters that can withstand blast waves and provide comfortable conditions for extended stays[2].

One of the main priorities of modern design is the integration of protective structures—shelters, bomb shelters, and safe rooms—into new buildings[**Ошибка! Источник ссылки не найден.**]. Green building allows these shelters to become part of a functional environment[1].

Examples of integrated shelters include basement spaces with reinforced ceilings and dual ventilation systems[**Ошибка! Источник ссылки не найден.**], earth shelters and shelters hidden beneath layers of soil with vegetation[2], and the use of modular underground capsules as temporary shelters based on bio-oriented technologies[1] (Fig. 1).

Advantages: reduced thermal signature of the object, energy and resource savings while maintaining protective functionality, and the possibility of camouflaging the shelter as part of landscape design[1].

For effective protection of civilians and military personnel during combat, not only the location of shelters but also the materials from which they are constructed are important[**Ошибка! Источник ссылки не найден.**]. Different types of materials have their advantages and disadvantages depending on the conditions of use. The table presents a comparison of three main types of shelters—concrete, earth, and “green”—based on the criteria of blast resistance and comfort.

Concrete shelters are distinguished by their high blast resistance and are the most common in urban infrastructure[**Ошибка! Источник ссылки не найден.**]. However, due to the rigidity of the structures and limited ventilation, the level of comfort in them is low.

Fig. 1. Modular underground shelter[7]

Earth shelters, constructed from clay or stone, offer medium-level protection but provide significantly better living conditions, especially in situations requiring long-term shelter[**Ошибка! Источник ссылки не найден.**].

Green shelters, built from ecological materials such as adobe or wood, combine high blast resistance with a high level of comfort[1]. These shelters also blend better into the landscape and have additional camouflage properties.

Table 1

Comparative characteristics of shelter types by material, blast resistance, and comfort

№	Shelter Type	Material	Blast Resistance	Comfort
1	Concrete Shelter	Concrete	High	Low
2	Earth Shelter	Clay, Stone	Medium	High
3	Green Shelter	Adobe, Wood	High	High

As seen in the table, green shelters provide high blast resistance and comfort, while offering environmental benefits due to the use of natural materials.

3. Overcoming the consequences of military actions, terrorist attacks, and ecocide.

Green technologies assist in the restoration of areas contaminated as a result of military actions. Bioremediation, phytotechnology, as well as the implementation of eco-friendly materials, play a crucial role in environmental rehabilitation and the restoration of residential infrastructure[4].

War leaves behind not only destruction but also significant harm to ecosystems[2]. Green construction plays a key role in recovery — both physical and ecological[1].

Key directions for overcoming the consequences: regeneration of contaminated areas (phytoremediation, bioremediation)[4], use of eco-friendly materials for rapid housing restoration, creation of “green corridors” in destroyed cities to improve the psychological well-being of the population, installation of solar stations, wind mini-turbines for energy independence of communities[1].

The role of green construction in post-war recovery:

Formation of sustainable, safe, and adaptive settlements.

Integration of environmental and security approaches into architecture.

Reconceptualization of urban space towards safety, autonomy, and self-healing[2].

In the current context of military threats, green construction emerges not only as a tool for sustainable development but also as an important factor in ensuring the safety, adaptation, and survival of the civilian population[**Ошибка! Источник ссылки не найден.**]. Its integration with elements of camouflage, shelters, and ecological rehabilitation allows for the combination of architectural functionalwith defense effectiveness[2].

The use of natural materials, landscape solutions, and bio-based technologies in design allows for the creation of structures that are not only undetectable by reconnaissance but also capable of withstanding the impact of military actions. Special value is placed on the approach to integrating shelters into the structure of civilian and military buildings, as well as the application of green technologies in the restoration of areas damaged by combat.

Thus, green construction in wartime is not only about sustainability but also about survival, adaptability, and the strategic mobility of infrastructure[1]. Its development should become one of the priorities for urban and defense planning in Ukraine[2]. Its integration into defense and civil strategies allows for the creation of a safe, resilient, and effective environment for life and recovery after crises. Camouflage, shelters, and restoration are key elements that will define the architecture of the future in the face of threats that we can no longer ignore.

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RATIONALE FOR THERMAL INSULATION PARAMETERS OF FIREPROOF PLASTER FOR CONCRETE

Tsapko Yuriy Volodymyrovych[1], Bondarenko Olga Petrivna[1], Tsapko Oleksiy Yuriyovych[1], Kaverin Konstantin Oleksandrovych[1], Yushchenko Alina Vitaliyivna[1]

[1]Kyiv National University of Construction and Architecture, juriyts@ukr.net, bondolya3@gmail.com, alekseytsapko@gmail.com, 1krik.1k1@gmail.com, alinka29yushchenko@gmail.com

Concrete and reinforced concrete structures are the basis of civil and industrial construction. They are characterized by resistance to loads, including high temperatures, such as fire. However, fire resistance decreases over time, as the fire resistance limit of a concrete structure depends on its heating. For example, when concrete is heated to 250 °C, intense water vapor emission begins, which leads to micro-explosions. When heated to 400...550 °C, the process of intensive dehydration of concrete components takes place with the formation of microcracks in the structure, and when the temperature rises to 900 °C, the cement stone loses strength and collapses [1, 2]. Excessive heating of concrete can be avoided by creating a heat-insulating layer on the surface of the structure.

Plaster for fire protection treatment should be chosen when the required fire resistance limit of concrete structures exceeds R60 (in some cases R45) and the use of fireproof paints for such fire resistance classes is not economically justified, and high requirements are imposed on the environmental characteristics of the coating, and fireproof boards cannot be used due to complex configurations as they increase the material consumption of the structure.

1. Plasters or fireproof dry building mixtures are cement or gypsum compositions with a complex of light fillers and special additives that form a coating with high adhesion to concrete and relatively low density (400...600 kg/m3), which are applied to the surface of the structure with a thickness of 10...50 mm, depending on the required fire resistance class, which can reach R240. However, the protection of concrete structures with plaster to some extent leads to significant material costs and an increase in the volume of the structure [3].
2. In this regard, there is a need to determine the thermal insulation ability of plaster filled with aluminosilicate microspheres, which necessitated research in this area.
3. To study the thermal conductivity of a thermal insulation product made of plaster filled with aluminosilicate microspheres, samples were made by mixing Portland cement and sand with aluminosilicate microspheres in a 1:2 ratio, from which a coating with dimensions of about 100x100x20 mm was formed and placed on concrete and kept for 21 days (Fig. 1). To conduct the research, we used equipment with a combustible gas burner, which was equipped with a device for measuring and recording the temperature.

The fire protection properties of the plaster were determined by evaluating the temperature characteristics of the reverse surface under the influence of the flame in controlled laboratory conditions. The tests were carried out for 1800 s, with the burner installed in a horizontal position with a flame height of 40 mm. After that, the burner was ignited, brought to the sample, and the temperature on the back surface of the plaster was measured [4]. The criterion for determining the thermal conductivity of a fireproofing coating under thermal action is the formation of a temperature on the inner surface of the plaster of more than 200 °C.

Fig. 1. Sample product for research

The results of studies to determine the effectiveness of concrete fire protection are shown in Fig. 2, and Fig. 3 shows the experimental temperature curve on the inner surface of the plaster.

Fig. 2. Determining the effectiveness of concrete fire protection

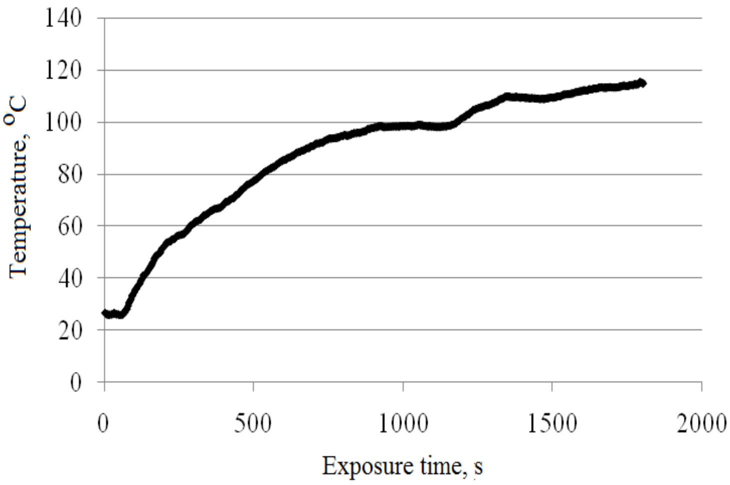

Fig. 3. Temperature on the back surface of the plaster when exposed to the burner flame

Studies have shown that the sample of the fireproof coating withstood the thermal impact of the burner flame. When exposed to high temperature, concrete was insulated for 1800 s, and the temperature on the back surface of the cable sheath did not exceed 120 °C.

Thus, the peculiarities of inhibiting the process of heat transfer to concrete treated with plaster (fireproof coating) are the formation of a heat-protective layer on the surface. Thus, a temperature was created on the surface of the sample that significantly exceeded the decomposition temperature of concrete, while on the unheated surface it did not exceed 120 °C.

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ESG FRAMEWORK FOR RECONSTRUCTION PROJECTS OF POOR HOUSING

Tsyba Artem Mykolaiovych, Kryvomaz Tetiana Ivanaina
Kyiv National University of Construction and Architecture, absqueee@gmail.com, kryvomaz.ti@knuba.edu.ua

The principle of “build back better than before” is not only becoming key to rebuilding after war devastation, but is also guiding Ukrainian builders to rethink approaches to rebuilding the aging city stock. This process is accompanied by a number of financial, technological, and social issues that need to be addressed. At the same time, ESG (environmental, social, and governance) reporting is becoming mandatory for construction companies. It is a way to measure business performance, ensure transparency, mitigate risks, and uncover opportunities. Standardized frameworks and methodologies for assessing qualitative and quantitative data allow companies to objectively assess and compare performance indicators. Is it possible to use this carefully developed framework and methodology for rebuilding and reconstructing aging housing stock projects?

Environmental component. Modern requirements for decarbonization of the construction industry create the basis for the implementation of green building principles in the reconstruction of old buildings. The environmental section of the ESG standards requires taking into account climate change, pollution, water and marine resources, biodiversity and ecosystems, resource use and the principles of the circular economy. All new buildings must be adapted to the increasing frequency of extreme weather events, and in conditions of military threats, additional protection and security must be taken into account. Saving water resources is facilitated by a system with separate circuits for drinking and "gray" water, which can be used for technical needs after local treatment. This reduces the load on the central water supply system and allows saving 50-70% of water [1]. And if you add a rainwater collection system, the savings become even more significant. However, such an effective water supply system cannot be created by overhauling substandard buildings; this requires a radical restructuring. The concept of decentralized, diversified local heating and energy supply with an increase in the share of renewable energy sources is gaining popularity not only due to environmental friendliness, but also due to the destruction of the centralized energy system due to enemy attacks. Effective thermal insulation and modernized heat supply provide a 60% reduction in CO^2 emissions [2]. Rational use of resources, waste reduction and adherence to the principles of the circular economy are becoming the norm in modern construction. However, residential complexes, in addition to garbage sorting points, lack a safe mobile installation for local processing of household waste. Much attention is paid to transport infrastructure, bicycle paths, pedestrian routes and green areas during reconstruction.

Careful calculations using online ESG calculators of embodied and operational carbon will allow determining the optimal scenario for handling an old building. The ratio of price and indicators of reducing the negative impact on the environment allows you to make an informed choice between demolition and reconstruction. It can be predicted in advance that the results of the comparative assessment will depend on the chosen technologies. If innovative technologies of 3-D printing from on-site recycled construction waste based on the principles of the circular economy are used, then the scenario of complete demolition of the old building with the construction of a new structure on the same site will be preferable. The reconstruction scenario may turn out to be cheaper, but it will not radically improve either the quality of the built environment or the infrastructure. Even a major overhaul of Khrushchev houses will not make them attractive enough and will not be able to bring them up to the level of modern construction quality standards. Such buildings distort urban landscapes and deprive their residents of the chance for decent living conditions. Despite this, the majority of residents of old houses are categorically against their demolition. They do not want to change their usual area of residence and do not trust the authorities and developers, as they are afraid of losing their housing or finding themselves on the outskirts. Only a transparent social policy, guarantees from the state and developers, as well as responsible management of reconstruction projects of outdated housing can convince residents to demolish and build a new one on the old site.

Social aspects. To discuss the reconstruction project at the concept stage, it is necessary to involve all possible stakeholders. One should focus on the existing social diversity in the area, depending on which the concept of the new house will be formed. During the reconstruction, residents should be given a choice of conditions for temporary relocation to vacant housing nearby or to other areas. In this case, the needs and requirements of each family should be taken into account, and the costs of relocation and compensation for inconvenience should be fairly divided between the state and developers. Residents should receive reliable guarantees of returning to the reconstructed housing, which should be supported by special insurance. For the social aspect, a team of psychologists, social workers, urban planners and lawyers should be formed. Special committees discuss proposals for specific target groups, in particular for children, youth and the elderly. Depending on the needs of certain social groups, the reconstruction plan includes schools, kindergartens, clinics, green areas, sports halls and shopping centers. Design coordinated with local residents creates new jobs close to the place of residence [2]. The social aspects of the ESG standards consider the own workforce, workers in the value chain, end users/consumers and vulnerable communities. In war-torn Ukraine, the most vulnerable groups of the population include veterans, displaced persons, children and the elderly. Inclusivity has now become the starting point of all construction and infrastructure projects. In new housing complexes, public spaces are formed depending on the needs of different social groups, which is especially relevant given the demographic challenges facing Ukraine. Play areas, kindergartens, and educational centers are built for children, which has a positive impact on birth rates [2]. Social diversity is supported by affordable housing projects for veterans and displaced persons. Community centers serve as a place for meetings, cultural events, and social initiatives.

Project management of the reconstruction and reconstruction of outdated housing stock. The management section in the ESG standards includes general information about management, internal control, business conduct, and risk management. At the stage of developing the concept of a building or neighborhood reconstruction project, it is advisable to create a stakeholder coordination council, a residents' association, or other associations of interested parties that will help make informed decisions and jointly defend common interests. Management is carried out on the basis of full accountability and transparency with the possibility of discussion and intervention at all stages of project implementation. This will help attract investment, guide the choice of contractors and protect the interests of local residents. Careful planning helps to avoid many mistakes during the implementation process. Management of a building or residential complex can take various forms even after the reconstruction is completed. For example, in ecological residential complexes, car-sharing associations are created to avoid using the adjacent area for parking. Different categories of the population should be involved in the planning and management of construction, reconstruction and reconstruction projects of residential buildings to take into account the diverse needs of stakeholders.

Using a structured approach to ESG reporting standards to streamline the process of reconstruction and reconstruction of outdated housing stock will help to solve environmental and social problems of project management, which will ensure transparency and trust of residents and potential investors.

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DEVELOPMENT OF A CLASSIFICATION OF FACTORS THAT DETERMINE THE OCCURENCE AND COURSE OF "SICK BUILDING SYNDROME"

Tsiuriupa Yurii[1], Bubon Sergyi[2]
[1,2]Kyiv National University of Construction and Architecture
jurij.zurupa.@gmail.com[1], *bybon_cergey@ukr.net[2]*

The term "sick building syndrome" (SBS) was coined by the WHO in 1986, when they also estimated that 10-30% of newly constructed office buildings in the West had indoor air quality problems [1].

The term "sick building syndrome" (SBS) is used to describe situations where prolonged occupancy of a building results in various ailments, but there is no objective cause to suggest a specific disease [2].

The Environmental Protection Agency (EPA) has defined "sick building syndrome (SBS)" as "a situation in which building occupants experience acute health and comfort problems that are likely to be related to time spent in the building, but no specific disease or cause can be identified." In addition, in the European Organization for Concerted Action (ECA), the term “sick building syndrome” refers to a category of various symptoms that are felt mainly by people working in air-conditioned buildings” [3].

Today, there is no clear classification of the negative factors of “sick building syndrome”. Climatic factors are not separately identified, and environmental pollutants are not clearly indicated, although their significance is emphasized everywhere. Some negative factors of the internal environment, such as anthropotoxins and tobacco smoke, aren't strictly included in one group of factors but are mentioned in several groups, which complicates their definition.

In the existing state classification “Hygienic classification of labour by indicators of harmfulness and danger of factors of the production environment, severity and intensity of the labour process” [4], climatic factors (temperature, relative humidity, illumination, air velocity) are considered as physical factors. In addition, there is an unclear question of the classification of some pollutants, for example, tobacco smoke and anthropotoxins, which are human excretions. Thus, it can be noted that the modern hygienic classification and the classification of active harmful factors, which are given in it, need to be expanded and improved.

Based on this, we propose the creation of a classification of hazardous factors of the "sick building syndrome". In the developed classification, it's proposed to divide the influencing factors into outdoor and indoor. The outdoor factors are proposed to include climatic (temperature, relative humidity, wind speed, solar radiation), environmental (chemical air pollution, biological pollution), radiation (radiation from natural sources, radiation from man-made sources) and video-ecological factors (aggressive construction development, depressive landscapes, lack of greenery, light pollution).

We propose to divide the indoor factors into parameters of the indoor environment (temperature, relative humidity, wind speed, lighting), physical (noise, vibration, infrasound, electromagnetic waves, electric fields, magnetic fields), technical (microclimate formation systems, equipment, technology), radiation (radon, background radiation), psychological (stress from imperfect design and video-ecological factors, discomfort, noise, vibration, infrasound) and biochemical (toxins, chemical elements, ENT, bacteria, mould, spores, viruses, smoking smoke).

There are technical methods for improving the parameters of the indoor environment, which are based on the use of various technical means to reduce the effects of harmful factors. For example, heating and air conditioning systems are used to optimize temperature; humidifiers, dehumidifiers and air-conditioning systems are used to improve relative humidity; for illumination, there are light-shielding agents and internal energy-efficient lighting. Household filters are used to combat biochemical factors.

Effective natural biotechnical filters include plants. The actions of plants are aimed to improve not one factor of the indoor environment, but the entire complex of factors. Plants improve psycho-emotional comfort, increase air humidity, absorb harmful substances and sequestrate CO2, destroy pathogenic microflora by released phytoncides, repel pests due to allelopathic substances and the chemical composition of plant sap, and contribute to noise absorption. Therefore, plants are actively and successfully used in biophilic design and zoning of premises. Based on the comprehensive positive effect of plants on improving all negative factors of the indoor environment, plants are considered a promising cheap means for combating SHB, creating a safe indoor environment, and improving occupational hygiene and human health.

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RISK MANAGEMENT FOR IT SECTOR WORKERS IN THE CONTEXT OF GREEN BUILDING PRINCIPLES

Yevhenii Shaidiuk
Kyiv National University of Construction and Architecture,
shaidiuk_ys@knuba.edu.ua

Current trends in the IT industry development and implementation of green building principles necessitate a comprehensive approach to organizing safe workspaces. The issue of risk management for IT sector workers in premises designed according to green building principles is becoming particularly relevant, as such buildings have specific features that can both positively and negatively affect the health and productivity of employees.

The aim of the research is to develop a comprehensive risk management system for IT sector workers that takes into account the specifics of "green" office spaces and their impact on the health and productivity of IT specialists.

The analysis of scientific research by Voloshkina O.S., Tkachenko T.M. [1], Hlyva V.A., Levchenko L.O., Panova O.V. [2], and MacNaughton P. et al. [3] showed that the organization of IT specialists' workplaces in buildings designed according to green building principles should consider a number of specific risk factors: the level of electromagnetic radiation from computing equipment (Hlyva V.A. et al. [2]), natural and artificial lighting features (Tkachenko T.M., Milich V.I. [4]), acoustic properties of premises, ergonomics of workplaces, and psychological comfort of employees (MacNaughton P. et al. [3], Thatcher A., Milner K. [5]).

The study included measurements of microclimate parameters (temperature, humidity, air velocity), electromagnetic radiation levels, and illumination indicators in three office buildings: traditional, "green" certified by LEED, and "green" certified by BREEAM. Certified equipment was used for measurements: Testo 435-4 thermoanemometer (for measuring temperature, humidity, and air velocity), AZ-77535 CO_2 gas analyzer (for determining carbon dioxide levels), PZ-50 electromagnetic field meter (for measuring electromagnetic radiation levels), and Testo 545 luxmeter (for determining illumination indicators). The studied premises had comparable characteristics: traditional building – open space office area of 145 m², volume 435 m³, with 24 computerized workplaces; "green" LEED building – office space of 160 m², volume 480 m³, with 26 computerized workplaces; "green" BREEAM building – office space of 152 m², volume 456 m³, with 25 computerized workplaces. Measurements were conducted on working days during an 8-hour workday at a height of 1.2 m from the floor with an interval of 1 hour. The measurement results are presented in the table 1.

Based on the conducted research, a standard risk management model for IT sector workers in buildings designed according to green building principles has been refined. Special attention was paid to the impact of the environment on health, including manifestations of the so-called "Sick Building Syndrome" (SBS), which is particularly relevant for offices with modern ventilation and technological equipment.

Table 1

Comparison of workplace environment parameters in different types of office buildings'

№	Parameter	Traditional building	"Green" building (LEED)	"Green" building (BREEAM)
1.	Average air temperature, °C	23.2 ± 1.8	22.4 ± 1.2	22.1 ± 1.3
2.	Relative humidity, %	42 ± 7	48 ± 4	50 ± 5
3.	CO_2 level, ppm	835 ± 125	672 ± 85	645 ± 70
4.	EMR level (near workplaces), µT	0.75 ± 0.25	0.62 ± 0.18	0.60 ± 0.15
5.	Daylight factor, %	2.1 ± 0.6	3.4 ± 0.5	3.6 ± 0.4

The proposed model includes five main components implemented as a sequential risk management cycle (fig. 1). Unlike the standard approach to risk assessment and other models that consider an integrated approach [6], this model is adapted to the functioning conditions of IT specialists in green office buildings, taking into account the impact of energy-efficient technologies, natural ventilation, high density of electronic equipment, and ergonomic factors on staff health and productivity. Specifically:

1. **Risk identification and assessment** includes considering the level of electromagnetic radiation[2, 7], CO_2 concentration, and manifestations of Sick Building Syndrome (SBS) characteristic of sealed energy-efficient premises;

2. **Development of risk minimization measures** is based on the integration of environmental solutions (for example, using natural cooling for server equipment);

3. **Implementation** involves the use of adaptive monitoring with IT systems that regulate microclimate parameters in real-time;

4. **Monitoring and control** is conducted based on automated data collection from smart sensors in the premises;

5. **Continuous improvement** is based on analyzing feedback not only from employees but also from building management systems.

Special attention in the study was given to ergonomics of workplaces and organization of IT infrastructure in green buildings. In particular, innovative approaches to placing server equipment using natural cooling systems were proposed, which allows for simultaneously reducing energy consumption and electromagnetic radiation levels.

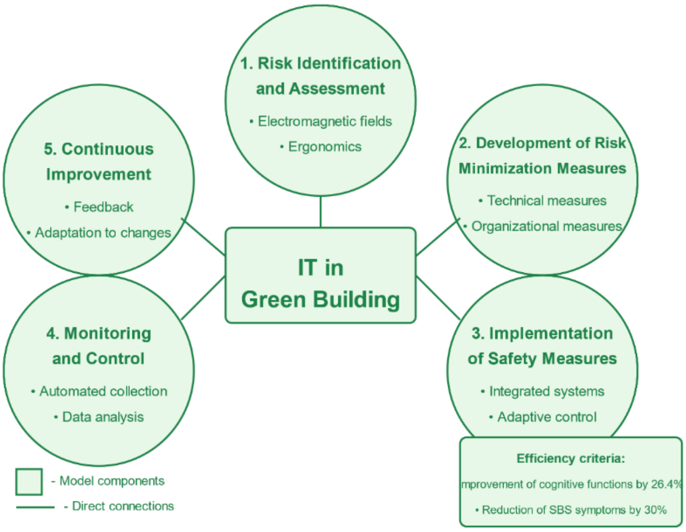

Fig. 1. Risk management model for IT sector workers in green buildings

An important aspect of the model is the integration of microclimate control systems with IT infrastructure management systems, which enables adaptive regulation of workplace environment parameters according to the intensity of computer equipment use and the number of employees in the premises. As noted by Bereznytska Yu.O. and Tkachenko T.M. [8], an important role is played by the ecologization of approaches to organizing work and educational spaces, which contributes to increasing environmental awareness of employees and the effectiveness of implementing green building principles.

The research results confirm that implementing the proposed risk management model based on green building principles provides significant improvements in working conditions for IT specialists. In particular, a comparative analysis of three types of office buildings (traditional, LEED-certified, BREEAM-certified) showed:

Additionally, based on data from previous studies [3, 9, 10], the implementation of environmental standards in the work environment is associated with a 26.4% improvement in cognitive functions and a 30% reduction in Sick Building Syndrome (SBS) symptoms**.** Thus, the model has proven effectiveness in both physiological and cognitive-psychological aspects.

Conclusions. The developed comprehensive risk management model for IT sector workers in green buildings allows for an effective combination of principles of environmental friendliness, energy efficiency, and occupational safety. Implementation of the model contributes to creating a healthy and productive work environment that meets modern sustainable development requirements. Further research will be directed at adapting the model to different types of green buildings and developing specific recommendations for various categories of IT specialists.

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CURRENT ISSUES OF GAS FUEL COMBUSTION IN MUNICIPAL HEAT ENERGY EQUIPMENT AND WAYS TO SOLVE THEM

Yaroslav Shvets
Kyiv National University of Construction and Architecture

Keywords: combustion process organization, oxidizer, heat units, physicochemical methods, combustion intensification.

The concept of technical solutions for the modernization and development of heat and power technologies is based on a combination of practice and theory aimed at ensuring high environmental and thermal performance.

The development of combustion theory is based on the laws of chemical kinetics, physical molecular transfer of active masses, and thermal conditions. The essence of these laws lies in the molecular interaction of different components of combustible substances with the oxidizer, which determines the complex process of combustion. An important factor is the physics of heat and mass transfer processes: diffusion, thermal conductivity, and viscosity.

Based on theoretical developments, various methods of organizing combustion processes have been mastered, resulting in practical solutions aimed at: optimizing the air excess coefficient; reducing the stay time of combustion products in high-temperature zones; lowering the thermal stress in the furnace volume; afterburning harmful combustion products by various methods.

The analysis of scientific and practical research of complex combustion processes has shown that the main reason for incomplete fuel combustion is the low reactivity of hydrocarbons with oxygen oxidizer. As a result, NOx, CO are formed in the combustion products, with increased CO2 contributing to the toxy in the atmosphere.

Operational experience has proven that in each specific case, the combustion process can’t be ideally organized and requires changes based on new physicochemical principles. In recent years, promising technologies for combustion reaction intensification have been developed, based on:

1. Laser radiation [1]. Experimental studies and numerical modeling have shown that a focused laser beam, even of low power, creates a micro-explosive turbulent regime in the furnace space. The cause is the absorption of photons by reagents, leading to vibrational heating of the combustible mixture with significant changes in combustion reaction kinetics. As a result of the explosive nature, solid hydrocarbon structures are formed in the direction of the laser beam, allowing control over the chemical process of the combustion regime in the furnace volume.

2. Electric discharge, electric and magnetic fields [2]. Existing directions can be divided into groups:

- Formation of chemically active ionised atoms and radicals under the influence of electric discharge;
- Excitation of O_2 molecules in a vibrational-electric field;

- Electrocatalytic method, which involves processing gas fuel and gas-air mixture with electric discharge using a magnesium-aluminum oxide catalyst placed in the combustion zone;

- Magnetic field (MF). According to the National Institute for Materials and Chemical Research (Japan), MF promotes combustion in a diffusion flame.

3. Ozone method [3]. Its feature lies in the high rate of oxidation reactions of simple alkanes at significantly lower temperatures than with oxygen.

These phenomena are also important for the development of combustion mechanisms in new technological furnace chambers.

The performed analysis of combustion intensification is oriented toward further research based on new principles. The use of ozone is proposed as an oxidizer, since its reactive properties are higher than oxygen's, and its production is technically simple and more environmentally friendly than other methods considered.

The technical and economic feasibility of using ozone as an oxidiser at a concentration of 100–250 mg/m³ for heat units with thermal capacity of 16–25 kW and an average gas consumption of 1 m³/h throughout the day requires about 50 g of ozone, the production of which consumes about 4.0 kWh.

Further research will focus on determining the rational organization of the interaction between multicomponent gas flame substances and ozone.

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ASSESSMENT OF THE ACOUSTIC EFFICIENCY OF A GREEN FACADE USING *PARTHENOCSISSUS QUINQUEFOLIA*

Konstantyn Shumbar[1], Tatiana Tkachenko[1]

[1]Kyiv National University of Civil Engineering and Architecture

The increase in noise pollution in cities and the lack of funds and space for placing noise-absorbing structures require effective biotechnological means, in particular the use of green structures, namely, vertical gardening to improve the acoustic comfort of residential buildings.

Intensive urbanization and the development of transport infrastructure lead to the growth of environmental problems, in particular noise pollution, the main sources of which are transport and industry [1]. Excessive noise levels negatively affect human health, causing stress, sleep disturbances and other disorders of well-being [2].

According to WHO, noise ranks second among environmental risk factors after air pollution [3].

Traditional noise protection methods, such as screens and soundproofing materials, are expensive and difficult to implement. An environmentally effective alternative is green constructions - green walls and roofs, which are able to naturally reduce noise levels due to the properties of vegetation [4]. They also provide additional ecosystem services: increased biodiversity, improved air quality, reduction of the heat island effect and efficient drainage, which is especially important in the context of climate change [5]. In the context of sustainable construction, which aims to reduce negative environmental impact and increase comfort, the use of green facades is becoming increasingly important. International building certification systems, such as LEED, BREEAM, DGNB, assess the environmental friendliness of objects according to various indicators, including acoustic comfort.

The study examines the potential of vertical gardening—specifically, the use of wild grapevine (*Parthenocissus quinquefolia*)—as an effective means of reducing noise levels both outside and inside buildings [6, 7]. Green roofs, consisting of vegetation, substrate, and waterproofing, improve the thermal insulation of buildings and reduce the impact of external noise. Studies show that they can reduce noise levels by up to 10 dB at low frequencies and up to 20 dB at mid-range frequencies [8].

Green walls effectively absorb and disperse sound waves, contributing to noise reduction both outdoors and indoors. They have been found to reduce noise levels by up to 10 dB, surpassing the effectiveness of traditional materials such as concrete or glass [9]. Their acoustic performance depends on the type of plants, the density of greenery and the characteristics of the substrate. Some structures demonstrate a sound absorption coefficient of more than 0.60, which indicates their high ability to reduce reflected sound [10]. Indoors, vertical structures reduce reverberation and improve speech intelligibility, and are also able to absorb up to 70% of sound energy at certain frequencies, reducing office noise [11, 12]. Most studies have been conducted in laboratory conditions using impedance tubes and reverberation chambers, but there is growing interest in studying the effectiveness of such systems in real urban conditions [6, 13].

A review of over 40 scientific papers confirms that vertical greening is particularly effective in the mid- and high-frequency range, provided that the structure is dense and free of air cavities [14]. The use of green facades in modern cities attracts particular attention, where they have significant potential to improve the acoustic environment.

In this context, a study on the assessment of the acoustic efficiency of facades greened with *Parthenocissus quinquefolia*, taking into account seasonal dynamics, makes an important contribution to the development of environmentally appropriate architectural solutions that combine functionality, aesthetics and sustainable development [15, 16].

The aim of the study is to determine the acoustic efficiency of a green facade using *Parthenocissus quinquefolia* in reducing noise pollution both in the external and internal environment of a residential building. The main focus is on the effect of leaf cover on reducing the sound pressure level indoors in order to increase the acoustic comfort of residents.

The study was implemented using a full-scale experiment using a facade model made of hard material. Acoustic measurements were carried out in accordance with the requirements of DSTU B V.2.6-86:2009 in two configurations: with and without leaf cover. For each option, sound pressure level measurements were performed, after which the data were subjected to statistical analysis.

In order to confirm the results, mathematical modeling of sound wave propagation was also used, taking into account the absorption characteristics of the vegetation layer. The study covered three seasonal states of the facade: full leaf cover, partial leaf fall and its complete absence, which allowed assessing the seasonal variability of acoustic properties.

The results of the study confirm the effectiveness of the green facade formed by *Parthenocissus quinquefolia* in reducing noise pollution in residential environments. It was found that the leaf cover forms a natural porous layer capable of partial absorption and scattering of sound waves, especially in the mid-frequency range.

In the phase of full greening, the sound pressure level in the indoor environment decreased by an average of 3–4 dB, which has a positive effect on the acoustic comfort of residents. A comparison of the three seasonal states of the facade demonstrated the presence of seasonal variation in acoustic properties, which indicates the dynamic variability of the effectiveness of greening throughout the year.

The obtained data are consistent with the results of mathematical modeling, which reinforces the reliability of the conclusions and confirms the feasibility of using vertical greening as a component of sustainable architectural design. Thus, the use of *Parthenocissus quinquefolia* as a plant component of facades can be considered as an effective natural solution for reducing noise pollution in the urban environment.

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INNOVATIVE APPROACHES TO MASKING BUILDING OBJECTS IN THE CONDITIONS OF MODERN THREATS

Oksana Kasianova

Kyiv National University of Civil Engineering and Architecture

kasianova.om@knuba.edu.ua

In the current conditions of escalation of military conflicts, hybrid threats and widespread use of high-precision weapons, the vulnerability of critical infrastructure objects to damage is increasing. A particular threat is posed by technical intelligence tools, in particular drones, satellite platforms, thermal imaging sensors and multi-spectral cameras, which allow detecting, identifying and hitting objects with high accuracy. This trend puts forward new requirements for engineering and construction protection, among which camouflage is gaining strategic importance.

Camouflage in such conditions is not only a visual adaptation of the object to the environment, but also a complex engineering and technical system that includes adaptive design solutions, integration of natural elements, use of materials with controlled physical properties and automated control systems. Effective camouflage should reduce the probability of detection of the object in all main spectral ranges - optical, infrared, radar - and accordingly minimize the risk of its destruction.

Before the start of the active phase of hostilities in Ukraine, researchers emphasized that the goals of complex protection of objects are to maximally reduce the probability of destruction of economic and infrastructure objects by high-precision weapons, reduce the size of possible damage and losses [1]. It is proposed to achieve these goals by solving the following main tasks:

– concealment of objects on the ground through the use of static and dynamic aerosol obstacles, mask-screens, heat-absorbing coatings and green plantings;

– changing the physical fields of objects by reducing contrast, constructing false targets and setting up static obstacles;

– countering high-precision weapon guidance systems by setting up “dynamic” obstacles based on the use of jamming ammunition;

– a rational combination of measures aimed at preserving objects and increasing their physical stability;

– reducing stocks of toxic and explosive and fire-hazardous substances, using means and methods of masking critical elements of economic objects [1].

However, given the nature of the use of weapons of mass destruction and the tactics of conducting combat operations, which are constantly being improved and used not only on the line of contact, but also in peaceful territories in the depths of the country, there is a growing need to develop scientifically based technical solutions that combine modern masking technologies with a systematic approach to risk assessment. Such solutions should become part of the architectural and construction design of objects, especially vulnerable to targeted attacks, and ensure the integration of camouflage systems into the general concept of territory protection. The presented study is aimed at analyzing such innovative approaches, their adaptability and effectiveness in countering modern threats, as well as identifying the main problems that prevent the widespread implementation of camouflage technologies in the practice of civil and industrial construction.

Existing approaches to security are limited by classical engineering solutions that do not take into account the dynamics of reconnaissance using UAVs, satellite monitoring and infrared detection, require active military elements of protection, which is associated with a significant budget and secondary risks of their use. In this context, camouflage acquires not only engineering, but also strategic importance.

To address the issues of this study, it is advisable to use the regulatory framework that regulates the assessment of risks and vulnerabilities and can be appropriately updated to the specifics of the task, namely: DSTU ISO 31000:2018 Risk Management. Principles and Guidelines [2], MIL-STD-882E. Standard Practice for System Safety [3], USAF Risk Identification - Integration and Ilities RI3 Guidebook [4] and other tools [5].

In the course of solving the task of finding the optimal solution for protecting vulnerable business facilities and critical infrastructure, a vulnerability assessment is carried out, a risk matrix is developed, expert assessment is applied, and elements of GIS modeling are used. Special attention is paid to assessing the probability of damage and potential economic consequences based on open statistical and empirical data. Modeling of camouflage options should take into account the features of the landscape, the type of facility, the density and nature of development, the number and presence of personnel and the civilian population, and the characteristics of camouflage materials.

According to the ISO 31000:2018 standard, risk assessment includes three key stages:

1. Risk identification - determination of potential threats associated with the detection of an object through optical, IR and radar channels.
2. Risk analysis - determination of the probability of detection and the degree of impact of damaging factors on the integrity of the object.
3. Risk assessment - comparison of the level of risk with acceptable levels according to the risk matrix.

Using the formula (1) for risk assessment, the results obtained can be interpreted as possible outcomes, as presented in Table 1:

$$R=P\times C, \tag{1}$$

where R - risk of damage;

P - probability of detection;

C - criticality of the consequences of damage (in points from 1 to 10).

Table 1

Assessment of the risk of hitting an object with UAV-type means

Channel of detection of the target	Probability of detection (P)	Criticality of consequences (C)	Risk (R)
Thermal imaging	0,7	9	6,3
Visual (day)	0,5	7	3,5
Radar	0,3	8	2,4

The above assessment takes into account that when identifying threats to the objects to be protected, detection by UAV-type means equipped with a thermal imager has a high probability, detection by satellite imaging with a resolution of ≤ 0.3 m is an average probability, and detection by artillery reconnaissance radar is a low probability for light structures.

In the selected model, a risk above 5 points is considered critical. Therefore, the main emphasis in complex measures that include camouflage should be placed on thermal imaging and optical signature reduction.

When assessing the risks of damage to protected objects using the provisions of MIL-STD-882E, it is appropriate to use a structure that provides for:

- Categorization of hazard levels by consequences (categories I–IV);
- Frequency of the event (A–E);
- A risk matrix to determine the level of risk (from Negligible to Catastrophic).

An example of such an assessment for a scenario in which an object for which camouflage is used is detected by drone reconnaissance with a subsequent artillery strike is given in Table 2.

The MIL-STD-882 matrix showed that with ineffective camouflage, the risk remains high, even with minimal visibility reduction.

Table 2

Assessment of the risks of damage based on MIL-STD-882E

Parameter	**Value**
Criticality of consequences	Category II - Serious
Frequency	Level B - Likely during execution
Risk level	High

A comprehensive approach and integration of assessment according to both standards will allow in real conditions

- to quantitatively justify the choice of structures that significantly reduce detection parameters;
- to create a risk zone map for the placement of objects in dense urban and open development;
- to calculate the economic feasibility of implementing certain camouflage systems depending on the reduction of the risk of damage to the object.

The use of green structures, such as green roofs and facades, is gaining increasing popularity as an effective means of masking critical infrastructure facilities [6]. These solutions not only improve the aesthetic appearance of buildings, but also provide a number of functional advantages that help reduce their vulnerability to detection and attacks.

The main advantages of green structures relevant for solving the camouflage problem (Table 3):

Reduction of thermal signature. Green roofs and facades help reduce the surface temperature of buildings, which makes them difficult to detect using thermal imaging equipment. Studies have shown that green roofs can have a surface temperature that is 1.4-7°C lower than traditional roofs [7].

Noise absorption. Vegetation on facades and roofs can absorb and scatter sound waves, reducing noise levels by 10-20 dB [8].

Reduced visibility in the optical spectrum. Green structures allow buildings to blend in with their surroundings, making them more difficult to detect from the air and space. An example is the use of green roofs as camouflage, making them look like parks when viewed from above.

Improved environmental performance. Green roofs can retain up to 75% of precipitation, reducing the burden on drainage systems and reducing the risk of flooding.

Improved energy efficiency. Green structures help reduce the energy consumption for air conditioning and heating of buildings, which also reduces their carbon footprint.

Table 3

Comparison of green and traditional camouflage means

Criteria	Green structures	Traditional camouflage means
Thermal signature	Low	Low
Noise absorption	Low	Low
Visibility in the optical spectrum	Reduced	High
Energy efficiency	Improved	Без змін No change
Environmental impact	Positive	Neutral or negative
Cost of implementation	Higher initial, but savings in the long term	Lower initial, but higher operational

For the effective use of green structures as a means of camouflage, it is recommended:

- *selection of appropriate plants:* use local plant species that are well adapted to the climatic conditions of the region.
- *integration with architecture:* design buildings taking into account the possibility of implementing green roofs and facades.
- *regular maintenance:* ensure proper care of vegetation to maintain its effectiveness and aesthetic appearance.
- *cooperation with specialists:* involve environmentalists, landscape designers and engineers in the process of planning and implementing projects.

Conclusions. The introduction of green structures as a means of masking critical infrastructure not only increases its safety, but also contributes to sustainable development and improvement of the environmental situation in urban areas.

Masking critical infrastructure facilities in conditions of armed conflict is interdisciplinary in nature and requires the involvement of expert knowledge in engineering, security, geoinformatics and materials science. Increasing the effectiveness of protection is possible provided that masking solutions are integrated into the overall security architecture of facilities. An interdisciplinary scientific task that requires further research is the creation of dynamic masking systems with adaptive control based on data from sensor monitoring systems, taking into account the spectral parameters of enemy intelligence and landscape features.

This task includes:

• creation of prototypes of multifunctional camouflage coatings;
• research into the behavior of such coatings in field conditions (various climatic, seasonal, urban scenarios);
• building digital models of objects and risk zones based on satellite/aerial data;
• calculating the reduction in the probability of damage taking into account the type of threat;
• integrating the results into the decision-making system for civil protection bodies of project organizations.

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EFFICIENT USE OF WATER RESOURCES

P.S. Starzhynskyi[1], V.H. Uzhyk[2], O.V. Novoselskyi[3]
[1,2,3]Kyiv National University of Construction and Architecture
[1]pavlostarzhynskyi@gmail.com

Currently, the issue of drinking water supply in Ukraine is extremely relevant due to the lack of clear water quality standards, imperfect purification technologies, and the continuous deterioration of water supply and sewage networks. All these factors contribute to additional water pollution, even after proper treatment before being supplied to consumers.

Failure to meet drinking water quality requirements, along with the presence of contaminants not covered by control standards, and other factors are key causes of an increase in diseases such as gallstone disease, viral hepatitis, and other illnesses in the country.

The main strategic goal of state water resources management is to achieve and maintain an economically efficient and environmentally safe level of water use. Achieving the dialectical unity of "economically efficient and environmentally safe water use" is defined by us as "sustainable water use," which is characterized by:

– balance between meeting the needs of economic development and ensuring the renewal of water resources;

– balance in the realization of the rights of current and future generations to use economically efficient and environmentally safe water resource potential [1]

To achieve this goal under the conditions of limited economic capacity — both for water-using enterprises and for the state — it is necessary to base the determination of the main directions of effective water management development on the principle of ergonomization of decisions (minimizing costs in water use and selecting ecologically effective solutions that also provide economic benefits). The scope of accompanying water protection measures should be limited to the most urgent and socially significant, implemented by the state through national and regional water resource protection and restoration programs, and by water users at their own expense within their economic activity in accordance with current legislation [1].

The analysis made it possible to identify the main shortcomings of the current water resources and water use management system in the region, which is based on an economic mechanism:

- lack of connection between resource blocks, where the assessment of water resource value and payment norms is based on entirely different fundamental approaches;

- lack of mechanisms for adapting the water resources management system to market relations, leading to an undervaluation of water resource costs, which in turn prevents the full implementation of economic tools in water use;

- lack of mechanisms for determining the priority of tasks in water use, protection, and restoration of water resources and a comprehensive approach to solving them;

- an urgent need to "ecologize" the taxation system;

- the non-economic nature of the norm-setting mechanism in water use and the distribution of water use limits[2].

The main cause of all these shortcomings lies in the absence of a scientifically grounded concept of regional development that takes into account the environmental (including water) factor.

The above issues indicate the need to create a unified mechanism for water use management in the region. The main characteristics of this mechanism, in our opinion, should include:

– targeting the rational use, restoration, and protection of water resources;

– systemic and integrated use of water resources;

– water supply to the economy and population of the region;

– coordination between resource blocks of the economic mechanism both among themselves and across hierarchical levels (national, regional, municipal);

– timeliness of water management decisions ensured by effective feedback mechanisms.

A complete resolution of problems in water use, protection, and restoration of water resources currently seems unfeasible, but it is necessary to identify several directions that will help significantly mitigate existing contradictions. The main directions of rational water use are presented in Figure 1.

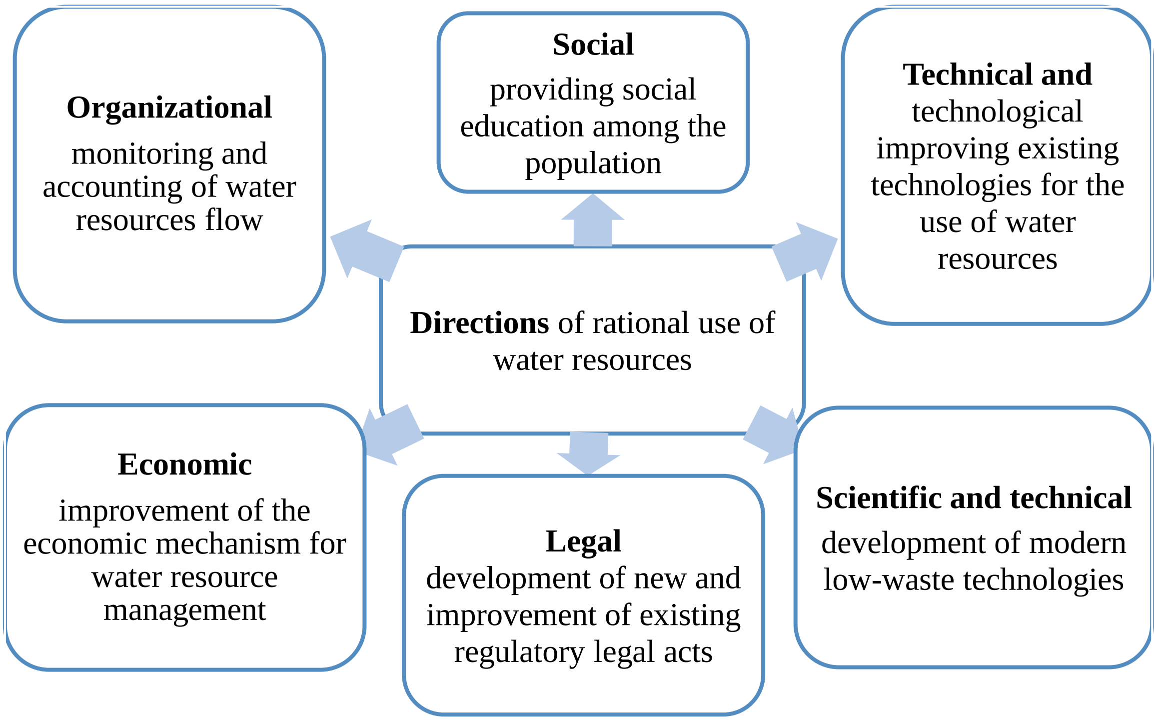

Figure 1. Directions for Rational Water Use

An important principle for improving state water resources management at the current stage should be the decentralization of direct administrative influences, transferring them to the regional level and considering the river basin as the main territorial unit of state water resources management. Water management planning should be carried out for the basin as a whole, taking into account the consequences of all the implemented measures. At the same time, the subject of federal state management should be the qualitative and quantitative characteristics of water bodies.

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ECO-INNOVATIONS IN CEMENT PRODUCTION: ENERGY EFFICIENCY, DIGITAL MONITORING, AND RENEWABLE RESOURCES

Mykola Klymenko[1], Mykhailo Hubchyk[1], Vasyl Marach[1]
[1]Kyiv National University of Construction and Architecture,
klymenko.mo@knuba.edu.ua

Concrete is the second most consumed material in the world: over 900 billion tons have been produced since the start of the industrial revolution. It forms the basis of roads, buildings, and infrastructure that are critically important for economic development. At the same time, the cement industry is one of the largest sources of greenhouse gas emissions responsible for climate change. Currently, about 4 billion tons of cement are produced annually worldwide and generating approximately 7% of global greenhouse gas emissions. Despite the introduction of new technologies, overall emissions continue to rise as new plants are being launched. Since 2010, cement production has increased by 25%, and the industry's emissions remain high, with process emissions accounting for up to 60% of the total.

To achieve net-zero emissions by 2050, the sector must undergo deep transformation: adopting more eco-friendly clinker substitutes, replacing fossil fuels with low-carbon alternatives, improving energy efficiency, integrating renewable energy sources, optimizing kiln and production processes, and capturing unavoidable CO_2 emissions. This will require global cooperation, policy reforms, changes in consumer behavior, and financial support. Decarbonizing the cement industry will demand transformation throughout the entire supply chain, along with unprecedented cross-sectoral and international collaboration, including between developed and developing countries.

According to a new report by The European Cement Association [1], the global cement market reached 4 billion tons in 2023 and is expected to grow to nearly 6 billion tons by 2030. Global cement consumption showed steady growth between 2011 and 2015. This growth was driven by demand from countries of the so-called Global South and transition economies in Asia, such as India, Vietnam, Egypt, Indonesia, and others. These gains were partially offset by moderate declines in consumption among developed economies such as the USA, Europe, Canada, and China, which alone accounts for over 50% of global cement consumption. Today, India consumes over 10% of global cement production.

Combined, the Chinese and Indian markets dominate global cement consumption trends. Despite being the world's largest cement producers, China and India export virtually none of their surplus, as nearly all of it is consumed domestically. Among the world major cement producers, the only significant exporters remain Turkey, Vietnam, and Japan.

Figures 1 and 2 show the percentage distribution and the characteristics of changes in the amount of cement produced globally in 2023 (compiled from [1, 2]).

Overall, the volume of cement exports has declined by an average of 6,6% for all exporting countries since 2015, when cement shipments were valued at USD 11 billion. From 2019 to 2023, cement exports fell by 11.5%.

For Ukraine, the cement industry is a strategic sector that supplies the basic material for the construction of industrial and transport infrastructure, as well as for commercial and residential development. Ukraine share in global cement production is only 0,2%. In the pre-war period, the industry development showed a gradual increase in production capacity, reaching 11 million tons in 2021. However, with the onset of the war, cement production dropped significantly due to a halving of demand and the loss of production facilities themselves. Of the 9 plants located in non-occupied territories, only 8 remain, and 3 of them have been shut down due to damage or proximity to the front line (see Fig. 3).

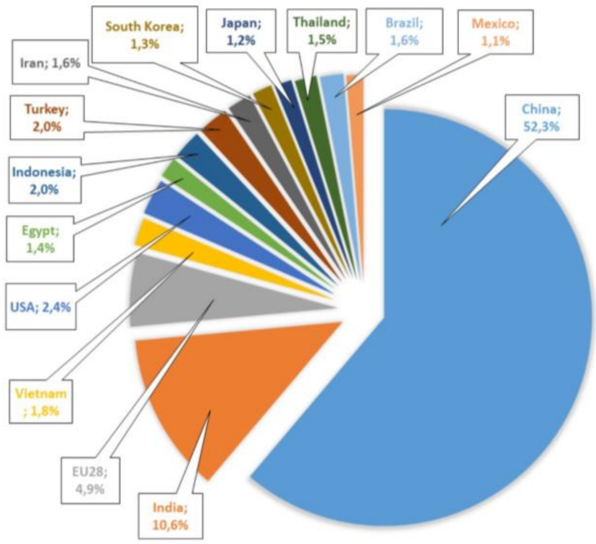

Fig. 1. Global Cement Production in 2023

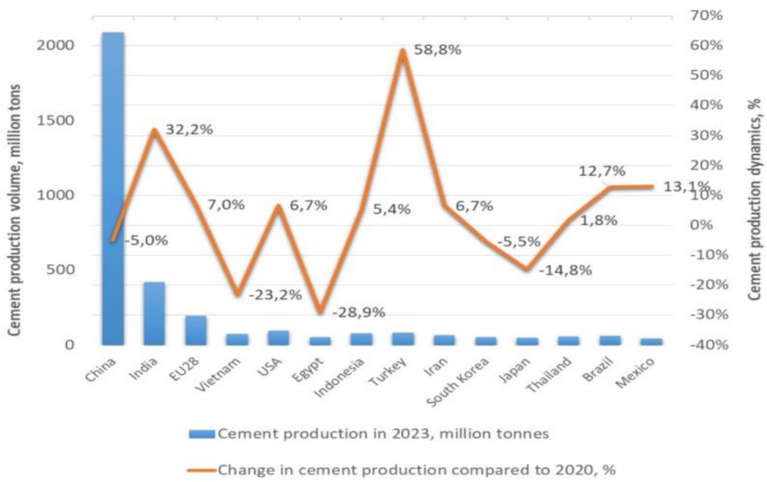

Fig. 2. Characteristics of Changes in Global Cement Production in 2023.

A general negative characteristic of all Ukrainian cement enterprises is outdated equipment, which is physically and morally worn out, with virtually no modernization or renovation having taken place. Most of the cement in Ukraine is still produced using the wet process. This is primarily due to the high moisture content of local limestone.

Alongside the dominant use (over 75%) of outdated wet grinding technology and old mills at Ukrainian facilities, a steady decline in the use of production capacity has been observed since 2008. Despite the total maximum capacity of all Ukrainian cement plants being 20-22 million tons, actual utilization in the pre-war period did not exceed 50-53%.

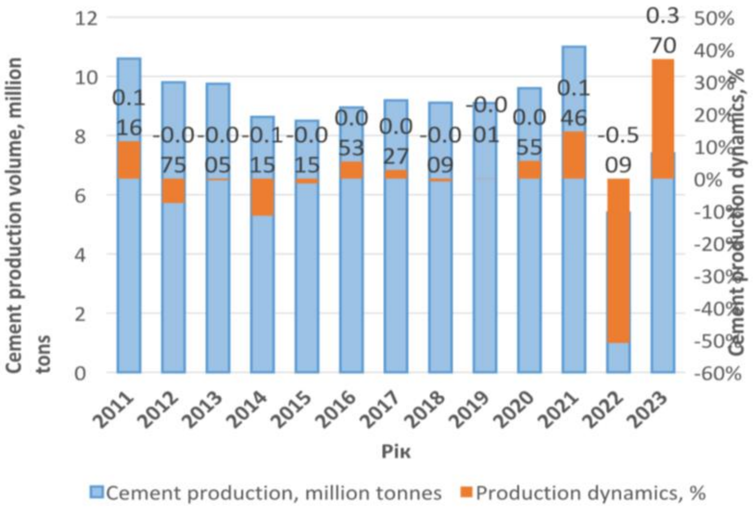

Fig. 3. Cement Production in Ukraine Over the Past 12 Years.

The use of the wet grinding process results in high energy consumption – both at the clinker production stage (up to 8000 MJ/ton of clinker) and during the final cement grinding (up to 150 kWh/ton of cement, compared to the current global benchmark of 92-102 kWh/ton).

Among global trends, several new technologies are emerging to improve the environmental sustainability of cement production. One of the most promising is carbon capture, utilization, and storage (CCUS), although its commercial viability remains limited. Major producers such as Heidelberg Materials (Germany) are implementing pilot CCUS projects. For example, the Brevik CCUS project in Norway will enable the production of the world's first «carbon-neutral cement» under the name evoZero. Holcim (Switzerland) aims to make its Lägerdorf plant climate-neutral by 2029, capturing over 1,2 million tons of CO_2 annually to convert into e-methanol.

Other technologies are also approaching commercial deployment: electric kilns and new processes for producing lime from silicate rocks instead of limestone.

Researchers note that the majority of cement industry emissions 60-65% - result from chemical reactions during clinker production, another 30-35% come from fuel combustion, and the rest are related to electricity consumption. Clinker production requires temperatures of about 2000 °C, and fossil fuels still remain the cheapest energy source. The International Energy Agency (IEA) states that the sector must take several steps to reduce emissions: increasing energy efficiency, transitioning to low-carbon fuels, using alternative materials to replace clinker, and developing near-zero-carbon production technologies.

A key factor is the increased use of alternative fuels such as biomass, municipal solid waste, and industrial residues. Achieving this will require investments in equipment and its integration into the production cycle. The use of green hydrogen also shows promise.

Another approach to improving energy efficiency involves waste heat recovery systems, which can supply up to 30% of a plant's energy needs, along with vertical roller mills, high-efficiency coolers, and more. Positive results have also been observed from the use of solar and wind energy, energy storage systems, or long-term clean electricity purchase agreements.

A separate area of innovation is the use of digital technologies and artificial intelligence (AI), which can optimize the operation of kilns, mills, and grinders, predict maintenance needs, and reduce raw material losses.

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