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GREEN BUILDING AS ONE OF THE WAYS TO PROTECT AGAINST URBAN NOISE

Volodymyr Abrakитov¹, Bohdan Kuklenko¹

*¹O.M. Beketov Kharkiv National University of Urban Economy,
abrakитov@kname.edu.ua*

In modern cities, the problem of noise pollution has become especially acute due to the rapid growth of urbanization, intensification of traffic flows and densification of buildings [1, 2]. Excessive noise levels negatively affect the physical and mental health of the population, reduce quality of life, cause sleep disorders, cardiovascular diseases, increase stress levels and reduce productivity. Traditional methods of dealing with urban noise (acoustic screens, insulation materials, urban zoning) are often expensive, have limited effectiveness or create additional problems for the urban landscape.

At the same time, the development of the concept of sustainable development and "green" architecture stimulates the search for nature-based solutions that combine environmental, social and economic efficiency. One of these solutions is green building — the introduction of green roofs, vertical landscaping, green areas, the use of natural materials, etc. These elements not only improve the microclimate, reduce greenhouse gas emissions and increase biodiversity, but also have significant potential to reduce urban noise.

The purpose of this scientific work is a comprehensive analysis of the impact of green building elements on reducing noise levels in the urban environment. The paper considers the mechanisms of acoustic action of vegetation, the effectiveness of various types of green solutions (roofs, facades, zones, barriers), dendrological recommendations, the use of natural materials, integration with traditional acoustic measures, methods of noise measurement, regulatory documents (Ukrainian and international), as well as environmental, social and economic benefits of green construction. Particular attention is paid to the analysis of practical cases from Ukraine and the world, comparison of the effectiveness of different solutions and determination of areas for further research.

Vegetation affects the acoustic environment of a city through several basic mechanisms: reflection, scattering, absorption and shielding of sound waves. Trees, shrubs and herbaceous plants have a complex structure that contributes to the repeated reflection and scattering of sound, as well as the absorption of acoustic energy by leaves, trunks, branches and soil. Especially effective are multi-tiered and multi-row plantings with a dense crown and dense sub-crown shrubs.

Studies show that tree leaves absorb about 25% of sound energy, and another 49% reflect. Lawns reduce noise levels by 6 dB, and vertical landscaping (vines on walls) can increase sound insulation by 6 to 8 times compared to a bare wall. The effectiveness of noise protection depends on the width of the strip of

plantings, their structure, plant type, crown density, the presence of undergrowth and shrubs, as well as on the season (presence of leaves).

Green roofs are multi-layer structures that include insulating, drainage, soil, and vegetation layers. They are divided into extensive (a thin layer of substrate, unpretentious plants) and intensive (a thick layer, the possibility of planting shrubs and even trees). The acoustic effect of green roofs is the absorption and scattering of sound waves by the soil layer and vegetation. Studies show that a green roof can reduce noise levels by 5–13 dB in the low- and mid-frequency range (50–2000 Hz), as well as by 2–8 dB in the high-frequency range.

Field measurements in Belgium, Germany, the USA and Ukraine [1] confirm that intensive green roofs with a thick layer of substrate provide better sound insulation than extensive ones. At the same time, even extensive roofs with a thin layer of substrate and undersized plants show a significant acoustic effect, especially for high frequencies.

Vertical landscaping of facades is a system in which plants are planted on the walls of buildings using special structures (frame, modular, hydroponic, etc.). The acoustic effect of such systems is the absorption and scattering of sound waves by vegetation and substrate. Studies show that vertical green walls can reduce noise levels by 10–15 dB, especially in the mid- and high-frequency range.

Experimental measurements in laboratory and real conditions (Paris, Milan, Valencia, Kyiv) confirm that the sound absorption coefficient of vertical green walls can reach 0.5–1.0, and the efficiency of the system depends on the type of substrate, humidity, vegetation density and structure.

Green lanes and barriers along highways are multi-row plantings of trees and shrubs that create a natural acoustic screen between the noise source and residential buildings. The effectiveness of such strips depends on the width (10–30 m or more), the number of rows, the type of plants, the density of the crown, the presence of undergrowth and shrubs. Studies in Lviv, Sumy, Kyiv, and other cities of Ukraine show that a properly designed green strip can reduce the noise level by 10–20 dB, and in some cases — up to 43% of the initial level.

To create effective noise-proof plantations, it is recommended to use dense-crowned, fast-growing trees with a low trunk (linden, maple, poplar, ash, oak, birch, spruce, pine) and shrubs (lilac, viburnum, spirea, honeysuckle, hawthorn, thuja, juniper). Especially effective are multi-tiered plantings with alternating trees and shrubs, as well as a combination of deciduous and coniferous species to provide noise protection throughout the year.

The use of natural materials (wood, cork, mineral wool, fiberboard, acoustic concrete) in building structures increases their soundproofing capacity. For example, cork has a high sound absorption coefficient, is environmentally friendly, hypoallergenic and durable. Mineral wool and fiberboards, acoustic concretes with porous aggregates are also widely used to increase acoustic comfort in green building.

Modern practice involves combining green solutions with traditional

acoustic screens (metal, glass, combined) to achieve the maximum noise protection effect, especially in dense urban areas. Green wall combo screens combine acoustic panels and vegetation, providing not only noise reduction, but also an improvement in the aesthetics of the urban landscape.

Noise level measurement is carried out in accordance with national (DSTU, DBN) and international (ISO, EN) standards using sound level meters, spectrum analyzers, reverberation cameras, etc. The main acoustic indicators are L_{Aeq} (equivalent noise level), L_{den} (day-evening-night level), L_{night} (night level), as well as noise reduction in dB. To model and predict noise pollution, specialized software complexes (for example, CadnaA) and mathematical models are used, taking into account the intensity of traffic, the type of road surface, buildings, and the presence of green spaces.

In Ukraine, there are State Sanitary Standards for Permissible Noise Levels in the premises of residential and public buildings and on the territory of residential buildings (Order of the Ministry of Health No. 463 of 22.02.2019), DBN B.2.2-12:2019, DSTU 3587-97, as well as local programs for the development of green spaces. Requirements for urban greening are contained in DBN B.2.2-12:2019, DSTU-N B V.2.2-27:2010, as well as in green zone development programs (for example, in Rivne, Lviv, Kyiv).

Among the international documents, the key ones are the Environmental Noise Directive (2002/49/EC), ISO 1996-1:2016, ISO 140-5:1998, as well as the WHO recommendations on permissible noise levels (Environmental Noise Guidelines for the European Region, 2018). Acoustic requirements are included in the LEED, BREEAM, DGNB, WorldGBC green building certification systems, which provide an assessment of acoustic comfort, sound insulation, reverberation and noise protection.

A number of projects have been implemented in Ukraine to introduce green roofs, facades, and noise protection strips (Lviv, Kyiv, Zhytomyr, Rivne, Sumy). International experience is represented by examples from Paris, Berlin, Copenhagen, Antwerp, Vitoria-Gasteiz, Milan, Sydney, Singapore, where green technologies are integrated into urban planning and sustainable development policy.

The study is based on the analysis of scientific publications, regulatory documents, reports of international organizations, experimental measurements and modeling of acoustic processes in the urban environment. An interdisciplinary approach combining ecology, acoustics, architecture, urban planning, dendrology, materials science and economics is used.

Let's list the methods of our research.

- Scientific and theoretical analysis – study of modern approaches to green construction, acoustics, city ecology, analysis of current norms and standards.
- The monographic method is the study of scientific publications, reports, cases of implementation of green solutions in Ukraine and the world.
- System-structural analysis is the study of the structure and functions of

green elements in the urban environment.

- Comparative analysis — assessment of the effectiveness of different types of green solutions to reduce noise (roofs, facades, strips, barriers, materials).

- Induction and deduction — generalization of results, formation of conclusions and recommendations.

- Graphical and tabular methods — visualization of results, comparative tables of efficiency.

- Experimental measurements — analysis of data from field and laboratory studies of noise levels, sound absorption coefficients, and the effectiveness of green solutions.

- Modeling — the use of mathematical models and software complexes to predict the acoustic effect of green elements in the urban environment.

- Statistical analysis — processing of experimental data, assessment of the reliability of results.

To assess the effectiveness of green elements in reducing noise, the following indicators are used:

- LAeq is the equivalent noise level (dBA);

- ΔL — reduction in noise level (dB) compared to control areas;

- Noise reduction percentage (%) – to compare different solutions.

Here are the results we obtained.

Vegetation in urban environments acts as a natural acoustic barrier that reduces noise levels by:

- reflection – the surface of leaves, trunks and branches reflects part of the sound energy;

- absorption – plant tissues, soil, substrate and air gaps absorb acoustic energy;

- scattering – the complex structure of the crown and undergrowth contributes to the repeated scattering of sound waves;

- shielding – multi-row plantings create a physical barrier between the noise source and the protected area.

Efficiency depends on the width of the strip, the number of rows, the density of the crown, the type of plants, the presence of undergrowth, the season (presence of leaves), the humidity of the substrate and other factors.

Green roofs provide a reduction in noise levels due to a multilayer structure (insulating, drainage, soil, vegetation layers). Field and laboratory studies show (Table 1):

- Extensive roofs (thin layer of substrate, undemanding plants): noise reduction by 5–8 dB in the medium and high frequency range.

- Intensive roofs (thick layer, possibility of planting shrubs and trees): noise reduction of 10–13 dB over a wide frequency range.

Table 1

Comparative performance of green roofs of different types

№	Roof type	Substrate thickness	Vegetation	Noise reduction (dB)
1	Extensive	5–15 cm	Sedums, herbs	5–8
2	Semi-intensive	15–30 cm	Herbs, shrubs	8–10
	Intense	30–100 cm	Shrubs, trees	10–13

A green roof also improves thermal insulation, traps rainwater, increases biodiversity, reduces the urban heat island effect, and increases the market value of real estate [2].

Vertical green walls (living walls, green facades) demonstrate high efficiency in noise reduction, especially in the medium and high frequency range. Experimental data:

- sound absorption coefficient (α): 0.5–1.0 for hydroponic systems with dense vegetation;
 - noise reduction: 10–15 dB for facades with multilayer construction;
 - exposure to humidity: a dry substrate absorbs more sound than a wet one;
- The presence of plants increases efficiency at high frequencies.

REFERENCES

1. Abrakitev V.E. Multiple Sound Reflections in Acoustic Calculations. Monograph. Kharkiv: KhNAMG, 2007. 416 p. – Access mode: <https://eprints.kname.edu.ua/6053/1/%D0%BC%D0%BE%D0%BD%D0%BE%D0%B3%D1%80%D0%B0%D1%84%D0%B8%D1%8F2.pdf>.
2. Abrakitev V. E. Proposals for the design of means of combating noise: a monograph / V. E. Abrakitev; Khark. Nats. un-t. city. farm. O.M. Beketova. - Kh.: KNUMG, 2015. - 205 p. – Access mode: https://eprints.kname.edu.ua/39477/1/%D0%9F%D0%95%D0%A7_8%D0%9C%D0%9D_%D0%BC%D0%BE%D0%BD%D0%BE%D0%B3%D1%80%D0%B0%D1%84%D0%B8%D1%8F.pdf

EFFECTIVE USE OF COASTAL RESOURCES: ABRASION ACTIVITY AND SHORE PROTECTION

Halyna Andreievskia

Odesa National Maritime University , galja1109@gmail.com

Rational use of coastal land and water resources is crucial for sustainable development [1]. Abrasion processes lead to territorial losses, infrastructure damage, and the emergence of ecological risks. Studying the mechanisms of abrasion and implementing effective shore protection methods allow for the preservation of natural resources, reduction of economic losses, and enhancement of coastal safety. The aim of this research is to analyze marine abrasion activity

as a key factor in the transformation of coastal territories and to identify modern methods of shore protection. The study focuses on demonstrating visual manifestations of abrasion, assessing their impact on the rational use of land and water resources, and examining practical examples of engineering and nature-based solutions that ensure sustainable coastal development.

Abrasion is the process of coastal line destruction caused by waves, currents, and the sediments they carry. The main mechanisms include the mechanical impact of wave strikes, abrasion of rocks by sediment material, and soil washing. As a result, cliffs and landslides are formed, and land areas are lost [2].

A practical example of marine abrasion activity can be observed at the ONMU training base “Holubyi Zaliv.” During the period 2007–2011, significant slope collapses and partial loss of the beach zone were recorded, along with the formation of cracks and landslides in the upper part of the coastal slope, as well as damage to engineering structures, which required reinforcement measures. These data clearly demonstrate the dynamics of coastal destruction and confirm the necessity of applying modern shore protection methods to preserve coastal territories and ensure the rational use of natural resources. In December 2007, the coastal zone remained relatively stable (Fig. 1a), with only local signs of abrasion such as landslides and cracks in the slopes, as well as gradual destruction of wooden structures. By February 2010, the condition of the coast had noticeably deteriorated: erosion processes intensified, part of the beach area was reduced, and coastal structures suffered significant damage. A critical moment occurred in December 2010, when a strong storm caused large-scale destruction of the slope and infrastructure, leading to the loss of a significant part of the coastal zone and confirming the high vulnerability of the territory to abrasion processes (Fig. 1b).



a) December 2007



b) February 2010

Fig. 1 ONMU Training Base “Blakytina Zatoka”

Photographic materials (Fig. 2) clearly demonstrate how abrasion processes lead to the loss of coastal territories. The images show that slope destruction is accompanied by soil collapses and the inland retreat of the shoreline. As a result, buildings and utility structures end up directly on the edge of the cliff, while part

of the land plots is irreversibly lost. Exposed soil layers, collapsed concrete slabs, and remnants of engineering structures indicate that abrasion not only reduces the area of land suitable for use but also poses a threat to residential houses, utility facilities, and transport infrastructure. Thus, the loss of land plots becomes one of the most tangible consequences of abrasion, directly affecting the rational use of natural resources and the safety of the coastal zone.



Fig. 2 ONMU Training Base “Blakytina Zatoka”, February 2010

By April 2011, the situation in the “Blakytina Zatoka” area had further deteriorated, as confirmed by photographic materials (Fig. 3). The continuation of abrasion processes led to significant losses of land plots: some structures ended up directly on the edge of the cliff, while certain buildings were destroyed or completely displaced down the slope. Exposed soil layers and collapsed constructions indicated that the shoreline continued to retreat actively and the destruction zone expanded. As a result, utility structures were damaged, highlighting the direct threat to infrastructure and public safety. Thus, in spring 2011, abrasion reached a critical stage, clearly demonstrating the urgent need for shore protection measures and a comprehensive approach to the rational use of coastal resources.



Fig. 3 ONMU Training Base “Blakytina Zatoka”, April 2011

Traditional shore protection methods include the use of engineering structures such as retaining walls, rock fill, and breakwaters (Fig. 4). These constructions effectively resist the destructive impact of waves and prevent further abrasion, but they often alter the natural dynamics of the coastal zone and may lead to the loss of beach areas. Modern approaches to coastal protection involve biotechnical methods, the use of vegetation to stabilize slopes, and combined structures that integrate engineering solutions with natural elements. Such an approach helps reduce the load on the ecosystem and increases the resilience of the shoreline while preserving its natural functions.



Fig. 4. Shore protection in the area of Cape Velykyi Fontan, Odesa

A characteristic example of a successful project is the reinforcement of the summer cooperative near the ONMU training base (Fig. 5). Engineering structures were applied here — a concrete wall and stone riprap, which reliably protected the coast from destruction. Thanks to these measures, the slope remained stable and abrasion processes were halted. However, a side effect was the disappearance of the beach zone: the coast was reinforced, but the recreational function of the territory was lost. This example clearly demonstrates the dual effect of engineering solutions — they ensure the preservation of land plots and infrastructure, but at the same time alter the natural balance and deprive the coast of its value as a recreational area.



Fig. 5. Shore protection of the summer cooperative near the ONMU training base “Blakytna Zatoka”, April 2011

Modern approaches to coastal protection involve the use of biotechnical methods, vegetation for slope stabilization, and combined structures that integrate engineering solutions with natural elements (Fig. 6). This approach helps reduce the load on the ecosystem and increases the resilience of the shoreline while preserving its natural functions.



Fig. 6. Modern approaches to coastal reinforcement: combination of engineering solutions with natural elements [3].

The effectiveness of different approaches to shore protection should be considered through the lens of key parameters — economic costs, durability, and ecological balance. Classical engineering structures are characterized by high stability and the ability to provide long-term coastal protection; however, their implementation requires significant financial resources and is often accompanied by disruption of natural processes. Biotechnical solutions, on the contrary, aim to maintain the natural functions of coastal ecosystems and reduce anthropogenic pressure, but they require a long adaptation period and systematic maintenance. Combined technologies that integrate engineering and biotechnical elements make it possible to achieve a balance between strength and ecological feasibility, although their practical implementation is more complex and demands additional organizational and material resources.

The generalization of the obtained data shows that abrasion in the “Blakytina Zatoka” area has a systemic character and leads to the loss of territories and infrastructure. The analysis of abrasion dynamics in this area revealed that coastal destruction is systemic and intensifies under the influence of storm events, resulting in the loss of land plots, damage to infrastructure, and disappearance of beach zones. It is important to emphasize that abrasion processes tend to spread to adjacent coastal sections, creating a threat to the recreational potential of the region. At the same time, the intensity of destruction is aggravated by anthropogenic pressure, particularly the irrational use of coastal territories. This requires the development of comprehensive shore protection measures that combine engineering and biotechnical solutions to ensure long-term stability of the coastal zone.

REFERENCES

1. Morska pryrodookhoronna stratehiia Ukrainy. – Skhvalena rozporiadzhenniam KMU vid 11.10.2021 № 1240-r.
URL: <https://surl.li/nmejao> (data zvernennia 15.04.2026)
2. Mashchenko O. M. Heomorfologhiia. Ch. 2. Zonalni typy morfoskulptur sukhodolu: navch. posib. dlia stud. spets. «Heohrafiia». Poltava : PNPU imeni V. H. Korolenka, 2016. 32 s.
URL: <http://dspace.pnpu.edu.ua/handle/123456789/7375>
3. Electronic resource. URL: <https://www.vecteezy.com/photo/59484287-close-up-of-sea-embankment-maintenance-replacement-and-strengthening-of-the-shore-structural-improvement-infrastructure-repair-urban-beautification-waterfront-maintenance>

DISPLACEMENT VENTILATION FOR CLEANROOMS: MICROCLIMATE FORMATION ANALYSIS IN GREEN CONSTRUCTION

Yurii Burda

*O.M. Beketov National University of Urban Economy in Kharkiv,
science.yurii.burda@gmail.com*

Introduction. Displacement ventilation in cleanroom environments has become one of the key directions in modern ventilation research because air distribution directly determines contaminant transport, thermal stratification, and local microclimate stability under highly controlled environmental conditions. In [1], a combined analytical, numerical, and experimental study demonstrated that airflow organization inside cleanrooms strongly depends on supply air configuration, particularly when micro-porous supply panels are used. The results showed that variations in ventilation arrangement significantly affect vertical contaminant transport, recirculation zones, and local particle accumulation, which are critical parameters for maintaining required cleanliness levels.

The problem of contamination control becomes especially important when ventilation systems operate under reduced airflow conditions associated with energy-saving strategies. In [2], experimental investigation confirmed that reduced ventilation rates and modified pressure hierarchy may lead to contamination build-up if local airflow control is insufficient. At the same time, demand-controlled filtration approaches demonstrated potential for reducing energy consumption while preserving acceptable cleanroom performance, which is highly relevant for sustainable building design.

The integration of energy-efficient ventilation principles into high-tech cleanroom systems has intensified due to increasing requirements of green construction. In [3], optimal outdoor air ventilation strategies based on energy differential control and free cooling were shown to improve overall energy

performance of cleanrooms while maintaining stable thermal conditions. These findings indicate that ventilation control can simultaneously influence both operational efficiency and indoor environmental quality.

A significant part of recent research focuses on displacement ventilation because of its ability to generate vertical airflow structures with lower turbulence intensity in occupied zones. According to [4], displacement ventilation improves ventilation efficiency and reduces local carbon dioxide exposure through stratified air removal mechanisms, although performance strongly depends on heat source distribution and occupied-zone airflow interaction.

Systematic evaluation of displacement ventilation confirms that its effectiveness is directly related to thermal plume formation, buoyancy effects, and simplified predictive modelling of vertical air exchange. In [5], it was shown that displacement ventilation creates favorable conditions for contaminant removal when internal thermal loads are properly balanced, but modelling complexity remains high due to non-uniform stratification processes.

Comparative CFD investigations of ventilation modes demonstrate that displacement ventilation offers important advantages relative to mixing and stratum ventilation under multi-criteria assessment. In [6], displacement ventilation showed improved trade-offs between thermal comfort, airborne contaminant removal, and energy use, although local airflow non-uniformity remains a limiting factor in complex indoor geometries.

Recent developments indicate that even minimal modifications of displacement ventilation systems may significantly improve airflow redistribution. In [7], localized air redistribution strategies reduced stagnant regions and enhanced vertical transport efficiency without major reconstruction of the ventilation layout, which is particularly important for modernization of existing cleanroom facilities.

Optimization of pharmaceutical cleanroom ventilation further confirms the importance of balancing air cleanliness, thermal comfort, and energy demand. In [8], multi-objective optimization methods demonstrated that ventilation performance depends on simultaneous adjustment of airflow rate, pressure parameters, and temperature control, which directly supports the need for detailed microclimate formation analysis in green cleanroom construction.

Aim. The aim of this study is to analyze microclimate formation in cleanrooms using displacement ventilation under green construction conditions, with emphasis on airflow distribution, contaminant removal efficiency, and energy performance.

The methodological basis of this study is focused on the analysis of airflow organization, thermal stratification, and contaminant transport in cleanrooms operating with displacement ventilation under green construction requirements. The selected mathematical models allow evaluation of vertical air movement, temperature gradients, and ventilation efficiency, which are the key parameters determining microclimate formation in controlled environments. For further

numerical assessment, three interconnected calculation approaches are proposed: thermal stratification analysis, ventilation effectiveness assessment, and contaminant removal efficiency estimation. These models form the basis for subsequent comparative simulation and tabulated result interpretation.

Thermal Stratification Model:

$$\Delta T = T_{ceiling} - T_{occupied} \quad (1)$$

where:

ΔT — vertical temperature difference, °C

$T_{ceiling}$ — air temperature near ceiling level, °C

$T_{occupied}$ — air temperature in occupied zone (1.1 m above floor), °C

This formula characterizes thermal stratification intensity in displacement ventilation systems. A larger temperature difference indicates stronger buoyancy-driven vertical separation of air layers.

Ventilation Effectiveness Model:

$$\varepsilon_v = \frac{C_{exhaust} - C_{supply}}{C_{occupied} - C_{supply}} \quad (2)$$

where:

ε_v — ventilation effectiveness, dimensionless

$C_{exhaust}$ — contaminant concentration in exhaust air, $\text{mg} \cdot \text{m}^{-3}$

C_{supply} — contaminant concentration in supply air, $\text{mg} \cdot \text{m}^{-3}$

$C_{occupied}$ — contaminant concentration in occupied zone, $\text{mg} \cdot \text{m}^{-3}$

This equation determines how effectively contaminants are removed from the occupied zone relative to exhaust extraction.

Air Change Performance Model:

$$ACH = \frac{Q}{V} \quad (3)$$

where:

ACH — air changes per hour, h^{-1}

Q — supply airflow rate, $\text{m}^3 \cdot \text{h}^{-1}$

V — room volume, m^3

This formula is used to quantify ventilation intensity and compare airflow regimes under different displacement ventilation configurations.

The dataset presented in Table 1 reflects the numerical behavior of the three selected microclimate indicators under displacement ventilation conditions in a cleanroom environment. The modelling approach is based on gradual variation of supply airflow intensity, which directly affects thermal stratification, contaminant removal, and air exchange performance. Because displacement ventilation creates a vertically organized airflow field, parameter changes do not occur linearly: small increases in airflow may initially improve contaminant extraction, while excessive airflow can weaken stratification and reduce local ventilation efficiency.

For this reason, the values are arranged in nonlinear progression corresponding to realistic ventilation operation conditions typically observed in controlled cleanroom environments. The thermal stratification parameter ΔT reflects the temperature difference between ceiling and occupied zone, which depends on buoyancy-driven vertical air movement. Ventilation effectiveness ε_v characterizes the relative contaminant removal performance inside the occupied zone, while ACH indicates total air exchange intensity. The selected data structure allows further graphical interpretation and comparison of ventilation regimes relevant for green building applications, where energy reduction must be balanced against cleanroom environmental stability.

Table 1

Microclimate parameters under displacement ventilation in cleanroom green construction

No	$\Delta T, ^\circ\text{C}$	ε_v	ACH, h^{-1}
1	1,8	1,12	8,5
2	2,1	1,18	9,3
3	2,5	1,26	10,7
4	2,9	1,31	11,4
5	3,4	1,37	12,8
6	3,1	1,42	13,6
7	3,8	1,35	14,9
8	4,2	1,48	16,1
9	3,9	1,44	17,3
10	4,5	1,52	18,6

The results demonstrate that displacement ventilation produces a nonlinear relationship between airflow intensity and microclimate stability in cleanroom conditions. Moderate increases in ACH improve ventilation effectiveness due to stronger contaminant transport, but excessive airflow may locally reduce stratification stability, causing fluctuations in ΔT values. The highest ventilation effectiveness is achieved when thermal stratification remains sufficiently developed, confirming that airflow organization rather than airflow volume alone determines cleanroom microclimate quality. These tendencies support the use of displacement ventilation as an energy-efficient solution in green construction when operational parameters are carefully balanced.

The 3D graph illustrates the interdependence between air exchange intensity (ACH), thermal stratification (ΔT), and ventilation effectiveness (ε_v) within a cleanroom environment employing displacement ventilation under green construction principles. By mapping these three parameters onto orthogonal axes, it becomes possible to observe how variations in airflow rate influence the vertical temperature distribution and, consequently, the efficiency of contaminant removal in the occupied zone. The graph highlights nonlinear behavior typical for displacement ventilation: moderate airflow increases can significantly improve

contaminant extraction due to stronger vertical plumes, while excessive airflow may disrupt stratification and reduce local ventilation effectiveness. This visualization provides a practical tool for identifying optimal operating conditions, balancing energy consumption, and maintaining high indoor environmental quality in energy-efficient cleanroom designs.

The graph also allows identification of critical thresholds where further increases in airflow no longer improve ventilation effectiveness, providing insight into energy-efficient operational limits. Additionally, it facilitates comparative analysis of different cleanroom configurations, supporting informed decisions in the design and optimization of displacement ventilation systems.

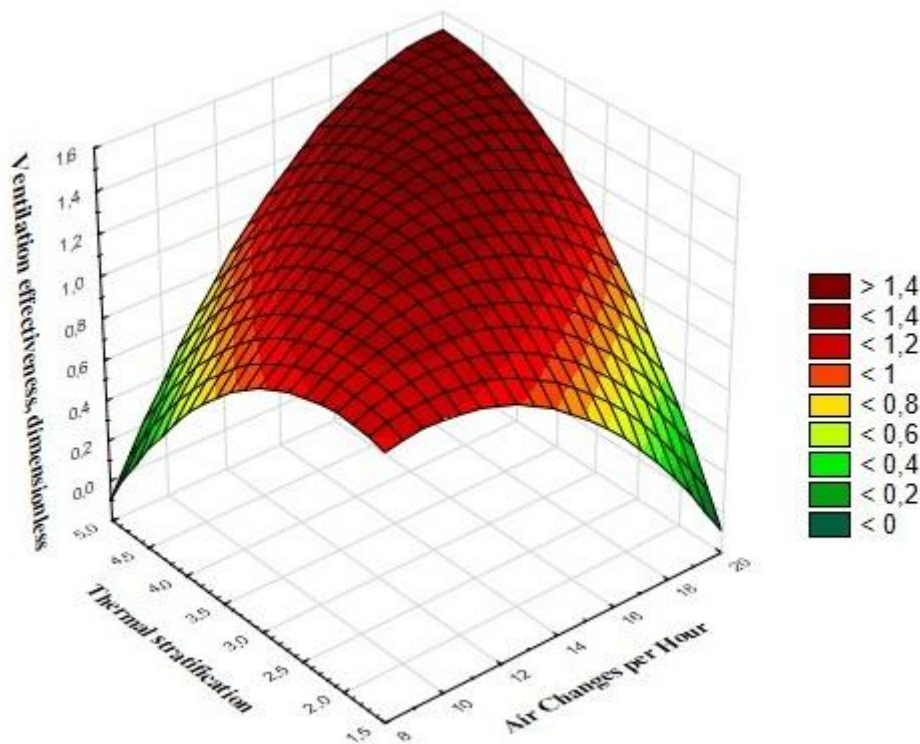


Fig. 1. 3D Surface of Ventilation Effectiveness as a Function of Thermal Stratification and Air Change Rate in Cleanroom Green Construction

X-axis: ACH, h^{-1} (Air Changes per Hour)

Y-axis: ΔT , $^{\circ}\text{C}$ (Thermal stratification)

Z-axis: ε_v (Ventilation effectiveness, dimensionless)

Conclusions. The analysis of displacement ventilation in cleanroom environments under green construction conditions demonstrates clear interdependence between airflow intensity, thermal stratification, and ventilation effectiveness. Data indicate that microclimate parameters respond nonlinearly to changes in supply airflow: moderate increases in ACH improve contaminant removal due to enhanced vertical transport, while excessive airflow can weaken stratification and locally reduce ventilation efficiency. Thermal stratification (ΔT) plays a key role in maintaining effective airflow organization, ensuring that

contaminants are efficiently transported from the occupied zone to exhaust outlets.

The 3D visualization confirms these trends, providing insight into optimal operating ranges where ventilation effectiveness is maximized without unnecessary energy expenditure. This approach highlights the practical significance of displacement ventilation for energy-efficient cleanroom design, balancing environmental stability, indoor air quality, and energy consumption. The methodology combining thermal, ventilation, and contaminant removal models proves to be a robust framework for microclimate analysis and optimization in modern cleanroom applications.

REFERENCES

1. Cheng, Z., Wang, J., Zhang, Z., Wang, H. S., Lu, Y., Mu, Z., Liu, J., & Lin, Z. (2026). Minimal modification to displacement ventilation for significant improvement through air redistribution. *Building and Environment*, 291, 114254. <https://doi.org/10.1016/j.buildenv.2026.114254>
2. Hatif, I. H., Wong, K. Y., Al-Rikabi, I. J., Tan, H., Kek, H. Y., Hawas, M. N., Zhang, M., Zhang, J., & Cai, T. (2025). A multi-criteria CFD investigation of mixing, displacement, and stratum ventilation: Trade-offs between energy efficiency, thermal comfort, and airborne infection control. *Building and Environment*, 289, 114042. <https://doi.org/10.1016/j.buildenv.2025.114042>.
3. Loomans, M., Ludlage, T., Van Den Oever, H., Molenaar, P., Kort, H., & Joosten, P. (2020). Experimental investigation into cleanroom contamination build-up when applying reduced ventilation and pressure hierarchy conditions as part of demand controlled filtration. *Building and Environment*, 176, 106861. <https://doi.org/10.1016/j.buildenv.2020.106861>
4. Lu, Y., Huang, J., Wagner, D. N., Lin, Z., Jung, N., & Boor, B. E. (2024). The influence of displacement ventilation on indoor carbon dioxide exposure and ventilation efficiency in a living laboratory open-plan office. *Building and Environment*, 256, 111468. <https://doi.org/10.1016/j.buildenv.2024.111468>
5. Tognon, G., & Zarrella, A. (2024). Displacement ventilation: A systematic review of the interactions with indoor environment and simplified modelling approaches. *Journal of Building Engineering*, 96, 110474. <https://doi.org/10.1016/j.jobbe.2024.110474>
6. Wu, Z., & Li, Y. (2025). Multi-objective optimization of ventilation in pharmaceutical cleanrooms based on response surface methodology and AHP-entropy weight method. *Energy and Buildings*, 329, 115279. <https://doi.org/10.1016/j.enbuild.2025.115279>
7. Zhao, F., Cheng, J., Liu, B., Huang, Z., & Li, X. (2020). Indoor airflow and pollutant spread inside the cleanroom with micro-porous supplying panel and different ventilation schemes: Analytical, numerical and experimental investigations. *Journal of Building Engineering*, 31, 101405.

<https://doi.org/10.1016/j.jobbe.2020.101405>

8. Zhao, W., Li, H., & Wang, S. (2023). Energy differential-based optimal outdoor air ventilation strategy for high-tech cleanrooms concerning free cooling and its performance evaluation. *Building and Environment*, 231, 110025. <https://doi.org/10.1016/j.buildenv.2023.110025>

GREEN TECHNOLOGIES, AS A MEANS OF ENGINEERING MASKING

Svitlana Verkalets

University King Danulo, svitlana.verkalets@ukd.edu.ua

In modern conditions of construction development and the growing threats to critical infrastructure, the issue of reducing the visibility of objects is becoming increasingly important. Traditionally, camouflage has been considered a component of military engineering; however, today it is increasingly being integrated into civil construction. At the same time, the concept of green building is actively developing, which involves the use of natural components such as vegetation and soil to improve the energy efficiency and environmental friendliness of buildings. The combination of these two approaches makes it possible to consider green technologies not only as an environmental tool but also as an effective means of engineering camouflage that reduces the visual and thermal visibility of objects.

The construction of a green building begins with an analysis of its location. The main principle of modern technologies is related to the harmonization of the building with the surrounding infrastructure and environment. In green construction, the key principles are compactness and efficiency of space, energy autonomy, self-cleaning systems, and a stable air and water balance. In other words, a green building is self-sustaining and remains in balance with nature.

It should be noted that green construction is based on the implementation of a complex of functional, planning, engineering, and structural solutions that allow reducing energy consumption. At the same time, the occupants of the building are guaranteed sanitary, epidemiological, and environmental safety [1].

The integration of greening systems, in particular green roofs and green walls, is currently an important component of modern urban development, as it is directly related to energy efficiency and sustainable development principles. Such natural solutions significantly improve the thermal performance of buildings and reduce energy consumption. At the same time, the effectiveness of these systems depends on their structural features as well as on variable physical and thermal properties, which complicates their research and implementation [2].

The practice of implementing green roofs in different countries has its own characteristics, but there are also common principles. In particular, when selecting plants, preference should be given to local species that are well adapted to the

climatic conditions of a specific region. In addition, the presence of an appropriate regulatory and legal framework plays an important role, as it stimulates the development and implementation of such technologies [3].

Green walls and facades created from plants growing in soil require regular maintenance, particularly to maintain the correct direction of growth. During periods of prolonged drought, additional irrigation may be required. If more complex vertical greening systems with automatic irrigation are used, they require constant professional maintenance [4].

Today, construction companies are actively implementing modern technologies that contribute not only to improving the quality and speed of construction work but also to reducing the negative impact on the environment. The main focus is on the use of environmentally friendly and energy-efficient solutions. One of the important areas is the use of renewable energy sources, particularly solar panels. They allow converting solar energy into electricity without harmful emissions into the environment. Unlike traditional energy sources such as coal, gas, or nuclear energy, solar energy is practically inexhaustible and much safer for the environment. Recycled materials such as recycled wood, glass, concrete, and plastic are also widely used in modern construction. This helps to reduce waste and lower construction costs. At the same time, the characteristics of materials, such as environmental friendliness, level of harmful emissions, durability, and the possibility of reuse, play an important role.

An important element is the implementation of energy-efficient solutions, including modern heating systems, facade insulation, and smart home technologies. These solutions significantly reduce energy consumption and increase living comfort. Special attention is also paid to the rational use of water resources. For this purpose, rainwater collection systems, water purification and reuse technologies, and special sensors for monitoring water consumption are installed. This helps to reduce freshwater consumption, which is important on a global scale. In addition, territory planning and landscaping are essential aspects. The placement of residential complexes away from major transport highways and the creation of green zones help to reduce noise levels and improve the quality of life. Trees and vegetation can significantly reduce noise pollution, acting as a natural barrier [1].

Camouflage is an important element of engineering support, the purpose of which is to reduce the visibility of objects and mislead the enemy about their location, purpose, and nature of use. In modern conditions, this is particularly relevant due to the development of surveillance technologies, including drones, satellites, and thermal imaging equipment. In the context of construction, camouflage is aimed at reducing the visual visibility of buildings, lowering thermal radiation, and integrating objects into the natural environment. Objects of camouflage may include individual buildings, entire complexes, engineering systems, or infrastructure elements.

In modern construction, the main methods of camouflage are concealment and deception. Concealment involves reducing or completely eliminating the revealing features of an object. In construction, this is achieved through the use of natural and engineering solutions, particularly green technologies. The main means of concealment include the use of green roofs and facades that allow buildings to blend with the natural environment, the use of vegetation to reduce visual contrast between the building and the surroundings, the reduction of thermal radiation due to soil and vegetation layers that perform a thermal insulation function, the rational placement of buildings taking into account natural landscape conditions, and the use of natural materials close to the characteristics of the surrounding environment. Thus, green technologies actually perform the function of natural camouflage, reducing both visual and thermal visibility of the object.

Another important method of camouflage is deception, which involves creating a false impression of an object. In construction, this principle can be implemented through the creation of green zones that conceal the real boundaries and structure of the object, the use of landscaping to change the external appearance of buildings, the combination of green technologies with other camouflage methods such as coloring or architectural solutions, and the imitation of the natural environment through landscape design. Such measures make it possible not only to conceal the object but also to create a false impression of its size, shape, or purpose.

Therefore, green technologies can be considered an effective means of engineering camouflage, as they provide both concealment and partial deception through the integration of objects into the natural environment. The use of green roofs, facades, and landscape greening significantly reduces the visual and thermal visibility of buildings. The combination of green building principles and engineering camouflage opens new opportunities for creating energy-efficient, environmentally friendly, and less visible objects, which is especially relevant for both civil and defense construction [5].

REFERENCES

1. Green technologies in construction: UKR-STANDART / Ukraine-Standart. URL: <https://ukraine-standart.com.ua/ua/news/zelenye-tehnologii-v-stroitelstve-ustojchivoe-budushhee.html> (accessed: 16.03.2026).
2. Integrating green roofs and green walls to enhance buildings thermal performance. ScienceDirect. URL: <https://www.sciencedirect.com/science/article/abs/pii/S036013232500006X> (accessed: 16.03.2026).
3. Green walls and facades as an element of ecological architecture: theory and practice. Bulletin of Taras Shevchenko National University of Kyiv. Ecology. URL: https://journals.urau.ua/visnuk_khnu_ecology/article/view/284331 (accessed: 16.03.2026).

4. Green walls and facades. WWF Ukraine. URL: <https://nbs.wwf.ua/solutions/zeleni-stiny-ta-fasady/> (accessed: 16.03.2026).

5. Camouflage of troops and objects: protection against precision weapons. URL: <https://jurkniga.ua/contents/maskuvannya-viysk-ta-objektiv-zakhist-vid-visokotochnoi-zbroi.pdf> (accessed: 16.03.2026).

THE IMPACT OF COMPACTNESS ON ENERGY EFFICIENCY OF COMPLEX-SHAPED HIGH-RISE BUILDINGS

*Akif Gasimov¹, Nurmammad Mammadov¹, Samira Akbarova¹,
Jamil Guliyev¹*

¹*Azerbaijan University of Architecture and Civil Engineering,
akif.qasimov@azmiu.edu.az, nurmammad.mammadov@azmiu.edu.az,
samira.akbarova@azmiu.edu.az, jamil.guliyev@azmiu.edu.az*

1. Introduction. High-rise multifunctional buildings are among the most energy- and resource-intensive building types. Their thermal envelope serves as the primary barrier between the controlled internal environment and external climatic conditions [1]. Among the geometric parameters affecting envelope energy performance, compactness plays a key role [2].

This study aims to evaluate compactness indicators in accordance with EN ISO 52016-1:2017 and EN ISO 13789:2017 for Flame towers, Baku, Azerbaijan, to determine their quantitative impact on the characteristics of the thermal envelope and to develop substantiated recommendations for compensating heat losses.

2. Materials and Methods. Flame towers (2007–2013), located on a hill in the historic center of Baku at an altitude of approximately 50 meters above the Caspian Sea, are an ensemble of three flame-shaped, curvilinear towers. The towers' shape creates a geometrically complex envelope, significantly complicating indoor climate control. The three towers are erected in a triangular configuration on a shared podium of 28000 m². The main structural characteristics are presented in Table 1, according to HOK, Lerch. Bates, Priedemann, authors' calculations.

Table 1

Main architectural and morphological parameters

Parameter	Residential	Hotel	Office	Total/Avg.
Height H, m	190	160	140	163
Number floors	39	33	29	101
Area of the base A_{base} , m ²	≈ 1100	≈ 950	≈ 850	≈ 2900
Facade area A_{env} , m ²	≈ 25200	≈ 22900	≈ 21700	≈ 69800
Construction volume V_e , m ³	≈ 209000	≈ 152000	≈ 119000	≈ 480000*

Parameter	Residential	Hotel	Office	Total/Avg.
Glass shell, %	≈ 91	≈ 92	≈ 92	≈ 92

The value $V_e \approx 480000 \text{ m}^3$ in Table 1 is given for external dimensions without taking into account the form factor ϕ (raw construction volume); the calculated conditioned volume taking into account ϕ is 411900 m^3 .

Baku (Azerbaijan) is characterized by a challenging climate: a semi-arid climate, an average annual temperature of $14\text{--}15^\circ\text{C}$, precipitation less than 225 mm/year , persistent strong winds—khazri (northern, up to 35 m/s) and gilavar (southern, up to 22 m/s), and $2200\text{--}2500$ hours of sunshine per year. The average monthly temperature in January is 4.3°C , in July–August— 26.4°C ; the absolute maximum is $+43^\circ\text{C}$ (record 2021); relative humidity is $60\text{--}80\%$. Significant differences in wind loads between seasons and their high inter-day variability necessitate calculating the dynamic stability of the building's microclimate.

Calculation indicators. Basic formula for the compactness coefficient (Surface - to - Volume Ratio, SVR) according to EN ISO 52016-1:2017, §7.2 [3]:

$$f = A_{env} / V_e, \text{ m}^{-1} \quad (1)$$

A_{env} - total area of the thermal envelope, m^2 ; V_e - heated/conditioned volume by external dimensions, m^3 . The higher f , the more intense the heat exchange through the envelope, all other things being equal.

Standardization according to EN establishes that the heat loss transmission coefficient is related to f by the formula [4]:

$$H_{tr} = \Sigma(A_k U_k) + \Sigma(\Psi_j l_j) + \Sigma(\chi_p), \text{ W/K} \quad (2)$$

A_k - area of the k -th shell element; U_k - heat transfer coefficient; Ψ_j - linear thermal bridge; l_j - length of the thermal bridge; χ_p - point thermal bridge. For a fixed U -value, H_{tr} is directly proportional to A_{env} .

Dimensionless Heat Loss Form Factor, H_{LFF} , by Passivhaus Institut/NHBC 2016 [5]:

$$H_{LFF} = A_{env} / A_{NFA} \quad (3)$$

A_{NFA} - net usable area of conditioned floors, m^2 . PHI requirement: $H_{LFF} \leq 3.0$ for a passive house. H_{LFF} is insensitive to the height scale effect and allows for accurate comparison of the compactness of buildings of different scales.

Normalized dimensionless compactness index CR (Compactness Ratio) by [6]:

$$CR = S / S_{min}, \text{ where } S_{min} = 6 \cdot V^{2/3} \quad (4)$$

S - real area of the shell; S_{min} - minimum area of the shell of a cube of the same volume. $CR = 1.0$ corresponds to a cube (theoretical optimum); $CR > 1$ indicates non-compactness. For a sphere $CR \approx 0.806$; for a cylinder with $H = D$: $CR \approx 1.08$; for rectangular plans of typical towers $CR = 1.05\text{--}1.12$; curvilinear flame-shaped plans give $CR = 1.15\text{--}1.25$.

Auxiliary correction coefficient of facade geometry K_{geom} for quantitative assessment of excess area of a curved shell:

$$K_{geom} = A_{env,real}/A_{env,rect} \quad (5)$$

$A_{env,rect}$ — the area of the shell of a rectangular building of the same volume and height. For Flame Towers $K_{geom} \approx 1.17\text{--}1.22$.

3. Results. Calculation of compactness indicators. The area of the thermal envelope A_{env} of each tower consists of three components:

$$A_{env} = A_{facade} + A_{roof} + A_{floor}, m^2 \quad (6)$$

A_{facade} - total area of the external glazing and walls; A_{roof} - covering of the tower; A_{floor} - floor above the podium/ground. Of the 64000 m² total façade surface of the three towers (data from Priedemann Facade Experts) shares are distributed according to the perimeter and height of each tower.

Table 2

Components of the thermal envelope area

Component shells	Living space, m ²	Hotel, m ²	Office, m ²	Σ towers
A_{facade} (side walls + stained glass)	23000	21000	20000	64000
A_{roof} (upper overlap)	1 100	950	850	2900
A_{floor} (floor above the podium)	1 100	950	850	2900
A_{env} (total)	25200	22900	21700	69800

The heated volume is determined by external dimensions according to EN ISO 52016-1:2017, §7.2. For curved towers, the average cross-section at the base, multiplied by the external height, is used; the stepped tapering towards the top is taken into account by the form factor φ :

$$V_e = A_{base} H \varphi, m^3 \quad (7)$$

Table 3

Calculation of the heated volume of Flame towers

Parameter	Residential	Hotel	Office	Note
A_{base}, m^2	1 100	950	850	By general plan
H, m	190	160	140	By certificate
Coefficient φ shapes	0.85	0.86	0.87	Narrowing upwards
$V_e = A H \varphi, m^3$	177650	130720	103530	411 900 (Σ)**

** The discrepancy with the V_e sum in Table 1 (≈ 480000 m³) is explained by the fact that Table 1 shows the raw construction volume by external dimensions (without φ), used for preliminary estimates. The calculated conditioned volume taking into account φ is 411900 m³ and is used in all subsequent calculations.

Table 4

Summary indicators of compactness (according to formulas 1, 3–5)

Tower	A_{env}, m^2	V_e, m^3	f, m^{-1}	H_{LFF}	S_{min}, m^2	CR	Grade
Residential, 190 m	25200	177650	0.142	0.691	1.33	Moderately non-compact	25,200
Hotel, 160 m	22900	130720	0.175	0.859	1.48	Not compact	22,900

Tower	A_{env}, m^2	V_e, m^3	f, m^{-1}	H_{LFF}	S_{min}, m^2	CR	Grade
Office, 140 m	21700	103530	0.210	1,036	1.67	Strongly non-compact	21,700
Standard cube CR=1	—	103–178 thousand	0.11–0.18	< 0.60	1,000	Optimum	—

4. Discussion. Despite the low absolute SVR value ($0.142\text{--}0.210\text{ m}^{-1}$) due to the scale effect of height, the normalized CR index significantly exceeds 1.0, reaching 1.67 for the office tower. This means that the flame-shaped form creates a 33–67% larger thermal envelope compared to the theoretically optimal cubic form of the same volume [7,8]. The scale effect automatically reduces the SVR with increasing height and masks the actual redundancy of the envelope—this is why CR is a more informative indicator when comparing buildings with different heights [9–11]. To contextualize the obtained values, Table 5 provides a comparison of compactness indices. Towers with other high-rise buildings of different climatic zones.

Table 5

Comparative indicators of compactness

Building/type	H, m	Form	f, m^{-1}	H_{LFF}	CR
Flame Towers (residential)	190	Flame	0.142	0.691	1.33
Flame Towers (hotel)	160	Flame	0.175	0.859	1.48
Flame Towers (office)	140	Flame	0.210	1.036	1.67
Typical skyscraper (prism)	150	Rectangular	0.160	0.65	1.08
Empire State Building	443	Stepped	0.09	0.42	1.18
Burj Khalifa (main body)	828	Y- plan	0.06	0.28	1.12
Standard cube $V=150000\text{ m}^3$	—	Cube	0.17	0.50	1,000

From Table 5 it follows that the Flame office tower The Towers have a CR of 1.67—the highest value among the listed buildings. This is explained by the combination of a relatively low height 140 m and an aerodynamically complex flame-shaped plan. For comparison, the Y-shaped plan of the Burj Khalifa, also geometrically non-compact, is compensated by its colossal height 828 m, reducing f to 0.06 m^{-1} .

5. Recommendations for compensating for suboptimal CR. Since the architectural shape of the towers cannot be changed, the negative impact of high CR is mitigated by improving the thermal and wind protection properties of the envelope. The key measure is to reduce the U-value to a level that compensates for the geometric redundancy A_{env} :

$$U_{comp} = U_{standard} / CR, W / (m^2 K) \quad (8)$$

For CR=1.33 with $U_{standard}=1.1\text{ W}/(m^2\text{ K})$: $U_{comp}=1.1/1.33 \approx 0.83\text{ W}/(m^2\text{ K})$ — triple low-e glazing. For CR=1.67: $U_{comp}=1.1/1.67 \approx 0.66\text{ W}/(m^2\text{ K})$ — triple glazing with argon/krypton filling.

Practical solutions for increasing the thermal efficiency of the envelope:

triple low-e glazing with $U_{gl} \approx 0.6\text{--}0.8 \text{ W}/(\text{m}^2 \text{ K})$; automatic sun blinds on SE – SW orientations; atrium buffer zones on typical floors; ventilated double facades with controlled convection. The optimal orientation of the tower triangle is with the apex opposite the prevailing khazri (N – NE). This provides aerodynamic shielding for the two rear towers and reduces wind speed at the base by 20–30%, according to CFD calculations for similar configurations [5]. A center-to-center distance of 30–40 m allows for the management of wind corridors at the podium level. Passive measures: highly reflective roof coverings (albedo ≥ 0.70) reducing heat gain in summer by 8–12%; green podium and water surfaces reducing the average radiant temperature near pedestrians by 3–5°C; 3–4m high wind protection screens around the perimeter of public areas of the podium, ensuring wind speeds near the ground below 14 m/s (Beaufort scale, 7 points).

6. Conclusion. The study calculated the compactness indicators of the Flame towers complex thermal shell (Baku) in accordance with EN ISO 52016-1:2017 and EN ISO 13789:2017. Key results:

1. SVR ($0.142\text{--}0.210 \text{ m}^{-1}$) is within the range typical for high-rise buildings of this height. However, the normalized CR of 1.33–1.67 indicates a geometric non-compactness 33–67% higher than the theoretical optimum—a consequence of the scale effect, which automatically reduces the SVR with increasing height and masks the actual redundancy of the envelope.

2. The flame-shaped shape of the towers increases A_{env} by 17–22% compared to a rectangular analogue of the same volume, increasing transmission heat losses $H_{tr} = 23\text{--}28 \text{ kW/K}$.

3. Baku's seasonal climate imbalance (summer overheating and winter blowdown) is exacerbated by high CR, creating a sustained load on HVAC systems in both modes.

4. Compensation for the suboptimal CR is ensured by façade engineering: $U_{comp} \leq 0.66\text{--}0.83 \text{ W}/(\text{m}^2 \text{ K})$ on the towers, triple low-e glazing, automatic sun protection systems, aerodynamic orientation of the complex with the apex of the triangle against the khazri.

REFERENCES

1. Mammadov N., Akbarova S. Tasks for implementation of building energy passportization process. *International Journal on Technical and Physical Problems of Engineering*. 2024. Vol. 16, No. 2. Pp. 349–355.
2. Akbarova S., Avramenko Y. Thermo-technical issues of ventilated facades in Azerbaijan. *Lecture Notes in Civil Engineering*. 2022. Vol. 181. Pp. 35–42.
3. EN ISO 52016-1:2017. Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads. Geneva: ISO, 2017. 244 p.
4. EN ISO 13789:2017. Thermal performance of buildings — Transmission and ventilation heat transfer coefficients. Geneva: ISO, 2017. 28 p.

5. Passivhaus Institute; NHBC Foundation. Heat Loss Form Factor guidance. Darmstadt; Milton Keynes: PHI; NHBC Foundation, 2016. 52 p.
6. Ciardiello A., Rosso F. Multi-objective approach to the optimization of shape and envelope in building energy design. Royal Society Open Science. 2020. Vol. 7, No. 2. P. 1–19.
7. Mostafavi S., Alborzi M. Wind-induced pressure on triangular tower clusters: CFD study. Journal of Wind Engineering and Industrial Aerodynamics. 2020. Vol. 199. P. 1–14.
8. Avramenko Y., Yurin O., Akbarova S., Zyhun A., Zadorozhnikova I. Investigation of the moisture condition of the outer wall at the junction of the brick pilasters to the wall. Lecture Notes in Civil Engineering. 2023. Vol. 299. Pp. 13–23.
9. Mammadov N., Akbarova S. Analysis of thermal stability of the wall enclosing structure of building for climatic conditions. International Journal on Technical and Physical Problems of Engineering. 2024.
10. Avramenko Y., Zyhun A., Akbarova S., Yurin O. Stability of thin-walled steel elements of composite steel and concrete structures. Lecture Notes in Civil Engineering. 2022. Vol. 181. Pp. 3–13.
11. Mammadov N., Akbarova S. Research areas on transition to renewable energy sources in bibliographic publications. Bio Web of Conferences. 2025. Vol. 151. P. 02007.

RESILIENCE OF UKRAINE'S WATER SYSTEMS IN WARTIME

Oleksandra Kovalska¹, Olena Mitryasova¹

*¹Petro Mohyla Black Sea National University,
alexandraschwarz2313@gmail.com, eco-terra@ukr.net*

Water resources under conditions of armed conflict cease to function as a stable component of the natural environment, as they are transformed into a dynamic and vulnerable element of ecosystems that rapidly responds to physical, chemical, technogenic, and hydrodynamic disturbances caused by military activities. This is particularly evident in the case of Ukraine after 2014 and during the full-scale war since 2022 [1–3].

In contrast to peacetime conditions, when the primary pressures on water resources stem from industry, agriculture, and urbanization, armed conflicts are characterized by the dominance of factors such as the sudden destruction of hydraulic infrastructure, uncontrolled releases of pollutants, abrupt alterations in hydrological regimes, and disruption of natural self-purification processes in water bodies. These impacts result in sharp, non-linear changes in the functioning of aquatic ecosystems [4, 5].

One of the most large-scale examples is the destruction of the Kakhovka Hydropower Plant in June 2023, which caused the sudden release of

approximately 18 km³ of water, leading to the flooding of more than 600 km² of territories, a rapid decline in the reservoir water level, and a transformation of the hydrological regime of the lower Dnipro River [6, 7].

This event triggered two simultaneous and contrasting ecological processes: the degradation of aquatic ecosystems within the exposed reservoir area and hydrodynamic stress within the flooded zone, where intensive leaching of organic matter, soils, and toxic substances into the aquatic environment was observed. During the first weeks after the destruction, the concentration of suspended solids in the lower Dnipro exceeded background levels by 5–8 times, indicating intensified erosion processes and secondary pollution [8,9].

Table 1 summarizes the main types of impacts of military activities on water resources, classified by source, nature of environmental consequences, and temporal scale of manifestation (Table 1).

As shown in Table 1, these impacts differ in nature but interact with one another, forming complex environmental consequences that significantly complicate their prediction and management. For example, hydrodynamic changes can intensify chemical pollution through the resuspension of bottom sediments, as observed following the destruction of the Kakhovka Reservoir [6–8]. An additional factor was the release of bottom sediments that had accumulated heavy metals over decades, including cadmium, lead, and mercury, leading to their reintroduction into biogeochemical cycles [9–11].

It is important to emphasize that the concentration of pollutants in water is determined by the ratio between the mass of contaminants and the volume of water, which can be described by the simplified relationship $C = \frac{M}{V}$, where C is the concentration of a substance, M is the mass of the pollutant, and V is the volume of water. The sharp decrease in water volume in the reservoir after the dam destruction led to a local increase in the concentration of toxic substances [10, 11]. Another example is the damage to the “Dnipro–Mykolaiv” water supply system in 2022, which not only caused a shortage of freshwater but also necessitated the use of alternative sources with elevated mineralization levels. This, in turn, affected groundwater and led to soil salinization in adjacent ecosystems [6, 12, 13].

Table 1

Major Types of Impacts of Armed Conflict on Water Resources and Their Environmental Consequences

Type of Impact	Source	Environmental Consequences	Time Horizon
Hydrodynamic (sudden changes in water levels)	Destruction of dams and reservoirs	Alteration of channel processes, bank erosion, disruption of hydrological regimes	Short- to medium-term
Chemical pollution	Explosives, fuels and lubricants, industrial	Water toxicity, accumulation of	Medium- to long-term

Type of Impact	Source	Environmental Consequences	Time Horizon
	accidents	heavy metals, bioaccumulation	
Geochemical impact	Flooding of mines, release of bottom sediments	Increased mineralization	Long-term
Biological impact	Eutrophication, alteration of trophic chains	Algal blooms, oxygen depletion, mortality of aquatic organisms	Medium-term
Hydroecological impact	Destruction of water infrastructure	Disruption of water exchange, reduced self-purification capacity of ecosystems	Short- to long-term

Under such conditions, the water–salt balance is altered and can be described by the equation $\Delta S = (S_{in} - S_{out})$, where ΔS represents the change in salt balance, S_{in} is the input of salts, and S_{out} is their removal. Under conditions of limited water exchange, salts tend to accumulate within the system [14–15]. This phenomenon has long-term consequences, as soil salinization reduces water retention capacity and disrupts vegetation cover, which in turn affects the hydrological cycle through changes in infiltration and evaporation processes. Thus, the presented systematization not only structures the diverse impacts of military activities on water resources but also highlights the need for an integrated approach to their assessment and management, which is critically important for ensuring environmental security under contemporary challenges.

However, beyond generalized impacts, specific case studies are of particular value for analysis, as they allow for tracing cause-and-effect relationships between military actions and transformations of water systems. A synthesis of such cases for Ukraine is presented in Table 2, which highlights the most illustrative examples of water resource disruption, their causes, and environmental consequences (Table 2).

As shown in Table 2, most of the recorded impacts are of a combined nature and simultaneously involve multiple environmental processes, which significantly complicates their localization and mitigation. For instance, the flooding of mines in the Donbas region has led not only to increased water mineralization but also to changes in redox conditions within aquifers, which activates the mobilization of heavy metals and renders the contamination nearly irreversible in the short term [16–18]. Similarly, the destruction of the Kakhovka Hydropower Plant acted as a trigger for cascading changes, ranging from hydrological to biological processes, thereby confirming the systemic nature of the impact of military activities on water resources.

Table 2

Major Case Studies of the Impact of Military Activities on Water Resources in Ukraine

Location / Object	Year	Type of Impact	Cause	Environmental Consequences	Long-term Effect
Kakhovka Reservoir	2023	Hydro-dynamic, chemical	Destruction of the HPP dam	Flooding of territories, spread of pollutants, biota mortality	Ecosystem degradation, alteration of channel processes
Dnipro River (lower reach)	2023	Hydro-ecological	Flow alteration after HPP destruction	Increased turbidity, bank erosion	Biodiversity disruption
“Dnipro–Mykolaiv” water supply system	2022	Infra-structural	Damage to the water supply system	Freshwater shortage, use of brackish water	Soil salinization
Donbas (mine waters)	2014 - 2024	Geo-chemical	Flooding of mines	Discharge of mineralized waters, river contamination	Persistent deterioration of groundwater quality
Siverskyi Donets River	2022 - 2023	Chemical	Military activities, destruction of facilities	Influx of toxic substances, decline in water quality	Long-term ecosystem contamination
Azov coastal area	2022 - 2024	Biological, chemical	Pollution and hydrological alterations	Mortality of marine organisms, eutrophication	Reduced ecosystem productivity

For a deeper understanding of the mechanisms driving the transformation of water systems, it is advisable to present a generalized conceptual framework illustrating the interaction of impact factors, which demonstrates the sequence of environmental changes (Fig. 1).

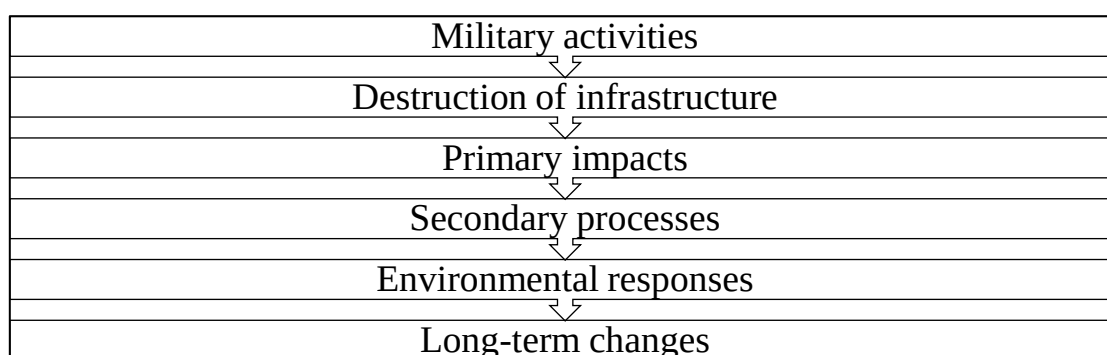


Figure 1. Transformation of Aquatic Ecosystems under the Impact of Military Activities

The proposed scheme demonstrates that the impact of military activities is not a single-stage process but rather a chain of interrelated reactions, where each subsequent stage amplifies the previous one. This implies that even localized destruction can result in large-scale environmental consequences due to cumulative effects. In this context, effective water resource management should account not only for direct losses of water or infrastructure but also for secondary processes, which are often more critical in terms of long-term impacts [16–19].

Under conditions of armed conflict, traditional approaches to water resource management lose their effectiveness, as they are designed for relatively stable systems and do not account for abrupt changes in hydrological and environmental parameters. Therefore, the development of an adaptive water resource management model is essential. Such a model considers both direct and indirect environmental risks associated with military activities and enables the minimization of their long-term consequences. This model is based on the principles of integrated water resources management, complemented by elements of crisis response and environmental adaptation [20–24]. It reflects the cyclical nature of management, where continuous monitoring and feedback play a key role, allowing management decisions to be adjusted to rapidly changing conditions. An important feature of this model is the integration of environmental indicators into the decision-making process, ensuring a focus not only on the technical restoration of water supply systems but also on maintaining the ecological functionality of aquatic systems (Fig. 2).

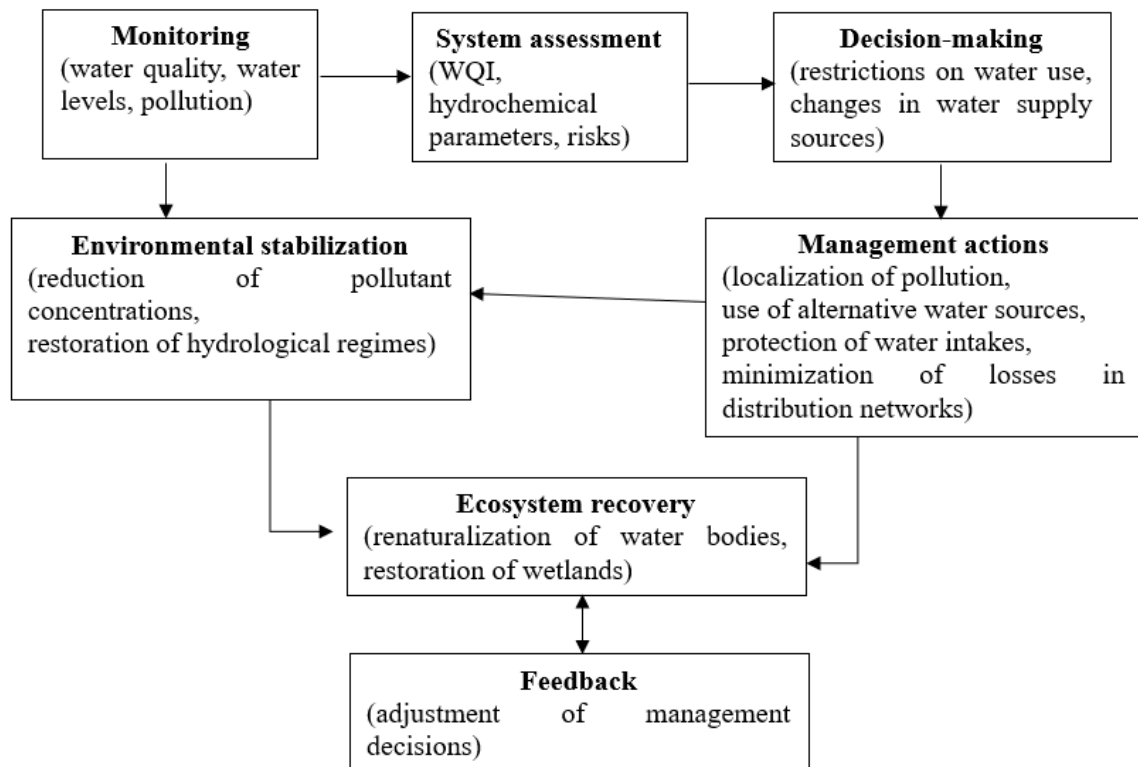


Figure 2. Adaptive Water Resource Management Model under Conditions of Armed Conflict

Thus, the proposed adaptive model enables not only a response to the consequences of military activities but also the reduction of their environmental impact through timely and well-informed decision-making, which is critically important for the long-term preservation of water resources and ecosystems.

REFERENCES

1. Gleick P. H. Water and conflict: Fresh water resources and international security // International Security. 1993. Vol. 18, No. 1. P. 79–112.
2. Water, security and peace. Paris : UNESCO Publishing, 2019. 184 p.
3. Environmental impacts of armed conflicts: a review. Nairobi: UNEP, 2009. 32 p.
4. Ukraine: Environmental impact assessment (preliminary review). Nairobi : UNEP, 2023.
5. Environmental impacts of the war in Ukraine and prospects for a green reconstruction. Paris: OECD Publishing, 2023.
6. Ukraine Rapid Damage and Needs Assessment: February 2022 – February 2023. Washington, DC: World Bank, 2023.
7. National Report on the State of the Environment in Ukraine in 2023. Kyiv, 2024.
8. Environmental consequences of the Kakhovka dam destruction. UNEP, 2023.
9. Chapman D. Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring. 2nd ed. London: E & FN Spon, 1996. 626 p.
10. Guidelines for drinking-water quality. 4th ed. Geneva: WHO, 2017. 541 p.
11. Irrigation and salinity: global review on water management. Rome: FAO, 2017.
12. Ukraine: Armed conflict and damage to critical infrastructure. 2023.
13. Water supply disruptions in Mykolaiv region. 2022.
14. Falkenmark M., Rockström J. Balancing water for humans and nature: The new approach in ecohydrology. London : Earthscan, 2004. 247 p.
15. Assessment of environmental impacts in eastern Ukraine. Vienna: OSCE, 2018.
16. Groundwater contamination and risk assessment. Vienna: IAEA, 2017.
17. Environmental impact of the war in Ukraine: water systems. 2022.
18. Ukraine: Environment and conflict assessment. Geneva, 2022.
19. Explosive remnants of war: environmental and health impacts. Nairobi: UNEP, 2015.
20. European waters: Assessment of status and pressures. Copenhagen: EEA, 2018.
21. Odum E. P., Barrett G. W. Fundamentals of ecology. 5th ed. Belmont: Brooks/Cole, 2005. 598 p.

22. Integrated water resources management. Stockholm : GWP, 2000.
23. Wetlands and water: supporting life, sustaining livelihoods. Gland: Ramsar Secretariat, 2013.
24. Ukraine: Environmental damage caused by Russian aggression. Brussels, 2023.

ENVIRONMENTAL ASPECTS AND THE KANIVSKY HAPP ROLE IN THE UKRAINE ENERGY INDUSTRY

Olena Kotovenko¹, Olena Miroshnychenko¹, Marina Kravchuk²

*¹Kyiv National University of Construction and Architecture,
kotovenko_ea@ukr.net , elenamiroshka@ukr.net*

²PJSC “Ukrhydroenergo”, shuvalovajuliia@gmail.com

Hydraulic accumulative power plants (HAPP) are the most effective tool for energy storage on an industrial scale. It is the HAPP that is the largest energy regulator in the world energy system, providing more than 161,000 MW of storage capacity globally [2]. The operation principle such a station is that it constantly pumps huge volumes of water back and forth between two reservoirs located at different heights.

The construction hydro-accumulating power plants in the existing classic hydroelectric power plants (HPPs) immediate vicinity forming a single hydroelectric node (as in the case of the Kanivska HPP and the planned Kanivska HAPP) is a classic engineering solution that has a deep technical and economic rationale.

The reason for the localization of the HAPP near the operating HPP is the possibility using the existing water reservoir of the channel hydroelectric power plant as a lower reservoir for the hydroaccumulating plant, since the creation artificial reservoirs the necessary volume requires colossal capital investments, large-scale earthworks and the withdrawal significant areas land resources from economic circulation.

In the the Kanivska HAPP case, the function the lower reservoir is performed by the Kanivska Reservoir, created by the existing Kanivska HPP dam. The total volume of this reservoir is 2.6 cubic kilometers, of which the useful (active) volume is 0.3 cubic kilometers. It is planned to use only 0.017 cubic kilometers this volume for the Kaniv HAPP needs, which is absolutely sufficient to ensure uninterrupted operation powerful pump-turbine units without significant impact on the general hydrological regime the Dnieper Cascade [6]. This configuration allows you to focus construction efforts exclusively on the upper artificial reservoir creation an on the adjacent heights (in the village Buchak area) and the pressure water pipelines laying.

The second important reason is how these two types power plants work together. Our energy system needs the production and electricity consumption to

always be in perfect balance every second. Major power plants, such as nuclear power plants (NPPs), operate continuously and cannot rapidly increase or decrease the amount current they produce. At the same time, we increasingly use "green" energy from the sun and wind [3]. But their work depends on the weather and is very uneven (for example, solar stations give the most current during the day). All this creates an additional load on the system and complicates its management.

To avoid such a situation, the HAPP is used — it works like a giant battery that smooths out these differences. At night, when little electricity is consumed, although nuclear plants continue to produce it, or when solar plants give too much energy during the day, HAPP starts to work. Using this excess and cheap electricity, it pumps water from the lower reservoir (the Kaniv Reservoir) into a special pool above [2]. In this way, excess electricity is converted into a water supply, ready for use.

When the demand for electricity increases sharply (most often it happens in the morning and evening) and there is a shortage of current, this accumulated water from the upper basin is directed to the turbines, and the station produces electricity again. Thanks to this, it is possible to cover the morning and evening shortage of energy in the Ukrainian power grid.

In addition, the joint operation of a conventional hydroelectric power plant and a storage power station (HAPP) makes it possible to very conveniently control the voltage and frequency in the entire power grid. Modern turbines (such as those planned to be installed at the Kanivska HAPP) are very fast: they can turn on from rest to maximum power in just a few minutes. This creates a quick and reliable backup in case of accidents. Since water circulation between the upper and lower reservoir will take place in the HAPP, this will allow the HPP to operate efficiently even in dry years, when the water level in the Dnieper falls to critically low levels.

If in the 1980s the Kanivska HAPP was designed as an optimizing element the Union nuclear power industry operation, and in the 2010s as a market balancing tool, today, in the conditions a full-scale war and a course towards European integration, its construction has acquired the critical national necessity status. The benefit that this project the implementation will bring now lies in three strategic planes: fortification-security, infrastructure-balancing and macroeconomic [4].

The most revolutionary argument in favor resuming construction right now is the conceptual change in the station's architecture, due to military realities. Starting in October 2022, Ukraine's energy infrastructure is under constant attack by Russian missile and drone attacks. According to the general director PJSC "Ukrhydroenergo" Igor Syrota, since the full-scale invasion beginning, the company's hydropower facilities have suffered about 120 targeted strikes [1]. As a result, the Kakhovskaya HPP was completely destroyed, the Dniprovskaya HPP was severely damaged, and the Dniester and the operating Kaniv HPPs were also

fired upon. In the absence of anti-aircraft defenses, classic land-based hydroelectric plants with their engine rooms and exposed switchgear proved extremely vulnerable [1].

With this in mind, Ukrhydroenergo made an unprecedented decision to make radical changes to the Kanivska HAPP project and move the main generating capacity (engine room, turbines, generators) underground [5]. Thus, Kanivska HAPP should become the first underground hydro-accumulating power plant in Ukraine, unreachable for damage by modern ballistic missiles and kamikaze drones [1].

This decision is based on the best global experience creating protected energy facilities, for example, in South Korea, where the underground infrastructure placement is dictated by the threat from North Korea.[1] In Ukraine, this concept is already being used to create a classified military factories network, as well as underground schools and hospitals in the frontline regions (Kharkiv, Zaporizhzhia). The underground location the Kanivska HAPP turbine hall will ensure the 1000 MW absolutely protected generating capacity creation.

The second strategic dimension of benefit from the Kanivska HAPP is its absolutely irreplaceable role in the implementation the "green transition". In April 2023, the Ukraine Cabinet Ministers approved the Ukraine Energy Strategy for the period until 2050. The document defines ambitious goals: achieving the share renewable energy sources (RES - solar, wind, bioenergy) in electricity generation at the level 25% already by 2030, with the growth prospect to 80% in the long term for the complete decarbonization of the sector [3].

The problem is that generation from solar and wind power plants (SPP and WPP) is extremely unstable and depends on weather conditions and day time. The SES widespread implementation leads to the special schedule formation when a huge surplus of electricity is generated during the day (which forces the system operator to limit the renewable energy sources generation), and in the evening, with a decrease in solar activity, a sharp deficit occurs, which must be immediately covered by something. According to analytical reports and system balance modeling, for the integration declared volumes RES, the Ukraine energy system critically lacks flexible maneuvering capacities: the estimated need is up to 1.45 GW highly maneuverable generation with the possibility quick start and stop, as well as up to 0.74 GW of energy storage systems (SNE).

The Kaniv HAPP, with its design capacity in 1000 MW, perfectly solves this problem, functioning as the largest "environmental battery" in the region [2]. It is capable consuming excess energy from the SPP during the day to pump water, and in the evening instantly deliver 1 GW of clean energy to the grid. Without the presence such large-scale storage systems, Ukraine will be forced to balance RES with the coal or gas thermal power plants help, which nullifies the very decarbonization meaning, increases carbon dioxide emissions and accelerates the wear and tear the TPP park resource.

In addition, the Kanivska HAPP will ensure the parallel operation stability with the European ENTSO-E grid. Integration with Europe requires strict adherence to electricity quality standards. The station highly maneuverable hydraulic units will provide primary and secondary frequency regulation services, providing a mobile emergency reserve, which is a prerequisite for reliable operation in the single European energy space [4]. Thus, HAPP acts as a technological guarantor of both climate neutrality and Ukraine European energy integration.

The Kanivska HAPP construction is a powerful catalyst for the Ukraine's economy post-war recovery. The project cost is estimated at 1.5–2 billion dollars, which fully meets international standards. These investments will give a huge boost to the national industry: they will load domestic producers of energy equipment, metal structures and cement with orders. In addition, the project will create thousands new high-paying jobs.

The implementation the construction project HAPP will lead to a change in the hydro-ecological conditions in the reservoir ecosystem functioning, in particular, the external water exchange. To the components water balance list includes the water volumes that will be pumped into the upper basin of the HPP and discharged from it into the reservoir.

In work [1] it is noted that the intensity water exchange in the reservoir is spread by approximately 15%. The water in the reservoir changes during 17.4 days (nowadays, the water exchange period is 20 days). Accordingly, this forecast may change, may be adjusted depending on the change in the design indicators of the HAPP capacity. Increasing the reservoir flow rate will affect the internal dynamics of the waters.

During the peak load hours, namely during the operation of the Kyiv and Kaniv HPPs and the HAPP - in the turbine mode, it is planned to significantly increase the water mixing along the right bank. There will be a more active of water masses in the entire water area, including the left bank shallow waters.

As research with the use of mathematical modeling showed, the structure of the current and the water circulation type in the reservoir will be somewhat different. There will be an outflow water from the reservoir, including shallow waters occupied by higher aquatic vegetation. That is, once or twice during the day, water exchange will be activated in almost the entire reservoir. All this will result in a positive impact on water quality.

In the winter period, the simultaneous functioning of the Kaniv hydraulic node complex will be almost the only factor in the dynamic activity water masses, determining the intraday fluctuations the water level throughout the reservoir lake part.

During the spring flood, when the Kyiv and Kanivska HPPs operate in a stable mode, passing their own water flows, the impact of the HAPP will not be too noticeable. The reservoir temperature regime will change significantly only near the HAPP: it will become warmer in the summer and colder in the winter.

The HAPP impact on the Kaniv Reservoir water quality formation will be positive. First of all, this concerns the oxygen regime, which will improve due to increased water exchange and mixing of deep layers of water with surface ones. As a result, water saturation with oxygen and self-cleaning processes is expected.

At the same time, the change in dynamics will lead to the reshaping the soil complex on a fairly significant (30-40 km²) area on the reservoir bottom. Process modeling showed that almost 6 million bottom sediments tons will be washed out from the bottom, which majority (up to 80%) will accumulate in the reservoir part near the dam. All the rest moves to the Kremenchutsk Reservoir [6]

REFERENCES

1. Kanivska HAPP will become the first in Ukraine inaccessible to missile strikes - general director of Ukrghidroenergo - Forbes.ua, <https://forbes.ua/news/kanivska-gaes-stane-pershoyu-v-ukraini-nedosyazhnoyu-dlya-raketnikh-udariv-gendirektor-ukrgidroenergo-16072024-22412>
2. Why are hydraulic accumulative power plants "environmental batteries" of energy systems? - Ukrhydroenergo, https://uhe.gov.ua/media_tsentr/novyny/chomu-haes-tse-ekolohichni-akumulyatory-enerhosystem
3. Capacity increase: synergy of hydropower and solar energy - Ukrhydroenergo, https://uhe.gov.ua/media_tsentr/novyny/zbilshennya-potuzhnostey-sinerhiya-gidroenergetiki-ta-sonyachnoi-energii
4. Hydropower and its role in restructuring the economy of Ukraine - Government Courier, <https://ukurier.gov.ua/uk/articles/gidroenergetika-ta-yiyi-rol-u-perebudovi-/>
5. It will be underground. "Ukrghidroenergo" revealed plans for the Kanivska HAPP, <https://www.rbc.ua/rus/news/bude-pid-zemleyu-ukrgidroenergo-rozkrili-1722428648.html>
6. Timchenko V.M., Galat V.V. The impact of the Kanivskaya HAPP on the ecosystem of the Kanivskaya reservoir //Hydroenergy of Ukraine, 2017. No. 1-2. P. 31-33.

KYIV RESERVOIR ENVIRONMENTAL PROBLEMS

Olena Kotovenko¹, Olena Miroshnychenko¹, Julia Shuvalova²

¹*Kyiv National University of Construction and Architecture,
kotovenko_ea@ukr.net , elenamiroshka@ukr.net*

²*PJSC "Ukrhydroenergo", shuvalovajuliia@gmail.com*

In the Ukraine energy complex, hydroelectric power plants occupy the third place after thermal and nuclear power plants. The total capacity hydroelectric power stations is 8%.

Ecological and technical possibilities using hydropower resources of Ukraine are equal to about 20 billion KWh. The main potential used is concentrated in the hydroelectric power stations of the Dnieper Cascade. The total Dnipro Cascade capacity is 3.8 GW, electricity production is 9.9 GWh.

The Kyiv Hydroelectric Power Station (Kyiv HPP) was put into operation in 1964–1966 and formed the Kyiv Reservoir (Kyiv Sea). Kyiv Reservoir design area was 922 km², its current area is 824 km², its volume is 3.73 km³, its length is 110 km, its width is 96 km. The Kyiv Reservoir provides electricity generation, the Dnipro flow regulation water supply and recreation. [1, 2].

The Kyiv Cascade also includes the Kyiv Hydro Accumulated Electric Power Plant (HAPP) - the first in the Soviet Union, which was built to increase the peak power in the Ukraine unified energy system and promote the thermal and nuclear plants even loading.

The Kyiv HPP construction and operation radically changed the Dnieper natural regime: instead of flowing, it is regulated, with a decrease speed in the current and seasonal fluctuations in the water level.

This caused the flooding and swamping floodplain areas, which are about 10,000 hectares of agricultural land in the reservoirs zones influence, the bank abrasion activation, erosive, suffusion and gravity processes, as well as the relief transformation and engineering and geomorphological conditions of adjacent territories [1,3].

Fluctuations in water levels during the turbines operation and discharges through the dam increase coastal erosion and periodic drainage/flooding of shallow waters, disrupting the dynamic balance coastal systems [3]

Slow water exchange in the Kyiv Reservoir (stagnant regime due to regulation) contributes to the biogenic substances (nitrogen, phosphorus) accumulation from tributaries, wastewater and flooded fertile soils. This leads to the massive of blue-green algae (cyanobacteria) development, which causes the "water bloom" phenomenon, which is especially intense from mid-summer to autumn. The reasons are the flow rate decrease an increase in the transparency and the water warming, an excess fertilizers and detergents.

An international review confirms that the Kyiv Reservoir eutrophication occurs due to both natural factors: floods, abrasion, climate change, and anthropogenic factors: agriculture, urbanization, and military operations. As a result, there is a change in trophic relationships, a decrease in biodiversity, the toxic cyanobacteria appearance, and a deterioration in the water quality for recreation and water use. Flowering is directly related to the hydroelectric power plants operation: 90% of the Dnieper is regulated by dams, which has disturbed the natural hydrological regime [1,4,5].

The reservoir formation caused deposition of sediments, especially in the upper reaches. During the decade of operation, its area decreased due to siltation and shallow waters overgrowth with aquatic vegetation, while the Kyiv Sea area of the decreased from 922 km² to 824 km². Old stumps of flooded forests appear

on the bare bottom. In addition, the silt accumulation reduces the useful volume of the reservoir, impairs hydrodynamics and contributes to secondary pollution. HPPs hydrodynamic processes increase erosion and siltation. [1]

The Dnieper regulation disturbed the migration routes of fish, changed spawning conditions due to fluctuating levels. Invasive fish species (such as grass carp, carp, etc.) have spread in the reservoir, competing with native species. In addition, blooms and lack oxygen in the water cause mass fish death. Changes in the ecosystem also affected the ichthyofauna: there was an increase in small, non-valuable species, and a transformation of the fish population. [1,4]

At the same time, it can be stated that the reservoir acts as a "sink" for pollution. The water quality in the monitoring station, which are located above the Kyiv HPP, has an excess ammonium nitrogen, phosphates, as well as HSK. Dissolved oxygen in most water bodies is satisfactory (7.95–14.05 mgO₂/dm³), but in some places it decreases to 1.92–3.04 mgO₂/dm³ [1].

Radioactive pollution is especially critical, as the Pripjat River carries radionuclides into the Kyiv Reservoir. After the Chernobyl accident, about 5.4×10^{13} Bq/m³ ¹³⁷Cs and 10¹³ Bq/m³ ⁹⁰Sr accumulated in bottom sediments. The risk of secondary radiation pollution increases with floods, dam breaks or dredging [6].

Studies show that the Kyiv Reservoir is the main "sink" for radionuclides: ¹³⁷Cs – since up to 90% of cesium settles here, also only 43% of soluble ⁹⁰Sr reaches the Black Sea. Radionuclides accumulate in bottom sediments, water level fluctuations and erosion can release them [7].

In 2021, the content ⁹⁰Sr in the water of Pripjat (Chernobyl) was up to 100 Bq/m³, ¹³⁷Cs — up to 26 Bq/m³; in closed reservoirs — much higher concentrations [1].

Level fluctuations and erosion under the Kyiv Reservoir influence can release radionuclides accumulated in bottom sediments.

Thus, it can be concluded that the functioning of the Kyiv HPP ensures energy and water security and stability, but causes complex negative environmental consequences: eutrophication, erosion, siltation, loss of biodiversity and accumulation of toxicants. These problems are exacerbated by anthropogenic stress and climate change.

To minimize negative consequences, enhanced monitoring Kyiv Reservoir state and the Dnieper Cascade as a whole, wastewater treatment facilities at enterprises modernization, ecologically safe modes of hydroelectric power stations and programs to restore the Dnieper Cascade ecosystem are necessary.

REFERENCES

1. Ecological passport of the Kyiv region (2023). Ministry of Environmental Protection and Natural Resources of Ukraine, 194 p. <https://mepr.gov.ua/wp-content/uploads/2023/04/Ekologichnyj-pasport-Kyyivska-oblast.pdf>

2. Kyiv Reservoir //Wikipedia .
https://uk.wikipedia.org/wiki/Київське_водосховище
3. Bagmet O. B. The influence Dnieper cascade of reservoirs on the modern geomorphogenesis the surrounding territories // Bulletin of the Kharkiv National University named after V. N. Karazin. "Ecology" series, 2017.
https://journals.urau.ua/visnukkhnu_ecology/article/view/120101
4. The Dnipro Reservoir Expedition investigated the problem of water bloom (2021).
<https://kyivregion.info/2021/09/26/ekspedytsiya-vodoshovyshhamy-dnipradoslidyla-problemu-tsvitinnya-vody>
5. Kurovska A. Eutrophication of the Kyiv reservoir of Ukraine: Review // Bioscience. 2024, т. 15, № 1. С. 61–72.
<https://bioscience.com.ua/en/journals/t-15-1-2024/yevtrofikatsiya-kiyivskogo-vodoskhovishcha-ukrayini-oglyad-pitannya>
6. Kivva S. et al. Modeling of major environmental risks for the Kyiv city, Ukraine from the Dnieper river waters — inundation of coastal areas and contamination by the radionuclides deposited in bottom sediments after the Chornobyl accident // EGU General Assembly 2021. 2021
https://presentations.copernicus.org/EGU21/EGU21-13038_presentation.pdf
7. IAEA. Radiological Conditions in the Dnieper River Basin: Assessment by an international expert team and recommendations for an action plan, Vienna: IAEA, 2006. 200 p. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1230_web.pdf

RESEARCH AND REDUCTION ENVIRONMENTAL RISKS INFLUENCED BY GALVANIC COPPER PLATING TECHNOLOGY

***Olena Kotovenko¹, Olena Miroshnychenko¹,
Maria Nosach¹, Elizaveta Hetman¹***

¹*Kyiv National University of Construction and Architecture,
kotovenko_ea@ukr.net , elenamiroshka@ukr.net, mmrns17@icloud.com,
liza.getman13@gmail.com*

Galvanic technologies are used in many branches of industry: in instrument and mechanical engineering, electronic, electrical engineering, energy, space industries, construction industry. Galvanic coatings make it possible to increase the hardness surface, which makes the product more resistant to mechanical damage, abrasion and metal fatigue, that is, it increases the wear resistance the products. In addition, they can provide products with anti-corrosion and anti-friction properties.

At the same time, the application galvanic technologies cause the emergence of an environmental risk. The use various chemicals, including toxic ones, such as heavy metals, cyanides, organic solvents, causes them to fall into solid, gaseous

and liquid waste. Wastewater from electroplating, for example, is one of the most toxic and harmful to the environment. [1,4]

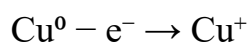
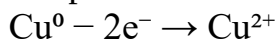
As an example of the galvanic technologies influence, copper plating was studied in the process manufacturing friction discs at the State Enterprise of Powder Metallurgy in Brovary, Kyiv region.

Friction disks are made on the basis powder and metal-ceramic materials. In the production process, both mechanical and chemical-technological operations are used, in particular galvanic copper plating during surface treatment.

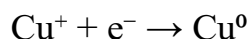
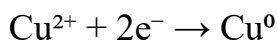
Galvanic copper plating is an important component the manufacturing process friction discs. It ensures the formation an intermediate metal layer, which improves the adhesion between the steel base and the metal-ceramic coating, and also increases the operational properties of the product.

The copper plating process is carried out in special galvanic baths filled with electrolyte. The processed product acts as the cathode, while the anodes are copper plates. Under the action an electric current, an electrochemical reaction dissolution copper from the anode and its deposition on the surface the cathode occurs.

Copper oxidation processes take place at the anode:



Reduction reactions take place at the cathode:



As a result of these processes, a uniform metal layer copper is formed on the surface the steel workpiece.

In the production friction disks, copper plating in cyanide electrolytes is used, which ensures uniformity coating even on complex surfaces products and high-quality adhesion the copper layer to the base metal.

The technological process copper plating includes several successive operations surface preparation and coating.

The first stage is etching, which is carried out in solutions hydrochloric and sulfuric acids at a temperature of 18–25 °C. This process provides removal the oxide film and activation the metal surface. The duration of processing is about 1 minute.

After etching, rinsing is performed in cold running water at a temperature 2–25 °C with a holding time of 0.5–1 minute. This allows you to remove acid residues from the surface products.

The next stage is chemical degreasing, which is carried out in alkaline solutions containing sodium hydroxide, soda ash, trisodium phosphate and other components. The temperature regime the process is 75–95 °C, which ensures effective removal organic impurities.

After degreasing, additional treatment (pickling) is carried out, which includes a short immersion in acid solutions for final cleaning the surface before coating.

The main stage the process — copper plating — is carried out in cyanide electrolytes. The temperature electrolyte is 50–80 °C. The process takes place under the influence an electric current, as a result of which copper ions are deposited on the surface steel billet, forming a uniform coating.

After applying the coating, a lighting operation is performed, which improves the appearance and surface quality the product. [1]

The process of copper plating is accompanied by the formation industrial wastewater, which contains copper ions, cyanide compounds, residues acids and alkalis. In addition, during preparatory operations (degreasing, etching) contaminated solutions are formed that require further cleaning.

Analysis the copper plating impact process showed that the main environmental risk factors this process is the impact on the aquatic environment (fig. 1). Environmental risk means the probability negative changes in the environment, or remote adverse consequences for the environment and (or) population.

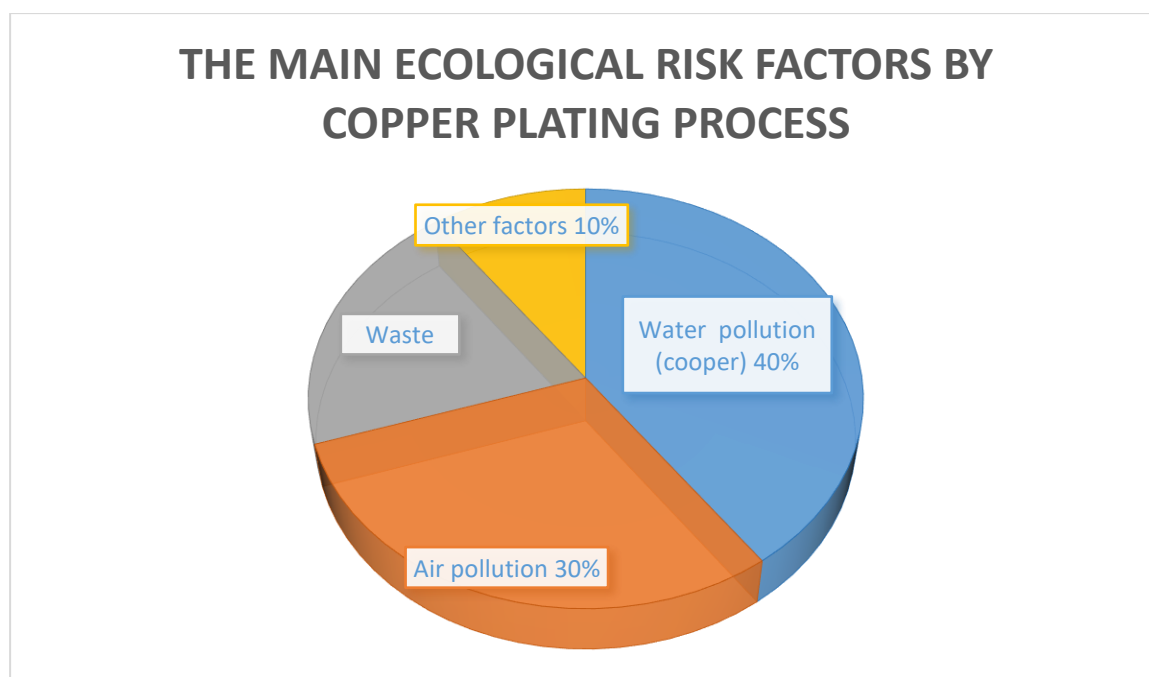


Fig. 1. The main environmental risk factors

The greatest impact on the formation environmental risk is caused by the pollution of water resources, which is associated with the possible ingress of copper compounds and cyanide components into the wastewater.

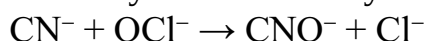
In case of non-compliance with environmental protection requirements, the quality environment may deteriorate, which leads to an increase in the level morbidity population and a decrease in the quality life.[2]

Currently, wastewater treatment involves its preliminary accumulation, physical and chemical treatment to remove copper ions, and further treatment at biological treatment facilities.

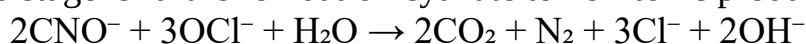
In the process galvanic copper plating, about 108 m³ cyanide-containing wastewater is formed per hour. Currently, the plant uses sodium hypochlorite (NaClO) to destroy cyanides. The process is carried out at a pH of 11.0-11.5 with an initial concentration cyanide ion in the solution of no more than 10.6 g/l. The temperature the working solution during the neutralization process should not exceed 70 ° C.

The process takes place in two stages:

The first stage is the oxidation cyanide ions to cyanate:



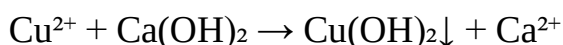
The second stage is further oxidation cyanate to non-toxic products:



As a result these reactions, toxic cyanides are converted into CO₂ and molecular nitrogen N₂, which are non-toxic substances. But in addition, chlorine ions are formed, which can create toxic compounds.

Carrying out this reaction requires strict adherence to technological regulations and safety measures: maintaining a strongly alkaline environment is mandatory to prevent the formation volatile toxic chlorine compounds.

After cyanides neutralization, precipitation of copper ions is carried out in the form of insoluble copper hydroxide by adding alkaline reagents - milk of lime Ca(OH)₂:



The Cu(OH)₂ precipitate formed is separated in settling tanks. Clarified water is sent to biological treatment facilities (BOS) for further treatment, and sludge is transferred to specialized enterprises for disposal.

This technology for decontamination of cyanide-containing effluents uses large-sized reactors, and the reaction proceeds slowly.

The analysis the existing waste water treatment technologies the friction discs production process using galvanic copper plating showed that the safest way to destroy cyanides in waste water is the use ozonation technology, since ozone is a powerful oxidizer that destroys toxic cyanide compounds into less harmful or harmless substances. [3]

Ozonation removes cyanides and heavy metals. The advantages ozonation are its environmental friendliness, since the product ozone decomposition is oxygen, which does not form secondary pollution. At the same time, the destruction cyanides occur quickly, ensuring a 99%-degree purification. In addition to cyanides, ozone simultaneously disinfects water, removes odors and tastes.

The application this technology for handling cyanide-containing discharges will provide an opportunity to reduce the environmental risk from the galvanic copper plating process.

REFERENCES

1. Environmental safety of electroplating. Part 1. Waste water. Mechanical and sorption cleaning: training. manual / M.I. Donchenko, S.V. Frolenkova. Kyiv: NTUU "KPI", 2016. 202 p.
2. Ecological risk // Dictionary-reference of ecology: educational method. manual / comp. O. G. Lanovenko, O. O. Ostapishyna. Kherson: PP Vyshemirsky V.S., 2013. P. 155.
3. Environmental protection technologies. Study guide. Part 2: Wastewater treatment methods / Petruk V.G., Severyn L.I., Vasylykivskyi I.V., Bezvoziuk I.I. Vinnytsia: VNTU, 2014. 258 p.
4. Zagrai Y.M., Kotovenko O.A., Miroshnychenko O.Yu. Impact of physical and chemical pollutants on ecosystems and biosystems: Monograph. Kyiv, 2009. 276 p.

ENSURING CONSTANT FLOW VELOCITY IN COLLECTING DRAINAGE PIPELINES WITH TRANSIT FLOW CONSIDERATIONS

Oleksandr Kravchuk¹, Andriy Kravchuk¹

*¹Kyiv National University of Construction and Architecture
kravchuk.oa2@knuba.edu.ua, kravchuk.am@knuba.edu.ua*

The design practice for radial water intakes and reclamation systems is based on the use of constant diameter pipes, which often operate in a transit flow mode [1, 2]. This leads to fluctuations in flow velocity, posing a risk of system sedimentation. Ensuring a constant fluid velocity achieves stable self-cleaning of the pipelines. Such an approach minimizes maintenance requirements and reduces the environmental impact, which is a priority for sustainable "green" construction.

In our view, the primary criterion for determining the law of diameter variation in a pressure collecting drainage pipeline is maintaining a constant average flow velocity along its entire length. With this approach, the nature of the diameter change depends on the intensity of fluid inflow at different sections of

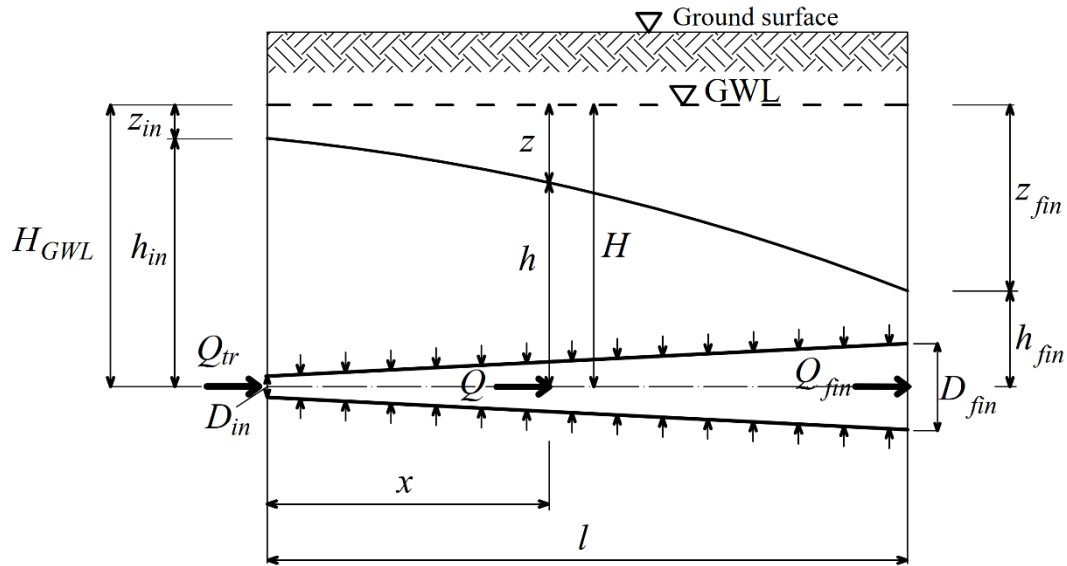
the pipeline ($q = \frac{dQ}{dx} = V \frac{d\Omega}{dx}$).

A case of non-uniformly increasing specific discharge along the collecting pipeline is analyzed. The hydraulic scheme of the collector is presented in Fig.1.

Subject to maintaining a constant average cross-sectional velocity, the fluid motion can be described by a mathematical model of the following form [3, 4]:

$$\frac{dh}{dx} + \frac{2V}{g} \frac{dV}{dx} + \frac{\lambda_{col} V^2}{2gD} = 0 \quad (1)$$

$$\frac{dQ}{dx} = \frac{d(V\Omega)}{dx} = V \frac{d\Omega}{dx} = k_f \frac{H-h}{\bar{F}} = k_f \frac{z}{\bar{F}}, \quad (2)$$



where H_{GWL} is the distance from the pipeline axis to the groundwater level; h is the piezometric head in the pipe, varying along its length; $z = H - h$ is the longitudinal varying head difference that determines the rate of fluid inflow into the drain from the surrounding soil; V is the specified average velocity in the flow cross-section at a distance x from the pipe inlet; D and Ω are the pipe diameter and cross-sectional area, varying along the length; $\bar{F}$ is the dimensionless filtration resistance of the drain (its determination constitutes a separate filtration problem [5]); k_f is the soil hydraulic conductivity around the pipe; λ_{col} is the hydraulic friction factor of the collecting drainage pipeline; g is the acceleration due to gravity.

The following new variables are introduced for further analysis:

$$\bar{x} = \frac{k_f x}{\Omega_{fin} \bar{F}} \sqrt{\frac{z_{fin}}{g}}, \quad \bar{z} = \frac{z}{z_{fin}}, \quad \bar{D} = \frac{D}{D_{fin}}. \quad (3)$$

It can be easily shown that $d\Omega = d\left(\frac{\pi D^2}{4}\right) = \frac{\pi}{2} \bar{D}d\bar{D}$.

By denoting $\bar{V} = \frac{V}{\sqrt{gz_{fin}}} = const$, and neglecting the second term in

equation (1), the initial system of equations (1), (2) can be rewritten as follows:

$$\frac{d\bar{z}}{d\bar{x}} = \zeta_{l_{col},fin} A_{col} \bar{V}^2 \frac{1}{D} \quad (4)$$

$$2\bar{V}D\frac{d\bar{D}}{d\bar{x}} = \bar{z}, \quad (5)$$

where $\zeta_{l_{col, fin}} = \lambda_{col} \frac{l}{D_{fin}}$ is the resistance coefficient of the collecting drainage pipeline, calculated based on the diameter in its end section; $A_{col} = \frac{1}{2\bar{x}_{fin}} = \frac{\Omega_{fin}\bar{F}}{2k_f l} \sqrt{\frac{g}{z_{fin}}}$ is the generalized parameter of the collecting drain, which accounts for its design and filtration characteristics.

Substituting $\bar{D}$ from (5) into expression (4) and performing separation of variables leads to the equation:

$$\bar{z}d\bar{z} = 2\zeta_{l_{col, fin}} A_{col} \bar{V}^3 d\bar{D}. \quad (6)$$

Its solution and subsequent transformations yield a relationship for determining the variation of the relative diameter along the collecting pipeline under transit flow conditions:

$$\varphi^3 + 3\bar{D}_{in}\varphi - \frac{3}{4\bar{V}\sqrt{1-\bar{D}_{in}}} \bar{x} = 0, \quad (7)$$

where $\varphi = \sqrt{\bar{D} - \bar{D}_{in}}$; D_{in} is the diameter at the inlet section of the drainage pipeline.

Relationships (7) for determining the variation of the relative diameter along the collecting pipeline under transit flow conditions should be solved by trial and error.

In this case, the diameter at the final section of the collecting pipeline in dimensional units is determined by the following relationship:

$$D_{fin} = D_{in} + \frac{2k_f g z_{fin}^2}{\lambda \pi \bar{F} V^3}. \quad (8)$$

Based on the analysis of the differential equations of fluid motion in pressure collecting drainage pipelines with a variable (increasing) cross-section, a methodology has been proposed for calculating the diameter variation along the pipe length under transit flow conditions. The proposed approach ensures a constant flow velocity, which is a key factor in the efficiency and durability of drainage systems.

REFERENCES

1. Kravchuk, O., Kravchuk, A., & Voznyi, O. (2026). Radial water intakes as a tool for enhancing the resilience of water supply systems in Ukraine. *Proceedings of the 3rd International Scientific and Practical Conference «Scientific Progress: Theories, Applications and Global Impact»*, Braga, Portugal, March 2-4, 2026, 297-299.
2. Wu, Z., Guo, C., Yang, H., Li, H., & Wu, J. (2022). Experimentally based numerical simulation of the influence of the agricultural subsurface drainage pipe geometric structure on drainage flow. *Agriculture*, 12(12), 2174.

<https://doi.org/10.3390/agriculture12122174>

3 Kravchuk, A., & Kravchuk, O. (2021). Analysis of the results of perforated drainage pipelines calculation in the presence of transit flow rate. *Problems of Water Supply, Sewerage and Hydraulic*, 37, 42–46. <https://doi.org/10.32347/2524-0021.2021.37.42-46>

4. Kravchuk, O., & Kravchuk, A. (2026). Operating features of a variable-diameter pressure collecting drainage pipeline with transit flow. *Problems of Water Supply, Sewerage and Hydraulic*, 53, 49–55. <https://doi.org/10.32347/2524-0021.2026.53.49-55>

5. Oleynik, O.Ya., & Poliakov, V.L. (1987). *Drainage of wetlands*. Kyiv: Naukova dumka, 279.

PROSPECTS FOR THE DEVELOPMENT OF PUBLIC SPACES: THE CASE OF THE BREEAM-CERTIFIED LIBRARY OF BIRMINGHAM

Tetiana Kryvomaz¹, Sofia Aleksandrova¹

*¹Kyiv National University of Construction and Architecture,
kryvomaz.ti@knuba.edu.ua, sofaalex26@gmail.com*

Green certification is undergoing a transformation from a tool for assessing individual buildings to a comprehensive instrument for evaluating the urban environment. However, a gap remains between theoretical certification models and their practical application in public spaces. Key developmental trends in green certification are directed toward the integration of climate resilience, digitalization, and holistic approaches [4]. The incorporation of biophilic design and visual quality into existing standards expands the conceptual framework of green certification for architectural environments and public spaces [3]. The concept of “regenerative” certification implies not only minimizing environmental impact but also generating positive ecological effects, applicable to landscapes and urban areas of varying scales.

An illustrative example of integrated implementation of sustainability principles in the urban environment is the Library of Birmingham. The project achieved BREEAM certification at the “Excellent” level, confirming compliance with high environmental standards in design, construction, and operation, and serving as a benchmark for sustainable public infrastructure [1]. The Library of Birmingham was realized as an integrated cultural and educational complex of approximately 35,000 m², combining library, educational, exhibition, community, and recreational functions, including a theatre space and an urban square, thereby establishing its role as a nucleus of civic life [2]. During construction, approximately 95% of waste was recycled, demonstrating an effective circular model of resource management and environmental impact minimization at the project implementation stage [5]. The building employs natural lighting and

ventilation, as well as low-carbon heating and cooling technologies, reducing energy consumption and ensuring a comfortable indoor environment [5].

The presence of green terraces (Discovery Terrace and Secret Garden), a “brown” roof, and urban gardens contributes to biodiversity, stormwater management, and the creation of additional public spaces within dense urban fabric [1]. The “brown roof” replicates natural or brownfield ecosystems, in contrast to conventional green roofs with decorative vegetation. It is constructed using local soils, sand, gravel, and residual building materials (brick, concrete), allowing vegetation to emerge naturally through self-seeding, thereby simulating ecological succession. Its primary function is to support biodiversity, particularly by providing habitats for pollinators, attracting birds, and restoring region-specific ecosystems. This compensates for the loss of natural biotopes in dense urban areas, improves stormwater management and microclimate regulation, and enhances urban adaptation to climate change.

The library functions as an open civic space, providing access to education, culture, media, and social services for diverse population groups, thereby improving quality of life and fostering social integration [1]. The project was implemented through interdisciplinary coordination and active stakeholder engagement via consultations and workshops, which facilitated alignment with BREEAM objectives and enhanced project management efficiency [2]. The Library of Birmingham serves as a flagship project for urban regeneration, integrated into the city’s strategic development plan (Big City Plan), demonstrating the potential of sustainable public facilities as catalysts for urban transformation [5].

In contemporary conditions, libraries as traditional knowledge institutions are gradually losing their prominence due to the digitalization of the information environment, the proliferation of electronic resources, and changing patterns of information consumption. The expansion of online platforms, open databases, and digital libraries reduces the necessity of physical visits, leading to declining attendance and diminishing their role as primary centers of knowledge access. At the same time, many existing library buildings are characterized by obsolescence, limited spatial flexibility, and insufficient adaptation to modern social demands. Consequently, the transformation of libraries is an objective necessity, involving a redefinition of their functions from repositories of books to multifunctional public spaces oriented toward interaction, learning, cultural activity, and social integration. Such spaces should provide conditions for co-working, informal education, events, and the development of creative industries.

Moreover, library transformation creates opportunities for embedding sustainability principles, including enhanced energy efficiency, integration of green infrastructure, and improved indoor environmental quality. The experience of the Library of Birmingham is particularly instructive, where the institution operates as a contemporary civic hub, combining informational, cultural, and ecological functions. Thus, library transformation is crucial not only for

maintaining relevance but also for shaping qualitatively new public spaces capable of addressing the challenges of the digital era while ensuring sustainable urban development.

The development of public spaces in Ukraine should be pursued on the basis of an integrated approach to sustainability, applying green building principles throughout the entire life cycle of facilities. Drawing on the experience of the Library of Birmingham, the implementation of international green certification systems is advisable as a means of standardizing requirements for energy efficiency, resource management, and environmental quality. Particular emphasis should be placed on integrating nature-based solutions, including green and “brown” roofs, rain gardens, permeable surfaces, and other elements of green infrastructure, which enhance biodiversity and climate adaptation in urban environments.

A key direction involves the advancement of multifunctionality in public spaces, combining cultural, educational, social, and recreational functions to ensure year-round utilization by diverse population groups. Inclusivity and accessibility must also be prioritized, guided by principles of universal design and social integration. The adoption of digital monitoring and management tools will improve operational efficiency and minimize discrepancies between projected and actual sustainability performance.

Furthermore, strengthening stakeholder participation in planning and implementation processes will facilitate the consideration of local needs and increase the social acceptability of decisions. At the policy level, it is essential to develop national standards for green certification of public spaces, harmonized with international practices, alongside financial and regulatory incentives for their implementation. Collectively, these measures will support the transition from fragmented urban improvement initiatives to a comprehensive model of public space development in Ukraine.

Green building is evolving from a narrowly defined construction tool into a comprehensive system for assessing urban environments, including public spaces. Green certification is a vital instrument for enhancing the sustainability of public spaces, yet its effectiveness depends on adaptation to local conditions. The experience of the Library of Birmingham demonstrates the relevance of applying green building technologies in Ukraine as a tool for reconstructing public spaces that integrate energy efficiency, ecological resilience, social inclusivity, and strategic urban planning, thereby ensuring long-term sustainability and improved quality of the urban environment.

REFERENCES

1. About the Library of Birmingham [Electronic resource]. – URL.: https://www.birmingham.gov.uk/info/50132/visiting_the_library_of_birmingham/1412/about_the_library_of_birmingham/8

2. BREEAM Case Study 2013 [Electronic resource]. – URL.: https://www.birmingham.gov.uk/download/downloads/id/8518/breeam_case_study_2013.pdf
3. Holius, V., Danylov, S. Analysis of BREEAM, LEED, WELL, DGNB green building rating systems in the context of visual quality consideration // Theory and Practice of Design. – 2025. – Вип. 37. – С. 70–79. – DOI: 10.32782/2415-8151.2025.37.6
4. Khan, H., Saf, S. The Next Frontier of Green Building Certifications: Evaluating the Future of LEED, BREEAM and WELL Standards // Journal of Engineering and Applied Sciences Technology. – 2025. – Vol. 7, № 6. – С. 1–7. – DOI: 10.47363/JEAST/2025(7)318
5. Library of Birmingham: Facts and Figures [Electronic resource]. – URL.: https://www.birmingham.gov.uk/download/downloads/id/8788/library_of_birmingham_facts_and_figures.pdf

GREEN TECHNOLOGIES FOR THE RECONSTRUCTION OF OUTDATED AND DESTROYED HOUSING

Tetiana Kryvomaz¹, Artem Tsyba¹

*¹Kyiv National University of Construction and Architecture,
kryvomaz.ti@knuba.edu.ua, absqueee@gmail.com*

The application of green building technologies in the reconstruction of outdated and damaged housing stock constitutes a strategic necessity for ensuring the sustainable development of Ukrainian cities. The ecological transformation of the urban environment entails the implementation of green construction technologies, the adoption of circular economy principles, the integration of digital methods, and an orientation toward ESG (environmental, social, and governance) criteria. The integration of ESG principles into Ukraine's green recovery processes is a key prerequisite for building a resilient economy and harmonizing national standards with those of the European Union.

The renovation of existing housing stock represents a priority direction for the implementation of green technologies in the construction sector, given its significant potential for reducing energy consumption and greenhouse gas emissions. Changing requirements regarding comfort and the quality of the built environment, combined with the aging of systems and components in existing buildings, necessitate their reconstruction and modernization. Buildings account for approximately 36% of total global emissions, with embodied carbon reaching 28% annually [2]. A number of studies demonstrate that the renovation of old buildings substantially reduces carbon emissions compared to new construction, primarily through adaptive reuse technologies [1].

Energy-efficient building envelopes play a particularly important role, including external insulation systems, high-performance windows, and airtight shells, the application of which reduces energy demand, lowers the carbon footprint, enhances thermal comfort, and ensures compliance with regulatory requirements. At the same time, the deployment of renewable energy technologies contributes to the decarbonization of energy consumption, strengthens the energy autonomy of buildings, and aligns with climate-oriented recovery policies.

A crucial dimension involves material reuse technologies, such as selective dismantling, reuse of structural elements, and recycling of construction waste, which reduce resource intensity in accordance with circular economy principles, create local economic opportunities, and enhance transparency in waste management. This approach is complemented by low-carbon construction materials, including modified concrete, cross-laminated timber panels, and recycled steel, the use of which significantly reduces embodied carbon emissions, improves material safety, and ensures supply chain accountability.

Equally important are water-efficient technologies, including rainwater harvesting systems, greywater reuse, and water-saving equipment, which alleviate pressure on water resources, enhance resilience to supply disruptions, and ensure compliance with resource management standards. Climate adaptation of the urban environment is facilitated by green roofs and façades, as well as rain gardens, which mitigate the urban heat island effect, improve biodiversity and microclimate, strengthen residents' psycho-emotional well-being, and integrate buildings into urban ecological strategies. Passive design solutions, such as optimal building orientation, natural ventilation, and solar shading, minimize energy consumption, foster healthy indoor environments, and adhere to sustainable design principles. Modular and industrialized construction, including prefabricated technologies and 3D printing, reduces waste and energy use, accelerates housing provision for internally displaced persons, and ensures quality standardization.

Enhancing building performance is achieved through the implementation of smart management systems, including energy monitoring, automation of engineering systems, and IoT solutions, which optimize resource consumption, improve comfort and safety, and enable data-driven transparency in management. The application of Building Information Modelling (BIM), digital twins, and Life Cycle Sustainability Assessment (LCSA) in green housing renovation projects demonstrates the effectiveness of transitioning from static calculations to modern data-driven technologies [5]. Artificial intelligence (AI) and machine learning (ML) can support stakeholders in identifying optimal housing modernization strategies, however, their use faces challenges related to data availability, model transparency, and compliance with national and European AI regulations [3].

It should be emphasized that the decarbonization of existing housing stock depends not only on technical solutions but also significantly on effective governance [4]. Transparent communication, user-centered design, and clear

demonstration of comfort and economic benefits increase households' willingness to invest in modernization. Housing recovery projects must evolve into dynamic socio-technical systems with coordinated governance, supported by state grant programs and fiscal incentives. Aligning modernization policies with emission accounting systems will facilitate the achievement of verifiable CO₂ reduction targets and enhance the effectiveness of housing sector decarbonization policies.

Contemporary research highlights a shift from isolated application of individual technologies toward the formation of integrated systems, where ESG criteria serve to align technological solutions. The environmental dimension (E) is grounded in LCSA, energy efficiency, and CO₂ reduction. The social dimension (S) reflects improved living comfort and the development of affordable housing. Governance criteria (G) ensure effective coordination of complex renovation projects and transparency in decision-making. A quantitatively measurable ESG profile enables the selection of optimal scenarios within a substantiated framework for technology choice, ensuring the transition from declarative "green ideas" to concrete technological solutions. ESG indicators thus function as a comprehensive tool for selecting the most appropriate technological solutions, taking into account environmental protection, social equity, and effective governance requirements.

Accordingly, ESG criteria constitute an integrative framework that aligns the application of green technologies with the achievement of measurable environmental, social, and governance outcomes in the reconstruction of housing stock. Green recovery of outdated and damaged housing should therefore be conceptualized as a system of ecological technologies, the effectiveness of which is substantiated through ESG assessment, thereby establishing a scientific and technical linkage between engineering solutions, environmental impact, and the sustainable development of urban territories.

REFERENCES

1. Ferriss L. Sustainable reuse of post-war architecture through life cycle assessment // *Journal of architectural conservation*. – 2021. – Vol. 27, № 3. – P. 208–224. – DOI: <https://doi.org/10.1080/13556207.2021.1943260>
2. Obead R., Khaddour L., D'Amico B. Historical building energy retrofit // *Architecture*. – 2025. – Vol. 5, № 3. – P. 49. – DOI: <https://doi.org/10.3390/architecture5030049>
3. Rempi P., Pelekis S., Tzortzis A. M., Spiliotis E., Karakolis E., Ntanos C., Askounis D. A Trustworthy by design classification model for building energy retrofit decision support [Electronic resource]. – 2025. – Режим доступа: <https://arxiv.org/abs/2504.06055>
4. Yan F., Winch G., Barker K. Green housing retrofits as complex micro-projects: delivery pathways and whole-life CO₂ [Electronic resource]. – 2025. – DOI: [10.20944/preprints202512.0378.v1](https://doi.org/10.20944/preprints202512.0378.v1)

5. Zou X., Tan Y., Zhang G., Hou L. BIM-based sustainability analysis for building green retrofit // *Energy and Buildings*. – 2026. – Vol. 354. – P. 116982. – DOI: <https://doi.org/10.1016/j.enbuild.2026.116982>

DETERMINATION OF THE AREA OF LAMELLA MODULES IN HORIZONTAL SETTLING TANKS DEPENDING ON RAW WATER TURBIDITY

Oleksandr Kushka¹, Anastasiia Synenko¹

*¹Kyiv National University of Construction and Architecture,
kushka.om@knuba.edu.ua, synenko_ao-2023@knuba.edu.ua*

Efficient use of land and water resources is achieved through the optimization of basic technological processes, one of which is the widely used clarification of water under the action of gravity.

The development of gravitational sedimentation processes is closely related to fundamental and applied research in the field of water treatment, which has established the decisive role of overflow rate, flow hydraulics, and geometric parameters of structures in determining clarification efficiency. The classical principles of clarification theory were formulated in the work of Hazen [1], where it was shown that the efficiency of sedimentation tanks is primarily determined by hydraulic loading rather than the detention time of water in the structure, which became an important step in the development of sedimentation theory. Further development of these principles led to the creation and widespread implementation of thin-layer (lamella) sedimentation technology, based on the use of systems of inclined plates or tubular modules. Such design solutions allow significant intensification of phase separation due to shortening the particle settling path, increasing the specific settling area, and forming an ordered, stabilized flow structure [2, 3].

Modern studies confirm that the use of thin-layer modules increases the productivity of sedimentation tanks, reduces their required area, and improves flow hydrodynamics [4, 5, 6]. This can be demonstrated, for example, using computational fluid dynamics (CFD) methods, which allow detailed analysis of flow structure, identification of stagnant zones, and assessment of the influence of module geometry on process efficiency [4, 5]. At the same time, current regulatory documents, in particular DBN V.2.5-74:2013 [7], lack generalized analytical relationships that would allow rapid determination of the area of thin-layer modules depending on the characteristics of raw water.

This study proposes an analytical approach to determining the area of thin-layer modules in horizontal sedimentation tanks, based on relationships between particle settling velocity and specific hydraulic loading as functions of water turbidity. The particle settling velocity is determined by a logarithmic relationship derived from tabulated data provided in DBN [7]:

$$U_0 = 0.041 \ln C + 0.2905, \quad (1)$$

where C is the turbidity of raw water, mg/L.

This form of dependence agrees well with experimental studies [8], which take into account changes in particle size distribution, shape, and aggregation at different concentrations of suspended solids, thus increasing the reliability of the proposed approach.

The specific hydraulic loading on the modules [m/h] is also proposed to be determined using an analytical relationship derived from clauses 10.8.3 and 10.2.1 of [7]:

$$\Delta Q = 0.5875 \ln C + 1.2206 \quad (2)$$

The values obtained using this relationship are consistent with modern studies of high-rate treatment systems [8] under standard operating conditions.

The area of thin-layer modules is determined as:

$$F_M = \frac{Q}{\Delta Q} = \frac{Q}{0.5875 \ln C + 1.2206}, \quad (3)$$

where Q is the hourly flow rate of water at the treatment plant, m³/h.

The area of a horizontal sedimentation tank is determined by:

$$F = 1.3 \frac{Q}{3.6 \cdot 0.041 \ln C + 0.2905}, \quad (4)$$

Based on these relationships, an expression for the fraction of module area is obtained:

$$\frac{F_M}{F} = \frac{\frac{Q}{0.5875 \ln C + 1.2206}}{\frac{1.3 \cdot Q}{3.6 \cdot 0.041 \ln C + 0.2905}} = \frac{3.6 \cdot 0.041 \ln C + 0.2905}{1.3 \cdot 0.5875 \ln C + 1.2206}, \quad (5)$$

For practical use, the relationship is approximated by a power function:

$$\frac{F_M}{F} = \frac{3.6}{1.3} \cdot 0.1766 \cdot C^{-0.079} \quad (6)$$

The use of this simplified expression makes it possible to accelerate engineering calculations and quickly estimate required parameters without complex computations.

Calculations were performed for a turbidity range of 10–200 mg/L, which corresponds to conditions of most surface waters. It was established that the fraction of thin-layer module area varies within 32–41%. At low turbidity, an increase in module area is required due to lower settling velocity, whereas with increasing turbidity, the module fraction decreases. At turbidity values above 500 mg/L, the module fraction may be less than 30%, which agrees with review studies [2, 9].

The hydrodynamic features of thin-layer module operation include the formation of a quasi-laminar flow regime, a significant reduction in turbulence, and minimization of stagnant zones, which is confirmed by CFD studies [5, 6, 10]. The formation of parallel flows in module channels ensures a more uniform velocity distribution across the cross-section and reduces the risk of sludge carryover into the treated water. In addition, reducing the settling height to 5–10 cm significantly intensifies the process, reduces water detention time, and increases plant capacity by 1.5–2 times, as confirmed by numerous experimental

studies on the treatment of natural and wastewater of various compositions [8, 10].

Comparison of the obtained results with modern literature data shows good agreement: thin-layer modules occupy 20–45% of the sedimentation tank area and provide suspended solids removal efficiency at the level of 70–95% [2, 9]. This confirms the adequacy of the proposed approach and its applicability in engineering practice.

The practical significance of the work lies in the development of a simple analytical tool for preliminary determination of thin-layer module parameters without the use of complex numerical methods, including CFD. The use of the proposed relationships allows improving the accuracy of engineering calculations, reducing design and operation costs, and ensuring compliance with regulatory requirements for treated water quality.

REFERENCES

1. Hazen, A. (1904). *On Sedimentation*. Transactions of the American Society of Civil Engineers, 53, 45–71. <https://doi.org/10.1061/TACEAT.0001655>
2. Reyers, C. et al. (2022). *Review on inclined settlers*. Minerals Engineering. <https://doi.org/10.1016/j.mineng.2022.107639>
3. Kim, S., & Kim, K. (2020). *Hydrodynamics of tube settlers*. Chemical Engineering Journal. <https://doi.org/10.1016/j.cej.2019.123225>
4. Tarpagkou, R., & Pantokratoras, A. (2014). *CFD study of lamella settlers*. Powder Technology. <https://doi.org/10.1016/j.powtec.2014.08.030>
5. Šíma, J., & Rieger, L. (2020). *CFD modelling of lamella units*. Water Research. <https://doi.org/10.1016/j.watres.2020.115728>
6. Nishimura, S. (2013). *Plate settler performance*. Water Science and Technology. <https://doi.org/10.2166/wst.2013.176>
7. DBN V.2.5-74:2013. *Water supply. External networks and structures. Basic design provisions*. Ministry of Regional Development of Ukraine. Kyiv: Ukrarkhbudinform, 2013. 115 p. https://polyplastic.ua/files/DSTU/dbn_v.2.5_74_2013.pdf
8. Muhammed, H. G. et al. (2022). *Lamella clarifier in HRAS*. Journal of Water Process Engineering. <https://doi.org/10.1016/j.jwpe.2022.103138>
9. Karches, T. (2023). *Dynamic model of lamellar settler*. Symmetry. <https://doi.org/10.3390/sym15040864>
10. Fuchs, S. et al. (2014). *Lamella settlers for storm water*. Water Science and Technology. <https://doi.org/10.2166/wst.2013.698>

THE IMPACT OF INTERNATIONAL CLIMATE AGREEMENTS ON ENERGY EFFICIENCY AND GREEN CONSTRUCTION IN UKRAINE

Mykola Moroz¹, Evgeniia Mykhailova²

*¹O. M. Beketov National University of Urban Economy in Kharkiv,
Mykola.Moroz@kname.edu.ua*

*²Simon Kuznets Kharkiv National University of Economics,
mykhailova.e@ukr.net*

Ukraine's international obligations in the field of energy efficiency and green construction are shaped through the country's participation in global climate initiatives, cooperation with the European Union (EU), and the implementation of sustainable development principles in the construction sector. The issues of developing energy-efficient and environmentally oriented construction are actively studied by both Ukrainian and foreign scholars, which confirms their relevance in the context of modern climate policy [1–4].

The international system for combating climate change began with the adoption of the United Nations Framework Convention on Climate Change (1992), whose main objective is to stabilize greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system. The Convention provides for the reduction of greenhouse gas emissions, improvement of energy efficiency of the economy, and the implementation of environmentally sound technologies. Given that the building sector is one of the largest consumers of energy resources, modernizing buildings, reducing energy consumption in the housing stock, and implementing energy-efficient technologies are key priorities for meeting international climate obligations.

Further development of international climate policy took place after the adoption of the Kyoto Protocol (1997), which established quantitative commitments to reduce or limit greenhouse gas emissions for participating countries. Ukraine's ratification of this document facilitated the implementation of international cooperation mechanisms in the field of emission reduction, particularly the Joint Implementation (JI) mechanism. Within such JI projects, measures are implemented to improve energy efficiency and modernize infrastructure, contributing to the reduction of carbon dioxide (CO₂) emissions and the development of energy-saving technologies, including in the construction sector.

An important stage in the development of international climate policy was the adoption of the Paris Agreement (2015), aimed at limiting the increase in global average temperature and ensuring the transition to low-carbon development. Ukraine joined this agreement and undertook commitments to gradually reduce greenhouse gas emissions, improve energy efficiency, and

expand the use of renewable energy sources. The implementation of these objectives involves the modernization of industrial production, development of renewable energy, and the enhancement of energy efficiency in buildings and structures.

A significant role in shaping national policy in the field of energy efficiency is played by the Association Agreement between Ukraine and the European Union (2014), which provides for the harmonization of Ukrainian legislation with European standards in the areas of energy, environmental protection, and energy efficiency. Within the framework of implementing this agreement, a number of regulatory legal acts have been adopted in Ukraine, in particular the Law of Ukraine “On the Energy Performance of Buildings,” aimed at improving the energy efficiency of buildings, reducing energy consumption, and lowering energy supply costs.

Further development of European climate policy is reflected in the strategic initiative European Green Deal (2019), which provides for achieving climate neutrality by 2050. For Ukraine, the implementation of this strategy implies the need to transition to a low-carbon economy, modernize infrastructure, develop energy-efficient residential construction, and introduce environmentally oriented technologies in the construction sector.

In general, international climate documents define the key directions for the development of green construction, including improving the energy efficiency of buildings, reducing greenhouse gas emissions in the construction sector, using environmentally friendly building materials, developing renewable energy, and modernizing the existing housing stock. International climate agreements and cooperation with the EU form the foundation of Ukraine’s state policy in the field of energy efficiency and green construction. Their implementation promotes the adoption of modern energy-saving technologies, the use of environmentally friendly materials, and the reduction of the negative environmental impact of the construction industry.

Even before the start of the full-scale war, Ukraine had begun implementing measures aimed at transitioning to sustainable development and forming an environmentally oriented energy policy. In particular, the state has developed strategic documents for the development of renewable energy. The National Renewable Energy Action Plan until 2030 provides for increasing the share of energy from renewable sources to at least 27% of final energy consumption by 2030 [5]. In addition, the Energy Strategy of Ukraine until 2050 defines long-term directions for the development of the energy sector, including a gradual transition to a low-carbon economy, an increase in the share of “green” energy in electricity generation, strengthening the country’s energy independence, and reducing greenhouse gas emissions.

One of the key mechanisms for stimulating the development of renewable energy in Ukraine is the “green tariff” (feed-in tariff), a system of state support for electricity producers from renewable sources. It provides for the guaranteed

purchase of electricity generated from solar, wind, biomass, and small hydropower plants at fixed tariffs, thereby encouraging investment in the development of green energy.

Ukraine also actively cooperates with international organizations in the field of renewable energy development, in particular with the United Nations Development Programme, the European Union, and international financial institutions that support the implementation of projects in the field of energy efficiency and the use of renewable energy sources.

At both the national and local levels, efforts are being made to stimulate the use of renewable energy sources in communities and households. These measures include the installation of rooftop solar power systems, the development of energy cooperatives, and the implementation of information campaigns promoting alternative energy. The implementation of such measures contributes to improving the energy efficiency of buildings and ensures the gradual transition of Ukraine's construction sector to the principles of sustainable development.

REFERENCES

1. Doroshenko V. Theoretical and Methodological Approaches to Defining the Concept of "Green Construction". *Actual Problems of Regional Economy Development*. 2018. No. 2 (14). P. 31–38. URL: <https://doi.org/10.15330/apred.2.14.31-38>.

2. Danyliuk M. M., Dmytryshyn M. V. Green Construction in Achieving Sustainable Regional Development. *Actual Problems of Regional Economy Development*. 2020. Iss. 16 (1). P. 153–162. URL: <https://doi.org/10.15330/apred.1.16.153-162>.

3. Solomnikov I. V., Chernenko N. V. "Green" Construction: Problems and Prospects for the Modern Economy. *Bulletin of Transport and Industry Economics*. 2024. No. 86. P. 124–130. URL: <https://doi.org/10.18664/btie.86.310020>.

4. Kibert C. J. *Sustainable Construction: Green Building Design and Delivery*. 5th ed. Hoboken : John Wiley & Sons, 2022. 656 p.

5. Energy Efficiency in Sustainable Buildings: A Systematic Review with Taxonomy, Challenges, Motivations, Methodological Aspects, Recommendations, and Pathways for Future Research. *Energy Strategy Reviews*. 2023. Vol. 45. Article 101013. <https://doi.org/10.1016/j.esr.2022.101013>.

5. On Approval of the National Renewable Energy Action Plan until 2030 and the Action Plan for Its Implementation: Resolution of the Cabinet of Ministers of Ukraine dated August 13, 2024, No. 761-r. URL: https://zakon.rada.gov.ua/laws/main/761-2024-%25D1%2580?utm_source=chatgpt.com#Text.

IMPEDANCE METHOD FOR ASSESSING ENVIRONMENTAL DAMAGE TO SOILS CAUSED BY MILITARY ACTIONS

Inna Pitak¹, Kiril Sebko¹

¹National Technical University «Kharkiv Polytechnic Institute»

Inna.Pitak@khpi.edu.ua, Kiril.Sebko@mit.khpi.edu.ua

The condition of soils is largely determined by anthropogenic pressure, which has increased significantly due to military actions. Explosions, fires, infrastructure destruction, and leaks of hazardous substances cause complex changes in soil properties. Under these conditions, operational monitoring of environmental damage and assessment of soil degradation are essential for ensuring sustainable development and the environmentally safe restoration of affected territories.

In the context of green building, soil assessment is crucial because it determines the safety of land use for construction, landscaping, and recreation. Soil quality affects the durability of structures, drainage capacity, and local microclimate. Contamination poses risks to public health and limits sustainable urban development.

A promising method for soil assessment is impedance analysis (or impedance spectroscopy), which enables non-destructive testing over a wide frequency range and provides comprehensive information on the electrochemical and structural properties of soils. This method is particularly effective for evaluating areas intended for construction or reclamation in accordance with green building standards.

Soil electrical conductivity is determined by the relation:

$$\sigma = \frac{1}{(R \times S)} \quad (1)$$

where l is the distance between electrodes, R is the resistance, and S is the cross-sectional area of the sample.

Dielectric properties are characterized by the complex permittivity:

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (2)$$

Energy losses are defined as:

$$\tan \varphi = \frac{\varepsilon''}{\varepsilon'} \quad (3)$$

Changes in these parameters reflect the impact of anthropogenic load. Explosive and thermal effects lead to degradation of soil structure, reduced porosity and humus content, and disruption of the water regime. At the same time, heavy metals and combustion products accumulate, altering electrical conductivity and acidity. These changes significantly reduce the soil's suitability for construction, landscaping, and the creation of environmentally stable landscapes.

The quality factor of the system is defined as:

$$Q = \frac{X}{R} \quad (4)$$

Where R – is the active (real) resistance component and X – is the reactive component.

For an integral assessment of soil condition, a generalized parameter is used:

$$x = a_0 + a_1\sigma + a_2pH + a_3 \tan \varphi + a_4Q \quad (5)$$

The obtained parameters allow evaluation of the degree of soil degradation, the level of environmental risk, and justification of appropriate restoration measures. Integrating impedance analysis into green building practices enables scientifically grounded land-use planning, identification of areas requiring reclamation, efficient use of natural resources, and improved environmental safety in construction.

Thus, impedance analysis is an effective tool for monitoring environmental damage caused by military actions and an important element in implementing green building principles. It supports the restoration of disturbed areas, the formation of sustainable urban ecosystems, and long-term environmental safety.

REFERENCES

1. Bairachnyi V. B., Samoilenko N. M., Pitak I. V. Sustainable Urban Development: Tutorial. Kharkiv: O. M. Beketov National University of Urban Economy, 2018. 188 p.
2. Lysenko Yu. Yu., Kuts Yu. V., Levchenko O. E. Pulsed eddy current testing using multi-element transducers // Instrumentation: State and Prospects: Proceedings of the XXI International Scientific and Technical Conference, May 17–18, 2022, Kyiv. Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2022. P. 207–209.

RECYCLING OF DESTRUCTION WASTE AS A TOOL FOR ENSURING SUSTAINABLE CONSTRUCTION

Olena Sorochynska

National Transport University, o.sorochynska@ntu.edu.ua

In the current conditions of intensive development of the construction industry and the increase in the volume of destruction of buildings and structures, the problem of effective management of destruction waste is of particular relevance. Significant volumes of construction waste generated as a result of dismantling, reconstruction and emergency destruction of objects create a significant burden on the environment and require the implementation of modern approaches to their processing and reuse.

One of the key areas of addressing this problem is the recycling of demolition waste, which allows transforming waste into secondary material resources. This approach helps reduce the volume of waste landfilled, reduces the consumption of natural resources, and reduces energy costs for the production of building materials.

In the context of the concept of sustainable development of construction, recycling is not only a technological process, but also an effective tool for ensuring the ecological, economic and resource balance of the industry. The use of secondary materials in construction allows for increased resource efficiency, reduced carbon footprint and optimized construction costs.

Thus, researching the possibilities and effectiveness of recycling demolition waste is an important task for implementing the principles of sustainable construction and forming a circular economy in the construction industry.

In Ukraine, the problem of waste management has become critical due to large-scale destruction since 2022. According to estimates provided in a joint report by the Government of Ukraine, the World Bank, the European Commission and the UN (Ukraine Rapid Damage and Needs Assessment), total direct damage to infrastructure exceeds 195 billion USD, while restoration needs are estimated at about 588 billion USD. Such a scale of destruction is accompanied by the generation of significant volumes of construction waste, which requires the implementation of effective systems for its recycling and reuse [1].

In this regard, innovative approaches are being actively implemented, in particular mobile processing complexes and automated sorting systems [2]. The use of such solutions increases the level of extraction of secondary materials to 60–80% and reduces logistics costs and minimizes the negative impact on the environment.

Demolition waste is considered as a source of secondary raw materials suitable for use as aggregate in concrete and the basis of road surfaces. Their use contributes to reducing the load on landfills, reducing the consumption of primary raw materials and increasing the level of environmental friendliness of construction activities [3]. Recycled materials can be effectively used in road construction, production of concrete mixtures and other structural elements, which meets the principles of the circular economy and ensures resource conservation in the construction industry [4].

Demolition waste is generated from the dismantling or demolition of buildings and includes a wide range of materials. The main types are shown in Figure 1.

Analysis of the structure of demolition waste (Fig. 1) shows that the predominant share is made up of mineral materials (concrete, reinforced concrete, brick), which together form about 70–80% of the total volume. The share of metals is on average 5–10%, while other components (wood, plastic, mixed materials) occupy no more than 10–15%. Such a structure confirms the expediency of focusing processing technologies precisely on the extraction and reuse of the mineral component.

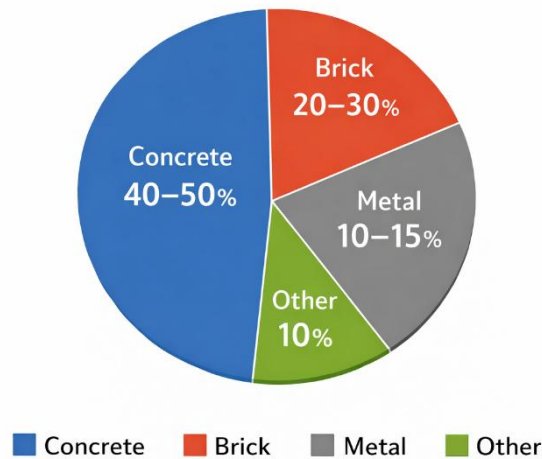


Fig. 1. Structure of waste from the destruction of construction sites

1. The largest share is made up of mineral materials (concrete, reinforced concrete, brick), which have a high potential for reuse after crushing and sorting [5].

The processing of demolition waste (Fig. 2) includes the following main stages: sorting; crushing; cleaning from impurities; fractionation. The result is secondary materials that can be used as aggregates in concrete, road base materials or bulk materials [6].

Unlike traditional schemes, the proposed sequence of processes with the integration of pre-sorting and local processing ensures a reduction in the share of mixed waste, an increase in the quality of secondary raw materials and a reduction in transportation costs. This allows to increase the degree of extraction of suitable materials, minimize resource losses and optimize logistics processes, which in general contributes to increasing the efficiency of recycling and reducing the environmental load.

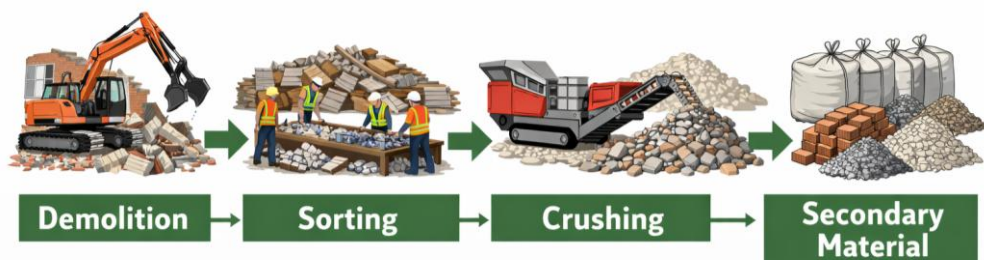


Fig. 2. Waste processing scheme for demolition

In order to increase the efficiency of demolition waste processing, an author's optimization scheme has been proposed, which, unlike the traditional approach, involves the integration of sorting and logistics stages based on the principle of preliminary selection of materials directly at the dismantling site.

The proposed scheme additionally takes into account the integration of pre-sorting, local processing and digital optimization of logistics directly at the dismantling stage, which ensures a reduction in the volume of mixed waste and an increase in the efficiency of recycling.

The proposed scheme includes the following additional elements:

- primary identification of materials at the dismantling stage;
- separation of waste streams by suitability classes;
- use of mobile crushing plants;
- optimization of transport routes based on digital models.

Implementation of this approach allows to reduce the volume of mixed waste by 20–30% and improve the quality of secondary raw materials.

The systematization of the areas of use of secondary materials is given in Table 1.

Table 1

Use of secondary resources in construction

Waste type	Processing product	Direction of use
Concrete, reinforced concrete	Secondary crushed stone	Road construction, concrete mixtures
Brick	Brick battle	Backfill, thermal insulation materials
Asphalt	Asphalt chips	Road surface repair
Metal	Scrap metal	Reproduction

The use of secondary resources allows to reduce the cost of building materials and reduce the amount of waste. The use of secondary resources has a number of advantages:

- reduction of waste disposal;
- reduction of the use of natural resources;
- reduction of energy consumption;
- reduction of CO₂ emissions [4].

In addition, modern research confirms the possibility of using recycled construction waste to create new cement materials with lower energy consumption and greenhouse gas emissions [6].

In the post-war reconstruction environment, the implementation of comprehensive demolition waste management systems, which involves the use of intelligent technologies, digital models and automated sorting systems, is particularly important.

A comparative analysis of traditional and innovative approaches to demolition waste management shows significant differences in their effectiveness. The traditional model, based on centralized sorting and disposal of waste, is characterized by a low level of material reuse (up to 30%) and significant logistical costs.

Instead, an innovative approach that involves pre-sorting, local processing and the use of digital technologies ensures an increase in the recycling rate to 60–80%, reduces transport costs and reduces the environmental burden. This confirms the feasibility of moving to decentralized waste processing models in the construction industry.

To quantify the efficiency of demolition waste processing, it is advisable to use the material utilization rate indicator, which is defined as the ratio of the mass of secondary resources to the total mass of waste. This indicator is a key indicator of the efficiency of the recycling system:

$$\eta = \frac{M_{rec}}{M_{tot}} \cdot 100\% \quad (1)$$

where M_{rec} – mass of recycled and reused materials;

M_{tot} – total mass of destruction waste.

Practical estimates show that when using modern sorting and crushing technologies, the value of the η indicator can reach 60–80%, while with the traditional approach (landfilling or minimal processing) this indicator does not exceed 20–30%.

The economic efficiency of using secondary materials is manifested in reducing construction costs by an average of 15–25% due to the reduction in costs for the purchase of primary raw materials and transportation. At the same time, the environmental effect is to reduce CO₂ emissions by 20–40%, which is achieved by reducing energy consumption for the production of new materials.

The paper substantiates the feasibility of considering demolition waste recycling as a comprehensive tool for ensuring sustainable construction, combining technological, logistical and digital solutions.

Unlike traditional approaches, the proposed waste management model involves the integration of pre-sorting processes at the dismantling stage, local processing and digital optimization of material flows, which allows to increase the manageability of processes and the quality of secondary raw materials.

The practical significance of the results obtained lies in confirming the effectiveness of decentralized approaches to waste processing, which ensure the simultaneous achievement of economic and environmental effects. This creates the prerequisites for the widespread implementation of circular principles in the construction industry. The results obtained can be used in the development of demolition waste management strategies and planning of restoration works, which is especially relevant in the conditions of post-war reconstruction of Ukraine.

REFERENCES

1. Ukraine Rapid Damage and Needs Assessment (RDNA3). (2024). Government of Ukraine, World Bank Group, European Commission, United Nations. URL: <https://www.worldbank.org> (дата звернення: 24.03.2026).
2. European Commission. (2020). *Construction and Demolition Waste*

Management Protocol. Publications Office of the European Union.
<https://ec.europa.eu>

3. Moschen-Schimek, J., Kasper, T., & Huber-Humer, M. (2023). *Recovery rates of construction and demolition waste in the EU*. *Waste Management*, 161, 12–23. <https://doi.org/10.1016/j.wasman.2023.05.020>

4. Bayram, B., & Greiff, K. (2023). *Life cycle assessment on construction and demolition waste recycling: A systematic review analyzing three important quality aspects*. *The International Journal of Life Cycle Assessment*, 28, 967–989. <https://doi.org/10.1007/s11367-023-02145-1>

5. Akhtar, A., Sarmah, A. K. (2022). Construction and demolition waste generation and properties of recycled aggregate concrete: A global perspective. *Journal of Cleaner Production*, 332, 129898. <https://doi.org/10.1016/j.jclepro.2021.129898>

6. Jean, B., Liu, H., Zhu, X., Wang, X., Yan, X., Ma, T. (2024). Enhancing the Mechanical and Durability Properties of Fully Recycled Aggregate Concrete Using Carbonated Recycled Fine Aggregates. *Materials*, 17(8), 1715. <https://doi.org/10.3390/ma17081715>.

INTELLIGENT MONITORING AS A TOOL FOR EXTENSION OF THE LIFE CYCLE AND REDUCTION OF THE CARBON FOOTPRINT OF CONSTRUCTION OBJECTS

Roman Stepaniuk,

Institute of Innovative Education of the Kyiv National University of Architecture and Construction, StepaniukR@gmail.com

At the current stage of the development of the world economy, the construction industry is faced with the challenge of radical transformation within the framework of the “green” course. The traditional model of “design-build-demolition” has exhausted its resource due to a critically high carbon footprint. According to the Global Status Report, the construction sector accounts for about 37% of global CO₂ emissions. The lion's share of these emissions is generated during the production of steel and cement. The most effective method of decarbonization is not only to increase the energy efficiency of new buildings, but also to maximize the life cycle of the existing stock. The implementation of intelligent monitoring systems allows you to transform passive structures into interactive objects, where repair decisions are made based on predictive analytics, which minimizes the need for new resource-intensive structures.

In the conditions of Ukraine, where infrastructure is experiencing unprecedented destruction, the task of decarbonizing the industry is inextricably linked to extending the period of safe operation of renovated objects. Prolonging the life of existing structures instead of completely dismantling them and replacing them with new ones is the most effective way to reduce "embodied

carbon". This requires the implementation of high-tech intelligent monitoring systems that are capable of providing predictive maintenance of critical infrastructure objects.

Methodological basis and three-level digital architecture of the system

The study proposes a transition from the concept of periodic visual inspections to continuous digital monitoring of the object. The architecture of the developed intelligent system has a hierarchical structure.

Level 1. Sensor level (Data Acquisition):

The basis of the system is a network of IoT sensors (strain gauges, accelerometers, inclinometers) that record the stress-strain state in real time. The use of UAVs equipped with high-resolution cameras and thermal imagers allows for non-destructive testing of hard-to-reach nodes. This provides the input array of "Big Data" necessary for training neural networks.

Level 2. Analytical core (AI Processing):

The central element is a neural network, the architecture of which is optimized using the Bayesian Optimization algorithm. This allows the system not only to record deviations, but also to classify defects and predict the speed of their development. The use of the ReLU activation function provides high computing speed.

Level 3. Visualization and management (BIM integration):

The analysis results are integrated into the Autodesk Revit environment. This transforms a static BIM model into a dynamic "digital twin". Each structural element receives a digital status, allowing engineers to see problem areas directly in the 3D model of the structure.

Environmental benefits of an intelligent approach in the Green Building concept

Intelligent monitoring is a key tool for implementing an ecological construction strategy in several areas:

- Circular Economy principles: The circular economy involves preserving the value and functionality of objects for as long as possible. Accurate diagnostics of the residual resource avoids premature demolition. Given that construction waste makes up up to 40% of the total volume of garbage in the world, extending the operation of the object by 10–20 years has a colossal environmental effect.

- Reduction of material consumption of maintenance: Thanks to predictive analytics, repair work becomes spot-on. Instead of completely replacing spans of buildings, AI indicates specific local nodes that need strengthening. This reduces the need for new concrete and metal.

- Integration with international standards (LEED/BREEAM): The implementation of SHM systems allows the facility to receive additional points in the categories of "Management" and "Innovation", which increases the market and environmental value of the property.

The value lies in the development of an adaptive model for assessing the technical condition, which takes into account not only physical parameters, but

also operational history and climatic factors. Experimental studies conducted on bridge structures have demonstrated a prediction accuracy of 94% when classifying the condition according to a five-point scale.

Five-step implementation algorithm:

1. Creation of a detailed information model (BIM) in Revit.
2. Automated extraction of parameters using Python scripts.
3. Cleaning and normalization of data to eliminate "noise" from sensors.
4. Training a neural network based on selected signs of structural degradation.
5. Deploy the model in a production environment to control the quality of forecasts in real time.

Rebuilding Ukraine: from destruction to "Resilient Cities"

For Ukraine, the issue of monitoring the technical condition is of existential importance today. Large-scale destruction of infrastructure as a result of military actions requires not just rapid restoration, but the implementation of the "Build Back Better" — to build better and more sustainably than before.

The introduction of intelligent systems into the reconstruction processes allows:

- Create sustainable infrastructure: New bridges and buildings should be equipped with integrated sensors even at the construction stage. This will allow for an instant response to deformations from possible further impacts, ensuring the safety of the population.

- Optimization of renewable resources: Using AI algorithms to analyze damaged objects allows you to determine which parts of the structure can be saved. This is critically important for reducing the volume of construction waste, which is currently one of the biggest environmental problems in the deoccupied regions.

Digital transformation of monitoring processes through the implementation of intelligent systems is an integral part of "green" construction. In the context of the reconstruction of Ukraine's infrastructure, the integration of AI and BIM into the operation processes becomes the key to creating sustainable and environmentally neutral cities. The transition to the concept of smart maintenance allows the construction industry to cease to be the largest polluter and become an example of sustainable resource management.

REFERENCES

1. DBN V.1.2-5:2007. System for ensuring the reliability and safety of construction objects. Scientific and technical support of construction objects. Kyiv: Minregionstroy of Ukraine, 2007. 32 p.
2. DSTU-N B V.2.3-37:2016. Guidelines for monitoring the technical condition of bridges and pipes. Kyiv: State Enterprise "DerzhdorNDI", 2016. 45 p.

3. DBN A.2.2-21:2015. Composition and content of scientific and design documentation for the implementation of building information modeling (BIM). Kyiv: Minregionstroy of Ukraine, 2015.
4. Trach R. V. Information modeling and intelligent systems in construction: monograph. Kyiv: Osnova, 2021. 240 p.
5. Sacks R., Eastman C., Lee G., Teicholz P. BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers. 3rd ed. John Wiley & Sons, 2018. 688 p.
6. Farrar C.R., Worden K. Structural Health Monitoring: A Machine Learning Perspective. John Wiley & Sons, 2012. 656 p.
7. Goodfellow I., Bengio Y., Courville A. Deep Learning. MIT Press, 2016. 800 p.
8. Snoek J., Larochelle H., Adams R.P. Practical Bayesian Optimization of Machine Learning Algorithms. Advances in Neural Information Processing Systems (NIPS). 2012. Vol. 25. P. 2951–2959.
9. Arutyunyan I. A. Optimization of neural network models for monitoring building structures. Journal of Engineering Sciences. 2022. No. 4. P. 112–119.
10. Kibert C. J. Sustainable Construction: Green Building Design and Delivery. 4th ed. John Wiley & Sons, 2016. 600 p.
11. ISO 15392:2019. Sustainability in buildings and civil engineering works — General principles. International Organization for Standardization, 2019.
12. U.S. Green Building Council. LEED v4.1 Building Design and Construction Guide. 2023. URL: <https://www.usgbc.org/leed> (access date: 08.04.2026).
13. Build Back Better: Report on the Strategy for the Restoration of Ukraine's Infrastructure. Ministry of Community, Territories and Infrastructure Development of Ukraine. 2024. 84 p.
14. Dovgalyuk V. B. Digital twins as a decarbonization tool for the restoration of destroyed objects. Bulletin of the Ukrainian National University of Architecture and Building. 2023. Issue 78. P. 44–51.
15. European Green Deal. European Commission communication on a set of policy initiatives. Brussels, 2019.

BIO-ORIENTED NANOMATERIALS FOR EFFECTIVE ARSENIC REMOVAL FROM CONTAMINATED GROUNDWATER: CHALLENGES AND PROSPECTS

Dmytrii Trokhymenko¹, Maryna Kravchenko¹

*¹Kyiv National University of Construction and Architecture
dmitrijtrohimenko@gmail.com*

Arsenic is the twentieth most abundant trace element in the Earth's crust and is a component of approximately 245 mineral species, mainly ores containing

copper, sulfides, lead, nickel, cobalt, or other metals. Due to its specific chemical properties, this element is widely used in many fields: the electronics industry, the agricultural sector, metallurgy, wood preservation, logging, as well as medicine [1]. Such widespread use leads to an increase in anthropogenic pressure which, together with natural processes — weathering of arsenic-containing minerals and volcanic activity — contributes to its accumulation in the environment.

Arsenic belongs to the group of highly toxic metalloids and, according to the classification of the World Health Organization, is classified as a Group 1 carcinogen. Its migration and behavior in the environment are determined primarily by the type of source mineral raw material, the degree of oxidation, and the characteristics of transport under specific conditions [2]. Arsenic contamination of water constitutes one of the most serious environmental problems and threats to public health on a global scale. Millions of people in different regions of the world are forced to use shallow groundwater containing elevated concentrations of arsenic for drinking purposes.

Nanomaterials are currently considered one of the most promising solutions for the effective removal of arsenic from water, since they can be applied both independently and in combination with other purification technologies, ensuring an increase in the overall efficiency of the process due to their high specific surface area, active sorption sites, and specific physicochemical properties.

At the same time, a comparative analysis of the main purification methods using different types of nanomaterials, covering their composition, functional characteristics, mechanisms of interaction with arsenic, as well as indicators of efficiency, selectivity, and possibilities for practical implementation, indicates that the choice of the optimal approach is determined by environmental conditions, the level of contamination, technological limitations, and the economic feasibility of each specific solution (Table 1) [3,4,5].

Table 1

Comparative analysis of arsenic removal methods using nanomaterials

№	Method	Mechanism	Materials	Advantages	Disadvantages
1	Adsorption	Binding of arsenic on the surface	Chitosan, biochar, iron oxides	Simplicity, low cost, high efficiency	Low selectivity, efficiency decreases over time
2	Membrane filtration	Filtration through nanopores	Nanofiltration membranes, TiO ₂	Up to 99% purification, selectivity	High cost, membrane fouling
3	Photocatalysis	Oxidation of As(III) to As(V) and adsorption	TiO ₂ , CNT, composites	Use of light, high efficiency	Dependence on illumination
4	Redox reactions	Conversion of toxic forms into more adsorbable forms	Fe/Cu, MnO ₂ , metal-organic and framework	Conversion of toxic As(III) into less toxic	Specific conditions required; material

№	Method	Mechanism	Materials	Advantages	Disadvantages
			structures	As(V)	degradation over time
5	Complexation	Formation of stable complexes between functional groups and arsenic ions	Fe/Cu biochar, chitosan-stabilized magnetic nanoparticles, MnFe ₂ O ₄ nanocomposites	High efficiency	Expensive modification
6	Ion exchange	Replacement of arsenic ions (As ⁵⁺ /As ³⁺) with functional groups (e.g., –NH ₃ ⁺ , –OH) on the nanomaterial surface	Chitosan, chitin	Highly effective for low arsenic concentrations, reversible process	Low capacity, sensitivity to competing ions
7	Coagulation	Formation of flocs	Chitosan, biopolymers	Low cost, rapid process	Sludge formation, additional purification required

One of the key areas of modern research is the in-depth understanding and purposeful optimization of the physicochemical properties of nanomaterials with the aim of increasing their selectivity and efficiency in arsenic removal processes. The development of such materials significantly depends on the conditions of their practical application, as the mechanisms of arsenic removal involve complex surface interactions, redox transformations (reactions), and ion transport processes. An additional complicating factor is the presence of competing ions, particularly phosphates, which reduce adsorption efficiency, creating difficulties in scaling technologies from laboratory to field (real-world) conditions. At the same time, the long-term environmental consequences and potential risks to human health associated with the use of nanomaterials remain insufficiently studied, which directly affects their sustainability and economic feasibility. Significant technical difficulties are also related to the effective separation and regeneration of nanoadsorbents after use. Overcoming these challenges requires a comprehensive approach that involves optimizing material design, developing effective and economically justified regeneration methods, as well as evaluating their performance in real operating conditions.

A significant modern challenge remains ensuring the chemical stability and selectivity of bio-oriented nanomaterials in real-world conditions of water remediation from arsenic. Although many bio-oriented materials, such as

chitosan-modified nanoparticles or biochar-based metal oxides, demonstrate high performance indicators in controlled laboratory conditions, their productivity significantly decreases during the transition to natural water systems [6]. The main reason for such a decrease is the presence of competing anions, which compete for active centers on the nanomaterial surface and hinder arsenic adsorption. Furthermore, some biocompatible nanocomposites may undergo structural or chemical degradation over time. This is related to their natural biocompatibility and environmentally friendly properties. In particular, microbial activity, prolonged exposure to pH fluctuations, and changing ionic conditions can significantly alter the surface chemistry of biochar-based materials.

Therefore, a key task is to increase the selectivity and long-term stability of these materials during operation in various environmental matrices. This can be achieved through targeted surface functionalization and enhancement of their chemical resistance [7].

An important aspect of the sustainable application of bio-oriented nanomaterials for the remediation of groundwater from arsenic is their potential for reuse and ease of regeneration. Although many adsorbents based on biopolymers or biochar initially demonstrate high arsenic removal efficiency, upon repeated use, they often undergo surface fouling, structural degradation, or irreversible arsenic binding, which leads to a gradual decline in their performance.

The regeneration of such materials should be carried out taking into account their environmental advantages; therefore, it is desirable to avoid the use of strong chemical reagents that could negate the "green" properties of the nanomaterials. "Mild" regeneration methods, in particular low-temperature thermal treatment or the use of weak alkaline solutions, are promising. These approaches allow for the restoration of adsorption capacity without significant damage to the material or the generation of hazardous waste

An additional effective solution is the creation of magnetic bio-oriented composites, for example, magnetite nanoparticles coated with chitosan. Such an approach ensures simple magnetic separation, rapid recovery, and repeated reuse of the material [8].

Bio-oriented nanomaterials, in particular those based on chitosan and biochar, demonstrate enhanced adsorption capacity due to strong electrostatic interactions, which makes them effective for arsenic removal both from aqueous solutions and from sediments. Recent advances in the field of arsenic remediation have attracted significant attention specifically to these materials [7]

In addition to high chemical and environmental stability, bio-oriented nanomaterials are characterized by rapid adsorption kinetics and exceptionally high efficiency of pollutant removal. One of the key factors determining their performance is particle size. Studies show that particles with a surface area-to-volume ratio of less than 30 nm exhibit significantly higher chemical reactivity, as well as superparamagnetic properties [9].

The reactivity of nanomaterials is also enhanced due to quantum size effects,

which alter the electronic structure of the substance at the nanoscale. Owing to these properties, bio-oriented nanomaterials provide faster kinetics and more efficient arsenic removal, opening new opportunities for sustainable environmental remediation.

Bio-oriented nanomaterials have become one of the most promising categories of adsorbents due to their biodegradability, environmental safety, and ability to participate in various pollutant removal mechanisms, including adsorption, oxidation, electrostatic interactions, and surface complexation interactions [10].

Thus, bio-oriented nanomaterials are a promising and environmentally justified alternative to traditional methods of water treatment for arsenic. Despite existing challenges regarding stability, selectivity, regeneration, and scaling, the further development of hybrid systems, improvement of surface functionalization, and creation of "green" regeneration methods will allow for the realization of their full potential. The integration of innovative nanotechnologies with the principles of sustainable development opens the way to effective, safe, and accessible solutions for providing high-quality drinking water in regions most affected by arsenic contamination.

REFERENCES

1. Sharma V., Sohn M., Aquatic arsenic: Toxicity, speciation, transformations, and remediation. - *Env. Int.* - 2009. - № 35. - P. 743-759.
2. Al-Abed S., Jegadeesan G., Purandare J., Allen D., Arsenic release from iron rich mineral processing waste: Influence of pH and redox potential. - *Chemosphere* - 2007. - № 66. - 775-782.
3. Chakraborty, R.; Asthana, A.; Singh, A.K.; Jain, B.; Susan, A.B.H. Adsorption of heavy metal ions by various low-cost adsorbents: A review. *Int. J. Environ. Anal. Chem.* 2022, 102, P. 342-379. DOI: <https://doi.org/10.1080/03067319.2020.1722811>
4. Gokcek, O.B.; Uzal, N. Arsenic Removal by the Micellar-Enhanced Ultrafiltration Using Response Surface Methodology. *Water Supply* 2020, 20, 574-585. DOI: <https://doi.org/10.2166/ws.2019.188>
5. Kolya, H.; Kang, C.-W. Bio-based polymeric flocculants and adsorbents for wastewater treatment. *Sustainability* 2023, 15, P. 9844. DOI: <https://doi.org/10.3390/su15129844>
6. Burbano, A.A.; Lassalle, V.L.; Horst, M.F.; Méndez, A. The Effect of Carbon Coating on the Arsenite Sorption by Magnetic Carbon Nanocomposites. *Int. J. Environ. Sci. Technol.* 2025, 22, 4749 - 4760. DOI: <https://doi.org/10.1007/s13762-024-05924-x>
7. Feng, W.Y.; Wei, S.D.; Liu, C.B.; Chen, T.; Tang, Y.H.; Ma, J.H.; Yin, K.; Luo, S.L. Efficient removal of arsenic from groundwater using iron oxide nanoneedle array-decorated biochar fibers with high Fe utilization and fast adsorption kinetics. *J. Hazard. Mater.* 2019, 373, P. 141–151. DOI:

<https://doi.org/10.1016/j.jhazmat.2019.03.042>

8. Shaumbwa, V.R.; Liu, D.; Archer, B.; Li, J.; Su, F. Preparation and Application of Magnetic Chitosan in Environmental Remediation and Other Fields: A Review. *J. Appl. Polym. Sci.* 2021, 138, 51241. DOI: <https://doi.org/10.1002/app.51241>

9. Chaturvedi, S.; Dave, P.N. Water Purification Using Nanotechnology: An Emerging Opportunity. *Chem. Methodol.* 2019, 3, 115–144 DOI: <https://doi.org/10.22034/chemm.2018.143461.1069>

10. Yamen, R.; Bashir, H.; Bibi, I.; Shaheen, S.M.; Niazi, N.K.; Shahid, M.; Hussain, M.M.; Antoniadis, V.; Shakoor, M.B.; Al-Solaimani, S.G.; et al. A critical review on arsenic removal from water using biochar-based sorbents: The significance of modification and redox reactions. *Chem. Eng. J.* 2020, 396, 125195. DOI: <https://doi.org/10.1016/j.cej.2020.125195>

STUDY OF THE IMPACT OF DEFECTS ON THE STRENGTH OF GLUED LAMINATED TIMBER BEAMS

Oleksandr Udovytskyi¹, Roman Rokun¹, Andrii Manziuk¹

¹Ukrainian National Forestry University, o.udvytskyi@nltu.edu.ua

The impact of wood defects on the strength of glued laminated structural timber (glulam) beams of strength class C24 (KVH) has been investigated.

The strength of wooden structures significantly depends on the quality of the raw material and its structural characteristics. Wood defects, such as knots, cracks, resin pockets, cross-grain, or biological damage [1, 2], significantly reduce its load-bearing capacity. In particular, numerous experimental studies show that the presence of large knots or cracks in beams can reduce the strength of elements by 20-40% [3]. Wood defects can substantially affect performance: from local reductions in bending and tensile strength to the total loss of element integrity under complex stress states.

In addition to natural wood defects, lumber often develops imperfections caused by the sawing and drying processes. These defects include drying checks (cracks), longitudinal and transverse warping (bowing and cupping), and twisting in various directions. Such flaws significantly complicate the manufacturing process and adversely affect the quality of the final product. Specifically, they distort the geometry of the finger joint, thereby reducing its overall strength and precision.

Imperfections in connections – whether bolted, screwed, dowelled, or glued – often cause premature structural failure. Inadequate surface preparation, uneven glue distribution, insufficient pressure during bonding, and errors during the installation of metal elements reduce the efficiency of the entire structure. Design errors, such as the incorrect choice of finger joint or glue joint types, as well as violations of bonding technology, lead to stress concentrations and decreased

durability [4, 5].

At the same time, new experimental research on the failure of timber joints under long-term and variable loads indicates that proper design and the use of high-quality adhesive formulations can significantly increase the durability of connections [4, 5].

Thus, the strength of timber structures when using wood with defects and imperfect joints remains a key focus of modern scientific research.

In this study, specimens with defects from glued structural timber beams, manufactured at the production facilities of the woodworking enterprise "Milwood" LLC, were examined. The results obtained will allow for an assessment of the technological process's efficiency, determination of the influence of wood characteristics on the strength development of glued structural timber beams, and the formulation of recommendations for improving structural design solutions.

Since the natural defects present in lumber have a significant impact on the physical and mechanical properties of the final product, identifying and removing these defects is a primary operation, after which the manufacturer can guarantee the mechanical properties of the product.

During experimental bending tests, it was found that structural glulam beams with existing defects exhibit different failure patterns depending on the type of defect and its location relative to the zone of maximum stress [6, 7].

In particular, knots proved to be most critical in the lower zone of the glulam beam, which was subjected to tensile stress (Fig. 1). Stress concentrations occurred in these areas, promoting the initiation of microcracks in the transition zone between the knot and the surrounding fibers. Subsequently, cracks propagated along the grain, causing the beam to fail in the vicinity of the defect. If the knot was large or located in the center of the cross-section, the failure became brittle, occurring without significant prior deformation.



Fig. 1. Failure of a structural glulam beam specimen with a knot defect [6]

The presence of pith within the wood structure also had a negative impact on the strength of the elements (Fig. 2).



Fig. 2. Failure of a structural glulam beam specimen with a pith defect [6].

Failure occurred primarily along the pith boundary, as this zone is characterized by lower density, a non-homogeneous structure, and a higher concentration of microcracks that accumulate under load. As a result, wood delamination and the formation of cracks propagating radially from the center to the periphery were observed, which significantly reduced the load-bearing capacity of the structural glulam beam.

The conducted analysis allowed for the identification of the primary factors influencing the strength of glued beams. Special attention was given to structural glulam beam specimens containing various types of wood defects. In most cases, the failure of such elements began precisely at the locations of defect concentrations – knots, cracks, grain deviation, or low-density zones. Thus, the presence of wood defects significantly influenced both the nature and the location of the damage. These defects were the determining factor in the reduction of load-bearing capacity and ultimate strength compared to defect-free beams, serving as critical risk factors for the durability and strength of structural elements.

REFERENCES

1. Barashykov A. Ya., Koliakova V. M. Building structures: a textbook. Kyiv: Slovo, 2011. 255 p.
2. The use of glued and cross-laminated timber in reconstruction and new construction – D. Mykhailovskyi, M. Komar, T. Skliarova, B. Bondarchuk. Building structures. Theory and Practice, 2024. № 15, pp. 54–65.
3. Mirski R., Dukarska D., Wieruszewski M., Dziurka D., Trociński A., Kawalerczyk J. The effect of storage conditions on the strength of glulam beams. Forests. 2023. Vol. 14, № 2. Article 281. DOI: <https://doi.org/10.3390/f14020281>.
4. M. Udovytska, V. Mayevskyy, O. Udovytskyi, Z. Kopynets, A. Manzyuk. Development of Mathematical Model for Predicting the Cupping of Lumber. Bulletin of the Transilvania University of Brasov Series II: Forestry Wood Industry Agricultural Food Engineering. Vol. 17(66) No. 2 – 2024, pp. 111-126. DOI: <https://doi.org/10.31926/but.fwiafe.2024.17.66.2.7>.
5. Haida S., Udovytskyi O., Rutkovska I., Salabai R., Salabai I. (2025).

Building a mathematical model of the strength of finger-jointed battens from reclaimed wood for roof structures of buildings. Bulletin of the Lviv National University of Nature Management. Series Architecture and Construction, (26), 7–12. DOI: <https://doi.org/10.31734/architecture2025.26.007>.

6. Bukhanevych, I., Maievskyi, V., Udovytskyi, O., Manziuk, A., Kopynets, Z. (2025). Investigation of the main strength characteristics of glued structural solid timber beams. Bulletin of the Lviv National University of Nature Management. Series Architecture and Construction, (26), 24–33. DOI: <https://doi.org/10.31734/architecture2025.26.024>.

7. V. O. Maievskyi, O. M. Udovytskyi, Z. P. Kopynets, M. V. Udovytska, A. O. Manziuk. Experimental studies of the strength of glued wooden beams with wood defects. Modern Technologies, Materials and Structures in Construction: Scientific and Technical Journal. – Vinnytsia: VNTU. – 2025. – № 2 (39). 27–37. DOI: <https://doi.org/10.31649/2311-1429-2025-2-27-37>.

RESILIENCE OF WATER SUPPLY SYSTEMS WITHIN THE GREEN CONSTRUCTION CONCEPT

Inga Uriadnykova

Kyiv National University of Construction and Architecture

ingavictory@gmail.com

Under current conditions of escalating military and technogenic threats, traditional approaches to ensuring the reliability of water supply systems as critical infrastructure objects—based on extensive component redundancy and the creation of static backup capacities in accordance with DSTU 2860-94 [1]—are gradually losing their effectiveness. These approaches proved efficient under stable operating conditions and were primarily aimed at preventing typical technical failures; however, they become insufficient in the context of targeted destructive impacts characterized by high uncertainty and dynamic variability. The mere increase in the number of reserve elements does not guarantee enhanced system security, as external impacts may simultaneously disable both primary and backup components, while resource limitations constrain further development of water supply systems through redundancy alone.

In this regard, there is a well-founded need to shift from the classical reliability theory to the resilience-based approach to water supply systems. Within this framework, technical systems are considered as dynamic structures capable of adaptation, reconfiguration, and recovery following disruptive impacts. The concept of resilience focuses on maintaining the core functions of water supply systems even under conditions of partial degradation, which is critically important for infrastructure operation in a context of military instability.

For the implementation of the proposed approach, the use of a set of scientific and methodological tools is considered appropriate.

1. Mathematical modelling based on fuzzy logic serves as an effective decision-support tool under conditions of uncertainty. The application of fuzzy logic is driven by the limited availability or complete absence of reliable statistical data regarding system states in crisis conditions. The use of fuzzy sets enables the formalisation of expert assessments and qualitative characteristics into quantitative parameters. The main advantages of this approach include: the formalisation of uncertainty through the use of linguistic variables; the possibility of multi-criteria analysis taking into account technical, environmental, and safety factors in accordance with the principles of risk management defined by ISO 31000 [2]; and the provision of intelligent diagnostics and prediction of potential failures.

2. The methodology for assessing the technological adaptability coefficient (K_{at}) is a key element of resilience analysis. This indicator reflects the system's ability to promptly adjust its operating modes in order to maintain functionality under destructive influences. In contrast to static reliability indicators, the K_{at} coefficient characterises the dynamic flexibility of technological processes. Its application involves: the analysis of functional flexibility of systems; the assessment of reconfiguration time; the determination of the level of resource autonomy; and the prediction of the probability of cascading failures. The implementation of this indicator enables a quantitative evaluation of system adaptability and the identification of optimal operational scenarios.

3. The localization of cascading effects through the creation of autonomous infrastructure segments is an important direction for enhancing resilience. Under destructive impacts, the failure of a single element may trigger a chain-like propagation of disruptions. The application of "green construction" principles contributes to the formation of decentralised, energy-efficient, and autonomous systems. The main measures include: the development of local energy and water clusters; segmentation of networks using intelligent control systems; and the reduction of rigid interdependencies between infrastructure sectors. This approach enables the localization of failure processes and ensures the continued operation of unaffected system components.

Thus, the results of the study confirm that traditional approaches to ensuring reliability under conditions of military-technogenic instability are insufficient. The transition to a resilience paradigm implies the use of integrated management methods combining mathematical modelling, adaptability assessment, and structural transformation of infrastructure. The proposed approach provides a scientific and methodological basis for the recovery of critical infrastructure in accordance with the "Build Back Better" principles [3] and for the implementation of the concept of environmentally oriented development within the framework of "Green Construction".

REFERENCES

1. DSTU 2860-94. *Reliability of technical equipment. Terms and definitions*. Kyiv: State Standard of Ukraine, 1994. Available at: http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=54021 (accessed: 05.05.2026).
2. ISO 31000:2018. Risk management – Guidelines [Electronic resource]. – Mode of access: <https://www.iso.org/standard/65694.html> (accessed: 05.05.2026).
3. Hallegatte S., Rentschler J., Walsh B. Building Back Better: Achieving resilience through stronger, faster, and more inclusive post-disaster reconstruction [Electronic resource]. – Washington, DC: World Bank, 2018. – 224 p. – Mode of access: <https://openknowledge.worldbank.org/handle/10986/29867> (accessed: 05.05.2026). – DOI: 10.1596/29867.

INTEGRATED RISK MANAGEMENT FOR IT INFRASTRUCTURE PERSONNEL: PSYCHO-EMOTIONAL SAFETY AND GREEN BUILDING PRINCIPLES IN THE ERA OF DATA CENTER EXPANSION

Yevhenii Shaidiuk

*Kyiv National University of Construction and Architecture,
shaidiuk_ys@knuba.edu.ua*

According to the International Energy Agency's special report "Energy and AI" (2025), global data center electricity consumption reached 415 TWh in 2024. Under the IEA's base-case projection, this figure is set to rise to 945 TWh by 2030 and to exceed 1,200 TWh by 2035, representing more than a threefold increase over the current level. The primary driver of this growth is the rapid deployment of infrastructure for artificial intelligence (AI) workloads: electricity consumption by AI-optimised accelerated servers is projected to grow at 30% per year, compared with only 9% for conventional servers. This expansion has triggered not only record construction activity for new data centers in Ukraine and across Europe, but also a significant increase in the workforce required to operate this infrastructure. Yet occupational conditions in server rooms and industrial IT facilities remain largely outside the scope of academic research in occupational safety. The defining characteristic of a modern data center is the co-occurrence of several categories of harmful factors within a single production environment: thermal hazards (temperature differentials between hot and cold aisles), acoustic hazards (continuous noise load from cooling systems), electromagnetic fields, chemical exposure during maintenance operations, and psychosocial stressors. This complex risk profile cannot be adequately captured by traditional single-factor approaches to occupational health assessment.

A review of international occupational safety literature on data centers [1] reveals a systemic pattern of compliance gaps: the absence of baseline noise assessments, inadequate evaluation of heat stress in server maintenance zones, and unregulated ergonomic conditions for technical staff. In the United Kingdom, the Control of Noise at Work Regulations 2005, which implement the relevant EU Directive, are systematically unmet in data center environments. Concurrently, the EU-OSHA report [2] identifies new categories of psychosocial risks arising from digitalisation and AI deployment: cognitive overload, intensified algorithmic monitoring, fear of technological displacement, and the erosion of boundaries between working and non-working time. Within data center environments, these risks are compounded by round-the-clock shift patterns, the physical isolation of production areas, and the heightened responsibility associated with maintaining critical infrastructure.

A significant, yet insufficiently studied aspect is the direct relationship between ergonomic quality of the workplace and the psycho-emotional condition of IT professionals. According to EU-OSHA [3], musculoskeletal disorders in digital work environments carry a pronounced psychosocial component: prolonged static posture is combined with information overload, time pressure, and depersonalised monitoring through digital systems. This combination of factors is characteristic of data center personnel and constitutes an elevated risk of professional burnout. Research by Zhao et al. (2025) [4] confirmed that the quality of the spatial work environment directly correlates with the psychological well-being of office workers: production spaces devoid of natural elements and ergonomic solutions represent an independent driver of psycho-emotional exhaustion. Given that data centers are typically closed buildings with no natural lighting or greenery, this relationship carries particular practical significance for occupational health.

The response to these challenges in contemporary international research is the concept of biophilic design applied to production spaces. A systematic review of 74 peer-reviewed publications [5] confirmed that integrating natural elements into the work environment yields measurable psychological, physiological, and cognitive benefits for workers. A study by Zhang et al. (2024) [6], conducted using functional near-infrared spectroscopy (fNIRS), demonstrated that combined biophilic exposure, specifically living plant greenery in conjunction with natural lighting, significantly restores cognitive performance following stress-induced mental fatigue. A two-wave panel study by Valor et al. (2024) [7], conducted on a sample of 636 office workers, showed that nature exposure enhances both overall and job-related well-being through the mechanism of vigor, independently of industry or office type. Gonçalves et al. (2023) [8], synthesising 16 quantitative studies, found statistically significant positive effects of natural spaces in all reviewed works. These findings indicate that the provision of recreational zones with living greenery, natural or high-quality artificial lighting, and acoustic comfort can serve as an effective means of restoring the psycho-emotional

resources of IT facility personnel. LEED, BREEAM, and WELL standards already include indoor environment quality criteria; however, the psycho-emotional safety of data center and server room staff has not yet been established within them as a distinct and independent priority.

On the basis of the analysis conducted, the following recommendations are formulated for employers in the IT sector:

1. When designing and certifying IT facilities under LEED, BREEAM, or WELL standards, establish psycho-emotional safety of personnel as a distinct evaluation criterion for occupational conditions in server rooms and industrial premises.

2. Incorporate dedicated recreational zones with biophilic design elements into data center planning solutions: living greenery, natural or high-quality artificial lighting, and acoustic comfort.

3. Introduce psychological support programmes that address the specific risk profile of data center personnel: chronic stress, cognitive overload, heightened responsibility, and burnout risk associated with round-the-clock operational regimes.

4. Provide ergonomic support across all levels of IT infrastructure, including server equipment maintenance zones where physical workload is combined with psychosocial demands.

Conclusions. The modern data center, particularly one oriented towards AI workloads, creates a fundamentally new production context in which health risks for personnel are complex in nature and encompass physical, ergonomic, and psychosocial dimensions. Psycho-emotional safety is becoming a distinct occupational health priority, and its effective management requires the systemic integration of green building principles and biophilic design into risk management models. Further research should be directed towards the development of normative criteria for assessing occupational conditions in IT infrastructure facilities and towards verifying the effectiveness of biophilic design solutions in industrial buildings of this type.

REFERENCES

1. Antea Group. Top 5 Health and Safety Findings from Data Center Audits. 2023. URL: <https://us.anteagroup.com/news-events/blog/top-5-health-and-safety-findings-from-data-center-audits>

2. EU-OSHA. Digital technologies at work and psychosocial risks: evidence and implications for occupational safety and health. Luxembourg: Publications Office of the European Union, 2024. URL: https://osha.europa.eu/sites/default/files/documents/Digitalisation-and-PSR_EN.pdf

3. EU-OSHA. Musculoskeletal disorders: association with psychosocial risk factors at work. Luxembourg: Publications Office of the European Union, 2021. URL: <https://osha.europa.eu/sites/default/files/2021->

11/MSDs_association_pshychosocial_risks_factors_at_work_executive_summar
y.pdf

4. Zhao M., Jiao D., Tang J. Research on the impact of biophilic office space environments on employee health promotion. *Work: A Journal of Prevention, Assessment and Rehabilitation*. 2025. DOI: 10.1177/10519815251345816
5. Investigating restorative effects of biophilic design in workplaces: a systematic review. *Intelligent Buildings International*. 2024. DOI: 10.1080/17508975.2024.2306273
6. Zhang P., Yu Z., Hou G. et al. Enhancing Cognitive Performance and Physiological Benefit in Workspaces Through Patterns of Biophilic Design: A Restorative Approach. *Buildings*. 2024. Vol. 14. P. 3293. DOI: 10.3390/buildings14103293
7. Valor C., Redondo R., Carrero I. Explaining the influence of biophilic design on employee well-being. *Scientific Reports*. 2024. Vol. 14. 32090. DOI: 10.1038/s41598-024-83791-9
8. Gonçalves G., Sousa C., Fernandes M.J., Almeida N. Restorative Effects of Biophilic Workplace and Nature Exposure during Working Time: A Systematic Review. *International Journal of Environmental Research and Public Health*. 2023. Vol. 20(21). P. 6986. DOI: 10.3390/ijerph20216986
9. IEA. Energy and AI. Paris: International Energy Agency, 2025. URL: <https://www.iea.org/reports/energy-and-ai>.

NUMERICAL CALCULATIONS OF BIOFILM THICKNESS AT WASTEWATER TREATMENT IN BIOREACTORS

Serhii Telyma¹, Yuriy Kalugin¹

*¹Institute of Hydromechanics of the National Academy of Sciences of Ukraine,
sertelyma@gmail.com*

The formation of a constant biofilm thickness occurs in a significant time interval. If processes such as substrate diffusion and its hydrodynamics occur within a few minutes then to achieve stationary conditions during the formation of the biofilm thickness at least several days and even weeks are required [1, 2, 5]. Thus when calculating the biofilm thickness it is advisable to determine the time when the stationary regime of its operation in the reactor occurs.

When modeling the biofilm the process of fixing microorganisms is omitted from consideration since the conditions of the primary deposition of biomass on the elements of the porous backfill are assumed. In addition a homogeneous structure of the biofilm was considered without taking into account its heterogeneity which occurs in real conditions of treatment. The mathematical model of the biofilm in this case can be represented by the following equations: the equation of substrate transport and its consumption inside the biofilm [1,5,6]:

$$\frac{\partial L}{\partial t} = D_L \frac{\partial^2 L}{\partial x^2} - \frac{\mu_{\max} X_L}{Y} \frac{L}{K_{mL} + L}, \quad (1)$$

with boundary conditions

$$\text{at } x=0 - D_L \frac{dL}{dx} = K_L (L_e - L), \quad (2)$$

$$\text{at } x=\delta \quad \frac{dL}{dx} = 0 \quad \text{and} \quad (3)$$

equation describing biofilm growth

$$\frac{d\delta}{dt} = \frac{\mu_{\max} X_L}{\rho_b} \int_0^\delta \frac{L}{K_{mL} + L} dx - r\delta. \quad (4)$$

here L is the substrate concentration inside the biofilm, g/m^3 ; $\mu_{\max}$ - specific maximum growth rate of microorganisms in the biofilm; X_L – initial concentration of biomass in the biofilm, g/m^3 ; Y – stoichiometric coefficient of biomass growth in the biofilm; K_{mL} - half-saturation coefficient, g/l ; L_e - substrate concentration at the exit from the biofilm, g/m^3 ; D_L – molecular diffusion coefficient in the biofilm, m^2/h ; r - intensity of biomass detachment from the biofilm surface, $1/\text{h}$. The system of equations (1)-(4) is solved with the following initial conditions:

$$L(0, x) = L_0, \quad \delta(0) = \delta_0. \quad (5)$$

The functions sought are concentration $L(x, t)$ and biofilm thickness $\delta(t)$.

To obtain a solution to the system of equations (1)-(5) the method of successive changes of stationary states was used that is at each moment of time t with appropriate film thickness δ concentration distribution $L(\delta)$ is found by solving the steady-state equations of substrate transport and biomass balance.

Let us consider the equation for biofilm growth [3,5]:

$$\frac{d\delta}{dt} = \frac{\mu_{\max} X_L}{\rho_b} \int_0^\delta \frac{L}{K_{mL} + L} dx - r\delta \quad (6)$$

here r – intensity of substrate detachment from the biofilm .

Let us write it using several dimensionless complexes in the next form (film thickness δ and time t remain dimensional):

$$\frac{d\delta}{dt} = \delta \lambda \int_0^1 \frac{\bar{L}(\bar{x}, \delta)}{\bar{K}_{mL} + \bar{L}(\bar{x}, \delta)} d\bar{x} - r\delta, \quad (6a)$$

$$\text{where } \bar{L} = \frac{L}{L_e}, \quad \bar{K}_{mL} = \frac{K_{mL}}{L_e}, \quad \bar{x} = \frac{x}{\delta}, \quad \lambda = \frac{\mu_{\max} X_L}{\rho_b}. \quad (7)$$

The desired concentration distribution functions $\bar{L}(\delta)$ and $\bar{X}_L(\delta)$ are found by solving the stationary substrate transport equations:

$$\frac{d^2 \bar{L}}{d\bar{x}^2} - \alpha \frac{\bar{L}}{\bar{K}_{mL} + \bar{L}} = 0, \quad (8)$$

with boundary conditions:

$$\begin{aligned} \text{at } \bar{x} = 0 \quad \frac{d\bar{L}}{d\bar{x}} &= \beta(\bar{L} - 1), \\ \text{at } \bar{x} = 1 \quad \frac{d\bar{L}}{d\bar{x}} &= 0, \end{aligned}$$

and biomass balance equation

$$\bar{X}_L = \gamma \frac{\bar{L}}{\bar{K}_{mL} + \bar{L}}, \quad (9)$$

transformed taking into account the new variables

$$\alpha = \frac{\mu_{\max} X_L \delta^2}{Y D_L L_e}, \quad \beta = \frac{K_L \delta}{D_L}.$$

It is obvious that with this approach the concentration distribution functions $\bar{L}$ and $\bar{X}_L$ are also functions through parameters $\alpha = \frac{\mu_{\max} X_{L0} \delta^2}{Y D_L L_e}$ and $\beta = \frac{K_L \delta}{D_L}$ from the thickness of the biofilm, i.e., $\bar{L} = \bar{L}(\bar{x}, \delta)$ and $\bar{X}_L = \bar{X}_L(\bar{x}, \delta)$. The solutions to equations (8) and (9) are obtained using the finite difference method.

Let us rewrite the equation for the biofilm thickness (6) as:

$$\frac{d\delta}{dt} = f(\delta), \quad (10)$$

$$\text{where } f(\delta) = \delta \left(\lambda \int_0^1 \frac{\bar{L}(\bar{x}, \delta)}{\bar{K}_{mL} + \bar{L}(\bar{x}, \delta)} d\bar{x} - r \right), \quad \bar{L} = \bar{L}(\bar{x}, \delta) \text{ and } \bar{X}_L = \bar{X}_L(\bar{x}, \delta)$$

we find from solving the steady-state substrate transport equations (8) and (9). The numerical solution can be represented in the following form as:

$$\int_{\delta_0}^{\delta} \frac{d\delta}{f(\delta)} = t, \text{ and } \int_{\delta_0}^{\delta} \frac{\left(ch(\sqrt{\alpha}\delta) + \frac{\sqrt{\alpha}}{\beta} sh(\sqrt{\alpha}\delta) \right) d\delta}{\gamma \frac{\sqrt{\alpha}}{\beta} sh(\sqrt{\alpha}\delta) - (b + b_s) \left(ch(\sqrt{\alpha}\delta) + \frac{\sqrt{\alpha}}{\beta} sh(\sqrt{\alpha}\delta) \right) \delta} = t$$

$$\text{where } \gamma = \frac{Y^2 K_L L_e}{X_L}.$$

Fig.1,2 show graphs of the stationary thickness of the biofilm and its stabilization time depending on the intensity of biomass separation from the biofilm r for different values of the half-saturation coefficient K_{mL}

$\left(K_{mL} = 5, 10, 20 \frac{\text{g}}{\text{m}^3} \right)$ and at the value of the biomass concentration in the biofilm $X_L = 20000 \text{ g/m}^3$.

The remaining input data used in the calculations are given in Table 1.

Analysis of the results of numerical modeling of the biofilm formation process with given input data shows that as the biomass separation rate increases its stationary thickness decreases from 1300 μm to 250-350 μm .

Table 1

$\mu_{\max} = 0.12 \text{ год}^{-1}$	$Y = 0.52 \frac{\text{г}}{\text{г}}$	$K_L = 0.08 \frac{\text{г}}{\text{г} \cdot \text{год}}$	$L_0 = 30 \frac{\text{г}}{\text{г}^3}$
$\delta_0 = 0.000010 \text{ м}$	$D_L = 2 \cdot 10^{-6} \frac{\text{г}^2}{\text{г} \cdot \text{год}}$	$L_e = 10 \frac{\text{г}}{\text{г}^3}$	$r = 0.02 \div 0.09 \frac{1}{\text{год}}$

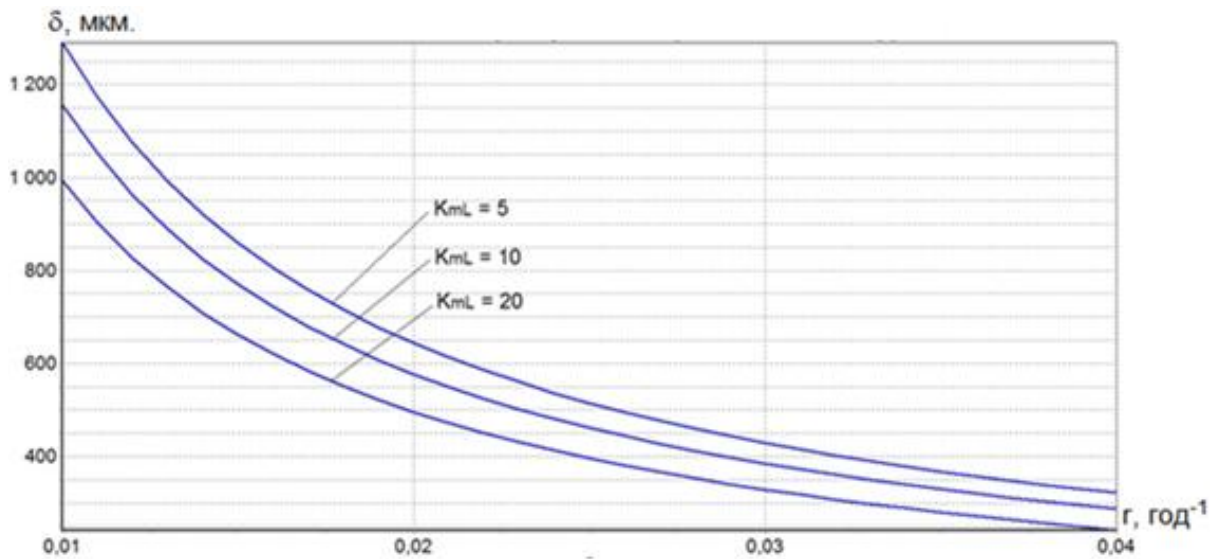


Fig.1. Graphs dependence of steady biofilm thickness from the value of r at

$$X_L = 20000 \frac{\text{г}}{\text{г}^3}$$

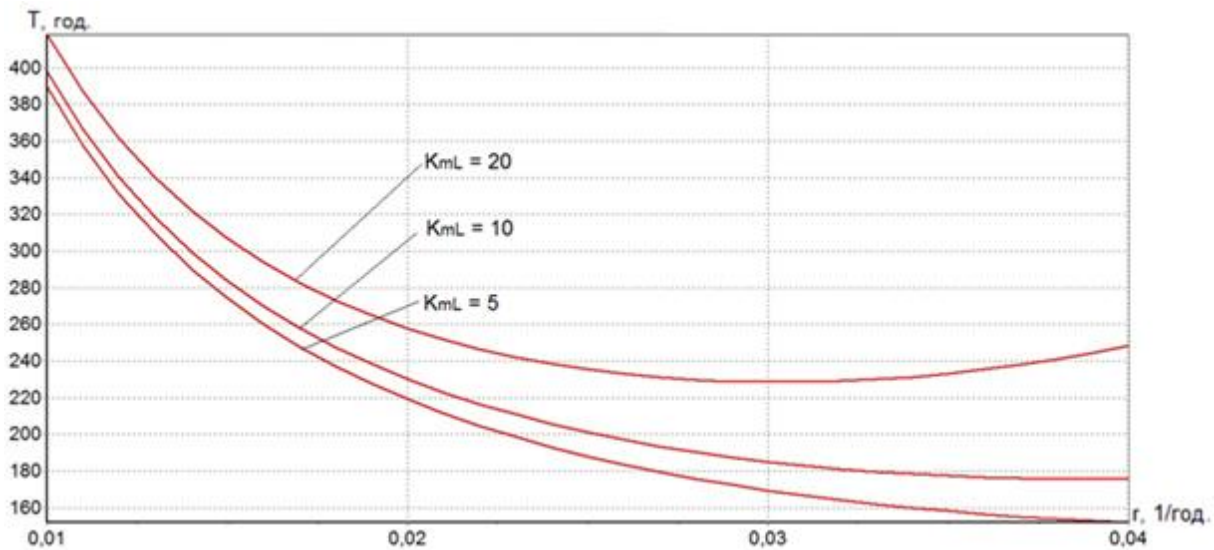


Fig.2. Graphs of the dependence of the time of stabilization of the biofilm

thickness from the value of r at $X_L = 20000 \frac{\text{г}}{\text{г}^3}$

According to experimental studies on the influence of biofilm thickness on the efficiency of the bioreactor work it is believed that its thickness should be within 250-400 μm and also depends on the concentration of biomass in it [2-5]. With given input data the relative stabilization of the biofilm thickness is observed approximately after 180-240 h at biomass detachment rates $r \geq 0.02 \text{ h}^{-1}$. The values of the half-saturation coefficient affect the process of forming a stationary biofilm thickness to a small extent as do the parameters presented in Table 1 which requires additional research and simulation modeling with a wide selection of input data.

Based on the obtained numerical modeling results it is planned to conduct further numerical experiments to refine the criteria and estimates of the main parameters affecting the efficiency of operation of treatment facilities using biofilm technologies.

REFERENCES

1. Henze M., M van Loosdrecht M.E, Ekama GA, Brdjanovic D.(2008). Biological Wastewater Treatment. IWA Publishing, London, 511p.
2. Moira Alvi et al.(2023). Deep learning in wastewater treatment: a critical review. Water Research, vol.245.pp.1-15.
3. Boltz J., Morgenroth C., Dipankar S.(2010).Mathematical modeling of biofilms and biofilm reactors.Water Science and Technology,vol.62(8). pp.1821-1836.
4. Levandowsky Z., Beynal H.(2014). Fundamentals of biofilm research. CRC Press. 157 p.
- 5.Elenter D., Milferstedt K., Zhang W., Hausner M., Morgenroth E.(2007). Influence of detachment on substrate removal and microbial ecology in a heterotrophic / autotrophic biofilm. Water Res., 41. pp.4657-4671.
- 6.Telyma S.V. (2025). On the formation of the structure of a fixed biocenosis in bioreactors at wastewater treatment. Materials 1Y International scientific and practical conference “Green Construction”.Kyiv, KNUBA,14-15 May, 2025. pp.292-297.

IMPROVING THE REGULATORY FRAMEWORK FOR THE DEVELOPMENT OF ENVIRONMENTALLY SAFE TECHNOLOGIES FOR THE PROCESSING OF PVC PROFILES

Sergii Kozhevnikov^{1,2}

¹*Kyiv National University of Construction and Architecture*

²*GEALAN Ukraine, e-mail: slondie7@gmail.com*

In the current conditions of the construction industry, the problem of effective management of polymer waste, in particular waste PVC profiles, is becoming critical. The rapid growth in the production of window structures, as

well as the increase in the number of dismantled products in the process of reconstruction of the housing stock, lead to the accumulation of significant amounts of waste, which are often not reused. In Ukraine, the PVC waste recycling system is at the stage of formation and is characterized by a low level of infrastructure development, the lack of uniform quality standards for secondary raw materials and the imperfection of the regulatory and legal framework. This leads to the loss of significant resource potential and creates an additional environmental burden on the environment.

The problem becomes particularly relevant in the context of Ukraine's European integration course and the need to harmonize national legislation with EU approaches in the field of circular economy. European practice proves that recycling PVC profiles can be not only environmentally expedient, but also economically beneficial if there are clear quality standards for secondary raw materials, traceability mechanisms for materials, effective collection infrastructure and economic incentives for market participants. That is why improving the regulatory framework for the development of environmentally safe technologies for processing PVC profiles is an important prerequisite for increasing resource efficiency, reducing greenhouse gas emissions and reducing dependence on imports of primary polymer raw materials [1].

The purpose of the study is to scientifically substantiate and develop comprehensive proposals for improving the regulatory framework for the development of environmentally friendly technologies for processing PVC profiles in Ukraine. To achieve this goal, the following tasks have been identified: to analyze the current state of legislative regulation in the field of PVC waste processing; to study European approaches to the standardization of secondary PVC; to draft a national standard for RePVC; to propose amendments to the laws of Ukraine "On Waste Management", "On Waste" and the Tax Code; to assess the expected economic and environmental effects of implementing the proposed changes.

A key direction for improving industry regulation is the development of a national standard for recycled PVC (RePVC), which should establish clear requirements for quality, environmental safety and methods of control of recycled raw materials. The proposed structure of such a standard includes general provisions, requirements for the composition of the material, standards for the content of polymeric and inorganic impurities, control of residual moisture, volatile substances and toxic components, as well as requirements for mechanical characteristics and particle size distribution. An important element of the standard are the rules for labeling, transportation, storage, conformity assessment and traceability of batches of material.

The study proposed that recycled PVC for industrial use should contain at least 96% of the base polymer, and the total polymer impurities should not exceed 3%. Particular emphasis was placed on the need to control the content of lead, cadmium and other hazardous residues, as well as on the use of instrumental

control methods - IR spectroscopy, DSC, gas analysis, gravimetry, ICP-MS and mechanical testing. This approach allows to ensure reproducible quality of RePVC and make its use technologically predictable for manufacturers of profile systems [2]. The structure of the Draft National Standard for Recycled PVC is presented in Table 1.

Table 1

Structure of the Draft National Standard for Recycled PVC

Element	Characteristic
General provisions:	requirements for the quality and safety of recycled PVC
Basic requirements:	impurities $\leq 3\%$, reuse $\geq 70\%$, control of toxic residues.
Process requirements:	carbon footprint ≤ 2.5 kg CO ₂ /kg, energy consumption ≤ 1.5 kWh/kg.
Quality control:	certification and annual monitoring.
Marking:	«RePVC-eco».

Significant attention in the work is paid to the technological aspects of recycling PVC profiles. Secondary material is formed as a result of successive stages of dismantling of waste products, sorting, crushing, cleaning from foreign impurities, reprocessing into granulate or powder and laboratory control. The quality of recycling depends not only on the technical equipment of the enterprise, but also on the availability of a regulatory framework that regulates the permissible parameters of the material, sampling rules and quality control systems. It is the absence of such requirements in Ukraine today that hinders the large-scale use of RePVC in the window industry.

An important block of the study are proposals for changes to the legislation. It is proposed to supplement the Law of Ukraine “On Waste Management” with provisions on the mandatory disposal of polyvinyl chloride products, which are presented in Figure 1. This includes determining the list of products subject to mandatory collection and recycling, establishing quotas for manufacturers and importers, reporting requirements in the electronic traceability system, and introducing liability for failure to comply with established standards. This approach forms the legal basis for the organized return of PVC products to the production cycle.

In addition, it is advisable to improve the mechanism of extended producer responsibility. Within the framework of the proposed model, manufacturers and importers of PVC products must ensure the achievement of collection and recycling targets, as well as participate in the financing of collective R&D systems. The introduction of a quota of not less than 50% of reuse or recycling with a gradual increase will contribute to the formation of a stable system of waste management of profile structures [3]. At the same time, the mechanism of “green

recycling certificates” can become a tool for confirming the fulfillment of obligations and stimulating the secondary raw materials market. The wording of the supplemented element is presented in Figure 2.

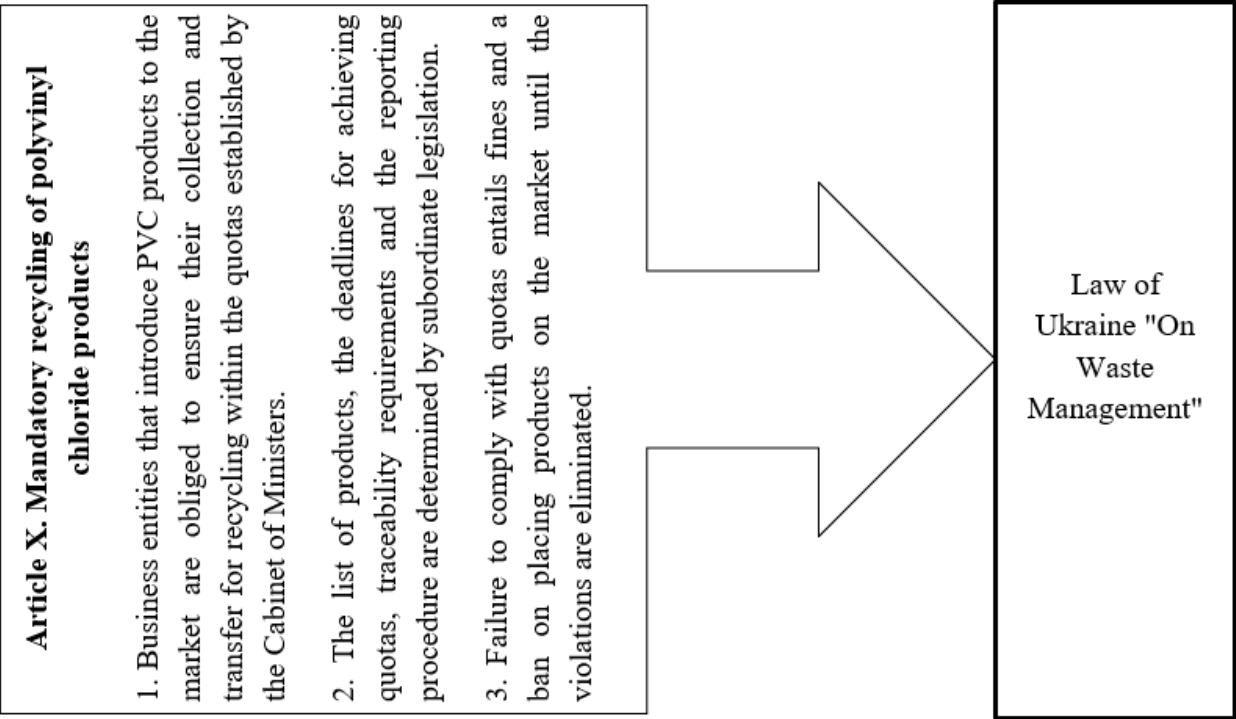


Fig. 1. Proposals for amendments to the Law of Ukraine “On Waste Management”

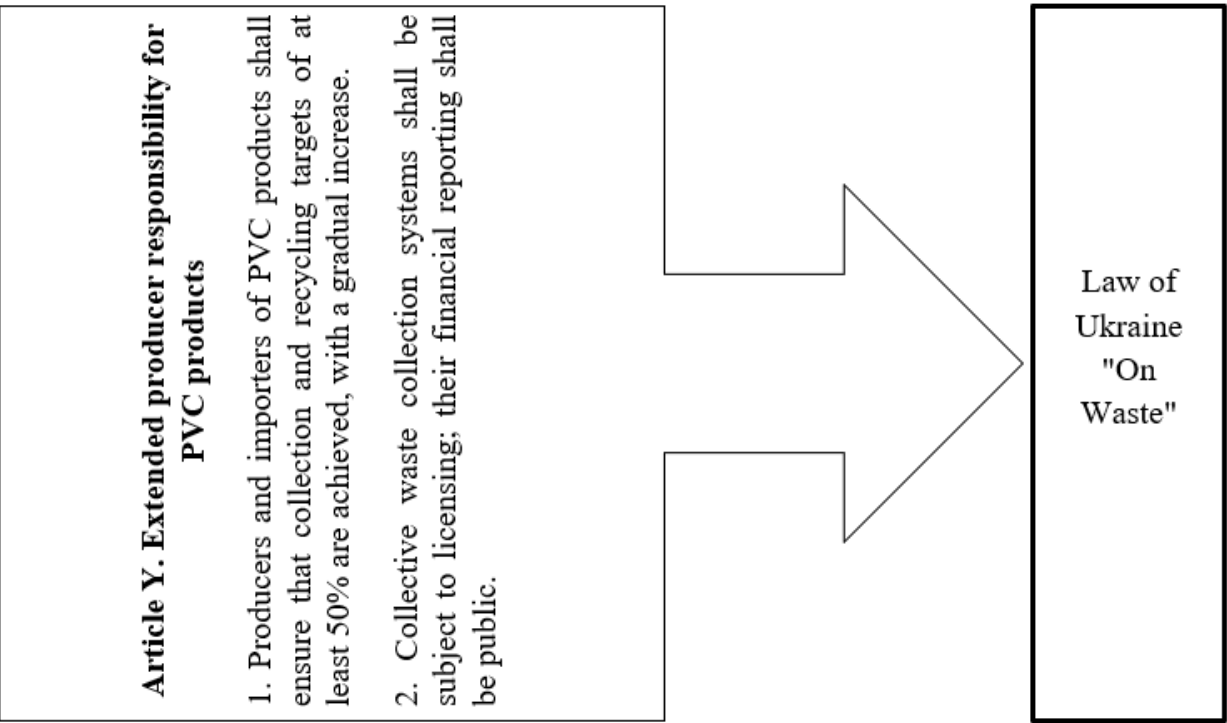


Fig. 2. Proposals for adding a separate element to the Law of Ukraine “On Waste Management”

A separate direction is related to tax incentives for enterprises that use environmentally friendly PVC processing technologies. It is proposed to introduce accelerated depreciation of processing equipment, a tax credit for investments in renewable energy sources for processing enterprises, as well as a reduction in income tax for the share of profit received from the sale of products from RePVC-eco. Such instruments reduce investment barriers at the stage of launching processing lines and increase the liquidity of projects.

To substantiate the feasibility of the proposed regulatory solutions, the work used the balance model “waste flow → output of secondary raw materials → economic benefits → tax effects”. The base scenario involves the creation of three regional processing hubs with a capacity of 15,000 tons/year each. The total capacity of such a network will be 45,000 tons/year, which can become the basis for scaling the PVC processing system in Ukraine [4].

Given a price difference between primary and secondary PVC of 800 euros per ton, annual savings on raw materials could amount to about 36 million euros. At the same time, the environmental effect using the substitution method is estimated at 90,000 tons of CO₂ per year. This confirms that the transition to large-scale use of RePVC has significant climate potential and can be considered as a tool for decarbonizing the construction industry.

Additionally, the fiscal effects of the proposed tax incentives were assessed. In particular, accelerated depreciation of equipment could provide income tax savings of 135 thousand euros per year, a tax credit for investments in renewable energy sources - another 200 thousand euros once, and a reduction in the income tax rate for products made from RePVC-eco - about 100 thousand euros per year. Together, this creates a favorable investment environment for the creation of a modern processing infrastructure [5].

The scientific novelty of the research lies in the formation of a comprehensive approach to improving the regulatory and legal support for the processing of PVC profiles, which combines the standardization of secondary raw materials, the improvement of legislative mechanisms, the introduction of extended producer responsibility and the use of tax incentives. The practical significance of the results obtained lies in the possibility of their application in the preparation of national standards, state support programs for processing enterprises and mechanisms of the RVR in the field of handling PVC products.

As a result of the study, it was found that the development of environmentally friendly technologies for processing PVC profiles in Ukraine requires a systematic update of the regulatory framework. The introduction of a national standard for RePVC will ensure stable quality of secondary raw materials, transparency of its origin and control of environmental parameters. Amendments to the laws of Ukraine “On Waste Management” and “On Waste”, as well as the use of tax incentives create the prerequisites for the development of a modern recycling infrastructure and the formation of a full-fledged system of circular use of PVC in the window industry.

Therefore, the implementation of the proposed set of measures will contribute to increasing the use of secondary PVC, reducing CO₂ emissions, reducing waste disposal costs and increasing the competitiveness of Ukrainian enterprises. The results obtained can serve as the basis for further research related to the assessment of the life cycle of PVC products, modeling the investment efficiency of recycling hubs and harmonizing national technical requirements with EU standards [6].

REFERENCES

1. Krylova G.V. Eco-safe disposal of household plastic waste in technologies with final biodegradation. Dissertation for the degree of Doctor of Philosophy in the field of knowledge 10 "Natural Sciences" in the specialty 101 "Ecology". – Lviv Polytechnic National University of the Ministry of Education and Science of Ukraine, Lviv, 2022. <https://lpnu.ua/sites/default/files/2023/radaphd/22210/disertaciya-krilova-gv.pdf>
2. Lupinos A. Analysis of trends in the development of entrepreneurial activity in the field of polymer waste utilization in Ukraine / A. Lupinos, N. Nurzhiy // Management and entrepreneurship: development trends. – 2018. – Issue 2, № 04. – C. 55-63. – DOI: <https://doi.org/10.26661/2522-1566-2018-2/04-06>.
3. Markina L.M. Determining the hazard of plastic waste for studying the possibility of its utilization by thermal methods / L.M. Markina, S.Yu., Ushkats, N.Yu. Zholobenko // Problems of occupational safety in Ukraine. – Municipal Agency “National Research Institute of Industrial Safety and Occupational Safety”. – 2021. – Volume 37 No. 2. – P. 25-37.– DOI: 10.36804/nndipbop.37-2.2021.25–37.
4. Matveeva N.M., Malovany G.O. Peculiarities of development of enterprises for processing waste and secondary raw materials. Economy and Society, 2024. №60 file:///C:/Users/%D0%9D%D0%B0%D1%82%D0%B0%D0%BB%D1%8C%D1%8F/Downloads/3586%D0%A2%D0%B5%D0%BA%D1%81%D1%82%20%D1%81%D1%82%D0%B0%D1%82%D1%82%D1%96-3502-1-10-20240321.pdf
5. Mykhaylova E. O. Analysis of methods for processing plastic waste / E. O. Mykhaylova, D. M. Deineka, G. M. Pancheva // Bulletin of the National Technical University "KhPI". Series: New solutions in modern technologies: collection of scientific works – Kharkiv: NTU "KhPI", 2021. – № 1 (7). – P. 80-89.
6. Nagurskyi O.A., Krylova G.V., Vasiychuk V.O., Kachan S.I. Utilization of polymeric household waste in technologies with final biodegradation // Problems of sustainable development: materials of the international scientific and practical conference dedicated to the 10th anniversary of the establishment of the institute (Lviv-Zozuli, October 22–23, 2021). – 2021. – P. 194–195.

ECOLOGICAL ASPECTS OF DEVELOPING ENERGY SUPPLY TECHNOLOGY FOR TYPICAL HUMAN DWELLINGS IN EMERGENCY SITUATIONS

Mykola Amirov

Dnipro University of Technology, amirov.m.h@nmu.one

There are no established energy consumption norms for the population in emergency situations (ES). Therefore, under such conditions, the capacity of alternative energy sources is determined primarily based on practical experience using mobile gasoline generators with a capacity of several kW, often ignoring the ecological aspects of their operation. However, it should be noted that emissions of ecologically hazardous substances into the atmosphere from gasoline engine exhaust - especially in conditions of limited air exchange and prolonged operation near dwellings - significantly reduce the level of environmental safety and pose a direct threat to human health. This danger increases during cold seasons when generators operate under increased loads, often exceeding their nominal capacity. Consequently, for the large-scale application of such mobile sources, it is necessary to minimize their capacity and ensure efficient operation in nominal mode. This will conserve liquid fuel resources, which are always scarce during an ES, and improve environmental safety by reducing atmospheric emissions, including through the purification of exhaust gases from low-power engines.

The objective of this work was to develop an environmentally safe energy supply technology for typical human dwellings in ES based on a rational choice of alternative energy sources. This approach aims to minimize fossil fuel consumption and hazardous emissions while maintaining a sufficient level of ecological safety.

To achieve this goal, existing social norms and energy consumption volumes for typical dwellings were studied to determine the required power for alternative sources during an ES. Calculations were performed for a household of four people based on an "economical social norm" of electricity consumption, determined to be 0.259 kW (excluding centralized heating). For a typical two-bedroom apartment, the ES requirement was minimized to 0.792 kW.

Additionally, the power required to compensate for heat losses during the heating period was determined for typical private houses and temporary shelters, such as field dugouts. A generalized analysis of heat loss was conducted using the heat conduction equation with parameters for area, temperature gradient, and thermal resistance of the building structures:

$$W = \frac{S(T_{in} - T_{out})}{R}, W, \quad (1)$$

where S – total surface area through which heat escapes (m^2); $(T_{in} - T_{out})$ – temperature gradient (difference between internal and external temperatures);

$R = d / \lambda$ – thermal resistance, $\text{m}^2\text{K}/\text{W}$, where: λ – the thermal conductivity coefficient (W / mK) and d – the thickness of the structure (m) (note: the value of R determines the specific heat transmission $U = 1 / R$, $\text{W} / \text{m}^2\text{K}$, allowing for quick adjustments of heat loss power in ES conditions).

The main results are summarized in Table 1, showing the required power for heating, water heating, and powering a selected group of household appliances.

Table 1

Power source capacities required to meet energy consumption in typical human dwellings during ES

Typical Human Dwellings	Energy source capacity (in kW) required for...			
	Heat Loss Compensation	Water Heating	Household Appliances	Total Energy Supply
1	2	3	4	5
Social Norm	0,326	0,205	0,259	0,79
Two-bedroom apartment (high-rise)	0,333	0,21	0,251	0,792
Typical private house	3,42	1,28	0,251	4,951
Temporary shelter	4,521	0,21	0,251	4,982

Analysis shows that energy demand in these dwellings during an ES is nearly 70% driven by space and water heating. The remaining 30% is required for electrical appliances. Given these conditions, it is proposed to use different types of alternative mobile sources for heat and electricity. Specifically, the need for mobile heat sources, such as heat pumps (air-to-air, air-to-water), becomes critical. Considering their electricity consumption with a Coefficient of Performance ($\text{COP} \approx 3,0 \dots 4,0$), it is proposed to combine a mobile gasoline generator and two heat pumps into a single alternative energy system. This allows for a reduction in generator capacity to 1–1.5 kW (approximately a three-fold decrease), thereby minimizing gasoline consumption and reducing emissions of greenhouse gases and toxic combustion products. Further emission reduction is proposed using exhaust gas filters made of heat-resistant fibers treated with neutralizers.

Conclusions. Using a gasoline generator up to 1.5 kW ensures fuel conservation (down to 0.4–0.6 l/h) and significantly reduces the ecological load on the area. This is achieved through a proportional reduction in CO_2 , nitrogen oxides, and carbon monoxide emissions, as well as a decrease in noise pollution.

REFERENCES

1. State Sanitary Norms for Heating: DSN 3.36.039-99. Available at:

<https://zakon.rada.gov.ua/rada/show/va039282-99#Text> (Accessed: 18.01.2026).

2. Typical Daily Electricity Consumption by Household Appliances / Ministry of Energy of Ukraine. Available at: <https://www.mev.gov.ua> (Accessed: 18.01.2026).

3. Amirov, M. H. (2025). "Heat conservation in human dwellings during emergency situations". Scientific Spring — 2025: Materials of the XV International Scientific and Technical Conference of Postgraduates and Young Scientists. Dnipro: Dnipro University of Technology, pp. 116–117. Available at: https://rmv.nmu.org.ua/ua/arkhiv-zbirok-konferentsiy/naukova-vesna-2025/Scientific_Spring_2025.pdf (Accessed: 18.01.2026).

4. Kolesnyk, V. E., Rudchenko, A. H., & Amirov, M. H. (2025). "Implementation of eco-safe mobile sources in private houses during emergency situations". Collection of Scientific Papers of the National Mining University, (83), pp. 338–348. DOI: <https://doi.org/10.33271/crpnmu/83.338> (Accessed: 30.04.2026).

5. Amirov, M. H. & Kolesnyk, V. E. (2026). "Energy and ecological aspects of autonomous power supply for temporary shelters in emergency situations". Scientific Spring — 2026: Materials of the XVI International Scientific and Technical Conference of Postgraduates and Young Scientists. Dnipro: Dnipro University of Technology, pp. 178–179.

RUDERAL BIOTOPES IN THE CONTEXT OF GREEN RECOVERY OF URBAN AREAS: RISKS OF INVASIVE PLANT SPREAD AND APPROACHES TO MONITORING

Leonid Chernov

Kyiv National University of Construction and Architecture, chernov_lo-2025@knuba.edu.ua

Green recovery of urban areas involves not only the reconstruction of buildings and the expansion of green spaces, but also environmentally sound management of disturbed sites. In this process, ruderal biotopes are of particular importance. They occur on vacant lots, road verges, railway embankments, construction sites, industrial areas and soil storage sites. Such habitats are often perceived as secondary elements of the urban landscape; however, they may become primary centres of plant invasions and sources for the spread of hazardous alien species within cities.

The ecological specificity of ruderal habitats is determined by exposed substrate, fragmented plant cover, regular mechanical disturbance, reduced competition from stable plant communities and input of diaspores through transport flows, construction materials or soil movement. Under these conditions, alien plants gain an advantage during the early stages of colonisation, while some species are able to establish stable populations and enter the invasive phase.

Therefore, disturbed urban sites should be considered not only as objects of landscaping, but also as potential zones of ecological risk.

Studies of ruderal vegetation in Ukraine confirm a substantial contribution of alien flora to such communities. In particular, 325 alien species belonging to 58 families and 198 genera were recorded in the ruderal vegetation of Ukraine; among them, 23 highly invasive species were identified [1]. Some taxa, including *Ambrosia artemisiifolia*, *Anisantha tectorum*, *Grindelia squarrosa*, *Heracleum mantegazzianum*, *Heracleum pubescens* and *Xanthium orientale* subsp. *riparium*, are regarded as transformer species [1]. These data show that disturbed communities do not merely serve as places of accidental introduction, but also function as active centres of further dispersal of invasive plants.

In the context of green recovery, special attention should be paid to species capable of rapidly establishing on disturbed sites and spreading beyond their initial localities. These include common ragweed, cocklebur species, some goldenrods, giant hogweed and Sosnowsky's hogweed. The latter is a representative example of an invasive plant dangerous for biodiversity and human health, which emphasises the practical importance of spatial monitoring [2].

Ruderal sites rarely exist in isolation. They are spatially connected with transport routes, urbanised zones, agricultural landscapes, industrial territories, riverbanks and floodplains. Through this network of anthropogenically altered localities, alien species can disperse over considerable distances: they first establish in the most disturbed places and later penetrate semi-natural biotopes, shelterbelts, fallow lands, urban green areas and riparian ecosystems. Research on the synanthropisation of the vegetation cover of Ukraine emphasises the importance of studies on plant invasions, urban flora and vegetation changes in disturbed territories [3].

A promising approach is systematic monitoring of such habitats using field surveys, geographic information systems, open biodiversity databases and citizen observations. It should include recording localities of invasive species, assessing population area and density, identifying the type of anthropogenic disturbance and analysing proximity to transport routes, watercourses, construction sites and green areas. The integration of these data in a GIS environment makes it possible to develop risk maps and identify priority sites for control.

Thus, ruderal biotopes in the context of green recovery of urban areas should be considered indicators of anthropogenic disturbance and potential centres of invasive plant spread. Their study is significant for recording the current state of invasive flora, predicting the spread of hazardous species, identifying risk zones and developing practical monitoring approaches. Taking this factor into account in the environmental support of green construction can contribute to the formation of more resilient, safe and manageable urban ecosystems.

REFERENCES

1. Dubyna D. V., Iemelianova S. M., Dziuba T. P., Tymoshenko P. A., Protopopova V. V., Shevera M. V. Alien plant invasion in the ruderal vegetation of Ukraine. *Environmental & Socio-economic Studies*. 2021. Vol. 9, No. 4. P. 57-70. DOI: 10.2478/environ-2021-0025.
2. Khomiak I. V., Onyshchuk I. P., Vakerych M. M., Hasynech Y. S. Adaptation strategies of *Heracleum sosnowskyi* in Ukrainian Polissia. *Biosystems Diversity*. 2024. Vol. 32, No. 1. P. 99-106. DOI: 10.15421/012409.
3. Shevera M. V. Current directions of research into the synanthropization of the vegetation cover of Ukraine. *Visnyk of the National Academy of Sciences of Ukraine*. 2025. No. 11. P. 78-93.

ARCHITECTURE OF HEALTH: DESIGNING GREEN PARKS AS SPACES FOR ACTIVE RECREATION

Bugai Veronika

*Kyiv National University of Construction and Architecture,
buhai_vo-2025@knuba.edu.ua, ver.bugai@gmail.com*

INTRODUCTION

Traditionally, "Green Building" (Fig. 1, 2) is perceived through the prism of energy efficiency and resource saving. However, the modern architectural paradigm expands this concept, defining buildings and urban spaces as an environment that directly shapes the nation's health. In conditions of rapid urbanization, where over 70% of city dwellers lead a sedentary lifestyle, architecture becomes an instrument of preventive medicine.



Fig. 1

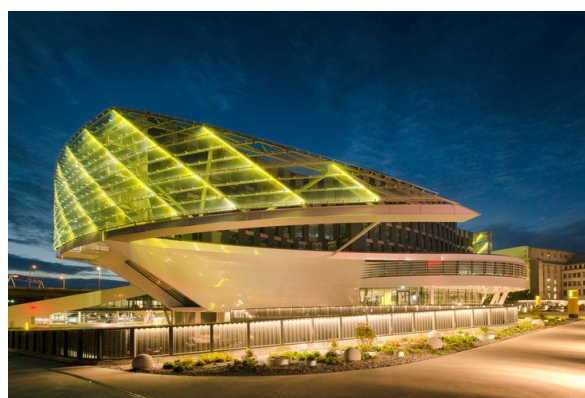


Fig. 2

The creation of active green zones is not just landscaping, but strategic "Active Design" planning, which stimulates physical culture without compulsion, through the comfort and aesthetic appeal of the environment.

SECTION 1: Landscape tools for stimulating activity

A landscape architect acts as a scriptwriter for physical activity. The main tools here are geoplastics and a communication network:

Path design: Different types of sports require different geometry.

Running: requires closed cyclic routes with soft surfaces (tartan, mulch) that cushion impact.

Nordic walking: requires natural paths with elevation changes that engage 90% of the body's muscles.

Cycling: requires a clear separation of flows for safety and high speed.

Intensity Zoning: An important architectural solution is the division of the park into an "active core" and "quiet lagoons."

Zones for yoga, pilates, and stretching are designed in remote parts of the park with maximum shade and the use of tactile surfaces (wooden decks), allowing for practice barefoot or on mats in silence.

Conversely, courts for team games (basketball, tennis) are located closer to entrance groups for easy access for large groups of people (Fig. 3).



Fig. 3

SECTION 2: Ecological aspects of sports infrastructure

The "do no harm" principle is key. Sports infrastructure should integrate into the landscape rather than dominate it.

Sustainable materials: Instead of traditional concrete and excess metal, renewable materials are used: thermowood for sports platforms, stabilized soil, and recycled rubber for running tracks. This reduces the "urban heat island" effect and ensures the ecological purity of the exercise site.

Eco-workout: A modern trend—equipment made from natural materials (wood, stone) that utilize natural resistance. Such grounds provide a high level of psychological comfort.

Energy independence: The implementation of innovative equipment that generates energy (for example, to light the park during evening workouts) creates

additional motivation and emphasizes the eco-orientation of the object.

SECTION 3: Psychophysical impact of the "green" environment

Outdoor fitness significantly exceeds indoor training in terms of effectiveness:

Oxygenation: A large number of green spaces increases the concentration of aeroions and oxygen, which speeds up metabolism and enhances cardiovascular endurance during cardio workouts.

Cortisol reduction: According to Attention Restoration Theory (ART), observing natural fractals reduces stress hormone levels. This is critically important for body recovery after physical exertion.

Phytoncides: Coniferous and deciduous trees release substances that have an antiseptic effect, turning the park into a natural inhalatorium, which is especially important for breathing practices.

SECTION 4: Digitalization and interactivity: "smart" parks

Modern "green architecture" integrates technologies to attract youth to sports:

Interactive navigation systems: Use of QR codes on routes that offer exercise sets for a specific location or allow competing with other park visitors via mobile apps.

Smart lighting: Intelligent lighting systems that adapt to a person's presence make parks safe for running in the evening, expanding the time limits for physical activity.

Eco-sensors: Installing air quality and humidity monitors allows visitors to choose the best time for workouts, making sports conscious and safe.

CONCLUSION

Green architecture transforms the park into a multifunctional "gym without walls." Strategic landscape design based on sustainability principles doesn't just provide space for sports but shapes a new movement culture. The park becomes an object that "compels" the city to move, making physical activity a natural and integral part of the architectural landscape.

REFERENCES

1. DBN B.2.2-12:2019. Planning and Development of Territories. — Kyiv: Ministry of Regional Development of Ukraine, 2019.
2. Jan Gehl. Cities for People / Translated from English. — Kyiv: Osnovy, 2018. — 304 p.
3. Active Design Guidelines: Promoting Physical Activity and Health in Design. — New York City: Center for Active Design, 2010.
4. Kocharyan K. S. Ecological and Biological Foundations of Creating and Maintaining Green Spaces in Cities. — Kyiv: Naukova Dumka, 2015.
5. Smart Cities and Health: Emerging Trends in Urban Design. — Journal of Urban Health, 2022.

FEATURES OF FORMATION OF THE LIGHTING REGIME IN I. STAROV SQUARE (DNIPR CITY)

Ivan Bulavka

Oles Honchar Dnipro National University, Ivanbulavka77email@gmail.com

Modern cities are developing incredibly quickly, which radically changes their microclimate. A large amount of asphalt, high-rise buildings and a reduction in green areas create new environmental challenges [1]. One of the key factors here is the light regime - the spatial distribution of solar energy, which directly controls the heat balance, humidity and comfort of residents. In such large industrial centers as the city of Dnipro, intense summer insolation against the background of dense construction regularly leads to the formation of dangerous zones of overheating and an increase in the effect of the "urban heat island" [2]. World experience proves that green spaces remain the most effective tool for mitigating these phenomena, because tree crowns not only mechanically block the sun, but also radically change the radiation balance of the territory. Today, geographic information systems (GIS) are increasingly used for spatial assessment of these processes, as well as phytoindication methods, where plants act as living biosensors of illumination [6–8, 12]. In turn, the integration of GIS analytics with photometry allows you to quickly identify such imbalances and create heat maps for targeted greening or thinning. However, comprehensive studies that combine these tools in Ukrainian realities are still lacking. Therefore, the purpose of our work was a detailed analysis of the specifics of the formation of the light regime in the urban ecosystems of the Dnieper using the example of the I. Starov square in order to find ways to optimize urban space.

The study was conducted in the I. Starov Park (Dnipro), which is a typical object of the recreational fund with a mosaic structure of plantings. Within the park, observation points were established on a regular grid (Fig. 1), covering areas with different levels of openness and shading [2]. At each location, the following were simultaneously measured: lighting intensity (luxmeter), temperature and relative humidity of the surface air (thermohygrometer), as well as soil temperature and humidity (Soil Analyzer) [5]. Important structural indicators were the density of tree crowns and their number in the accounting area. Analysis of the obtained data allowed us to establish clear relationships between the spatial structure of urban green spaces and the microclimate of its territory.

The range of changes in microclimatic parameters indicates that green areas are a complex conglomerate of microecosystems. The level of illumination varies from 0.82 lux in deep shade to 75.12 on an open paved area. This amplitude of energy input heats the soil surface to 37.9 °C, due to which its humidity drops to 1.4%, indicating significant drying (Table 1).

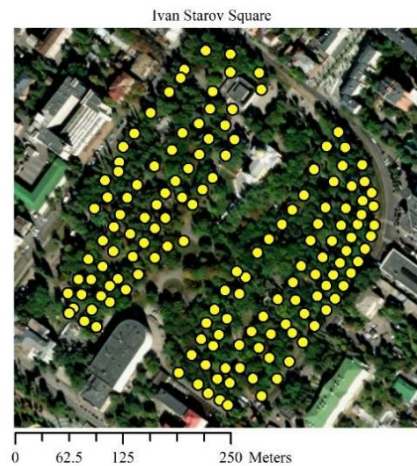


Fig 1. Location of registration points in Ivan Starov Square (Dnipro city)

Table 1

Main characteristics of microclimatic parameters in the I. Starov park

Environmental indicator	Average value of the indicator	Minimum	Maximum	It is better to calculate the standard deviation	Average value (Median)
Soil temperature, °C	33-34	28,9	37,9	9,0	33,5
Soil moisture, %	7-8	1,4	17,3	15,9	7,5
Lighting, Lk	20-25	0,82	75,12	74,3	22,5
Air temperature, °C	35-36	29,6	39,2	9,6	35,6
Air humidity, %	28-32	21,1	50,5	29,4	30,0
Crown closure (0-1)	0,6-0,7	0	1,0	1,0	0,65
Number of trees	2-3	0	6	6	2,5

The barrier that regulates the inflow of solar energy is the closed nature of tree crowns (Table 2).

Table 2

Lighting dynamics depending on the level of canopy closure

Degree of crown closure (parts of a unit)	Structural characteristics of space	Illumination range (Lx)	Average lighting
0–0,1	Open spaces (paved areas, open lawns)	65–75	> 70
0,2–0,4	Weak shading (single trees, alleys with a large step)	35–60	45–50
0,5–0,7	Moderate shading (classical park area, loose groups)	10–35	20–25
0,8–1,0	Strong shading (dense massif, intertwining of crowns)	0,8–10	3–6

The filtration of rays through the canopy follows an exponential law of attenuation. The transition to moderate shade (0.5–0.7) reduces the light flux by more than half, and areas with dense canopy cover receive less than 10% of insolation. From a practical point of view, this means that the city does not need solid thickets to relieve the summer heat load. Optimal protection can be achieved with a canopy cover of 0.5–0.6. This level leaves enough “light windows” to maintain lawns and pedestrian comfort. Understanding how light is converted into heat and humidity is the key to rational urban planning (Table 3) [3].

Table 3

Dependence of microclimatic parameters on the gradation of lighting regimes

Light gradient (Lk)	Soil surface temperature (°C)	Surface air temperature (°C)	Relative humidity (%)
Heavy shade (< 5)	30–33	33–36	30–38
Moderate shade (5–20)	31–34	34–37	27–33
Semi-exposed areas (20–50)	32–36	35–38	25–30
Open insolation (> 60)	33–38	36–39	21–28

In open areas, the sun significantly heats the soil surface, heating the surface air to 39.2 °C and critically reducing its humidity to 21–25%. In conditions of strong shading, thermoregulation is provided by the synergistic action of two biophysical factors: selective screening of short-wave solar radiation by tree crowns and intensive evapotranspirational cooling. As a result, the air temperature decreases to 33 °C, which contributes to the reduction of physiological heat stress and brings conditions closer to acceptable limits according to biometeorological comfort indices (for example, PET or UTCI). The obtained patterns allow for ecological typification of the territory of the studied park according to the light regime (Table 4).

Table 4

Ecological typification of urban spaces according to complex lighting regime

Space type	Structural features	Light mode settings	Microclimatic conditions
I. Open	Lack of trees, low density	60–75 (high insolation)	Maximum temperatures, low humidity, risk of heat stress
II. Semi-shaded	1–3 trees, medium density (0.3-0.6)	20–45 (comfort lighting)	Moderate temperatures, maximum comfort for recreation
III. Shaded	3–6 trees, density >0.8	<10 (insolation deficit)	Reduced temperatures (cooling oasis), increased humidity

A healthy urban ecosystem requires a smart mosaic. Open spaces are vital in the spring for warming and disinfecting areas, but in the summer they turn into local microclimatic thermal anomalies. Excessive tree density, on the contrary, can block street ventilation.

The spatiotemporal dynamics of solar insolation are a determining factor in microclimatic transformations in the city. Open areas provoke radical overheating and enhance the urban heat island effect [4]. The only effective countermeasure is the architecture of a tree tent, and the most optimal environment is a semi-shaded ecotonic landscape. It cuts off extreme temperatures, but retains enough light for people's comfort and the development of grass cover [3]. Therefore, the city management strategy should be flexible: combine planting trees with wide crowns in open spaces and jewel-like formation of light corridors in dense building massifs. Further research should focus on studying the effects of light pollution (ALAN), developing digital twins of cities for 3D microclimate modeling, and synergy of phytoindication methods with satellite sensing (Sentinel-2) for proactive protection of urban space [9].

REFERENCES

1. Adamenko O. M., Kodenko Ya. V., Konsevich L. M. Fundamentals of Ecology: a textbook for higher educational institutions. Kyiv, 2015. 314 c.
2. Bessonova V. P., Ivanchenko O. E., Sklyarenko A. V. Species richness of tree plantations and their vital state in the Obukhiv Park of Dnipropetrovsk region. Scientific Bulletin of UNFU. 2024. T. 34, № 2. C. 17–25. URL: <https://doi.org/10.36930/40340202>.
3. Dudin R. B., Kurnytska M. P., Levus T. M. Park science: a textbook. Lviv: PP "Novyi Svit 2000", 2023. 191 c.
4. Sukharev S. Fundamentals of Ecology and Environmental Protection: Textbook. Uzhhorod National University. Kyiv, 2016. 391 c.
5. Shevchenko S. M., Krulikovskiy S. V. Street plantings in the system of greening of populated areas of Ukraine. Podolsk readings: collection of scientific papers based on materials of the international scientific and practical conference (Kamenets-Podilskyi, October 9–11, 2018). Kamyanets-Podilskyi, 2018. C. 442–447.
6. Kunakh O. M., Zhukov O. V. Method of indicating the lighting mode of a park: patent 160189 Ukraine: MPK A01G23/00 G02F1/00. Application No. 2025 0435; filed 03.02.2025; publ. 13.08.2025.
7. Tutova, H., Lisovets, O., Kunakh, O., & Zhukov, O. (2025). Procrustean analysis of the set of spectral indices reveals the transformations in plant community hemeroby and functional structure induced by anthropogenic disasters. Biosystems Diversity. 2025. Vol. 33(2). P. e2528. URL: <https://doi.org/10.15421/012528>.
8. Lisovets, O., Kunakh, O., Tutova, H., & Zhukov, O. (2025). Phytoindication is an Effective Method for Accurately Determining the Lighting

Intensity in Urban Parks. *Ekológia (Bratislava)*. 2025. Vol. 44(2). P. 129–137. URL: <https://doi.org/10.2478/eko-2025-0015>.

9. Pettorelli N. et al. Framing the concept of satellite remote sensing essential biodiversity variables: challenges and future directions. *Remote Sensing in Ecology and Conservation*. 2016. Vol. 2(3). P. 122-131.

10. Amani-Beni M., Zhang B., Xie G.-D., Odgaard A. J. Impacts of the Microclimate of a Large Urban Park on Its Surrounding Built Environment in the Summertime. *Remote Sensing*. 2021. Vol. 13, No. 22. P. 4703. URL: <https://doi.org/10.3390/rs13224703>.

11. Ziter C. D., Pedersen E. J., Kucharik C. J., Turner M. G. Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. *Proceedings of the National Academy of Sciences*. 2019. Vol. 116, No. 15. P. 7575–7580. URL: <https://doi.org/10.1073/pnas.1817561116>.

12. Shirinyan E., Stefanov K., Petrova-Antonova D. 3D Solar Analysis of the Street Network and Impact Estimation of the Shade of Trees at the District Scale. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* 2025. Vol. XLVIII-G-2025. P. 1339–1346.

13. Jägerbrand A. K., Spoelstra K. Effects of anthropogenic light on species and ecosystems. *Science*. 2023. URL: <https://www.science.org/doi/10.1126/science.adg3173#:~:text=DOI%3A%2010.1126/science.adg3173>.

EFFICIENCY OF THERMALLY ACTIVATED BUILDING SYSTEMS (TABS)

Yuri Volokh¹, Mykhailo Kyrychenko¹

*¹Kyiv National University of Construction and Architecture
volokh_yl-2024@knuba.edu.ua, kyrychenko.ma@knuba.edu.ua*

In the context of the global transition towards nearly zero-energy buildings (NZEB) and the tightening requirements of the EU Energy Performance of Buildings Directive (EPBD Recast 2024), traditional convective engineering systems (VAV, VRF) are approaching the limits of their thermodynamic efficiency. Microclimate provision in commercial real estate accounts for about 40% of total energy consumption. The use of high-potential energy carriers to achieve relatively low indoor temperatures (+20...+24°C) leads to an irreversible massive increase in entropy and a decrease in efficiency. An alternative approach is Thermally Activated Building Systems (TABS), which transform monolithic reinforced concrete structures into large-scale radiant heat exchange surfaces.

A fundamental drawback of traditional air conditioning systems is the use of air as the primary heat carrier. Due to its low density ($\approx 1.2 \text{ kg/m}^3$), this process is accompanied by significant mechanical energy losses for fan operation. The

TABS concept is based on a mass of heavy reinforced concrete; due to its high density (from 2400 kg/m³), concrete can absorb and accumulate thermal energy over the long term (Table 1).

Table 1

Comparative characteristics of the thermophysical properties of accumulating medium

Medium type	Density (kg/m ³)	Volumetric heat capacity (kJ/m ³ ·K)	Thermal conductivity (W/m·K)
Air (convective systems)	≈ 1,2	≈ 1,2	≈ 0,026
Reinforced concrete (TABS slabs)	≈ 2 400	≈ 2 000 – 2 400	≈ 1,5 – 2,0

According to the regulations of international standards (ISO 7730, ASHRAE 55), the determinant of thermal comfort is the operative temperature. A person at rest dissipates more than 50-60% of their sensible heat through long-wave infrared radiation. Since the air velocity in rooms with TABS does not exceed 0.2 m/s, the influence of the surrounding structure's temperature becomes equal to the influence of the air temperature on a person.

$$t_{op} \approx \frac{t_a + t_{mrt}}{2} \quad (1)$$

During the summer period, TABS allow achieving normative thermal comfort (PMV ≈ 0) by lowering the slab surface temperature to +20...+21°C while simultaneously raising the air temperature to +26...+27°C. Conversely, in winter, the air temperature can be similarly lowered; this temperature shift of 2–4 K significantly optimizes the thermodynamic cycle of the machines. Exergy analysis (LowEx) proves that narrowing the generation temperature gradient provides an exponential increase in efficiency.

In heating mode, supplying the heat carrier at +28...+32°C leads to an increase in the seasonal coefficient of performance (COP) of heat pumps from 2.5–3.0 to 4.4–5.2. In cooling mode, supplying water at +16...+19°C increases the efficiency of chillers by 50–52% and allows the implementation of Free Cooling technology. Since concrete slabs (TABS) fully take over the cooling and heating of the room, central ventilation is used exclusively for supplying fresh air according to sanitary standards. As a result, the air volume is halved, which, according to the laws of aerodynamics, reduces fan electricity consumption by up to 8 times.

The realization of the mentioned thermodynamic potential and the safe operation of surface heat exchange systems critically depend on control algorithms. Operation in cooling mode requires precise control of the heat carrier temperature for continuous dew point monitoring (to avoid condensation) and rapid adaptation to dynamic heat loads. As contemporary studies prove, the

implementation of intelligent automation systems is a key factor that not only guarantees stable maintenance of indoor thermal comfort but also determines the actual energy efficiency of the entire surface cooling system.

The climate resilience of buildings deserves special attention; the time constant of a building with TABS is tens of hours. Under extreme heat waves and emergency power outages (blackouts), facilities with active concrete slabs demonstrate unprecedented thermal stability, as reflected in the dynamic simulation results (Fig. 1).

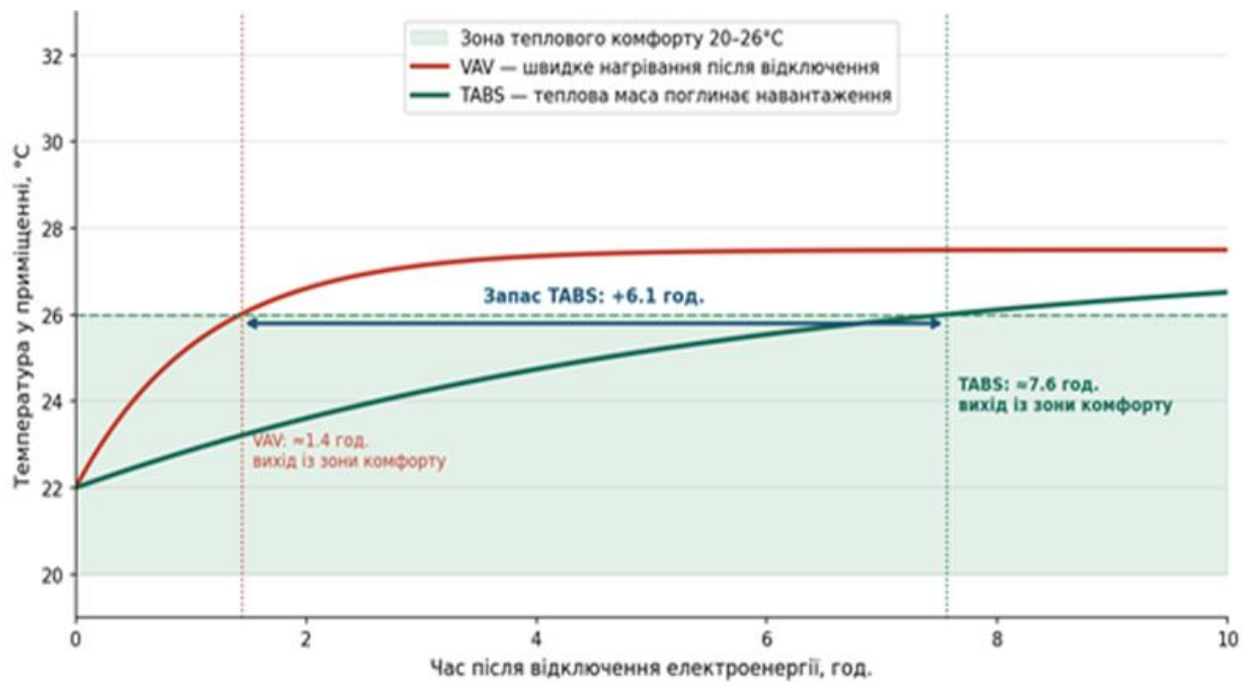


Fig. 1. Building resilience to blackouts: indoor heating dynamics (TABS vs. VAV)

Unlike convective systems, where violation of sanitary standards occurs 1.5–2 hours after equipment shutdown, a building with TABS retains the ability to passively absorb heat and maintains a permissible temperature of up to +27°C for 6.5–8 hours. A summary energy analysis comparing the parameters of annual energy consumption (OPEX) and operational advantages of surface systems against convective ones (VAV/VRF) is presented in Table 2.

Table 2

Summary comparison of annual energy costs and overall efficiency (TABS vs. Convective Systems)

No.	Parameter	Traditional convective systems (VAV/VRF)	Thermally activated building systems (TABS)	Overall efficiency / Savings (%)
1	Cold generation (Summer period)	Water supply at +7...+12°C. High load	Water supply at +16...+19°C.	Chiller COP increase by 50–

No.	Parameter	Traditional convective systems (VAV/VRF)	Thermally activated building systems (TABS)	Overall efficiency / Savings (%)
		on chillers	Active use of Free Cooling	52%
2	Heat generation (Winter period)	Heat carrier supply at +50...+70°C. Heat pump COP: 2.5–3.0	Heat carrier supply at +28...+32°C. Heat pump COP: 4.4–5.2	Heat pump COP increase up to 70%
3	Air transportation (Fans)	High air exchange to remove 100% of sensible heat	DOAS operation: air volume halved (sanitary standard only)	Reduction in fan electricity costs by up to 87.5% (8 times)
4	Peak loads and resilience	Direct dependence: shutdown = overheating in 1.5–2 hours	Peak Shaving, blackout resilience for 6.5–8 hours	Reduction of installed generation capacity by 30–40%
5	Total annual energy consumption (HVAC)	Baseline indicator (100% of costs)	Comprehensive use of LowEx technology	Reduction of overall OPEX by 40–55%

Thus, the implementation of TABS is a fundamental shift in the paradigm of engineering design for energy-efficient buildings. The elimination of convective heat transfer removes local drafts and radiant asymmetry, while the synergy of exergy optimization and high thermal inertia makes TABS an objective component of sustainable, energy-independent construction. Modern automation and predictive control are integral components for unlocking the full potential of such systems.

REFERENCES

1. Babiak J., Olesen B. W., Petras D. Low temperature heating and high temperature cooling. REHVA Guidebook No. 7. Brussels: REHVA, 2009. 84 p.
2. ISO 7730:2005. Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using the PMV and PPD indices. Geneva: International Organization for Standardization, 2005.
3. Sourbron M., Helsen L. Evaluation of energy efficiency and comfort of thermally activated building systems (TABS). Energy and Buildings. 2011. Vol. 43, Issue 8. P. 1779-1785.
4. Volokh, Yu., & Kyrychenko, M. (2025). Impact of an automation system on the efficiency of surface cooling in creating thermal comfort. Ventilation, Illumination and Heat and Gas Supply, 54, 30–38.
5. Pohosov, O., Skochko, V., Solonnikov, V., Kyrychenko, M., & Chepurna, N. (2024). Review and concept of passive individual housing construction for a temperate continental climate. Architectural Studies, 10(2), 14–24.

6. Doroshenko, A., & Kyrychenko, M. (2024). Investigation of linear inhomogeneous inclusions in the junction zone to the load-bearing slab for metal-frame buildings. *Proceedings of the MNL Conferences*, (April 26, 2024, Odesa), 288–291.
7. Shapoval, O., Chepurna, N., & Kyrychenko, M. (2021). Analysis of the efficiency of an air source heat pump depending on outdoor temperature fluctuations. *Ventilation, Illumination and Heat and Gas Supply*, 37, 24–30.
8. Podenezhko, Y., Kirichenko, M., Chepurna, N., & Chepurnyi, V. (2019). Investigation of heating devices based on a first-order phase transition. *Ventilation, Illumination and Heat and Gas Supply*, (31), 63–70.
9. Doroshenko, A., & Pasichnyk, P. (2025). Features of the application of low-temperature radiant indoor heating systems in terms of their operation. *Proceedings of the MCND Conferences*, (May 2, 2025, Ivano-Frankivsk, Ukraine), 398–402.
10. Pohosov, O., Pasichnyk, P., & Kulinko, Ye. (2023). Impact of certain design solutions on the energy efficiency class of a building. *Collection of Scientific Papers «SCIENTIA»*, (December 22, 2023; Coventry, UK), 214–217.
11. Pohosov, O., Kulinko, Ye., Koziachyna, B., & Kolchyk, M. (2025). Analysis and ways of development of Ukrainian legislation in the field of building energy efficiency requirements. *Ventilation, Illumination and Heat and Gas Supply*, 55, 33–46.

FEATURES OF CONSTRUCTION OF DECENTRALIZED SYSTEMS FOR THE PRODUCTION OF ELECTRICITY FROM WASTE WITHIN THE LIMITS OF "WASTE-TO-ENERGY" TECHNOLOGY IN MODERN CONDITIONS OF TERRITORIAL COMMUNITIES

Dmytro Prusov¹, Denys Yalovyi², Henrykh Kravchenko²

*¹Institute of Innovative Education of the Kyiv National University of
Construction and Architecture, dmytro.prusov@iino.in.ua;*

*²Ukrainian Association of Alternative Electric and Hydrogen Energy,
info@uaaehe.org*

Relevance and strategic importance for territorial communities. In the current conditions of the transformation of Ukraine's energy sector and the global course towards decarbonization, the construction of decentralized "waste-to-energy" (WtE) systems ceases to be a purely technological issue and moves into the realm of strategic security of territorial communities [1, 2]. The transition from a centralized model to local energy hubs operating on community resources is the only effective mechanism for ensuring sustainability in the face of military and economic challenges.

The strategic importance of decentralization lies in the creation of so-called "energy islands". Instead of complete dependence on large thermal power plants

and main grids, united territorial communities (UTC) receive an autonomous source of generation capable of supporting the operation of critical infrastructure - hospitals, water utilities and social facilities 24/7. Unlike solar or wind energy, thermal waste utilization provides a stable base load, which is critical for stabilizing local networks.

For united territorial communities, the implementation of WtE systems solves a set of critical needs:

First, it is ecological decompression. The shortage of land resources and the critical state of existing landfills require radical solutions. WtE technology allows to reduce the amount of waste requiring disposal by 90%, effectively stopping the growth of landfills and minimizing methane emissions (an aggressive greenhouse gas). The community is transformed from a "landfill area" to an environmentally safe zone.

Secondly, it is an economic entity. Today, most communities spend significant amounts of money on waste logistics to remote landfills and on purchasing natural gas for heating. The construction of a local WtE station fundamentally changes this paradigm. Given the logistical optimization, the short-haul transportation of waste within the UTC significantly saves budget funds. The problem of import substitution is solved, since each ton of waste converted into energy replaces the equivalent of up to 300 m³ of expensive natural gas, providing the community with its own cheap heat. In addition, the presence of a guaranteed source of thermal energy and stable electricity makes the community an attractive platform for industrial investors, agro-processing complexes and greenhouse farms, which generates new jobs and taxes.

Thirdly, it is socio-political capital. The implementation of such projects is an indicator of the readiness of the UTC for European integration [3]. This opens access to international "green" grants and recovery funds, which finance exclusively projects with a high level of environmental responsibility and energy efficiency.

Therefore, waste-to-energy facilities are considered multifunctional energy nodes, the strategic importance of which lies in the transition from a linear consumption model to a cyclical one, where waste is converted into a resource, which guarantees energy independence at the level of a separate district or city.

The construction of decentralized WtE systems in modern conditions is a way to transform the "garbage problem" into a strategic asset of the community. The result for the UTC is not only a clean environment, but also energy independence, economic sustainability and a new level of quality of life for residents, since the decentralized WtE system is the transformation of a passive expense item into an active resource, which is a transition from a linear consumption model to a circular economy, where waste is not a burden, but a fuel for development.

Energy security and environmental standards in the construction of decentralized WtE systems.

In the face of modern threats to the integrity of the energy system, decentralized waste-to-energy facilities are the foundation of local energy security. Unlike large generating capacities, which are vulnerable targets, a network of small WtE stations creates a distributed system that cannot be knocked out with a single blow. WtE facilities ensure stable energy production regardless of weather conditions or the availability of imported gas, which allows maintaining the viability of regional energy nodes. Using waste as fuel eliminates the risks associated with disruption of traditional energy supply chains.

Modern construction conditions require uncompromising adherence to the highest environmental standards (in particular, the EU Directive on Industrial Emissions). The strategic importance of WtE lies in the radical reduction of environmental pressure on the region. Preventing organics from entering landfills avoids the uncontrolled formation of methane and leachate, which poisons groundwater. The construction of decentralized systems involves the use of integrated dry and wet gas cleaning systems, which guarantees significantly lower emission levels than traditional coal-fired power plants. This allows such facilities to be safely located in close proximity to consumers (cities).

The construction of energy recovery systems is a key tool for decarbonization. By replacing fossil fuels with waste, the community receives a "green" component in its energy balance. Modern technologies allow the use of the inert residue (slag) formed after incineration as a material for road construction, ensuring the concept of "zero waste". The implementation of decentralized WtE projects allows communities and the state as a whole to fulfill international obligations to reduce CO₂ emissions.

A feature of construction in modern conditions is the digitalization of environmental control. The introduction of automated emission monitoring systems (CEMS) ensures transparency of the plant's operation for the public. This relieves social tension and ensures that energy security is not achieved at the cost of environmental well-being.

Therefore, energy security and environmental standards in decentralized WtE systems are inseparable. The strategic outcome is to create a system where energy security is achieved through high environmental responsibility, transforming a potential threat (waste) into a guaranteed and clean energy resource.

Features of the technologies for designing, building and operating decentralized WtE systems in modern conditions

Modern decentralised facility design is based on the principle of modularity. Unlike the giant plants of the past, modern systems are designed as scalable units, allowing communities to gradually increase capacity. At the design stage, it is critical to take into account the variable morphology of waste. Priority is given to grates with high thermal stability or low-temperature pyrolysis systems for small volumes. The use of BIM technologies in design allows for the creation of a

virtual model of the facility, which minimizes installation errors and allows for the calculation of fuel logistics and energy output in advance.

In the context of unstable logistics chains, the construction of decentralized systems focuses on prefabrication. For small territorial communities, block-container-type installations are used, which require minimal general construction work and can be put into operation within 6–10 months. The design provides for increased protection of power units and the use of materials resistant to aggressive environments (corrosion from flue gases), which extends the service life to 25–30 years without major repairs.

A feature of operation in modern conditions is the transition from manual control to fully automated process control systems. Implementation of neural networks to optimize the combustion process in real time. The system automatically regulates the air supply and temperature depending on the calorific value of the fuel supplied. Decentralized facilities are designed with the possibility of remote control. This is critical for communities that may not have narrow-profile specialists on site – service support and diagnostics can be carried out centrally via cloud platforms. The operating model necessarily involves the simultaneous production of electricity and heat. The use of waste heat for local needs (heating, drying of agricultural products) raises the overall efficiency of the system to 85–90%.

In modern conditions, special attention is paid to the autonomy of safety systems. Each facility is equipped with independent power sources for gas purification and emergency shutdown systems, which guarantees the environmental safety of the facility even in the event of a complete blackout of external networks.

Thus, the modern approach to the construction of WtE facilities is a symbiosis of compactness, intelligent management and flexibility. The technology ceases to be a bulky industrial structure, turning into a high-tech IT-controlled "energy gadget" of the community, which is easily integrated into the urban environment and does not require a huge maintenance staff.

Technologies for designing, constructing and operating WtE systems: Ukrainian context and perspective.

In Ukraine, the morphology of waste differs significantly from that of EU countries due to the lower level of pre-sorting and high moisture content of organic matter. The design should be based on technologies that can withstand fluctuations in calorific value (for example, water-cooled grates). This allows for the incineration of residues without expensive preliminary preparation. In modern conditions, designs should provide for decentralized placement of control units and the ability to operate in self-starting mode of the facility without external voltage. Transition to modular design, where the capacity of the plant can be increased in parallel with the growth of the community or industrial cluster.

The main challenge for Ukraine in modern conditions is the need for quick solutions to replace destroyed capacities. The strategic priority is to involve

Ukrainian machine-building enterprises for the manufacture of metal structures, waste heat boilers and filtration systems. This reduces the cost of the project and simplifies subsequent maintenance. The use of block-modular structures allows to reduce the construction period from the typical 3–4 years to 18–24 months, which is critical for critical infrastructure facilities that urgently need uninterrupted supply of electricity and heat today. Creating a network of typical small WtE facilities (up to 5 MW), which will allow standardizing construction and reducing design costs.

Therefore, for Ukrainian territorial communities, WtE facilities should be small, protected, digitalized nodes that make maximum use of local resources and work in close cooperation with the local economy, and will become an effective network of community energy centers.

REFERENCES

1. Law of Ukraine dated 06/20/2022 No. 2320-IX. "On Waste Management" <https://zakon.rada.gov.ua/laws/show/2320-20>
2. State Strategy for Regional Development for 2021-2027 (with amendments from 2024 regarding energy decentralization). <https://zakon.rada.gov.ua/laws/show/695-2020-п>
3. Manual for developing a local waste management plan for a territorial community (U-LEAD Publishing, 2025). <https://decentralization.ua/news/19338>

SOLAR RESOURCE ASSESSMENT AND PHOTOVOLTAIC INTEGRATION FOR THE UPPER CARAVANSERAI

Mammadov Nurmammad¹, Guliev Jamil¹, Aliyeva Maleyka¹

*¹Azerbaijan Architecture and Construction University,
nurmammad.mammadov@azmiu.edu.az, camil.quliyev@azmiu.edu.az,
meylekeliyeva16@gmail.com*

1. INTRODUCTION

Historical buildings require energy-modernization strategies that improve energy performance without damaging architectural value, visual identity, or cultural character. The integration of renewable-energy systems into traditional architecture therefore requires a balance between technical, environmental, and aesthetic factors [1]. The Upper Caravanserai is an 18th-century historical monument which currently functions as a hotel, restaurant, and tourism complex. Because the building has continuous electricity demand for lighting, ventilation, cooling, pumping, and service equipment, rooftop photovoltaic integration was selected as a suitable renewable-energy option. This paper focuses only on the PV subsystem and evaluates solar-resource potential, preliminary PV sizing, selected equipment, expected annual generation, economic performance, and avoided CO₂ emissions.

2. CASE STUDY AND METHODOLOGY

The study is based on the Upper Caravanseraï in Sheki, Azerbaijan. Solar-resource data for the site were taken from Global Solar Atlas, including specific PV output, irradiation values, and optimum tilt/azimuth [2]. PVGIS-ERA5 climate data were used to support the evaluation of local climate and temperature conditions [3]. Roof suitability was considered according to available roof area, solar exposure, orientation, shading risk, and the architectural sensitivity of the historical building. Revit-based solar analysis was used to support the preliminary selection of suitable roof surfaces [4].

Table 1

Main design inputs	
Parameter	Value
Annual electricity demand	520,000 kWh/year
Available roof area	3,200 m ²
Target PV contribution	45%
Specific PV output	1,378.3 kWh/kWp·year
Optimum tilt / azimuth	35° / 180°

PV capacity was estimated from the target PV contribution and site-specific PV yield, in line with grid-connected PV sizing principles [5]:

$$E_{target} = E_{annual} \times f_{PV}, P_{DC} = \frac{E_{PV,target}}{Y_{specific}} \quad (1)$$

This approach links the required PV capacity with electricity demand and local solar-resource availability.

3. PV SYSTEM CONFIGURATION

For this project, the LONGi Hi-MO X6 Max Explorer LR7-72HTH-610M photovoltaic module was selected as the reference technology. The selected module has high rated power, suitable dimensions, and a low temperature coefficient, which are important for rooftop PV systems where installation area is limited [6]. The use of high-efficiency monocrystalline modules is also consistent with rooftop PV feasibility studies, where module efficiency, roof area, shading conditions, solar radiation, and electricity generation are key factors [7]. Studies also show that N-type silicon PV modules provide stable performance in different outdoor operating conditions [8]. In this design, 280 PV modules are used, providing 170.8 kWp of installed DC capacity. The inverter configuration was selected according to the PV-to-inverter sizing ratio, which is an important design parameter for grid-connected PV systems [9]. Three Sungrow SG50CX-P2 string inverters were selected, giving a total AC capacity of 150 kW [10]. The inverter selection follows PV-plant design principles related to string arrangement, inverter operating limits, AC connection, disconnection, and protection coordination [11].

Table 2

Selected PV configuration and main results

Indicator	Value
PV system size	280 modules / 170.8 kWp
Inverter capacity	3 × 50 kW / DC-AC ratio 1.14
Annual PV generation	234–235 MWh/year
Grid reduction	≈45% / remaining grid demand ≈286 MWh/year
Economy and CO ₂ result	21.7 years payback / 96.2 tCO ₂ /year reduction

4. RESULTS AND DISCUSSION

The yearly PV electricity production was calculated from the installed system capacity and the PV output value for this location [2], [5]:

$$E_{PV,annual} = P_{DC} \times Y_{specific} \quad (2)$$

The selected 170.8 kWp PV system can generate approximately 234–235 MWh of electricity per year, which corresponds to about 45% of the annual electricity demand of the Upper Caravanserai. As a result, the remaining annual grid electricity demand is reduced to approximately 286 MWh/year. The 1.14 ratio works well for a PV system connected to the grid. It allows the inverters to work better and keeps possible energy losses low during very sunny periods. Since exact price quotations for this project were not available, the economic analysis was based on NREL PV cost benchmarks and conservative design assumptions [12]. For electricity-cost savings, the official non-residential electricity tariff was adopted [13]. The simple payback period was calculated as

$$PBP = CAPEX/S_{annual} \quad (3)$$

Based on the estimated PV subsystem CAPEX and annual electricity saving, the simple payback period is approximately 21.7 years. In this approach, electricity produced by the PV system replaces part of the electricity taken from the grid [14]. Using the adopted grid-emission factor, the system can avoid approximately 96.2 tCO₂/year.

5. CONCLUSION

This paper analyzed rooftop photovoltaic integration for the Upper Caravanserai in Sheki, Azerbaijan. The results show that a 170.8 kWp PV system with high-power N-type monocrystalline modules and three 50 kW string inverters can provide approximately 45% of the building's annual electricity demand. This PV system can generate about 234–235 MWh/year, reduce grid electricity consumption by about 234 MWh/year, and avoid approximately 96.2 tCO₂/year.

Although the simple payback period is relatively long, the proposed PV system gives clear energy-saving and environmental benefits. Therefore, rooftop PV integration can be considered a technically suitable modernization strategy for the Upper Caravanserai, provided that roof placement respects the architectural and historical character of the building.

REFERENCES

1. Hasanli, A.N. and Mehrabova, M.A., 2021. The influence of alternative energy means on architectural shaping. *International Journal of Cultural Heritage*, 6, pp. 26–30. Available at: [https://www.ias.org/iasar/filedownloads/ijch/2021/017-0004\(2021\).pdf](https://www.ias.org/iasar/filedownloads/ijch/2021/017-0004(2021).pdf)
2. ESMAP, 2020. *Global Photovoltaic Power Potential by Country*. World Bank / Global Solar Atlas. Available at: <https://globalsolaratlas.info/global-pv-potential-study>
3. European Commission JRC, 2024. *PVGIS: Monthly climate data for Sheki, Azerbaijan, PVGIS-ERA5, 2005–2023*. Available at: https://re.jrc.ec.europa.eu/pvg_tools/en/
4. Autodesk, 2018. *Evaluating PV Potential in Revit*. Available at: <https://www.autodesk.com/support/technical/article/caas/tsarticles/ts/21EbZH17pb5YpBs1FswjdM.html>
5. Abo-Khalil, A.G., Sayed, K., Radwan, A. and El-Sharkawy, I.I.A., 2023. Analysis of PV system sizing and economic feasibility in a grid-connected PV system. *Case Studies in Thermal Engineering*, 45, 102903. Available at: <https://doi.org/10.1016/j.csite.2023.102903>
6. LONGi Solar, 2024. *LR7-72HTH 605–615M Hi-MO X6 Max Explorer module datasheet*. Available at: https://static.longi.com/LR_7_72_HTH_605_615_M_30_30_and_15_Frame_Explorer_20240511_V2_d0c9b7df55.pdf
7. Shi, K., Li, C. and Koo, C., 2021. Techno-economic feasibility analysis of rooftop mono-Si and poly-Si PV systems. *Sustainability*, 13(9), 4709. Available at: <https://doi.org/10.3390/su13094709>
8. Park, H., Chang, S., Park, S. and Kim, W.K., 2019. Outdoor performance test of bifacial N-type silicon PV modules. *Sustainability*, 11(22), 6234. Available at: <https://doi.org/10.3390/su11226234>
9. Hazim, H.I., Baharin, K.A., Gan, C.K. and Sabry, A.H., 2024. Techno-economic optimization of PV-inverter sizing ratio. *Results in Engineering*, 23, 102580. Available at: <https://doi.org/10.1016/j.rineng.2024.102580>
10. Sungrow Power Supply Co., Ltd., 2023. *SG36/40/50CX-P2 string inverter datasheet*. Available at: https://info-support.sungrowpower.com/application/pdf/2023/12/21/DS_20231219_SG36_40_50CX-P2_Datasheet_V4_EN.pdf
11. ABB, 2019. *Photovoltaic Plants: Technical Application Paper*. Available at: <https://library.e.abb.com/public/fb75869122d24b408ab985833cd472db/9AKK107492A3277%20Photovoltaic%20plants%20-%20Technical%20Application%20Paper.pdf>
12. Ramasamy, V., Zuboy, J., Woodhouse, M., O'Shaughnessy, E., Feldman, D., Desai, J., Walker, A., Margolis, R. and Basore, P., 2023. *U.S. Solar*

Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2023. NREL. Available at: <https://www.nrel.gov/docs/fy23osti/87303.pdf>

13. Azerbaijan Energy Regulatory Agency, 2025. *Electricity tariffs*. Available at: <https://regulator.gov.az/en/elektrik/elektrik-enerjisinin-olkedaxili-tarifleri>

14. European Investment Bank, 2023. *EIB Project Carbon Footprint Methodologies*, Version 11.3. Available at: https://www.eib.org/attachments/lucalli/eib_project_carbon_footprint_methodologies_2023_en.pdf.

THE EFFECT OF BLAST AIR OXYGENATION ON THE COMPOSITION OF COAL COMBUSTION PRODUCTS IN INDUSTRIAL STEAM GENERATORS

Pavlo Glamazdin¹ Yevhen Vakulenko¹

*¹Kyiv National University of Construction and Architecture,
sib.kiev@gmail.com, eugenvak@ukr.net*

The thermal power sector remains one of the key sectors for the production of electricity and heat in Ukraine. According to the Ministry of Energy of Ukraine, the share of coal-fired thermal power stations in the overall electricity generation mix traditionally exceeds 29% [1]. Despite the gradual development of renewable energy sources, coal-fired thermal power stations and combined heat and power plants will remain the backbone of the country's energy infrastructure for a long time to come.

Coal combustion is accompanied by emissions of a whole range of pollutants: sulphur oxides, nitrogen oxides, particulate matter, heavy metals and greenhouse gases. Among these, sulphur oxides are of particular concern due to their multifaceted negative impact: toxic effects on human health, acid rain, corrosive damage to structures, and the accelerated degradation of soil and aquatic ecosystems [2].

The transition to oxy-fuel combustion technologies (or partial enrichment) opens up opportunities to improve fuel combustion efficiency and reduce flue gas volumes. At the same time, the increase in oxygen concentration in the combustion air causes qualitative changes in the chemical composition of combustion products – in particular, an increase in the proportion of sulphur trioxide (SO₃), which replaces SO₂, complicating both the technical operation of boiler equipment and compliance with environmental standards. Sulphur is one of the most common heteroelements in coal. During the combustion of coal, sulphur undergoes thermochemical transformations, resulting in the formation of a whole range of compounds. The main gaseous products of sulphur oxidation are:

- sulphur dioxide (SO_2) – the main sulphur compound formed during the combustion of organic and pyrite forms of sulphur; it is a toxic gas with a pungent odour that irritates the respiratory tract. The maximum permissible concentration (MPC) in the air of populated areas is 0.05 mg/m^3 (daily) [3];
- sulphur trioxide (SO_3) – formed in small quantities during the catalytic oxidation of SO_2 involving vanadium pentoxide contained in fly ash, as well as at elevated temperatures and oxygen concentrations; SO_3 is significantly more toxic than SO_2 , is hygroscopic and reacts rapidly with moisture in the air, forming sulphuric acid (H_2SO_4) aerosols (MPC 0.003 mg/m^3);
- hydrogen sulphide (H_2S) – may form in a reducing atmosphere during incomplete combustion and is an extremely toxic gas (MPC 0.008 mg/m^3); however, under normal combustion conditions in an atmosphere with an excess of combustion air, its concentration is minimal;
- sulphate aerosols – products of the interaction of SO_3 with moisture and other substances [ammonium sulphate $(\text{NH}_4)_2\text{SO}_4$, calcium sulphate CaSO_4 , etc.], which form suspended particles in the submicron range.

From an environmental and health perspective, the most hazardous substances are SO_3 and its hydration product, sulphuric acid (H_2SO_4). H_2SO_4 droplet aerosols have pronounced fibrogenic and carcinogenic effects and damage the alveolar tissue of the lungs. According to the IARC (International Agency for Research on Cancer) classification, aerosols of inorganic acids containing sulphuric acid belong to Group 1 (proven carcinogens) [4].

Sulphur dioxide (SO_2) reacts with atmospheric moisture and oxidants (ozone, hydrogen peroxide) to form H_2SO_4 , which is the main component of ‘acid rain’. Acidic precipitation with a $\text{pH} < 5.6$ causes soil acidification, the mobilisation of heavy metals (Al, Mn, Cd), the degradation of forest stands and the acidification of water bodies [5]. According to various estimates, the damage caused by acid rain to agriculture and forestry in Central and Eastern Europe amounts to billions of euros annually [5].

Furthermore, SO_2 and SO_3 react with nitrogen oxides to form photochemical smog – a form of secondary atmospheric pollution that is extremely harmful to the health of people living in urban areas [3].

Ukraine's coal deposits are concentrated mainly in the Donetsk and Lviv-Volyn and Dnipro coalfields, as well as the lignite deposits of the Dnipro Basin. Each coal grade is characterised by specific sulphur content and forms.

Total sulphur in coal comprises three forms: organic (So), pyrite (Sp) and sulphate (Sc). Organic sulphur is chemically bound to the carbon matrix of the coal and is the most difficult to remove during fuel preparation. Pyrite sulphur is present in the form of pyrite-marcasite crystals (FeS_2) and is partially removed by gravity separation. Sulphate sulphur (mainly CaSO_4) is present in negligible quantities and has no practical environmental significance [6].

Anthracite (AS grade) has the lowest total sulphur content among hard coals – 0.5–1.5%. This is due to the high degree of metamorphism and the leaching of

some sulphur compounds during the geological transformation of the coal [6]. Anthracite from the Donetsk Basin is the most common fuel type for domestic thermal power stations.

Таблиця 1

Sulphur content and forms in coal of different grades from deposits in Ukraine [6, 7]

Type of coal	Total S, %	Organic S, %	Pyrite S, %	Sulphate S, %
Anthracite (ASH)	0,5÷1,5	0,3÷0,9	0,1÷0,5	0,01÷0,05
Gas (G)	1,5÷3,5	0,8÷2,0	0,5÷1,2	0,05÷0,15
Brown (B)	2,0÷5,0	1,0÷3,0	0,5÷1,5	0,1÷0,3

Gas coal (grade G) is characterised by a significantly higher sulphur content – ranging from 1.5 to 3.5 per cent. The elevated organic sulphur content is due to a lower degree of metamorphism and the preservation of primary sulphur-containing organic structures [7].

Lignite (grade B) has the highest sulphur content – up to 5% and above (particularly for some deposits in the Dnieper Basin). The high moisture content of lignite and the presence of significant amounts of sulphates in the ash further complicate the problem of controlling SO₂ emissions during its combustion [7].

To reduce sulphur oxide emissions in the power sector, a range of technologies is employed, which can be broadly divided into three groups [8]:

1. Pre-treatment of fuel. This includes gravity and flotation enrichment of coal with partial removal of pyrite sulphur, thermal treatment (desulphurisation in a fluidised bed), as well as microbiological leaching of sulphur. These methods are effective mainly for pyrite sulphur and do not ensure complete removal of organic sulphur [9].

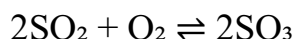
2. Process methods (primary measures). These involve optimising the combustion process: flue gas recirculation, combustion in a circulating fluidised bed (CFB) with limestone sorbents. The CFB method ensures up to 90–95% capture of SO₂ directly in the furnace at temperatures of 850–900 °C [9].

3. Flue gas treatment (FGT). The most common methods are: wet limestone desulphurisation (Wet FGD) – capture of SO₂ using a limestone slurry to form gypsum (efficiency up to 98%); wet-dry absorption and dry adsorption; and the activated carbon method. These systems are standard for large power units with a capacity exceeding 100 MW [10].

Recently, there has been active research into the oxygenation of blast air, where the oxygen content is artificially increased to 40% instead of the usual 21%, depending on the fuel composition. Given the promise of this method from a thermal technology perspective [11,12,13], there is a need to examine the behaviour of sulphur under such conditions.

Since the temperature rises during the oxygenation of the blast air and the furnace environment becomes reactive, the conversion of sulphur dioxide (SO₂) to sulphur trioxide (SO₃) in the combustion products is clearly accelerated.

In the furnace space at temperatures above 900 °C, the conversion of SO₂ to SO₃ is negligible; however, as temperatures decrease in the convective heating zones (400–700 °C), the catalytic oxidation reaction:



is catalysed by vanadium and iron oxides present in the fly ash. An increased concentration of O₂ in flue gases accelerates this reaction, and the conversion rate of SO₂ → SO₃ rises from the typical 1–3% (in normal air) to 5–8% or more when the O₂ content exceeds 25% [14].

Sulphur trioxide, in the presence of water vapour, forms a sulphuric acid mist that condenses on cold surfaces at temperatures below the dew point (acid dew point). The acid dew point temperature is significantly higher than that of water vapour, and at typical SO₃ concentrations of 5–30 mg/m³ it is 120–160 °C [14]. The condensation of H₂SO₄ causes low-temperature sulphuric acid corrosion of the tail heating surfaces (air preheaters, economisers), which drastically reduces their service life – from 15–20 to 3–7 years. [14]

Unlike SO₂, which is synthesised relatively slowly in the atmosphere, SO₃ instantly forms H₂SO₄ sulphate aerosol upon contact with atmospheric moisture. These submicron particles ($d < 1 \mu\text{m}$) are extremely stable in the air, have a long sedimentation time and are capable of penetrating deep into the respiratory tract. Furthermore, H₂SO₄ aerosols act as condensation nuclei for the formation of secondary organic aerosols, which reduce visibility (haze effect) and exacerbate the toxic effects of photochemical smog [4, 15].

The traditional strategy for protecting the rear heating surfaces from sulphuric acid corrosion involves maintaining the flue gas temperature at the outlet above the acid dew point. This, however, results in significant heat loss via the flue gases and the direct emission of SO₂ and SO₃ into the atmosphere. A fundamentally different approach could be to deliberately switch the boiler to condensing mode, in which the flue gas temperature at the end of the convective section is reduced below the water vapour dew point and, moreover, below the acid dew point.

In this mode, simultaneous condensation of water vapour and sulphuric acids—sulphuric acid H₂SO₄ and sulphurous acid H₂SO₃ (formed when SO₂ dissolves in the condensate)—occurs in the tail condenser. Condensation takes place on specialised heat exchange surfaces, which requires the use of corrosion-resistant materials.

The main problem with the condensation mode is the aggressive effect of the acidic condensate (pH 1–3) on the pipe material. Conventional carbon steel corrodes at a rate of 2–5 mm/year under such conditions, rendering it unsuitable for service [10]. The solution is to use:

- corrosion-resistant stainless steels of grades AISI 316L and Incoloy 825 (with increased Ni, Mo and Cr content) – offer a service life of over 20 years in sulphuric acid condensate at concentrations of up to 70% H_2SO_4 ;
- PTFE (polytetrafluoroethylene) or polymer pipes made from heat-resistant plastics (PPS, PVDF) – withstand temperatures up to 150–180 °C and are chemically inert to all acids; they are significantly cheaper than special alloys and easier to install.

Switching to condensation mode when using oxygen-enriched blast air offers a range of benefits.

Simplified flue gas cleaning. The condensation of SO_3 and H_2SO_3 directly in the tail condenser allows a significant proportion of the sulphuric acids to be removed from the gas stream before it enters the wet desulphurisation system. This reduces the load on scrubbers and FGD units, increases their efficiency and reduces reagent consumption (limestone, lime).

Neutralisation of acids and production of chemically treated water. Acidic condensate (a solution of $\text{H}_2\text{SO}_4 + \text{H}_2\text{SO}_3$ containing heavy metals and chlorine) is neutralised using alkaline solutions (NaOH , $\text{Ca}(\text{OH})_2$, Na_2CO_3). With a properly organised neutralisation and filtration process, the resulting water meets the requirements for make-up water for heating systems or for the plant's process water. Thus, sulphuric acid, which is a waste product, is converted into a useful product – chemically purified water.

Additional heat recovery. The condensation of water vapour releases a significant amount of latent heat of vaporisation ($r = 2257 \text{ kJ/kg}$). This heat can be transferred to the return water from the heating system. As a result, the boiler's lower heating value fuel utilisation efficiency can reach 97–98%, which is typical for condensing boilers fuelled by natural gas [10].

Formation of calcium sulphate. When condensate is neutralised with limestone ($\text{Ca}(\text{OH})_2$), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is formed – a valuable building material that serves as a commercial product of wet FGD desulphurisation at leading thermal power stations in Europe. Consequently, the industrial implementation of the condensation process can generate additional revenue.

An analysis of the technological and environmental aspects of coal combustion allows the following conclusions to be drawn. Coal combustion is one of the main sources of sulphur compound emissions into the atmosphere. The most dangerous pollutants are SO_2 , SO_3 and sulphuric acid (H_2SO_4) aerosols, which have toxic effects on humans, cause acid rain and lead to the degradation of ecosystems. Different grades of coal are characterised by varying sulphur content: anthracite (A) contains 0.5–1.5%, bituminous coal (B) – 1.5–3.5%, and lignite (L) – up to 5% and above.

The technology of injecting oxygen-enriched air has significant potential for improving the efficiency of thermal power stations: the temperature in the furnace increases, the degree of fuel combustion increases, mechanical under-combustion is reduced, and the specific volume of flue gases decreases. This results in a 1.5–

3.0% (abs.) increase in the boiler unit's efficiency. At the same time, increasing the O₂ concentration in the combustion air leads to a rise in the conversion rate of SO₂ to SO₃ to 5–8%. This raises the acid dew point, increases the risk of sulphuric acid corrosion of equipment and increases emissions of toxic sulphate aerosols into the atmosphere.

This contradiction is resolved by switching the boiler to condensing mode: the deliberate condensation of sulphuric acid in a tail condenser made of corrosion-resistant materials (stainless steel, fluoroplastic or heat-resistant polymer pipes). This allows: (a) a reduction in the load on FGD units and a reduction in reagent consumption; (b) the neutralisation of acids with alkali and the production of chemically purified water suitable for replenishing district heating networks or for technical purposes; (c) further utilise the latent heat of water vapour condensation, thereby increasing the overall thermal efficiency.

The comprehensive use of oxygen-enriched blast air in combination with the condensation mode is a promising direction for the modernisation of Ukraine's coal-fired thermal power stations, which simultaneously increases energy efficiency, reduces the cost of flue gas treatment and minimises the environmental impact.

REFERENCES

1. International Energy Agency. Ukraine Energy Profile / Energy Security. Paris : IEA, 2023. URL: <https://www.iea.org/reports/ukraine-energy-profile/energy-security> (дата звернення: 01.03.2025).
2. Варламов Г. Б., Любчик Г. М., Маляренко В. А. Теплоенергетичні установки та екологічні аспекти виробництва енергії : підручник. Київ : Видавництво «Політехніка», 2003. 232 с. URL: <https://core.ac.uk/download/pdf/11315104.pdf>.
3. Seinfeld J. H., Pandis S. N. Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. 3rd ed. Hoboken : John Wiley & Sons, 2016. 1152 p. ISBN 978-1-118-94740-1.
4. IARC Monographs on the Identification of Carcinogenic Hazards to Humans. Volume 54: Occupational Exposures to Mists and Vapours from Strong Inorganic Acids. Lyon : IARC Press, 1992. URL: <https://monographs.iarc.who.int> (дата звернення: 05.03.2025).
5. Likens G.E., Bormann F.H. Acid rain: a serious regional environmental problem. Science. 1974. Vol. 184, No. 4142. P. 1176–1179.
6. Саранчук В. І., Ільяшов М. О., Ошовський В. В., Білецький В. С. Основи хімії і фізики горючих копалин : підручник. Донецьк : Східний видавничий дім, 2008. 600 с. ISBN 978-966-317-024-4.
7. Sachsenhofer R. F., Privalov V. A., Panova E. A. Basin evolution and coal geology of the Donets Basin (Ukraine): An overview. International Journal of Coal Geology. 2012. Vol. 89. P. 26–40. DOI: 10.1016/j.coal.2011.07.010.

8. Вольчин І. А., Гапонич Л. С., Згоран І. П. Вибір технології десульфуризації димових газів для українських вугільних теплових електростанцій. *Наукові праці Національного університету харчових технологій*. 2018. Т. 24, № 4. С. 154–168.
9. Маляренко В. А. Енергетичні установки. Загальний курс : навчальний посібник. 2-ге вид. Харків : Видавництво САГА, 2008. 320 с. ISBN 978-966-2918-54-0.
10. Sarbassov Y., Duan L., Manovic V., Anthony E. J. Sulfur trioxide formation/emissions in coal-fired air- and oxy-fuel combustion processes: a review. *Greenhouse Gases: Science and Technology*. 2018. Vol. 8, No. 3. P. 402–428. DOI: 10.1002/ghg.1767. URL: <https://dspace.lib.cranfield.ac.uk/items/2e30353f-6b9f-4893-9bf6-8c5e5d6fd50a>
11. Гламаздін П.М., Дяченко А.А. Збагачення киснем дуттьового повітря для підвищення енергоефективності енергетичних парогенераторів: Вчені записки ТНУ імені В.І. Вернадського. Серія: Технічні науки, 2021. – 8с.
12. Вакуленко Є. С. Підвищення ефективності спалювання непроектного палива шляхом збагачення киснем дуттьового повітря. *Енергія. Ресурси. Екологія*. 2024. Т. 1, № 2. С. 39–41.
13. Гламаздін П. М., Вакуленко Є. С. Проблема використання непроектного вугільного палива в парових енергетичних парогенераторах. *Енергія. Ресурси. Екологія*. 2025. Т. 1, № 4.
14. Fleig D., Andersson K., Normann F., Johnsson F. SO₃ formation under oxyfuel combustion conditions. *Industrial & Engineering Chemistry Research*. 2011. Vol. 50, No. 14. P. 8505–8514. DOI: 10.1021/ie2005274.
15. Fleig D., Andersson K., Johnsson F. Influence of operating conditions on SO₃ formation during air and oxy-fuel combustion. *Industrial & Engineering Chemistry Research*. 2012. Vol. 51, No. 28. P. 9483–9491. DOI: 10.1021/ie301303c.

ENVIRONMENT-FRIENDLY ADVANCED PILING TECHNOLOGIES: PROSPECTS FOR UKRAINE

Michael Doubrovsky¹, Olga Dubrovskaya²

¹*Odesa National Maritime University, m.doubrovsky@gmail.com*

²*Energean PLC, Odubrovskaya90@gmail.com*

INTRODUCTION

Taking into account a very long sea (river) shoreline of the country the problem of slope stability is a very topical one. Among the most dangerous areas from the point of view of coastline stability, we may indicate Odessa-city suburbs, Chernomorsk-city and related marine health-resort zones, Izmail-city precincts. Over several recent years, there have been large-scale (sometimes disastrous)

landslides with heavy damage to both soil slopes and buildings. Another topical aspect is the development of some large cities (with a population of more than a million) located in the hilly country. For example, undulating land is characteristic of the Ukrainian capital, Kyiv, and the City of Dnipro (both on the Dnipro River). Recent numerous landslides, development of construction projects in the dangerous areas, and actual tasks of historical architectural heritage protection created a very serious engineering situation.

That's why for some current and future projects, the application of the pressing technology is the most promising approach to solve the mentioned problems.

Pressing machines and technologies in Ukraine

At the moment, different types of pressing machines are used in Ukraine. In the Ukrainian construction market, both imported machines (mainly from Chinese producers) and equipment of local production are in operation.

Chinese machines are presented in the Ukrainian market by several producers and brands. Among them, «Liyuan Hydraulic Machine Company Ltd», «Hunan Sunward Intelligent Machinery Co. LTD», «Hunan Titan Heavy Industries Co. LTD» should be mentioned.

There are several Ukrainian producers/contractors who have worked out different original rigs for pile pressing: VIF and Viant (Kyiv), Stikon and Transzvuk (Odesa).

Advanced Press-in Method and its GRB technology

In recent years, advanced pile technologies based on the Press-in method, proposed and actively implemented by the Japanese corporation Giken Ltd (<https://www.giken.com/en/>), have been increasingly used in the world practice of construction. Back in 1975, the world's first hydraulic machine for driving piles using the reaction of the soil base, called "SILENT PILER", was invented. As piling was considered an important cause of many social and environmental problems, the silent and vibration-free machine was the solution to the problem of significant construction pollution. To date, 44 countries of the world have implemented or are implementing large and responsible pile projects that provide silent and vibration-free immersion of various pile profiles to great depths in difficult soil conditions.

This "gentle" and environmentally positive method of hydraulic pressing is also referred to by its authors as "implantation" of structural elements, emphasizing the absence of shock and dynamic impacts, as well as drilling operations. This makes it possible to constantly meet the five construction principles adopted by Giken, i.e., to ensure a high level of environmental protection, safety, speed, economy, and aesthetics.

A significant contribution to the development of the scientific, technical, and methodological basis for this method of driving piles by hydraulic pressing is made by the International Press-in Association (IPA, www.press-in.org).

Of particular interest are technologically complex urban "green" projects

related to construction on the water: improvement of river banks and canals in dense urban development; coastal protection from floods, tsunamis, shore erosion; and, no less difficult to implement and due to high environmental responsibility, are projects for the construction of port engineering structures (breakwaters and quay walls). For such projects, the original GRB technology is proposed - the Giken Reaction-Based system, considered below.

The GRB System is a silent, vibration-free, and "temporary work-free" piling system by Giken that uses completed piles to support the installation of new ones. It is designed for confined spaces, over-water, and environmentally sensitive sites, enabling all piling steps - transportation, pitching, and pressing - to occur from the top of the existing wall. GRB System™ was developed as a press-in system that carries out all piling procedures, such as pile transportation, pile pitching, and press-in work on top of installed piles.

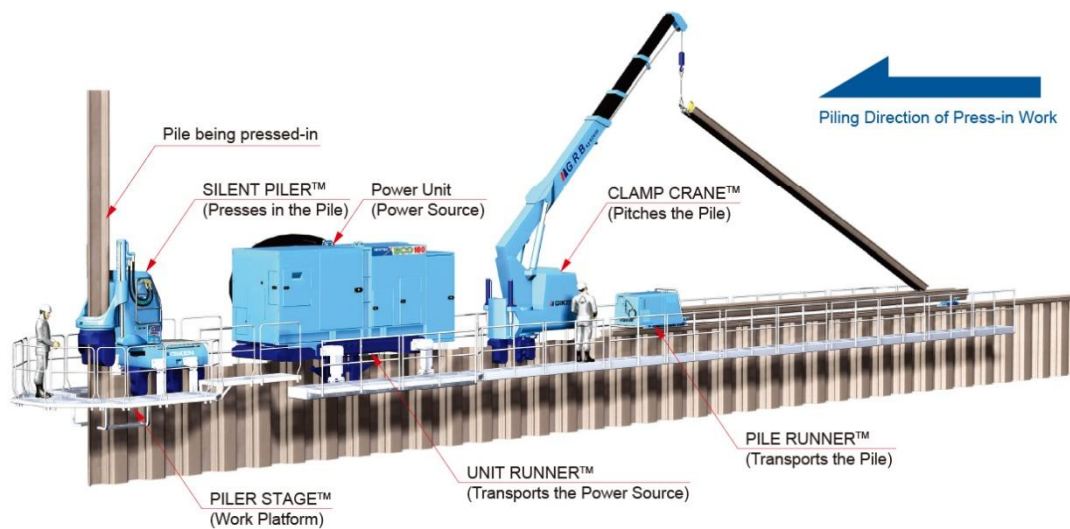


Fig. 1. Standard Components of the GRB System™

Key components and features of the system are:

- **Silent Piler:** The core unit that grips installed piles and uses hydraulic pressure to press in new ones with minimal noise or vibration.
- **Clamp Crane:** Operates on top of the established pile wall to transport and pitch new piles.
- **Pile Runner:** Moves piles from the storage yard to the piling spot.
- **Unit Runner:** Transports the power unit along the piles.
- **Efficiency:** The system is "temporary work-free," meaning no temporary platforms or crane pads are required for operation.

System's advantages:

- **Minimal Environmental Impact:** The method produces no vibration or noise.
- **High Stability:** Since the machine operates from a secure position on existing piles, there is no risk of the machine tipping.

- **Versatility:** It can be used for U-profiles, tubular sheet piles, Z-piles, and pre-cast concrete piles, often paired with the Gyro Piler for working in hard ground or for zero-clearance installations.

All system equipment is self-supported by holding existing installed piles with no risk of overturning. Temporary working platforms or detour roads are not required even at unstable ground conditions, in narrow locations, on water, on a slope, and under other restricted site conditions, since the influence range of work is minimized to just the width of the machinery.

Below are some illustrative examples of GRB technology implementations.



Fig. 2. GRB system for tubular pile retaining wall projects in Japan (left) and Germany

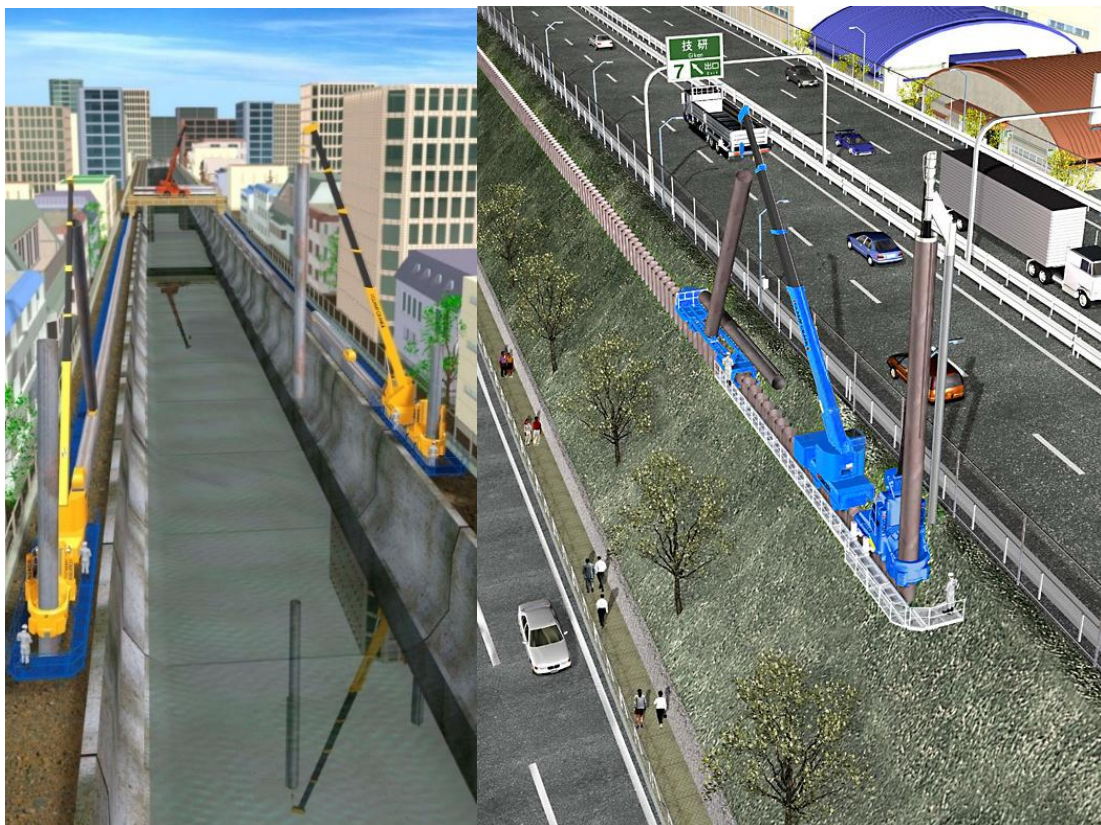


Fig. 3. GRB system in Japan: widening of Hodogaya bypass (left); improvement works of Kandagawa-River



Fig. 4. GRB system for the dike reinforcement, The Netherlands

CONCLUSION

If we consider the possibilities of using the Press-in Method in general and GRB technology in particular in the current conditions of Ukraine, the following should be noted:

1. As a result of hostilities, many objects of civil and industrial infrastructure of Ukraine are subject to restoration, reconstruction or modernization. The technical condition of a number of the mentioned infrastructure facilities dictates the need to use such modern construction technologies that exclude dynamic and vibrational effects both on the infrastructure facility itself and on neighbouring buildings and structures.

2. From the point of view of meeting environmental requirements, when performing a large amount of piling work in urban conditions, including in adjacent water areas, it is necessary to exclude/minimize driving technologies (noise, dynamic effects), vibration immersion (noise, vibration), and drilling operations (noise, vibration, pollution of soils and groundwater).

3. Under these conditions, preference in the choice of piling technology, in our opinion, should be given to the methods of static pile driving, one of the modern options of which is the Press-in method of hydraulic penetration (silent, vibration-free, non-polluting the environment). The most universal technology of this method (high performance for both land and water pile driving) is provided by the Giken Reaction-Based system.

REFERENCES

1. Malcolm D. Bolton, Akio Kitamura, Osamu Kusakabe, Masaaki Terashi. New Horizons in Piling. Development and Application of Press-in Piling. CRC Press, 2022. 170 p.
2. A Brief Development History of Press-in Machinery. IPA Booklet Series. International Press-In Association, 2022. 61 p.
3. Doubrovsky M. Press-in piling survey in Ukraine. Proceedings of the First International Conference on Press-in Engineering 2018, Japan. Pp. 587-592.
4. Meshcheryakov G., Doubrovsky M., Dubrovskaya O. Press-in

Technologies in Ukraine: Some Recent Developments. Proceedings of the First International Conference on Press-in Engineering 2018, Japan. Pp. 361-370.

5. M. Doubrovsky, V. Petrosyan. Improvement Of Technological Solutions For Sheet Piling Walls. Journal of Civil Engineering and Architecture, volume 11, Number 4, USA, 2017. Pp. 335-341.

6. M. Doubrovsky. IPA and Giken activity in Odesa, Ukraine. IPA Newsletter, Vol.1, Issue 1, Tokio, Japan, 2016. Pp. 12-13.

SUSTAINABLE STRATEGIES FOR STORMWATER MANAGEMENT IN URBAN AREAS: FROM TRADITIONAL TO HYBRID SOLUTIONS

Daria Kulikova

Dnipro University of Technology, kulikova.d.v@nmu.one

Modern urban development is characterized by intense anthropogenic pressure on aquatic ecosystems, primarily due to the disruption of the natural hydrological cycle. The expansion of impermeable surfaces (asphalt, concrete, and roof covers) significantly increases the runoff coefficient, leading to a rapid rise in stormwater volumes. This process reduces natural precipitation infiltration into the soil, accelerates surface runoff velocity, and creates critical peak loads on existing drainage infrastructure.

Climate change further exacerbates these challenges, manifesting in the increased frequency and intensity of short-term high-intensity rainfall events. Traditional «grey» infrastructure, designed primarily for the rapid conveyance of water, proves insufficient under such dynamic conditions. These systems often lack integrated treatment components, resulting in the direct discharge of untreated runoff – contaminated with suspended solids, heavy metals, and hydrocarbons – into natural water bodies.

This issue is acutely relevant for the industrial regions of Ukraine, where high anthropogenic loading transforms stormwater into a primary source of diffuse pollution. In these areas, surface runoff acts as a major vector for secondary environmental contamination, necessitating a fundamental shift from traditional «collect-and-convey» methods toward more adaptive and sustainable management paradigms.

In modern practice, alternative approaches to stormwater management are becoming increasingly widespread, specifically nature-based solutions (NBS) and Sustainable Drainage Systems (SuDS) [1]. These strategies rely on the restoration of natural processes such as infiltration, evapotranspiration, and biological purification. Alongside these, hybrid systems are being developed to bridge the gap between traditional «grey» engineering and «green» infrastructure. By combining the hydraulic reliability of pipe networks with the ecosystem services

of natural elements, these systems provide higher efficiency and greater adaptability to the dynamic conditions of urban development.

In this context, a comparative analysis of existing stormwater management strategies becomes particularly relevant. Such an assessment is necessary to determine their functional effectiveness, operational limitations, and economic feasibility. Furthermore, it serves to justify the implementation of integrated water management models tailored to the specific environmental and infrastructural conditions of Ukraine.

Stormwater runoff is defined as the surface flow generated by precipitation and its subsequent movement across the landscape. Under natural conditions, the hydrological cycle is balanced: a significant portion of precipitation infiltrates into the soil, recharging groundwater aquifers, or is intercepted by vegetation through evapotranspiration. However, in urbanized environments, this balance is fundamentally disrupted. The expansion of impermeable surfaces leads to a dramatic increase in both the volume and peak velocity of surface runoff.

The alteration of the hydrological regime entails several critical consequences. First, increased peak flow rates exert excessive hydraulic pressure on drainage infrastructure, significantly raising the risk of urban flooding. Second, the reduction in natural infiltration leads to the depletion of regional groundwater resources. Third, stormwater acts as a primary vector for the transport of non-point source pollutants.

The qualitative composition of runoff is highly dependent on the land-use characteristics of the catchment area. In industrial and densely urbanized zones, stormwater accumulates high concentrations of suspended solids, heavy metals, hydrocarbons, and chemical de-icing agents. Without adequate treatment, this runoff becomes a major driver of anthropogenic degradation in receiving water bodies. To mitigate these impacts, a transition to integrated management is required, as illustrated in the hybrid system model (Fig. 1), which prioritizes both flow regulation and qualitative treatment [2].

Historically, the traditional approach to stormwater management has been based on the principle of rapid conveyance, utilizing centralized drainage networks. In modern engineering practice, three distinct paradigms have emerged: traditional engineering systems («grey» infrastructure), nature-based solutions («green» infrastructure), and hybrid systems [3]. To identify the most effective strategy, a comparative analysis was conducted, focusing on functional capacity, environmental impact, and long-term sustainability.

The traditional approach relies on the immediate collection and transport of surface runoff away from urbanized areas via subterranean concrete pipes and engineered channels. The primary objective of such systems is strictly hydraulic: to prevent localized flooding and ensure rapid drainage.

While this approach offers a relatively straightforward design and high conveyance velocity, it possesses critical drawbacks. A significant limitation is the absence of treatment mechanisms, leading to the direct discharge of

contaminated runoff into natural aquatic ecosystems. Furthermore, these rigid systems are highly vulnerable to peak loads during intense rainfall events, which frequently results in hydraulic overload and system failure.

Nature-based solutions (NBS) are designed to emulate natural processes to manage stormwater at its source. The fundamental philosophy of this approach is to reintegrate the urban water cycle into the natural hydrological balance. By prioritizing source control, these strategies transform stormwater from a waste product into a valuable resource for urban ecosystems.

Typical NBS interventions include bioretention systems, green roofs, permeable pavements, constructed wetlands, and filter strips. These elements facilitate the retention of precipitation, encourage gradual infiltration into the subsoil, and provide multi-stage treatment of pollutants through physical filtration, adsorption, and biological uptake. Depending on design and climatic conditions, green roofs and permeable pavements can reduce stormwater runoff volumes by 40-70%. As illustrated in the second and third stages of Fig. 1, these «green» components act as a primary buffer, reducing runoff volumes by up to 50-80% before water reaches the centralized network [4].

The primary advantages of NBS lie in their high environmental efficiency, their capacity to mitigate the load on existing «grey» infrastructure, and their contribution to the urban microclimate through evapotranspirative cooling. However, their implementation may be constrained by spatial requirements in high-density urban areas and the dependence of their performance on local soil conditions and maintenance regimes.

Hybrid stormwater management systems represent a synergistic integration of traditional engineering infrastructure and nature-based technologies. This dual approach enables simultaneous control of runoff volumes (hydraulic regulation) and multi-stage qualitative treatment. By combining the strengths of both paradigms, hybrid systems offer a robust solution that addresses the limitations of purely «grey» or «green» methods.

As demonstrated in Fig. 1, a typical hybrid configuration utilizes biofiltration or infiltration components for preliminary treatment and retention of the «first flush». The traditional drainage network is then employed to safely convey excess water during high-intensity rainfall events that exceed the capacity of natural elements. This strategic distribution of functions significantly mitigates the hydraulic load on municipal infrastructure and enhances the overall environmental resilience of the urban area.

Hybrid systems are characterized by high flexibility and adaptability. Their modular nature allows for seamless integration into existing urban fabrics without requiring large-scale structural reconstruction. This makes them a particularly viable and cost-effective strategy for the gradual modernization of infrastructure in densely populated and industrial regions.

The fundamental advantage of the hybrid approach is its ability to manage the «first flush» effect. Studies indicate that the initial portion of stormwater

runoff carries up to 80% of the total pollutant load, including hydrocarbons, heavy metals, and suspended solids. Bioretention systems are capable of removing up to 65-90% of suspended solids and heavy metals from the initial runoff volume [4]. In the proposed hybrid model, nature-based components (bioretention units) are sized to intercept and treat this highly contaminated portion of runoff. Once the filtration capacity is reached, the subsequent cleaner runoff is diverted to the traditional sewer network, preventing hydraulic overload without compromising water quality.

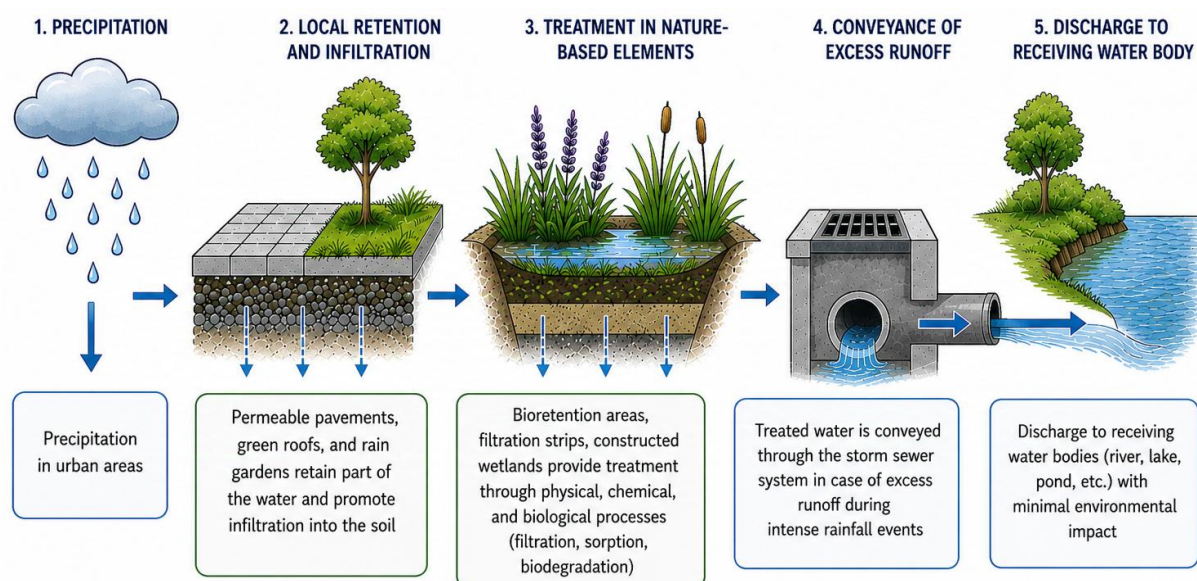


Fig. 1. Schematic of a hybrid stormwater management system operation

To synthesize the characteristics of the evaluated stormwater management strategies and determine their relative efficiency, a comparative assessment was conducted. The results, categorized by functional, environmental, and operational criteria, are summarized in Table 1

Table 1
Comparative characteristics of stormwater management strategies

Criteria	Traditional engineering systems	Nature-based solutions (NBS)	Hybrid systems
Principle of operation	Rapid conveyance of water away from the area	Retention, infiltration, and natural purification	Combination of conveyance and natural processes
Primary function	Runoff conveyance	Runoff volume regulation and treatment	Balance between conveyance and treatment
Effectiveness in runoff reduction	Low	High	High
Water treatment	Absent or minimal	High (biological and physical)	Medium to high

Criteria	Traditional engineering systems	Nature-based solutions (NBS)	Hybrid systems
Resistance to stormwater loads	Low	High	High
Environmental effect	Negative or neutral	Positive	Moderately positive
Implementation cost	High	Medium or low	Medium
Operating costs	High	Low	Medium
Climate change adaptation	Low	High	High
Suitability for urban areas	Limited	High	Highly suitable

The comparative analysis of stormwater management strategies demonstrates a paradigm shift from rigid, rapid-conveyance engineering toward integrated and adaptive solutions. While conventional engineering systems fulfill the basic requirement of drainage, they fail to address critical issues of qualitative treatment and environmental safety. In contrast, NBS exhibit high efficiency in runoff volume reduction and water quality improvement; however, their large-scale deployment is often constrained by the high density of existing urban development.

For the industrial regions of Ukraine, the transition to hybrid systems should follow a modular retrofitting strategy. This involves:

1. *De-paving*: Converting redundant asphalt areas into permeable surfaces or rain gardens;
2. *Local Infiltration*: Directing roof drainage into bioretention strips instead of direct sewer connections;
3. *Buffer Zones*: Establishing filter strips along high-traffic roadways to intercept tire wear particles and oil residues.

Such «micro-interventions» are economically feasible as they utilize existing infrastructure while extending its operational lifespan by reducing siltation and pressure.

Under the specific environmental and infrastructural conditions of Ukraine, hybrid systems represent the most balanced and effective approach. By combining robust engineering networks with natural retention and biofiltration technologies, these systems enhance urban resilience to extreme precipitation events. Their implementation significantly reduces anthropogenic pressure on aquatic ecosystems and fosters a more sustainable model of urban water management.

A particularly promising strategy is the modular integration of local nature-based elements (bioretention areas, filter strips, and permeable pavements) into existing municipal drainage networks. This approach facilitates the gradual modernization of urban infrastructure, allowing for significant environmental improvements without the need for prohibitive capital investment.

REFERENCES

1. European Commission. (2015). Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-naturing Cities. Brussels: Publications Office of the European Union.
2. ISO 24536:2023. Service activities relating to drinking water supply, wastewater and stormwater systems – Guidelines for the management of stormwater systems.
3. Fletcher, T. D., et al. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12(7), 525-542.
4. CIRIA. (2015). The SuDS Manual (C753). London: Construction Industry Research and Information Association.

HYDROGEN IN INTERNAL COMBUSTION ENGINES OF CONSTRUCTION MACHINES AS A WAY TO REDUCE EMISSIONS IN GREEN CONSTRUCTION

Dmytro Mishchuk¹, Yevhen Mishchuk¹, Maksym Balaka¹

*¹Kyiv National University of Construction and Architecture,
mischuk.do@knuba.edu.ua, mishchuk.iew@knuba.edu.ua,
balaka.mm@knuba.edu.ua*

The construction industry is one of the largest consumers of energy and a major source of atmospheric pollution. Most construction machinery operates using diesel engines, which are characterized by high emissions of carbon dioxide, nitrogen oxides, and particulate matter. Within the concept of green construction, one of the key objectives is the reduction of the carbon footprint associated with construction processes.

Among the most promising alternatives to diesel fuel, hydrogen has attracted considerable attention. Unlike conventional hydrocarbon fuels, hydrogen contains no carbon; therefore, its combustion does not produce carbon dioxide (CO₂).

Currently, research interest is primarily focused on two major approaches:

- the use of hydrogen in fuel cells;
- the use of hydrogen in internal combustion engines (Hydrogen ICE).

For construction machinery, the second option appears particularly promising, as it enables the adaptation of existing engine designs without requiring a complete replacement of the powertrain.

In recent years, the number of studies devoted to hydrogen internal combustion engines has increased significantly in scientific databases. Research conducted by Polish and other European scholars indicates that Hydrogen ICE technology may provide rapid decarbonization of heavy machinery without radical modifications to existing industrial infrastructure.

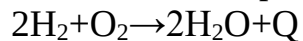
The works [1, 2] demonstrates that modern hydrogen engines possess the following advantages:

- high combustion velocity;
- a wide flammability range;
- the ability to operate under lean-burn conditions;
- low CO₂ emissions.

However, the primary challenge remains the formation of nitrogen oxides (NO_x) caused by the high combustion temperature of hydrogen. To reduce NO_x emissions, researchers employ exhaust gas recirculation, lean fuel mixtures, and multi-point hydrogen injection systems.

A study conducted by British researchers [3] in the field of construction machinery demonstrated that low-emission hydrogen engines can significantly reduce the environmental impact of off-road machinery, including excavators, loaders, and bulldozers.

The hydrogen combustion reaction can be expressed as:



where Q represents thermal energy.

The main advantage of this process is the absence of carbon dioxide formation. Water vapor is the primary reaction product. Nevertheless, due to the high flame temperature, nitrogen oxides still generated, although their concentration is substantially lower compared to conventional diesel engines.

An important advantage of Hydrogen ICE technology is the possibility of retrofitting existing engines. This is particularly relevant for construction machinery, where full electrification remains challenging. In contrast to battery-electric systems, hydrogen engines provide rapid refueling and a higher energy density per unit mass of fuel.

One of the major limitations of hydrogen utilization is the relatively low overall energy efficiency of the complete production and utilization cycle. Hydrogen is not a primary energy source. Its production requires energy expenditures for water electrolysis, compression, transportation, and storage.

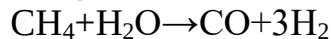
The most environmentally sustainable option is “green hydrogen,” which is produced via electrolysis powered by renewable energy sources. However, the efficiency of electrolysis typically ranges between 65–75%. Additional energy losses occur during hydrogen compression (approximately 10–15%) and transportation and storage (approximately 5–10%).

As a result, the total efficiency of the “electricity → hydrogen → mechanical energy” cycle, considering the efficiency of internal combustion engines, may fall below 30%. This value is significantly lower than the efficiency of battery-electric systems. Consequently, many researchers consider hydrogen engines to be an intermediate transitional technology rather than a final solution.

The origin of the energy used for hydrogen production is another critical issue. Currently, approximately 90% of global hydrogen production is derived from natural gas through steam methane reforming. In such cases, fossil fuels are

indirectly utilized, substantially reducing the environmental benefits of hydrogen technologies.

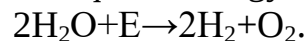
The steam methane reforming reaction is describe by:



This process also produces CO_2 , partially offsetting the ecological advantages of hydrogen utilization.

One widely discussed concept involves producing hydrogen directly onboard a vehicle through water electrolysis. Although theoretically feasible, such a system cannot be fully autonomous from a thermodynamic perspective.

The water-splitting reaction requires energy input:



According to the law of energy conservation, it is impossible to obtain more energy from hydrogen combustion than was consumed during its production. Due to energy losses in the generator, electrolyzer, and engine, the system inevitably exhibits a negative energy balance. Therefore, the concept of an “engine that produces its own hydrogen” within a closed-loop system is physically impossible.

Hydrogen may only be generated onboard in limited quantities as a supplementary additive to the primary fuel. Such HHO generator systems are occasionally used to improve diesel fuel combustion, reduce fuel consumption, and decrease exhaust smoke opacity. However, most scientific studies indicate that the effect of these systems is limited and insufficient for creating an energetically autonomous engine.

Based on the analysis of contemporary studies, the following conclusions can be drawn:

- Hydrogen internal combustion engines represent a promising technology for the decarbonization of construction machinery.
- The primary advantage of hydrogen lies in the near-zero CO_2 emissions during engine operation.
- The use of hydrogen produced from natural gas does not ensure complete environmental sustainability.
- The development of an engine fully capable of supplying itself with hydrogen without external energy sources contradicts the laws of thermodynamics and is impossible in a closed system.
- The most promising approach is the utilization of “green hydrogen” produced using renewable energy sources.

Thus, hydrogen engines may become an important transitional stage in the shift of the construction industry toward low-carbon technologies. However, their effectiveness directly depends on the method of hydrogen production and the development of appropriate energy infrastructure.

REFERENCES

1. Wróbel K., Wróbel J., Tokarz W., Lach J., Podsadni K., Czerwiński A. Hydrogen Internal Combustion Engine Vehicles: A Review. *Energies*, 15(23), 2022. 8937 p. <https://doi.org/10.3390/en15238937>.
2. Olenich G.S., Mishchuk D.O., Balaka M.M. Reducing fuel consumption by road transport through the use of a hydrogen generator. *Resource and Energy Saving Technologies and Materials. Contemporary Innovation Technique of the Engineering Personnel Training for the Mining and Transport Industry (CITEPTMTI 2022)*, 2022. 61-65 p.
3. Webster L.J., Ballard R., Beamish T., Burnhope T., Humbert J., Lewis A. C., Piaszyk J., Moller S.J. Evaluating low NO_x hydrogen engines designed for off-road and construction applications. *Environmental Science: Processes Impacts*, 27, 2025. 486-497 p. <https://doi.org/10.1039/d4em00448e>

ENERGY-EFFICIENT MICROCLIMATE FORMATION IN BUILDING-INTEGRATED GREENHOUSES USING SECONDARY AND RENEWABLE ENERGY SOURCES

Serhii Morkovnyk¹, Viktor Mileikovskiy¹

*¹Kyiv National University of Construction and Architecture,
s.morkovnyk@gmail.com, mileikovskiy.vo@knuba.edu.ua*

The current development of green construction is associated not only with reducing the specific energy consumption of buildings, but also with the rational use of urban areas, reduction of logistics-related impacts and improvement of infrastructure resilience. One promising direction is the placement of protected cultivation facilities within buildings, primarily on roofs or upper levels of public, residential, educational and commercial buildings. In the scientific literature, such solutions are described using the concepts of building-integrated agriculture (BIA), rooftop greenhouse (RTG), integrated rooftop greenhouse (iRTG) and building-integrated rooftop greenhouse (BiRTG) [1-4]. A common feature of these systems is that the building is used not only as a supporting platform, but also as a source or receiver of heat, air, water and material flows.

Unlike a stand-alone greenhouse, a building-integrated greenhouse operates under conditions of mutual interaction with the host building. It can reduce heat losses through the roof, use the heat of exhaust air, partly utilize indoor CO₂ for photosynthesis, receive solar heat gains and at the same time influence the building demand for heating, cooling and ventilation. Therefore, such a system should be considered as a single “building - greenhouse” complex in which the microclimate is formed not only by the greenhouse engineering systems, but also by the building characteristics, its operating schedules, the properties of shared enclosing structures and the availability of secondary resources. This feature

determines the relevance of developing approaches to energy-efficient microclimate formation in building-integrated greenhouses.

The analysis of published studies shows that the effect of integration is not unequivocal and strongly depends on climate, season, greenhouse geometry, optical and thermal properties of the envelope, crop production method and control algorithms [5-8]. In the cold period, the greenhouse can act as a thermal buffer above the upper floor of a building. In this case, the temperature difference between the indoor space and the outdoor environment through the roof is reduced, and therefore the heat losses of the building through enclosing structures decrease. For integrated rooftop greenhouses in a Mediterranean climate, calibrated modelling has shown a substantial potential for passive heat recovery due to the interaction between the greenhouse and the building [7]. However, in the warm period, the transparent envelope, which is useful for plant lighting, can cause overheating and increase energy consumption for ventilation or cooling.

Consequently, the assessment of integrated greenhouses should not be based on an averaged annual indicator only, but should take into account hourly or at least seasonal dynamics. In different periods of the year, the same physical link can be useful, neutral or harmful. For example, heat transfer through a shared roof slab can reduce building losses in the cold period, but during summer overheating it can increase the risk of heat transfer to the upper rooms. Similarly, building exhaust air can be a source of heat and CO₂, but without air-quality control, filtration and restrictions on air transfer, it becomes a potential source of sanitary and operational risks. Thus, the key task is not the maximum use of any available resource, but controlled use of the resource at the moment when it improves the microclimate and does not compromise system safety.

Secondary energy sources in the “building - greenhouse” system should be classified by physical nature, temperature potential, availability schedule and usage constraints. The first group includes heat transfer through shared enclosing structures, in particular the roof slab and junctions. This is mainly a passive resource that does not require additional movement of a heat carrier, but has limited controllability. The second group includes the heat of building exhaust air. Its advantage is a temperature close to the indoor temperature, as well as the possible CO₂ content useful for photosynthesis. The third group may include excess heat from engineering equipment, refrigeration machines, heat pumps or local energy systems. Such resources are more controllable, but require more complex engineering infrastructure.

The use of exhaust air as a secondary resource requires particular attention. From an energy point of view, it can reduce the greenhouse heating demand and maintain the CO₂ concentration in the plant zone. However, building ventilation flows cannot be evaluated only by temperature and airflow rate. Air quality, dust, volatile organic compounds, odours, microbiological pollutants and possible moisture transfer between zones must also be considered. Field measurements of air quality above a rooftop farm showed that the PM_{2.5} concentration at roof level

can be lower than near the street, but the result substantially depends on meteorological conditions, pollution sources and the configuration of the built environment [9]. Therefore, the use of exhaust air should be accompanied by filtration, sensors, protection against reverse flows and safe control algorithms.

The renewable energy source that determines the behaviour of an integrated greenhouse is solar radiation. It has a dual role: it provides light for photosynthesis and simultaneously forms heat gains to the air, plants, substrate and enclosing structures. This duality creates a design compromise. Increasing light transmittance can improve crop productivity in the cold or transition period, but in the warm season it leads to overheating and increased ventilation losses. Studies of the productivity of integrated greenhouses in a Mediterranean climate and works on sustainable rooftop food-energy-land nexus show that solar solutions should be assessed not only by the amount of heat gains, but by a set of indicators related to microclimate, energy consumption and yield [10, 11].

From an engineering point of view, solar radiation should be considered as a controllable natural resource. In the cold period, solar gains can be used for passive heating and reduction of building heat losses. In transition periods, they can cover a significant part of the daytime heat load, but require storage or controlled removal of excess heat. In the warm period, screens, shading, natural or mechanical ventilation, and coordination with building systems become necessary. Therefore, the efficiency of an integrated greenhouse is determined not by a single structural element, but by the interaction of the transparent envelope, solar protection, ventilation, thermal inertia, crop type and automatic control system.

Methodologically, the most informative analysis tools are hourly building energy simulation, co-simulation of the “building - greenhouse” system, CFD modelling of local air processes, field monitoring and predictive control approaches [8, 12, 13]. Hourly energy modelling makes it possible to assess seasonal heat balances, the influence of the envelope, and heating, cooling and ventilation modes. Co-simulation is appropriate when the building and the greenhouse have a two-way influence, and data on temperature, airflow or heat fluxes are exchanged between models. CFD modelling is useful for clarifying local distributions of air velocity, temperature, humidity and CO₂, but it is too resource-intensive for annual scenario analysis.

Modelling results must be verified against experimental data because they are sensitive to assumptions about infiltration, optical properties of the envelope, crop transpiration, actual positions of ventilation openings, building operation schedules and automatic control systems. It is especially important to consider that the greenhouse microclimate is a multi-criteria problem. Minimum heating energy does not guarantee acceptable temperatures for plants, just as maximum ventilation is not always energy-efficient because of heat losses and the risk of excessive drying. Therefore, assessment criteria should include heating and cooling demand, peak loads, stability of temperature and relative humidity, CO₂

concentration, air quality, condensation risk, duration of acceptable parameter ranges and possible influence on crop productivity.

Based on the review, an approach to energy-efficient microclimate formation in building-integrated greenhouses can be formulated. First, the level of integration should be defined not by the name RTG, iRTG or BiRTG, but by actual physical links: a shared envelope, controlled air exchange, use of exhaust air, heat recovery, solar protection and automatic control. Second, secondary resources should be classified by temperature potential, availability over time and sanitary constraints. Third, solar radiation should be considered as a resource whose usefulness changes depending on the season and operating mode. Fourth, the mathematical model should describe unsteady heat and mass transfer and should be suitable for experimental validation.

Thus, a building-integrated greenhouse can be an efficient element of green construction only under the condition of system-oriented design. Potential advantages include reduced heat losses through the roof, use of secondary heat, improved local food resilience and reduced logistics-related impacts. The main risks are associated with overheating, excessive humidity, condensation, uncontrolled airflows and air-quality requirements. Further research should focus on developing physical and mathematical models of the “building - protected cultivation facility” system, experimental verification of temperature and humidity regimes, and formulation of engineering recommendations for the use of secondary and renewable energy sources.

REFERENCES

1. Astee L. Y., Kishnani N. T. Building Integrated Agriculture: Utilising Rooftops for Sustainable Food Crop Cultivation in Singapore. *Journal of Green Building*. 2010. Vol. 5, no. 2. P. 105-113. DOI: 10.3992/jgb.5.2.105.
2. Gould D., Caplow T. Building-Integrated Agriculture: A New Approach to Food Production. *Metropolitan Sustainability*. Elsevier, 2012. P. 147-170. DOI: 10.1533/9780857096463.2.147.
3. Appolloni E. et al. The Global Rise of Urban Rooftop Agriculture: A Review of Worldwide Cases. *Journal of Cleaner Production*. 2021. Vol. 296. 126556. DOI: 10.1016/j.jclepro.2021.126556.
4. Drottberger A. et al. Urban Farming with Rooftop Greenhouses: A Systematic Literature Review. *Renewable and Sustainable Energy Reviews*. 2023. Vol. 188. 113884. DOI: 10.1016/j.rser.2023.113884.
5. Nadal A. et al. Building-Integrated Rooftop Greenhouses: An Energy and Environmental Assessment in the Mediterranean Context. *Applied Energy*. 2017. Vol. 187. P. 338-351. DOI: 10.1016/j.apenergy.2016.11.051.
6. Muñoz-Liesa J. et al. Building-Integrated Greenhouses Raise Energy Co-Benefits through Active Ventilation Systems. *Building and Environment*. 2022. Vol. 208. 108585. DOI: 10.1016/j.buildenv.2021.108585.

7. Muñoz-Liesa J. et al. Quantifying Energy Symbiosis of Building-Integrated Agriculture in a Mediterranean Rooftop Greenhouse. *Renewable Energy*. 2020. Vol. 156. P. 696-709. DOI: 10.1016/j.renene.2020.04.098.
8. Yeo U.-H. Dynamic Energy Analysis of Building-Integrated Rooftop Greenhouse for Urban Agriculture: dissertation. Seoul National University, 2021.
9. Tong Z. et al. A Case Study of Air Quality above an Urban Roof Top Vegetable Farm. *Environmental Pollution*. 2016. Vol. 208. P. 256-260. DOI: 10.1016/j.envpol.2015.07.006.
10. Montero J. I. et al. Productivity of a Building-Integrated Roof Top Greenhouse in a Mediterranean Climate. *Agricultural Systems*. 2017. Vol. 158. P. 14-20. DOI: 10.1016/j.agry.2017.08.002.
11. Jing R., Hastings A., Guo M. Sustainable Design of Urban Rooftop Food-Energy-Land Nexus. *iScience*. 2020. Vol. 23, no. 11. 101743. DOI: 10.1016/j.isci.2020.101743.
12. Jans-Singh M. K., Ward R., Choudhary R. Co-Simulation of a Rooftop Greenhouse and a School Building in London, UK. *Building Simulation* 2019. Rome, 2019. P. 3266-3273. DOI: 10.26868/25222708.2019.210355.
13. Yeo U.-H. et al. Rooftop Greenhouse: Design and Validation of a BES Model for a Plastic-Covered Greenhouse. *Agriculture*. 2022. Vol. 12, no. 7. 903. DOI: 10.3390/agriculture12070903.

CLIMATE SERVICE PRODUCTS FOR CLIMATE RISK ASSESSMENT IN CONSTRUCTION AND ARCHITECTURE

Larysa Nedostrelova¹, Halyna Borovska¹

*¹Odesa I.I. Mechnikov National University,
nedostrelova@ukr.net, halyna.borovska@onu.edu.ua*

To address practical social and economic problems related to the environment, meteorological and climatological information is used to the fullest extent possible. Assessments of the impacts of climate variability and climate change on human activities are currently among the key factors influencing local, national, and global economic development, social programs, and resource management. Climate services are oriented toward a wide range of users from governmental, commercial, and industrial sectors [1-3].

In response to the growing demand, specific fields of climatological research have developed within the practice of meteorological and climate information services. These fields are based on data describing the state of all components of the climate system. The sources of this information are various meteorological observation systems, each of which has its own objectives, areas of application, and methodologies for measuring meteorological variables [1-3].

Observational data from meteorological stations in Ukraine are stored in the regional divisions of the hydrometeorological organizations of the State

Emergency Service of Ukraine (SES of Ukraine), the Ukrainian Hydrometeorological Center of the SES of Ukraine, and the Borys Sreznevskyi Central Geophysical Observatory (CGO). This information is actively used by research and industrial organizations from various sectors of the economy for factual assessments, forecasting, and retrospective calculations of the environmental state of Ukraine.

To obtain climate information, open web platforms that use global reference meteorological databases of the World Meteorological Organization (WMO) can be utilized. Ukraine officially submits national meteorological observation data to these databases, including:

✓ ClimateCharts.net – an application for creating meteorological diagrams developed by the Dresden University of Technology, which allows users to generate climate charts for temperature and precipitation in various formats based on long-term observation periods for 20 major meteorological stations in Ukraine. URL: <https://climatecharts.net/>;

✓ ERA5 Explorer – an application for visualizing local climate data on the Climate Data Store portal of the European Centre for Medium-Range Weather Forecasts (ECMWF). The application allows users to obtain climate charts and statistical indicators for temperature, precipitation, wind speed and direction, as well as the number of tropical and frost nights for any location worldwide using coordinates or an interactive map. This service uses the ERA5 reanalysis datasets of historical climate data, which represent a consistent combination of model data and the results of global meteorological observations. URL: <https://cds.climate.copernicus.eu/apps/c3s/app-era5-explorer>

Current climate characteristics and their spatial distribution across Ukraine can also be obtained from the Regional Climate Centre on Climate Monitoring (RCC Node-CM), which produces climate maps for the Europe and Middle East region. These maps are freely available for viewing and have a spatial resolution ranging from 0.05° to 1°, which is sufficient for obtaining regional climate characteristic values within Ukraine.

URL: <https://wmo.int/activities/csis/rcc/regional-climate-centre-europe>

A powerful and convenient source of historical climate data is the Climate Explorer portal, jointly developed by the Royal Netherlands Meteorological Institute (KNMI) and the World Meteorological Organization (WMO).

URL: <https://crt-climate-explorer.nemac.org/>

Climate characteristics of the main meteorological parameters for the period 1991–2020 (standard climate normals) across the territory of Ukraine can be obtained upon request from the Climate Cadastre of Ukraine, compiled by the Borys Sreznevskyi Central Geophysical Observatory and the Ukrainian Hydrometeorological Research Institute.

Climate change is one of the most important challenges of our time. Climate change significantly affects the economy and ecology of countries, as well as the social and political life of people. The warming of the climate system is now

unequivocal. According to experts, the last 30 years in the Northern Hemisphere were probably the warmest in the past 1,400 years, while many of the observed changes in the climate system are unusual or unprecedented over recent decades or even millennia. Changes in air temperature indicate substantial alterations in the thermal regime and the entire climate system. The consequences of these changes are predominantly negative and are expected to intensify in the future [1-6].

At the end of the previous and the beginning of the current century, in addition to classical climate indicators (annual and seasonal mean values, etc.), a system of quantitative indicators for monitoring, analyzing, and assessing changes in extreme climate characteristics was developed based on daily meteorological observation data. These indicators became known as climate extreme indices. The proposed system of extreme indices makes it possible to provide a more detailed analysis and assessment of climate change and to reveal the internal structure of these changes [7].

Known climate indices can be grouped into the following four categories:

- ✓ Absolute indices – monthly, seasonal, or annual maximum and minimum values of a climate variable within a year, season, or month;
- ✓ Mean indices – mean monthly, seasonal, or annual values of “extreme” climate variables (in particular, the mean daily maximum or minimum temperature). This group also includes long-term mean values of some classical indicators (for example, the long-term mean daily air temperature);
- ✓ Threshold indices – the number of days or the duration of a continuous period during which the value of a climate variable is above or below a specified threshold level;
- ✓ Composite indices – indices calculated using two or more climate variables, including indices from the first three groups. Examples include the number of dry and simultaneously warm days, or the number of wet and simultaneously cold days, etc.

There are also composite indices that are determined using rather complex algorithms.

Currently, 27 extreme climate indices are used in international practice.

Expected climate changes contribute to significant risks for ensuring the sustainable development of the national economy in the future, which is associated with increasing risks that can be divided into two groups. The first group is determined by vulnerabilities to climate change that are common to all economic sectors. The second group is related to the specific characteristics of individual sectors of the economy. The most vulnerable sectors include Ukraine’s agro-industrial and energy complexes, water supply systems, and construction. Therefore, climate information should be adapted according to the specific economic sector and provided to specialists in the relevant field for use in measures aimed at adapting the sector to current climate changes [8, 9].

Adapted climate information for the construction and architecture sector:

- ✓ Air temperature (monthly and annual mean values, temperature of the coldest day and the coldest five-day period with 98% and 92% probability of exceedance, mean daily amplitude, dates of the beginning and end of the heating period);
- ✓ Wind (frequency of prevailing wind direction and its mean speed for each month, long-term mean monthly wind speed by direction, and frequency of calm conditions);
- ✓ Solar radiation (mean monthly totals of direct and diffuse radiation reaching a horizontal surface and vertical surfaces of different orientations under clear-sky conditions and average cloudiness; total solar radiation over the heating period for horizontal and differently oriented vertical surfaces under average cloudiness; solar energy irradiance of surfaces with different orientations under clear-sky conditions and 10-octas cloudiness);
- ✓ Air humidity (mean monthly relative humidity, and mean daily amplitude averaged over each month);
- ✓ Cloudiness (mean monthly total cloud cover and low-level cloud cover; mean monthly number of clear and overcast days based on total cloudiness; mean height of the cloud base for each month of the season, the cold period (November-March), and the warm period (April-October));
- ✓ Precipitation (long-term mean monthly precipitation totals and annual sums), snow cover (number of days);
- ✓ Natural illumination (monthly mean values of total and diffuse daytime horizontal illumination and its duration).

REFERENCES

1. Assessment of the Impact of Climate Change on the Economic Sectors of Ukraine (2011) / Edited by S.M. Stepanenko and A.M. Polovyi. Odesa: Ecology, 694 p. <http://eprints.library.odku.edu.ua/id/eprint/2252>
2. Climate Change and Its Impact on the Economic Sectors of Ukraine: monograph (2015) / edited by S.M. Stepanenko and A.M. Polovyi. Odesa: TES, 520 p. <http://eprints.library.odku.edu.ua/id/eprint/2269>
3. Climate Risks for the Functioning of Economic Sectors of Ukraine under Climate Change Conditions: monograph / edited by S.M. Stepanenko and A.M. Polovyi. Odesa State Environmental University. Odesa: TES, 2018. 548 p. <http://eprints.library.odku.edu.ua/id/eprint/4916/>
4. Balabukh V. O. et al. Extreme weather events in Ukraine: occurrence and changes. Extreme Weather / Edited by P. J. Sallis. London, UK: Intech Open, 2018. Pp. 85-106.
5. Crespi A., Terzi S., Cocuccioni S., Zebisch M., Berckmans J., Füssel H-M (2020) "Climate-related hazard indices for Europe". European Topic Centre on Climate Change impacts, Vulnerability and Adaptation (ETC/CCA) Technical Paper 2020/1. DOI: 10.25424/cmcc/climate_related_hazard_indices_europe_2020

6. State of the Climate in Europe State of the Climate in Europe 2022. WMO-No. 1320. 2022. 40 p.
7. Climate Assessment & Dataset (ECA&D). Project team ECA&D: Royal Netherlands Meteorological Institute KNMI: December 9, 2021, Version: 11, 53 P.
8. Climate Change: Impacts and Adaptation Measures: analytical report / edited by S.P. Ivanyuta. Kyiv: National Institute for Strategic Studies (NISS), 2020. 110 p. ISBN 966-554-344-2
9. Climate Change Adaptation: A Short Guide for Communities. Rivne, 2023. 38 p. State of climate services. FIVE-YEAR PROGRESS REPORT (2019-2024). WMO-No. 1363. ISBN 978-92-63-11363-4

GIS MONITORING AND REMOTE SENSING AS AN INSTRUMENTAL BASIS FOR SUSTAINABLE MANAGEMENT OF LAND RESOURCES IN AN INDUSTRIAL CITY

Mykyta Guba¹, Nataliya Neposhyvaylenko², Volodymyr Kremin³

¹Municipal Institution "Scientific Lyceum named after Anatoliy Lyhun" of the Kamianka City Council, Kamianka, nickitapost@gmail.com

²Dnipro State Technical University, nna2013@ukr.net

³Department of Ecology and Natural Resources of the Kamianka City Council, eko@kam.gov.ua

In the modern paradigm of "green construction", the development of the urban environment is considered not only through the energy efficiency of individual structures, but as a comprehensive optimization of the functioning of the urban system. The key resource in this context is the city's "green frame", which acts as a natural regulator of the microclimate, an engineering barrier for pollutants and a tool for preserving land resources. For large industrial centers such as Kamianske, the issues of resource conservation and advanced methods for monitoring ecosystem services are of critical importance. In the context of global climate change and the need for systemic ecological restoration of industrial regions of Ukraine, the development of objective methods for assessing natural capital becomes the foundation for implementing sustainable development strategies and implementing ESG standards at the municipal level.

Traditional methods of inventorying plantations are resource-intensive and do not allow for a rapid assessment of the dynamics of changes on a large scale. The study proposes the implementation of a high-tech monitoring system based on a combination of remote sensing (RS) data and geoinformation modeling.

Remote sensing technologies are considered as a methodological basis for modern environmental monitoring and the advantages of using multispectral satellite images to audit the state of phytocenoses using the normalized differential vegetation index NDVI are substantiated. An algorithm for forming a geospatial

database has been developed that describes the procedure for processing Sentinel satellite images, and also details the mathematical apparatus for calculating vegetation indices. To ensure high reliability of spectral characteristics in conditions of significant aerosol pollution in the city of Kamianske, an algorithm for synthesizing composites by maximum values (MVC) has been used. This approach allows you to effectively level the influence of industrial smog and cloudiness on the results of calculating the NDVI index.

The use of Sentinel-2 satellite systems allows obtaining multispectral data with a high time frequency (up to 5 days), which turns the monitoring system into a dynamic tool for managing the city's "green assets". The spectral analysis technology using the NDVI index allows classifying the state of vegetation by the level of photosynthetic activity, which is a digital indicator of ecosystem health. The ArcGIS Desktop 10.8 GIS platform is used as an environment for integrating heterogeneous data, conducting spatial interpolation and building predictive models of landscape transformation. It has been established that consistently high NDVI values (>0.6) are characteristic mainly of ancient park areas and central squares of the city. These territories are the main energy-efficient nodes that provide a local temperature reduction of 3–5°C and the formation of stable comfort zones. The use of GIS modeling in combination with regular updating of satellite data allows forming a dynamic automated system of the city's green framework. This transforms monitoring from passive observation into a tool for predictive management of ecosystem services within the Smart Green City strategy, providing object identification accuracy up to 10 meters.

The efficiency of urban land use directly depends on the balance between development and natural components. The results of the study demonstrate how remote sensing data help to identify hidden reserves of the land fund and assess the quality of operation of existing territories. The generated cartographic models with a spatial resolution of 10 meters provide sufficient accuracy for the transition from city-wide analysis to object design. This opens up opportunities for microclimatic modeling at the level of individual residential blocks, allowing to justify the location of windbreaks and "green roofs" as elements of passive energy efficiency of buildings.

Analysis of the ten-year dynamics (2015–2025) of digital maps of the urbanized territory of Kamianske based on the calculated NDVI indices showed that a significant part of the lands of industrial zones and adjacent territories is subject to secondary succession or expansion of invasive species. This indicates inefficient use of urban land resources, which would be advisable to transform into productive "green zones" with a high coefficient of ecosystem services. In addition, it was recorded that in years with abnormal temperatures (for example, 2019), the vegetation index decreased to critical levels in 90% of the city's territory, which indicates the need to implement "smart irrigation" technologies and select sustainable tree species within green building projects to preserve soil fertility and moisture. Based on the constructed cartographic models, zones of

"heat islands" were identified, where the expansion of green areas is a priority for reducing energy costs for air conditioning buildings and creating a comfortable microclimate of urban systems not only in the summer period of the year due to the increase in biomass, but also throughout the year by creating windbreaks in dense multi-storey buildings.

Based on the results of the study, the following solutions are proposed for the purposes of green construction:

1. The implementation of the methodology used in the work allows municipalities and developers to save up to 40% of the budget for field research and auditing the condition of plantations.

2. Stable functioning of highly productive vegetation ($NDVI > 0.6$) is capable of locally reducing air temperature by 3–5°C in the summer. The creation of "green corridors" based on degradation zones identified by GIS methods is an effective means of combating thermal pollution.

3. For the conditions of the industrial Dnieper region, the possibility of using satellite composites of maximum values for leveling industrial smog when assessing natural resources has been demonstrated. This opens the way to the implementation of "Smart Green City" standards in the most environmentally burdened regions.

The results of the study prove that GIS and remote sensing are not just visualization methods, but full-fledged engineering systems that provide scientifically sound management of natural resources. The implementation of such an engineering platform is important for optimizing municipal costs for irrigation and care of plantings, ensuring maximum return on each unit of resources invested in "green building". The use of these technologies is a prerequisite for designing energy-efficient and sustainable urban spaces within the framework of a green building strategy. The results obtained confirm that the integration of remote sensing methods into municipal management creates a scientifically sound platform for resource conservation, allowing to optimize the costs of maintaining a green frame while simultaneously increasing the overall energy efficiency of the urban system.

REFERENCES

1. Guba M.O., Neposhyvaylenko N.O. Research on the long-term dynamics of the scale of greening of the urbanized part of the city of Kamianske using remote sensing and GIS technologies. – Dnipro: Small Academy of Sciences of Ukraine”, 2026. – 33 p.

2. Denysenko N. I. Urban-ecological aspects of the formation of green zones in large industrial cities of Ukraine // Ecological Sciences. – 2019. – No. 3 (26). – P. 45–52.

3. Remote sensing of the Earth: analysis of space images in geoinformation systems: teaching-methodical manual. / S. O. Dovgy, S. M. Babychuk, T. L.

Kuchma [et al.]. – Kyiv: National Center “Small Academy of Sciences of Ukraine”, 2020. – 268 p.

METHODOLOGICAL APPROACHES TO ENHANCING TECHNOLOGICAL EFFICIENCY IN MULTI-STOREY MONOLITHIC REINFORCED CONCRETE CONSTRUCTION

Farzaliyev S.A.¹, Abdullayev N.K.¹, Abbasova G.S.¹

*¹Azerbaijan University of Architecture and Construction,
sahib.farzaliyev@azmiu.edu.az, abdullayev037@mail.ru,
abbasova.gulbade@azmiu.edu.az*

INTRODUCTION

The economic transition in Azerbaijan has fundamentally shifted the construction industry's strategic trajectory from Soviet-era precast systems to monolithic reinforced concrete frameworks. While this shift enhances structural flexibility, it introduces complex technological sequences requiring rigorous management to prevent operational bottlenecks, which otherwise lead to protracted timelines and increased prime costs [1].

As expanding the residential housing stock remains a socio-economic priority, multi-storey monolithic structures offer a superior alternative to traditional precast assembly, though their execution necessitates highly structured organizational approaches [2]. Field observations in major urban centers like Baku and Sumgayit reveal that firms employ divergent technological solutions based on their technical infrastructure and machinery. However, frequent oversights regarding technological specificities during the initial design phase often create substantial operational hurdles. To address these inefficiencies, this research evaluates the integration of modernized technologies, specifically focusing on optimizing concrete pumping systems, refining formwork assemblies, and mechanizing reinforcement (rebar) workflows.

ANALYSIS AND RESEARCH METHODOLOGY

Investigations in Baku and Sumgayit reveal that while monolithic systems improve architectural flexibility and material efficiency, they are often hindered by high labor intensity and technological breaks [3, 4]. Efficiency is typically assessed via unit metrics (1.0 m³ of concrete or 1.0 m² of area); however, isolated optimization of labor or timelines often fails to reflect holistic economic performance. Thus, identifying optimal structural solutions requires a multifaceted comparison of technological and economic indicators [5]. In high-rise projects, foundation systems face significant labor challenges inherently linked to formwork organization and mechanization levels [6, 7]. Modernizing formwork processes can reduce labor consumption by 40.0-50.0% and costs by 20.0-25.0%, addressing current average intensities of 0.7-1.3 man-days per 1.0 m³.

Technical scrutiny of column-and-slab configurations in local projects suggests that refining column cross-sections and increasing structural spans to 6.6 x 6.6 m can optimize performance, though this necessitates precise technical adjustments in reinforcement detailing. Depending on reinforcement density, concrete mixes with specific technological parameters are required during casting. Furthermore, transitioning from conventional manual methods to automated reinforcement workflows is strongly recommended. The utilization of BP-1 and BP-2 grade steel wires has proven both technically and economically viable for these high-rise applications, as illustrated in Figure 1.

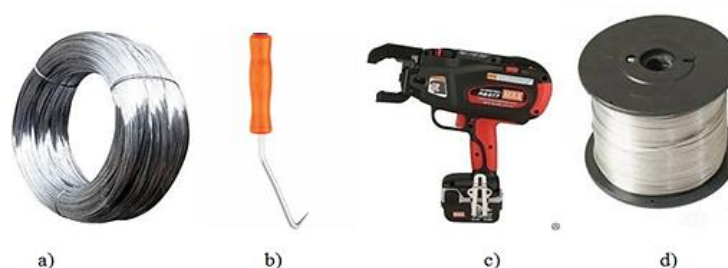


Fig. 1. Equipment and materials for reinforcement tying.
a) binding wire coil; b) manual rebar tying hook; c) automated (cordless) rebar tying tool; d) wire spool for automated tying systems.

The efficiency of automated rebar tying tools, specifically models KW-0038, RG-400T, and RB-398, was rigorously investigated. The technical and economic parameters of these devices are detailed in Table 1.

Table 1

Technical characteristics of automated rebar tying tools

№.	Tool model	Rebar diameter range (mm)	Wire diameter (mm)	Wire coil length (m)	Ties per coil (units)	Time per tie (seconds)
1	KW-0038	4-28	0.8-1.0	95	330	0.8
2	RG-400T	4-40	0.8-1.2	75	320	0.8
3	RB-398	4-68	0.8-1.5	45	280	0.8

To accurately calculate the required material volume, it is essential to determine the weight per linear meter and the total length per kilogram of the binding wire. These values are presented in Table 2.

Table 2

Physical parameters of binding wire

№	Wire diameter (mm)	Weight per 1.0 m (kg)	Length per 1.0 kg (m)
1	0.6	0.002	450.45
2	0.8	0.004	253.17
3	1.0	0.006	162.0

№	Wire diameter (mm)	Weight per 1.0 m (kg)	Length per 1.0 kg (m)
4	1.2	0.009	112.6
5	1.4	0.012	82.6
6	1.6	0.015	65.4
7	1.8	0.022	50.0
8	2.0	0.028	40.5

Empirical findings indicate that the integration of such equipment leads to a tenfold increase in labor productivity compared to manual tying methods. This aligns with the technical specifications provided by manufacturers, asserting that a single automated tool can effectively replace the manual output of ten workers [8].

Concrete workflows in Baku and Sumgayit high-rise projects emphasize machinery efficiency during transportation and placement. Most operations utilize concrete pumps and long-distance pipelines, where transmission efficiency is governed by mix composition—specifically cement-sand-aggregate ratios and entrained air content [9, 10]. Optimizing flow velocity and minimizing hydraulic resistance are critical for extending delivery distances [11]. In Azerbaijan, diesel-powered pumps remain the preferred industrial choice; their primary technical specifications are summarized in Table 3.

Table 3

Technical parameters of diesel-powered concrete pumps

№	Technical indicators	Putzmeister BSA 1408 E	Putzmeister BSA 1407 D	SANY HBT 60 E	SANY HBT 80 D
1	Productivity (m ³ /hour)	79/53	71/47	60/37	85/50
2	Delivery pressure (bar)	71/106	71/106	78/130	100/180
3	Vertical delivery distance (m)	100	100	200	320
4	Horizontal delivery distance (m)	250	250	700	1000

As shown in Table 3, the availability of diverse technical parameters allows for the strategic selection of equipment to enhance the overall technological efficiency of multi-storey monolithic frame buildings. Research indicates that using the Putzmeister BSA 1407 D for column and slab placement reduces labor intensity by 4.1 times compared to standard construction norms. Furthermore, the unit cost per 1.0 m³ of concrete work is reduced threefold.

The analysis of Figure 2 demonstrates that for buildings ranging from 4 to 16 storeys, utilizing concrete pumps can shorten the overall construction duration by approximately 2.5 to 4.0 months. Consequently, the automation of concrete workflows significantly reduces labor intensity, material consumption, and project costs while augmenting technological efficiency.

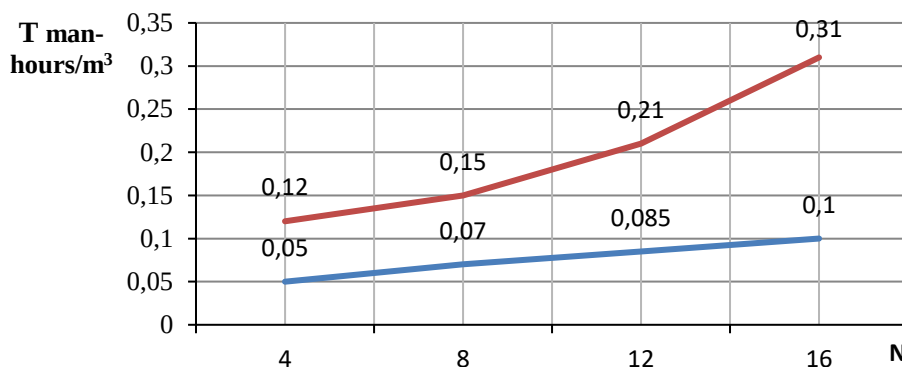


Fig. 2. Correlation between labor intensity (T) per 1.0 m³ of concrete and the number of storeys (N).

CONCLUSION

The comprehensive investigation into high-rise monolithic reinforced concrete construction within Baku and Sumgayit unequivocally confirms that transitioning from manual methods to automated technological sequences significantly augments both operational efficiency and organizational reliability. Findings underscore that integrating automated reinforcement tying results in a transformative tenfold productivity increase, while the systematic deployment of specialized concrete pumping systems-specifically the Putzmeister BSA 1407 D-reduces labor intensity 4.1-fold and decreases unit costs threefold compared to conventional norms. Beyond direct technical metrics, these advancements facilitate a profound reduction in material waste and overall project expenditures, ensuring higher economic viability for complex structural projects. By successfully compressing construction timelines by several months, such methodological improvements foster a resource-efficient paradigm that directly aligns with the strategic socio-economic objectives of sustainable urban development and green building practices in the Republic of Azerbaijan.

REFERENCES

1. Afanasyev A.A. Intensification of work in the construction of buildings and structures from monolithic reinforced concrete. Moscow: Stroyizdat, 1990. 384 c.
2. Ibadov N., Farzaliyev S.A., Landyukli I. Selection of technological and organisational solutions for construction works with the use of a fuzzy relation of preferences // Archives of Civil Engineering. Warsaw University of Technology, 2023.
3. Farzaliyev S.A., Guluzade Sh.R. Possibilities of organising the construction of multi-storey monolithic reinforced concrete buildings by the flow method // Scientific Collection of AzUAC. 2023.
4. Farzaliyev S.A., Abbasova G.S. Reintegration of liberated territories into the country's economy: targets and directions // International Scientific Conference. Baku, 2023.

5. Fokov R.I. Selection of optimal organization and technology for the construction of buildings. Kyiv: Budivelnyk, 2012. 192 c.
6. Ginzburg A.V. Information model of the life cycle of a construction object // Industrial and Civil Engineering (Promyshlennoye i Grazhdanskoye Stroitelstvo). 2016. № 9. C. 61-65.
7. Ginzburg A.V. Organizational and technological reliability of construction systems // Vestnik MGSU. 2010. № 4(1). C. 251-255.
8. Faltinsky E.A. Methods of substantiation and selection of organizational and technological solutions taking into account risk. St. Petersburg: DNK, 2006. 280 c.
9. Korolev K.M. Mechanization of preparation and placement of concrete mix. Moscow: Stroyizdat, 1986. 134 c.
10. Khayutin Yu.G. Monolithic concrete. Moscow: Stroyizdat, 1981. 447 c.
11. Belegozov E.M. Technology of construction of buildings and structures from monolithic and precast-monolithic reinforced concrete. Baku: TI-MEDIA, 2011. 134 c.

TEACHING OPTIMISATION ALGORITHMS FOR THE CROSS-CUTTING OF SAWN TIMBER INTO WORKPIECES FOR JOINERY AND CONSTRUCTION PRODUCTS

Serhii Shevchenko¹, Olena Skrypnyk¹, Anna Opashniuk¹

¹*State Biotechnological University, serg.shevchen@btu.kharkiv.ua, elenases2015@btu.kharkiv.ua, a.opashniuk@btu.kharkiv.ua*

The need for the efficient utilisation of wood has led to the widespread adoption of technology for manufacturing glued wood products based on the finger-jointing of defect-free workpieces obtained by removing defective parts from slats, boards and similar sawn timber. This technology is used in the manufacture of joinery and construction products, as well as timber housing components such as glued laminated timber and cross-laminated timber wall panels [1].

The removal of defective parts is performed using an automatic programmable cut-off saw (essentially a high-speed circular sawing machine equipped with sensors and computer control for determining and implementing a rational cutting pattern for sawing timber into workpieces), which operates according to one or several predefined algorithms. Consequently, when teaching the structure, functional capabilities, and application technologies of automatic programmable cut-off saws, there is a need to explain the typical operating algorithms used in such equipment.

Typical algorithms implemented in automatic programmable cut-off saws produced by many manufacturers include the following [2]:

- an algorithm for cutting a slat (or a defect-free part of a slat) into workpieces of given lengths;
- an algorithm for cutting a slat (or a defect-free part of a slat) into workpieces of variable lengths within a given range, intended for subsequent finger-joint milling and longitudinal joining (where the lower limit of the range is determined by the minimum permissible workpiece length, and the upper limit is determined by the technical limitations of the finger-jointing equipment);
- a combined algorithm integrating the aforementioned algorithms.

Thus, the tasks solved by automatic programmable cut-off saws represent a variation of the classical one-dimensional cutting stock optimisation problem, an overview of mathematical solution methods for which is presented in study [3] (including linear programming and heuristic methods).

However, teaching practice in the course *Technology for Manufacturing Glued Wood Products* for students specialising in *Woodworking and Furniture Technologies* demonstrates that, for the initial study of automatic programmable cut-off saw applications, it is advisable to model their operating algorithms using spreadsheets with built-in optimisation tools. Moreover, collaborative work is conveniently organised using cloud-based spreadsheets.

Let us consider the technique for modelling the operation of an optimisation algorithm for cutting a slat into workpieces whose nominal lengths correspond to a predefined list. It is advisable to begin with the simplest case, where no restrictions are imposed on the number of workpieces of each type. Accordingly, the input data consist of the slat length, kerf width, and given nominal workpiece lengths. The variable parameters are the numbers of workpieces of each nominal length, while the quality criterion is the residual wood remaining after cutting the workpieces. Typically, constraints such as integer constraints and non-negativity of the variable parameters are conveniently specified within the settings of the built-in optimisation tool. Upon completion of the calculations, a wood balance is determined, reflecting the transformation of raw material into workpieces, solid waste, and sawdust. Such a balance should be calculated both in physical and monetary terms.

A variation of this algorithm is the optimisation of slat cutting according to the total value of the resulting workpieces, taking into account the required quantity of workpieces of each given length.

The next stage, involving increased complexity, is the modelling of an algorithm for cutting a slat into workpieces of given and variable lengths (within a given range). In this case, additional variable parameters are introduced, namely the lengths of the variable-length workpieces. Optimisation is performed according to the criterion of the total value of the workpieces, considering that the value of variable-length workpieces is proportional to their length while accounting for wood losses during finger-joint machining (equal to the length of one finger joint per workpiece).

In industrial practice, the operating algorithms of automatic programmable

cut-off saws are considerably more complex, since it is necessary to plan the cutting of multiple slats in order to fulfil a production schedule. Consequently, the next level of complexity involves modelling the search for a rational cutting pattern for several slats of given length in order to satisfy a production programme, as well as modelling operation under conditions where slats of different lengths are processed sequentially and the remaining production programme is updated after each cutting operation.

It should be noted that the algorithms discussed above concern cases where the boundaries of wood defects have already been identified, as occurs in automatic programmable cut-off saws employing laser pointers or fluorescent chalk marking of defects [2].

If, however, technical vision systems or non-destructive testing methods (for example, X-ray inspection or computed tomography) are used to determine defect part boundaries [4], an additional problem arises: the optimal determination of the boundaries of parts to be removed, taking into account the possible underutilisation of sound wood or the occurrence of processing defects when cuts are located too close to wood defects (primarily wood knots). Consequently, a more advanced task suitable for research projects is the selection of cutting positions while considering the probability of wood splintering during subsequent finger-joint milling due to deviations in wood grain direction from the longitudinal axis of the slat [5, 6].

As an additional assignment for the considered tasks, the creation of a schematic graphical representation of the slat indicating cutting positions may be recommended.

Such modelling may also prove useful in studying cross-cutting optimisation of profiled materials, for example profiles for furniture sliding systems, edge-banding materials, or materials used in upholstered furniture manufacturing (in such cases, kerf width is not taken into account).

As the use of reclaimed wood expands within the transition towards a circular bioeconomy, these algorithms will become increasingly widespread and will continue to be improved.

REFERENCES

1. Fredrik Ljunggren, Maria Fredriksson, Nils Johansson, Angela Sasic Kalagasidis. Cross-laminated timber: a state-of-the-art review of moisture, fire, acoustics, and energy-related aspects. *Wood Material Science & Engineering*. 2026. 21:2. P. 1224-1246. URL: <https://doi.org/10.1080/17480272.2025.2507145> (access date 02.05.2026).
2. T 2030 NC. <https://www.omginc.com/products/2117-t-2030-nc.html> (access date 02.05.2026).
3. Ben Amor H., Valério de Carvalho J. Cutting Stock Problems. In: Desaulniers G., Desrosiers J., Solomon M. M. (eds). *Column Generation*. Springer, Boston, MA. 2005. URL: https://doi.org/10.1007/0-387-25486-2_5

(access date 02.05.2026).

4. Peter Niemz, David Mannes. Non-destructive testing of wood and wood-based materials. *Journal of Cultural Heritage*. 2012. Volume 13. Issue 3. Supplement. Pp. S26-S34. <https://doi.org/10.1016/j.culher.2012.04.001> (access date 02.05.2026).

5. Shevchenko S. A. Research into the Influence of Swirling Wood Grain on Wood Splintering at Milling Finger Joint Elements. *Technical Service of Agriculture, Forestry and Transport*. 2025. №27. P. 2016-221. URL: <http://tsafts.btu.kharkiv.ua/tsafts/uk/article/view/217/215> (access date 02.05.2026).

6. Shevchenko Serhii. Raw and Analyzed Data for: Research into Influence of Swirling Wood Grain on Wood Splintering at Milling Finger Joint Elements : [data set]. Kharkiv, Ukraine, 2026. URL: <https://doi.org/10.5281/zenodo.18914780> (access date 02.05.2026).

REMOTE MONITORING OF HYDROECOLOGICAL DAMAGE CAUSED BY WARFARE AS AN INFORMATION BASIS FOR GREEN POST-WAR RECOVERY OF TERRITORIES

Vladyslav Maksymenko¹, Vitalii Bezsonnyi²

¹V. N. Karazin Kharkiv National University,
maksymenko.vladyslav.o@gmail.com

²Simon Kuznets Kharkiv National University of Economics,
vitalii.bezsonnyi@hneu.net

Green post-war recovery of damaged territories should not be reduced to engineering reconstruction, urban planning measures or the introduction of isolated resource-saving technologies. Its scientific basis must include reliable environmental diagnosis of areas affected by hostilities, destruction of hydraulic infrastructure, flooding, drying, secondary contamination and disturbance of the natural regime of water bodies. This is particularly important for large river basins and reservoirs, where water resources perform environmental, sanitary, economic, recreational and infrastructural functions. In this context, remote monitoring becomes an essential information tool for assessing ecological damage caused by warfare, identifying environmental risks and substantiating priorities for green recovery [1, 2].

The aim of this study is to substantiate the potential of open Sentinel-2 satellite data for rapid indication of hydroecological consequences of warfare and for forming an information basis for environmentally safe post-war recovery of territories. The study is based on the analysis of spatial and temporal transformation of the Kakhovka Reservoir after the destruction of the Kakhovka HPP dam on 6 June 2023 and on the concept of compensatory monitoring of

surface waters under conditions where conventional field control is limited, unsafe or impossible.

The methodological framework combines visual interpretation of satellite scenes, spectral index analysis and comparative temporal assessment. Cloud-minimized Sentinel-2 MSI L2A scenes obtained through the Copernicus Data Space Ecosystem were used [4]. The key temporal sections included the pre-accident state on 25 May 2023, the post-accident state on 25 June 2023 and the autumn state of the area on 3 October 2023. The Normalized Difference Water Index (NDWI) was applied to identify open water surfaces, while the Normalized Difference Vegetation Index (NDVI) was used to detect photosynthetically active vegetation on the exposed reservoir bed [5, 6]. Frequency distributions of pixel values were additionally considered to confirm changes in dominant spectral characteristics.

The results indicate a rapid hydrological and landscape reorganization of the Lower Dnipro geosystem after the destruction of the Kakhovka HPP dam. The continuous water surface typical of the pre-accident reservoir state was transformed within the first weeks into the narrowed Dnipro channel, a system of residual water bodies, wet areas and extensive exposed bottom sediments. Positive NDWI values, which had dominated within the water area before the accident, remained mainly within channel and residual-water fragments after the dam destruction. This confirms the loss of spatial integrity of the reservoir and the formation of a new mosaic structure of the surface cover [2, 3].

The NDVI analysis for autumn 2023 revealed the appearance of photosynthetically active vegetation on part of the exposed reservoir bed. Since these areas had been underwater before the dam destruction, their vegetation cover can be interpreted as an indicator of early successional colonization of exposed bottom substrates. However, this process has an ambiguous ecological meaning: it may indicate the beginning of spontaneous recovery of floodplain, meadow and wetland biotopes, but it can also be accompanied by risks of secondary pollution, dust transfer of contaminated sediments, degradation of residual water bodies and fire hazards.

For the subject area of green construction, these results are important not only as an example of remote documentation of ecocide consequences, but also as a decision-support instrument for territorial recovery. Engineering, water-management and landscape solutions in zones of hydroecological transformation should be based on up-to-date spatial information about the boundaries of residual water bodies, wet areas, potentially hazardous bottom sediments, vegetation colonization zones and areas of possible secondary contamination. Without this information, green recovery may become formal reconstruction that does not take into account the actual environmental state of the territory.

Satellite monitoring should therefore be considered as a compensatory spatial-temporal contour. It does not replace laboratory water-quality control, but it reduces spatial and temporal uncertainty under crisis conditions. Sentinel-2 data

make it possible to detect changes in open water surfaces, map flooded or dried areas, document shoreline transformation, identify locations for priority field surveys and support the preparation of cartographic materials for environmental management. At the same time, final conclusions concerning the chemical, toxicological or microbiological state of water bodies must be based on laboratory studies and field validation.

A promising direction is the integration of Sentinel-2 data with Sentinel-1 radar imagery, digital elevation models, hydrochemical data, field observations and intelligent data analysis methods. In such a system, machine-learning models may support automated classification of satellite scenes after proper training and validation, while controlled reporting based on Retrieval-Augmented Generation may provide transparent documentation of sources, indicators and management conclusions. Thus, remote monitoring of hydroecological damage can become one of the core instruments of scientifically grounded green recovery of Ukraine [7, 8].

REFERENCES

1. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy. Official Journal of the European Communities. 2000. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CElex:32000L0060>.
2. United Nations Environment Programme. Rapid Environmental Assessment of Kakhovka Dam Breach, Ukraine, 2023. Nairobi : UNEP, 2023. URL: <https://www.unep.org/resources/report/rapid-environmental-assessment-kakhovka-dam-breach-ukraine-2023>.
3. Shumilova O., Sukhodolov A., Osadcha N. et al. Environmental effects of the Kakhovka Dam destruction by warfare in Ukraine. Science. 2025. Vol. 387, No. 6739. P. 1181-1186. DOI: <https://doi.org/10.1126/science.adn8655>.
4. Drusch M., Del Bello U., Carlier S. et al. Sentinel-2: ESA's Optical High-Resolution Mission for GMES operational services. Remote Sensing of Environment. 2012. Vol. 120. P. 25-36. DOI: <https://doi.org/10.1016/j.rse.2011.11.026>.
5. McFeeters S. K. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing. 1996. Vol. 17, No. 7. P. 1425-1432. DOI: <https://doi.org/10.1080/01431169608948714>.
6. Tucker C. J. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment. 1979. Vol. 8, No. 2. P. 127-150. DOI: [https://doi.org/10.1016/0034-4257\(79\)90013-0](https://doi.org/10.1016/0034-4257(79)90013-0).
7. Dosovitskiy A., Beyer L., Kolesnikov A. et al. An Image is Worth 16x16 Words: Transformers for Image Recognition at Scale. ICLR 2021. URL: <https://arxiv.org/abs/2010.11929>.

8. Lewis P., Perez E., Piktus A. et al. Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks. Advances in Neural Information Processing Systems. 2020. Vol. 33. P. 9459-9474.

INFLUENCE OF ALKALI METALS IN BIOMASS ON THE POLLUTION PROCESSES OF CONVECTIVE SURFACES OF HEAT GENERATORS

Mykola Beliuzhenko

*Kyiv National University of Construction and Architecture,
n.beliuzhenko@gmail.com*

Currently, the main source of biofuel and energy production from biomass in the world is wood biomass - firewood, wood chips, pellets and charcoal account for more than 85% of the total biomass consumption for energy needs. A promising direction for the development of bioenergy and increasing the volume of energy use of biomass is considered to be the involvement of agricultural residues in the fuel and energy balance of countries. Today, only 3% of the total volume of bioenergy is produced from biomass of agricultural origin, but according to expert estimates, the potential of biomass in the world of this type is from 356 to 1646 million tons of equivalent per year, which can provide 3-14% of the total supply of primary energy in the world [1].

The main problem of using agricultural biomass in energy is its specific chemical composition, in particular the high content of chlorine and alkali metals - potassium (K) and sodium (Na). During thermal decomposition, these elements actively pass into the gas phase with the formation of volatile compounds, such as potassium chloride (KCl) and hydrogen chloride (HCl) [2]. The high concentration of KCl in flue gases intensifies the processes of deposit formation, while the significant content of chlorides in the deposits themselves significantly accelerates corrosion processes on heat exchange surfaces.

Biomass boilers use different types of fuel (wood, straw, sunflower husks, etc.), which are characterized by different chemical composition, content of mineral components and impurities. The main components of biomass are carbon, hydrogen and oxygen, but the fuel also contains inorganic elements: N, P, K, Ca, Mg, Na, Si, S and Cl. In addition, trace concentrations of heavy metals, in particular cadmium and lead, may be present.

Biomass fuels such as straw are rich in alkali metals (K and Na), which are mainly present as simple salts and organic compounds, as well as chlorine. These compounds are rapidly released into the gas phase during combustion, forming HCl and KCl.

High levels of KCl in the flue gas are often associated with increased deposit formation. This in turn leads to corrosion of convective surfaces in biomass boilers [2]. Sulfur also contributes to corrosion-related phenomena.

During biomass combustion, a complex set of physicochemical processes occurs, including evaporation, pyrolysis, oxidation, and gas-phase reactions. Alkali metals, primarily potassium, transition to a gaseous state at temperatures around 700 °C.

With intensive contamination of the convective heating surfaces of a biofuel heat generator, the aerodynamic resistance of the convective packages increases due to partial or complete blockage of the intertube space by deposits. This leads to a deterioration of heat exchange conditions and a decrease in the heat transfer coefficient, which, in turn, causes overheating of the convective heating surfaces and an increase in the temperature of the exhaust gases.

As a result of these processes, there is a decrease in the efficiency of the boiler equipment, which is manifested in excessive fuel consumption and a decrease in boiler efficiency. Additionally, the thermal power of the plant is limited, ash and nitrogen oxides (NO_x) emissions increase, and the reliability and service life of the equipment deteriorate.

Operational consequences include increased frequency of repairs, increased maintenance costs, and the need for periodic manual deslagging of heating surfaces.

Operating experience shows that the values of thermal efficiency and pollution coefficients obtained on operating boiler units differ significantly from the recommended regulatory values, and the nominal productivity of the heat generator is limited due to the temperature of the metal of the pipes of the heating surfaces exceeding the permissible values [3]. In this regard, to increase the reliability of the operation of heat generators on biofuels, it is necessary to identify and substantiate the factors that affect the thermal efficiency indicators when burning various types of biofuels.

The main purpose of the tests was to analyze biofuels and ash to determine the effect of potassium (K) and sodium (Na) compounds in biofuels on the intensity of contamination of convective surfaces.

The formation of ash deposits on the heating surfaces of biofuel heat generators is a multi-stage process. First, condensation of volatile compounds (mainly KCl) occurs, after which ash particles and combustion products settle on the formed thin layer.

Potassium promotes the formation of low-melting compounds that increase the adhesion of particles to metal surfaces. This leads to intensification of slagging processes and contamination of heat exchange surfaces.

In addition, the presence of chlorides in deposits is the main factor in the development of high-temperature corrosion by the chloride mechanism, which significantly reduces the service life of heating surfaces.

Unlike potassium, calcium in biomass forms mainly refractory compounds (oxides, sulfates), which do not condense in the gas phase and are removed together with the ash.

Several types of biomass were selected for analysis: willow, bark, untreated wood, demolition wood, straw and peat. Data on the chemical composition of the biomass were obtained from the “ECN Phyllis Database”.

Reliable data were taken from the biomass chemical composition database “ENC Phyllis data base” (<https://phyllis.nl/Browse/Standard/ECN-Phyllis>).

The analysis indicates the active participation of potassium in the processes of transfer and precipitation in the form of low-melting compounds, in particular chlorides and potassium oxide. The formation of such compounds contributes to increased adhesion of particles to heating surfaces and intensification of slagging processes and contamination of heat exchange surfaces.

During biomass combustion, different chemical elements interact with each other, forming compounds with different physicochemical properties. In particular, calcium (Ca) usually reacts with oxygen (O₂) or sulfur (S) in the fuel bed on the grate of the furnace to form high-temperature (refractory) compounds. Due to the high eutectic temperatures, such ash components mainly remain in the solid state and are removed directly in the furnace or captured in ash collection devices (e.g. electrostatic precipitators).

Unlike calcium, potassium (K) has much lower melting and vaporization temperatures. During combustion, it passes into the gas phase, with intensive vaporization starting at temperatures around 700 °C.

Potassium is released from the fuel bed as gaseous compounds. This is followed by alkali capture, during which potassium reacts with components of the gas phase. Depending on the sulfur (S) and chlorine (Cl) content of the fuel, the formation of potassium sulfates or chlorides is possible. Since most biomass types are characterized by a relatively low sulfur content and a high chlorine content, the dominant compound is potassium chloride (KCl).

Potassium chloride has a low condensation temperature, so in the high temperature zone it is in a gaseous state, and upon contact with colder heating surfaces (with a temperature below ≈ 700 °C) it intensively condenses on the metal. As a result, an initial thin layer of deposits is formed, which subsequently serves as the basis for the accumulation of thicker ash layers.

In addition, the presence of KCl in deposits contributes to the development of high-temperature corrosion due to the chloride mechanism, which further worsens the condition of heat exchange surfaces and shortens their service life.

Thus, the content of alkali metals, primarily potassium, is one of the determining factors of the intensity of pollution and high-temperature corrosion of convective heating surfaces of biomass-fired heat generators. Taking into account the chemical composition of biofuels is a necessary condition for increasing thermal efficiency, reliability and resource of boiler equipment.

One of the directions of reducing the intensity of slagging and ash deposition is the optimization of the temperature regime of the combustion process in the combustion chamber and the reduction of the content of ash particles in the combustion products at the entrance to the convective surfaces of the heat

generator [4]. A combined shaft-layer technological scheme for organizing the solid fuel combustion process is promising, which is implemented in the design of mechanized heat generators. The design of the heat generator provides for fuel pyrolysis in the shaft, fuel combustion in the layer, combustion of dust particles in the volume of the primary combustion chamber and in the secondary chamber with ash deposition, which ensures the purification of combustion products. Ash particles are deposited at the entrance to the zone of convective heat exchange surfaces, which significantly reduces the intensity of their contamination and, accordingly, contributes to increasing the thermal efficiency of the heat exchange process. With the combined combustion process scheme, the estimated average values of the increase in the efficiency of the heat generator at nominal load are almost 8% compared to the single-chamber combustion scheme and 4% compared to the scheme with combustion chambers and ash settling [5]. Such a scheme provides energy and environmental performance at the level of European requirements and allows for the effective use of cheap local fuels.

REFERENCES

1. Heletukha H. H. Scientific and Technical Principles of Energy Production from Biofuels. Institute of Engineering Thermophysics of NAS of Ukraine, 2021.
2. Håkan Kassman. Strategies to Reduce Gaseous KCl and Chlorine in Deposits during Combustion of Biomass in Fluidised Bed Boilers. Chalmers tekniska högskola, 2012.
3. Yalova A.M., Bondar N.V. Influence of dressing and contamination of surfaces heating on reliability of solid fuel boilers in HES. *Jornal of Kryvyi Rih National University*. 2021. No. 53. Pp. 151–157.
4. Senchuk M. Increasing the efficiency of burning solid fuel in the layer. *Ventilation Illumination and Heat Gas Supply*. – 2021. - Iss. 39. - pp. 29-37.
5. Senchuk M., Rybka A., Yurko O. Reducing the Impact of Pollution on Heating Surfaces in Low-Power Solid Fuel Heat Generators. *Ventilation Illumination and Heat Gas Supply*. – 2020. - Iss. 33. - pp. 15-21.

GREEN BUILDING AND UNIVERSAL DESIGN: STRATEGIES FOR SOCIAL ADAPTATION OF PERSONS WITH DISABILITIES IN THE POST-WAR PERIOD

Karyna Danova¹, Viktoriya Malysheva¹, Lyudmila Kolibelnikova¹

¹*O.M.Beketov National University of Urban Economy in Kharkiv,
karyna.danova@kname.edu.ua*

Modern demographic processes in Ukraine, caused by the full-scale military aggression of the Russian Federation, the rapid growth of morbidity and traumatization of the population, lead to a trend of a sharp increase in the number

of people with disabilities. Such dynamics were recorded even before the war, but today it has acquired threatening proportions. Given these challenges, there is an urgent need for a fundamental rethinking of the principles of urban development within the framework of future post-war reconstruction, because Ukraine has a unique chance not only to restore destroyed cities, but to build a fundamentally new infrastructure that will meet the requirements of the future. In general, sustainable development of the city is a process based on the principles of justice, equality and accessibility. The city should be planned and managed as an open system, supported by democratic and inclusive tools [1]. This approach is fully supported by the concept of "green building" (Green Building). Today, green trends are a priority, as they correlate with the UN Global Goals for Sustainable Development, allow for high environmental friendliness of construction processes and minimize anthropogenic impact on the environment. Simultaneously with the implementation of green practices, the construction sector can provide a significant improvement in the social climate and physical environment of the city through inclusive practices [1].

Persons with disabilities and the elderly belong to vulnerable groups of the population, to whom increased requirements are imposed in the context of environmental friendliness, ergonomics and safety of social space. For this category of residents, the architectural environment serves either as a basis for maintaining functional and psychological indicators, or as a factor that rapidly worsens them. Unfortunately, the modern focus of developers is often limited only to the formal provision of physical accessibility (the presence of ramps), which significantly limits the development of true inclusion. For example, New Zealand's experience shows that building designs tend to only consider mobility limitations, leaving out the needs of people with visual, hearing or cognitive impairments [2]. Green building approaches allow for a much deeper development of inclusivity. On the one hand, the implementation of the principles of ecological design and green building GBD (Green Building Design) is a catalyst for saving resources and creating healthier living spaces. For example, in China, this momentum has been developed precisely thanks to the introduction of international standards such as LEED [3]. On the other hand, green building directly affects the social fabric of the community. Studies conducted in Chicago have shown that residents of buildings located near green spaces have higher levels of social trust, feel closer to their neighbors and are more likely to show willingness to help each other [4]. People living in "healthy" environmental conditions demonstrate lower levels of mental stress, anxiety and depression [5]. Public spaces filled with greenery stimulate the development of social networks in libraries, parks and centers, guaranteeing equitable access to resources and removing obstacles to an active lifestyle [4].

The practical implementation of the principles of inclusive green construction in the world is carried out through a system of international certification standards that combine environmental, social and safety criteria for

evaluating buildings. A systematic solution to the issues of providing comfortable and safe living space for people with disabilities in the face of existing challenges in Ukraine can be ensured through the integration of leading international standards, in particular LEED and WELL:

1. LEED (Leadership in Energy and Environmental Design) standard. LEED certification is based on several key principles that assess the sustainable development of buildings. The criteria include the choice of environmentally friendly materials, effective management of water resources and energy consumption, as well as the quality of the indoor environment. Priority is given to reducing the carbon footprint and increasing energy efficiency. For Ukraine, it is important that at the LEED level the building is designed as energy-independent as possible. In conditions of frequent blackouts, this ensures uninterrupted operation of elevators, lifting systems and forced ventilation, which is critical for ensuring the safety and continuous life of low-mobility groups of the population.

2. The WELL Building Standard is based on scientifically based research that demonstrates the significant impact of buildings on the health, satisfaction and productivity of their residents. It sets standards for factors that affect human health and safety: from air quality and water purity to lighting, acoustics and materials that do not emit harmful chemicals. The standard also takes into account such aspects as mental health, a healthy lifestyle and work-life balance. For Ukraine at the WELL level, for example, a promising direction is to fill the indoor environment with elements of vertical gardening.

The integration of international LEED and WELL standards into the practice of post-war reconstruction of Ukraine should be considered as one of the key areas of forming a modern model of sustainable and inclusive urban development. In modern conditions, the concept of green building should go beyond the exclusively environmental and energy-efficient characteristics of buildings and provide for comprehensive consideration of human needs, in particular, people with disabilities, the elderly and other low-mobility population groups. In this context, the architectural environment should be considered not only as an element of physical infrastructure, but also as an important factor in maintaining health, psychological well-being, social integration and safety of the population.

Further development of green building in Ukraine requires the adaptation of international approaches to national conditions and challenges of the post-war period. First of all, we are talking about the need to develop national criteria for inclusiveness and safety of the built environment, which should be based on the principles of universal design, biophilic design and a human-centered approach. Energy efficiency, autonomous functioning of engineering systems, safe evacuation and maintenance of appropriate microclimate parameters should become mandatory components of the design of social facilities.

The implementation of a comprehensive approach to reconstruction, based on a combination of the principles of sustainable development, inclusiveness and security, will create the prerequisites for the formation of a modern living

environment in Ukraine, focused on ensuring a high quality of life, social equality and long-term sustainability of communities

REFERENCES

1. Selanon, P., & Chuangchai, W. (2023). The Importance of Urban Green Spaces in Enhancing Holistic Health and Sustainable Well-Being for People with Disabilities: A Narrative Review. *Buildings*, 13(8), 2100.
2. Flemmer, C.L., & McIntosh, A. (2025). Equitable Access to the Built Environment for People with Disability. *Athens Journal of Technology & Engineering*.
3. Mei Dong, Agyemang Kwasi Sampene, Cai Li, Francis Kyere, Innovative pathways to green building development: Integrating technology, policy, and industry collaboration, *Cleaner and Responsible Consumption*, Volume 19, 2025, 100329.
4. Harris, E., Franz, A., & O'Hara, S. (2023). Promoting Social Equity and Building Resilience through Value-Inclusive Design. *Buildings*, 13(8), 2081.
5. Ekhaese EN and Ndimako OO (2023) Eco-friendly construction materials and health benefits in the design of an all-inclusive health resorts, Nigeria. *Front. Built Environ.* 9:1011759.

GREEN APPROACHES IN GREENHOUSE FARMING AS A COMPONENT OF SUSTAINABLE AGRICULTURAL PRODUCTION

Anastasiia Kovalova¹, Viacheslav Visianyi¹

*¹Kyiv National University of Construction and Architecture,
kovalova.an@knuba.edu.ua, v.vivsyanyi@knuba.edu.ua*

Modern green approaches implemented in greenhouse farming are aimed at improving resource efficiency and reducing environmental pressure. The study analyzes the main directions of greenhouse production ecologization, including energy-efficient technologies, precise microclimate control systems, integrated plant protection, and rational water resource management. It is demonstrated that the comprehensive implementation of these approaches forms the basis for the sustainable development of the modern agricultural sector.

Greenhouse farming is considered one of the most intensive forms of agricultural production due to its high consumption of energy, water resources, and plant protection products. In the context of increasing environmental challenges and the transition toward sustainable development models, the implementation of green technologies becomes particularly relevant, as they allow minimizing negative environmental impacts without reducing production efficiency.

The modern development of greenhouse farming is characterized by a gradual transition from traditional agricultural practices to integrated

technological systems combining energy efficiency, automation, and environmental safety. This transformation is driven not only by the need to increase crop productivity, but also by stricter requirements regarding rational resource consumption and the reduction of anthropogenic pressure on the environment. Under current conditions, greenhouse complexes are regarded as sophisticated engineering and biological systems whose operation requires continuous monitoring of energy, climatic, and technological processes [1].

One of the most relevant directions in greenhouse modernization is energy optimization. Maintaining the required temperature conditions during cold seasons is associated with considerable energy consumption; therefore, the implementation of alternative heat supply systems has become an important element of sustainable sector development. Modern greenhouse facilities increasingly utilize solar collectors, geothermal systems, bioenergy installations, and heat pumps capable of partially or fully covering the enterprise's energy demand [2]. The use of such technologies not only reduces fossil fuel consumption but also decreases greenhouse gas emissions, which is particularly important in the context of international environmental regulations and agricultural decarbonization strategies.

Alongside renewable energy sources, heat recovery systems also play a significant role. Their operation is based on the repeated utilization of thermal energy generated by ventilation and technological systems. As a result, heat losses are substantially reduced, the energy efficiency coefficient of the facility is improved, and a stable greenhouse microclimate is maintained [3]. The experience of modern European greenhouse complexes demonstrates that combining heat recovery technologies with automated control systems significantly decreases operational costs.

Another important component of sustainable greenhouse farming is the digitalization of production processes. Intelligent monitoring systems enable continuous control of microclimatic parameters and provide rapid responses to environmental changes. Modern sensor technologies allow real-time measurement of air temperature, humidity, illumination, carbon dioxide concentration, and substrate moisture levels [4]. The collected data are processed by automated software systems regulating ventilation, irrigation, heating, and artificial lighting.

The implementation of automated microclimate management contributes to the creation of optimal conditions for plant growth and development. Precise maintenance of environmental parameters increases photosynthetic efficiency, improves nutrient absorption, and reduces the risk of fungal diseases. Furthermore, automation significantly decreases irrational water and electricity consumption, positively affecting both the economic performance of greenhouse enterprises and their environmental sustainability [5].

The integration of artificial intelligence technologies and precision agriculture elements into greenhouse management systems is becoming

increasingly important. Modern software solutions are capable of predicting microclimatic changes, analyzing the physiological condition of plants, and automatically adapting cultivation regimes according to the requirements of specific crops. This approach ensures increased productivity while simultaneously reducing resource consumption, which fully corresponds to the contemporary principles of sustainable agricultural production [6].

Equally important is the implementation of digital microclimate management technologies. The use of sensor systems and automated environmental regulation algorithms ensures accurate control of temperature, humidity, and carbon dioxide concentration, thereby improving photosynthetic efficiency and overall crop productivity.

Special attention within green approaches is given to integrated plant protection systems. Their essence lies in reducing the application of chemical agents and transitioning to biological methods of pest management. The use of entomophages, pheromone traps, and agronomic techniques allows maintaining ecological balance within greenhouse agroecosystems.

Rational water resource management represents another key component of sustainable greenhouse production. Drip irrigation systems and water recycling technologies provide substantial reductions in water consumption, which is especially important under conditions of increasing freshwater scarcity in the agricultural sector.

Therefore, the implementation of green approaches in greenhouse farming represents an important direction for the modernization of contemporary agricultural production and a necessary condition for ensuring environmental safety. The use of energy-efficient technologies, automated microclimate control systems, resource-saving irrigation methods, and biological plant protection contributes to increasing greenhouse productivity while simultaneously reducing adverse environmental impacts. The integrated combination of technological and ecological solutions makes it possible to optimize the use of water, energy, and material resources while decreasing anthropogenic pressure on agroecosystems.

The conducted analysis demonstrates that modern greenhouse farming is gradually transforming into a high-tech sustainable system in which rational natural resource management, energy efficiency, and environmental responsibility become priority principles. Further development of the sector is associated with the wider implementation of innovative technologies, digital production management systems, and integrated ecological solutions capable of ensuring stable greenhouse production under current economic and climatic challenges.

REFERENCES

1. Hassanien R. H. E., Li M., Yin F. Advanced renewable-energy applications in agricultural greenhouses // *Renewable and Sustainable Energy Reviews*. 2021. Vol. 54. P. 989–1001. URL:

<https://journals.sagepub.com/doi/10.3233/JIFS-200618> (дата звернення: 10.05.2026).

2. Li H., Guo Y., Zhao H., Wang Y., Chow D. H. Towards automated greenhouse: a state of the art review on greenhouse monitoring methods and technologies based on internet of things // *Computers and Electronics in Agriculture*. 2021. Vol. 191. Article 106558. DOI: 10.1016/j.compag.2021.106558.

3. Maraveas C., Bartzanas T. Application of Internet of Things (IoT) for optimized greenhouse environments // *AgriEngineering*. 2021. Vol. 3, № 4. P. 954–970. DOI: 10.3390/agriengineering3040060.

4. Maraveas C., Bartzanas T. Application of Internet of Things (IoT) for optimized greenhouse environments // *AgriEngineering*. 2021. Vol. 3, № 4. P. 954–970. DOI: 10.3390/agriengineering3040060.

5. Mellit A., Benganem M., Herrak O., Messalaoui A. Design of a novel remote monitoring system for smart greenhouses using the Internet of Things and deep convolutional neural networks // *Energies*. 2021. Vol. 14, № 16. Article 5045. DOI: 10.3390/en14165045.

6. Karanisa T., Achour Y., Ouammi A., Sayadi S. Smart greenhouses as the path towards precision agriculture in the food-energy and water nexus: case study of Qatar // *Environment Systems and Decisions*. 2022. Vol. 42. P. 521–546. DOI: 10.1007/s10669-022-09862-2.

ANALYSIS IMPACT CEMENT PRODUCTION EMISSION SOURCES ON THE ENVIRONMENT

Yulia Lapshyna¹, Iryna Klimova¹, Olena Miroshnychenko¹

¹*Kyiv National University of Civil Engineering and Architecture,
lapshyna_ys@knuba.edu, uaklimova.iv@knuba.edu.ua, elenamiroshka@ukr.net*

Today, the cement industry is one of the key industries, playing an important role in many construction areas. Cement is widely used for the manufacture concrete and reinforced concrete products and structures, building mortars, the construction surface and underwater facilities, as well as in the road's construction, hydraulic structures and other infrastructure facilities.

The cement industry has a significant impact on the environment and human health. The operation the enterprises is accompanied by emissions significant pollutants amounts, such as nitrogen, carbon and sulfur oxides, carbon dioxide, greenhouse gases (methane and nitrous oxide), as well as particulate matter in the suspended solids form. This is problematic even with the installation modern treatment equipment.

Currently, the issue minimizing the harmful impact cement production on the environment is particularly relevant. Solving this problem involves the active

implementation the latest technologies for cleaning flue gases generated during cement production using coal.

The goal is to conduct a comprehensive analysis the impact production activities of PJSC "Yugcement" on the atmospheric air quality within the Mykolaiv region.

In the cement industry, three production methods are used, which differ in the technology preparing raw materials: wet, dry and combined.

The technological process choice depends on the characteristics the raw materials, such as their humidity, hardness, uniformity, etc.

The YuGcement branch operates using the wet clinker production technology. The main activity the enterprise is cement production. The production process includes several stages: a mining and crushing plant, a clinker roasting plant and a cement grinding plant. At the same time, clinker is a key raw material for the production of cement.

For the production clinker, the following basic raw materials are used: limestone, clay and loam, which are mined in a quarry. To improve the composition, cinders and kaolin are added as auxiliary components.

The main raw materials are limestone-shell rock, red-brown clay, loam and an iron-containing additive. Granulated blast furnace slag and gypsum stone are used as mineral additives in cement grinding.

The cement production process at the YuGcement branch includes the following stages:

1. Conducting overburden works. This stage begins with geological exploration using drilling machines to identify minerals needed for cement production.

2. Raw materials extraction. In limestone, clay and loam quarries, the extracted resources are loaded by excavators into trucks with a carrying capacity up to 27 tons. The raw materials are then transported to the production site for unloading and storage.

3. Preparation raw slurry. At this stage, averaged materials such as limestone, clay, kaolin, alumina cake and wet fly ash are sent to the receiving hopper the jaw crusher.

Materials such as clinker, gypsum and slag are fed through feeders to a 55 m long bucket conveyor (one for each mill) and then directly to the cement mills. This workshop has five cement mills with a diameter of 3.2 m and a length 15 m with a capacity of 45 t/h.[1]

To increase productivity and improve the fluidity the cement, a grinding intensifier propylene glycol is used, which is added via dosing pumps from on 16 m³ tank. To ensure cooling the cement, especially in the summer, the mills have been equipped with a water injection system into the second chamber from the company Estanda.

The finished cement is transported to storage silos by pneumatic screw pumps (five units) through a network of cement pipelines with a diameter of 250 mm.

Portland cement is stored in a silo warehouse. Bulk cement is shipped using railway transport (cement wagons) with a carrying capacity of 69-75 tons. Weighing such wagons is carried out on railway scales.

Cement bags placed on pallets are moved by belt conveyors and roller conveyors to the loaders. Pallets with finished products immediately after palletizing are sent to a buffer warehouse for temporary storage. Further shipment of finished pallets is carried out both in vehicles and in covered railway wagons using loaders with a load capacity of 2.5 tons. [2]

The cement plant creates a significant negative impact on all components the environment. For a comprehensive assessment this impact, a phased analysis a number key factors is proposed:

- The first stage involves determining the main sources hazardous substances that are formed during cement production and identifying the most active sources emissions.

- The second stage involves analyzing potentially polluting substances, focusing on the largest of them, which is based on calculations the total emissions from the most intensive sources.

- The third stage is aimed at assessing the financial costs the enterprise aimed at improving the state the environment and minimizing the consequences the most dangerous pollution.

- The fourth stage assesses the impact of individual pollutants on the environment.

- The fifth stage includes the identification areas greatest impact pollutants and the analysis risks associated with environmental threats.

- The final sixth stage substantiates the relationship between environmental pollution and the activities a specific cement company.[3]

Let us consider in detail the sources emissions within the structural elements the enterprise. Production shop: The first source emissions here is the rotary kiln, in particular its cold part. Pollutants are formed during the transportation and grinding raw materials. During the firing period, the clinker firing process is also added, which also contributes to the appearance of emissions.

The second source is the clinker cooler. In this case, the dust generated during cement production is released and removed during the cooling process hot clinker on the grate. At the same time, atmospheric air is used, which is heated by fans. Emission sources No. 3, No. 4, No. 5 are the raw material mixture silos No. 1-3. At this stage, environmental pollution occurs.

The following emission sources are associated with the operation the technological equipment of the dosing unit (No. 10, No. 12, No. 13). These include: conveyors, silos, silo feeders and their batchers. Pollution is formed during transportation, overloading of materials, as well as their mixing on the conveyor.

In the case a system serving clay processing equipment, coal ash and inorganic dust containing 20-70% silica may enter the ambient air. Considering emission

source No. 16, i.e. the raw meal elevator, it should be noted that it emits inorganic dust with a silica content below 20%, which is formed and discharged during the transportation of raw meal.[4,5]

Another source emissions is the combined warehouse, which emits inorganic dust with a silica content of 20-70%. As for emission source #75, namely clinker warehouse #1, dust generated during the cement production process enters the air. Similarly, source #13, represented by clinker warehouse #2, also emits dust from cement production.

Emission source No. 6 is a ground coal silo that provides dust and gas removal to the air. When it comes to a system that serves clay processing equipment, coal ash and inorganic dust containing 20-70% silicon dioxide can enter the air. Considering emission source No. 16, i.e. the raw meal elevator, it should be noted that it emits inorganic dust with a silicon dioxide content below 20%, which is formed and removed during the transportation of raw meal.[6]

Having analyzed the sources emissions, based on the gross emission indicators cement industry enterprises, it was clearly determined that the most polluting substance is inorganic dust, as well as significant amounts greenhouse gases, in particular carbon dioxide. This nature the impact necessitates the transition from traditional approaches to cement production to more ecologically oriented solutions.

In this direction, the concept green construction, which involves minimizing the negative impact on the environment during the entire life cycle building materials and objects, is of particular importance. The cement industry, as a basic component the construction sector, plays a key role in the implementation these principles.

- technological modernization production, which involves a gradual transition from a wet method clinker production to a more energy-efficient dry method, which allows to significantly reduce CO₂ emissions and fuel consumption; modern gas purification systems (electrical filters, bag filters) are additionally introduced, which ensure effective dust capture;

- reduction of the clinker factor cement: one of the key principles green construction is the use of alternative materials, such as granulated blast furnace slag, fly ash, pozzolan additives; it allows reducing the share clinker in cement, which directly affects the reduction greenhouse gas emissions;

- introduction resource-efficient and closed production cycles: the use waste from other industries as secondary raw materials (for example, industrial slag) corresponds to the principles the circular economy and reduces the burden on natural resources.

- optimization energy consumption and the use alternative fuels: the use biofuels, waste as an energy resource and the introduction energy-saving technologies contribute to reducing dependence on fossil fuels and reducing emissions.

Thus, the integration the principles green construction into the activities cement enterprises, in particular YuGcement PJSC, is a necessary condition for reducing the negative impact on atmospheric air and ensuring the sustainable development of the construction industry. The implementation these measures will not only improve the environmental safety of production, but will also contribute to the adaptation enterprises to modern environmental standards and requirements.

REFERENCES

1. Babich M., European standards for cement: implementation practice / AVCU "Ukrtsment". Kh.: PP "Unisoft", 2016. 72 p.
2. DSTU B EN 197-1:2015 (EN 197-1:2011, IDT). Cement. Part 1. Composition, technical conditions and conformity criteria for ordinary cements. Kyiv: Ministry of Regional Development of Ukraine, 2016. 53 p.
3. Kovaliv L.M. Environmental risks in cement production - Scientific Bulletin of the National Technical University of Ukraine.– Issue 24.1, 2014. - pp. 114-117.
4. Oplačko I. O. Problems and prospects of managing the activities of cement industry enterprises in modern conditions / Series "Economic Sciences", Issue 4(84). – 2018.
5. Romanets O. M. Ecology of cement production. URL:<https://www.heidelbergcement.ua/uk/hcu>
6. Uzunova G. D., Prykhodko V. Yu., Improving the methodology for comprehensive assessment of the impact of enterprises on the environment. Effective functioning of ecologically stable territories in the context of a sustainable development strategy: agroecological, social and economic aspects. – Poltava. 2018. – 37 p.

ANALYSIS OF SPECTRAL CHARACTERISTICS OF NOISE AT INDUSTRIAL ENTERPRISES

Maksymenko Artem¹, Klimova Iryna¹

*¹Kyiv National University of Construction and Architecture,
mksmnkart@gmail.com, iklimova@i.ua*

Different types of machines and mechanisms generate noise with characteristic frequency features, which determine the specifics of its distribution and impact on workers. The spectral composition of noise depends on the design of the equipment, operating mode, speed of rotation of mechanisms and features of the technological process. The study of the frequency characteristics of industrial noise is important for assessing acoustic working conditions, identifying the main sources of noise pollution and choosing effective noise protection methods.

Ventilation and compressor equipment is one of the main sources of constant industrial noise. Axial and radial fans are characterized by the generation of low-frequency noise in the bands 63, 125, 250 Hz, which is associated with the impeller rotation frequency and aerodynamic processes of air movement. Pronounced tonal components can also be observed in the spectrum, due to the rotation of the fan blades. Compressor installations are characterized by the presence of broadband noise in the frequency range 125-1000 Hz, which arises from the operation of piston or screw mechanisms and vibration of engineering communications. During the operation of large compressors, maximum noise levels are recorded in the range 250-500 Hz. Low-frequency noise from such equipment can spread through enclosing structures and can create acoustic pollution even in adjacent rooms.

One of the most common methods of reducing noise from ventilation equipment is the use of silencers in air ducts. Plate, tubular and chamber silencers allow you to effectively reduce noise levels in the high-frequency and medium-frequency ranges. Their action is based on the use of sound-absorbing materials that convert acoustic energy into heat. Mineral wool and fiberglass materials with a porous structure are considered the most effective. An important direction for reducing noise from ventilation equipment is the optimization of the aerodynamic characteristics of ventilation systems. Reducing the speed of air movement in air ducts, smooth transitions of sections, minimizing the number of sharp turns and eliminating local resistances allow you to reduce the level of flow turbulence and, accordingly, aerodynamic noise. Studies show that the most intense noise level occurs precisely in places where channels narrow and the direction of air movement changes.

Vibration isolation is widely used to combat low-frequency noise from ventilation equipment. Vibration isolation is performed by installing the equipment on special vibration isolation foundations or separate vibration supports or (in the case of suspended equipment) by suspending the equipment from the ceiling using vibration isolation hangers.

One of the modern directions of acoustic protection is the use of acoustic metamaterials and special filters for ventilation systems. Scientific studies describe the use of three-dimensional structures of periodic elements, which provide noise reduction in individual octave bands, especially in the high-frequency range of 4000-8000 Hz. Such designs allow to reduce the tonal components of fan noise without a significant increase in the aerodynamic resistance of the system [1].

Metalworking machines generate medium-frequency and high-frequency noise. Lathes are characterized by noise in the frequency range of 250-1000 Hz, which is generated due to spindle rotation, interaction of the cutting tool with metal, and bed vibrations. Milling machines generate noise with pronounced maxima in the 500-2000 Hz bands due to the intermittent cutting process and high speeds of milling cutters. Drilling machines create noise in the 500-4000 Hz

range, where high-frequency components associated with the friction of the drill against the metal surface dominate. Grinding machines are the most unfavourable in terms of spectral characteristics, the noise of which is concentrated in the high-frequency region of 2000-8000 Hz. Such frequencies arise due to the high speed of rotation of the abrasive wheel and the significant intensity of contact processes between the abrasive and the surface of the part. High-frequency noise is particularly dangerous, as this is the range that most often causes hearing loss in workers.

Reducing acoustic pollution from the operation of metalworking machines is achieved by increasing the rigidity of the machine tool design, optimizing cutting modes and using damping systems. Studies show that the correct choice of spindle speed and feed allows you to significantly reduce the noise level and avoid resonant vibrations.

An effective method of noise reduction is the optimization of cutting parameters. Reducing the cutting depth, optimizing the feed and speed of the tool rotation allow to minimize dynamic loads in the contact zone of the tool with the workpiece. This is especially true for milling processes, where the intermittent nature of cutting creates intense pulsed vibrations. Scientific studies show that the correct selection of cutting modes can significantly reduce both noise and tool wear [2].

A modern trend is the use of noise and vibration monitoring systems based on acoustic sensors and machine learning. Acoustic sensors allow you to detect the appearance of tool defects, increased wear or instability of the cutting process even before critical vibrations occur.

Maintenance of machine tools plays an important role. Bearing wear, guide clearances, insufficient lubrication, and damage to the cutting tool significantly increase the noise level. Regular equipment diagnostics, spindle condition monitoring, and timely tool replacement can maintain stable acoustic characteristics of machine tools [3].

Press equipment is characterized by broadband noise with short-term peak sound pressure values. During the operation of mechanical presses, the maximum noise energy is concentrated in the 500-4000 Hz bands. The impact of a hammer on a metal workpiece is accompanied by the appearance of high-frequency components up to 8000 Hz, as well as low-frequency vibrations of building structures. Stamping equipment is characterized by the presence of repetitive pulses, the frequency of which depends on the performance of the press. Impulse noise has a much greater harmful effect compared to constant noise of a similar level, since it is accompanied by sharp changes in sound pressure.

The most effective method of dealing with noise is to reduce it directly at the source. For press equipment, this is achieved by replacing impact processes with less noisy ones, optimizing the design of presses, and reducing dynamic loads. Scientific studies indicate that the transition from mechanical impact processes to hydraulic systems allows for a significant reduction in the level of impulse noise

and vibration.

An effective method is acoustic decoration of enclosing structures in production premises. In workshops with press equipment, sound reverberation plays a significant role, which increases the overall noise level. To reduce it, sound-absorbing wall and ceiling cladding is used. The best results are provided by porous materials with a high sound absorption coefficient in the mid- and high-frequency ranges. Perforated panels with mineral wool filling can significantly reduce the level of reflected noise.

The noise generated by pumping stations, refrigeration units and air conditioning systems is mostly of a constant nature. For pumping equipment, low-frequency bands of 63-250 Hz are typical, which is associated with the operation of electric motors and fluid pulsation in pipelines. Refrigeration units generate noise in the range of 125-1000 Hz and can also create tonal components due to the vibration of compressors. For air conditioning systems, a combination of aerodynamic and mechanical noise is characteristic, in the spectrum of which maxima are observed in the bands of 250-2000 Hz.

For pumping equipment, noise reduction is achieved by optimizing the design of impellers, reducing flow turbulence and balancing rotating elements. Studies show that proper shaft alignment and pump balancing can significantly reduce vibration and noise levels, especially in the low-frequency range. For refrigeration compressors, the use of multi-chamber silencers and improved refrigerant release systems is effective, which reduce pressure pulsations and tonal noise components [4].

Also, the main measures to reduce the noise level from engineering equipment include the use of vibration isolation. Pumps, compressors and external units of air conditioning systems are installed on elastic shock absorbers, vibration isolation supports or vibration isolation foundations. This allows you to reduce the transmission of structural noise to building structures. Flexible inserts between pumps, compressors and pipelines are especially effective, which prevent the spread of mechanical vibrations through the pipeline network [5].

Thus, different types of production equipment are characterized by individual spectral noise features, which determine the specifics of its impact on workers and the production environment. Detailed analysis of frequency characteristics allows to increase the effectiveness of acoustic control, optimize noise protection systems and ensure safe working conditions in modern production facilities.

REFERENCE

1. Trematerra A., Bevilacqua A., Iannace G. Noise Control in Air Mechanical Ventilation Systems with Three-Dimensional Metamaterials // Applied Sciences. 2023. Vol. 13, № 3. Article 1650.
2. Lipski J., Litak G., Rusinek R., Szabelski K., Teter A., Warmiński J., Zaleski K. Surface Quality of a Work Material Influence on Vibrations in a

Cutting Process // Journal of Sound and Vibration. 2002. Vol. 252, № 4. P. 729–737.

3. Józwik J., Wac-Włodarczyk A., Michałowska J., Kłoczko M. Monitoring of the Noise Emitted by Machine Tools in Industrial Conditions // Journal of Ecological Engineering. 2018. Vol. 19, № 1. P. 83–93.

4. An L., Shao S. Two-phase flow noise in refrigeration systems: Recent advances and state-of-the-art review // International Journal of Refrigeration. 2025. Vol. 178. P. 418–443.

5. Cao H.-F., Yang C.-J., Ma R.-L., Ni S.-W., Song Z.-K., Wang X., Chen Y.-X., Jiang C.-X. An Investigation of the Acoustic Enclosure of an Air Conditioning Compressor Using Response Surface Analysis and Topological Rigidity Optimization // Shock and Vibration. 2024. Vol. 2024. Article ID 1909530. 15 p.

ECONOMIC, ORGANIZATIONAL AND MANAGERIAL ASPECTS OF GREEN BUILDING (USING THE EXAMPLE OF AZERBAIJAN)

Afat Mammadhuseyn Mammadova

Baku, Azerbaijan University of Architecture and Construction

afat.mammadova@azmiu.edu.az

1. Introduction

Modern global challenges, including climate change and the depletion of natural resources, reinforce the need for a transition to sustainable development models. In this context, green construction is becoming one of the key areas of transformation of the construction industry. It involves the introduction of technologies and standards aimed at reducing the negative impact of buildings on the environment at all stages of their life cycle. Green building is one of the key areas of sustainable development aimed at reducing the negative impact of the construction sector on the environment. In the context of global climate change and rising energy consumption, buildings are becoming the most important object of environmental transformation.

In recent years, the transition to energy-efficient and environmentally sustainable construction practices has increasingly been considered as one of the priorities for achieving decarbonization goals, due to the significant role of the buildings sector in shaping global energy consumption and greenhouse gas emissions. A number of modern studies indicate that buildings can play an important role in the process of achieving carbon neutrality, with increased energy efficiency and the introduction of low-carbon technologies considered as key tools for reducing the carbon footprint [Jørgensen & Ma, 2025; Wang, 2025]. At the same time, it is emphasized that the decarbonization of the construction sector probably requires an integrated approach, including optimization of design solutions, the use of energy-efficient materials and technologies, as well as taking into account the life cycle of buildings, which can help reduce both operational

and embedded carbon emissions [Madadizadeh et al., 2024; Karimi et al., 2023]. In this context, the development of the principles of green building, it seems, can be considered as one of the significant tools for the implementation of the global climate agenda.

2. Economic aspects of green building.

Green building is associated with a number of economic advantages: lower operating costs due to energy efficiency; higher property values; increased investment attractiveness of projects; lower maintenance costs for buildings in the long term.

At the same time, there are limitations: high initial investments; limited access to finance; lack of economic incentives from the government.

In Azerbaijan, the development of green construction is linked to the implementation of the national sustainable development policy and integration into international environmental initiatives, but institutional and financial constraints remain.

Thus, the economic efficiency of green construction is manifested mainly in the long term.

The economic component of green building is characterized by a dual nature: high initial investments are offset by lower operating costs in the long term.

According to estimates by the International Finance Corporation [IFC], the introduction of energy-efficient technologies in buildings can lead to a reduction in energy consumption by an average of 20-40%, which, in turn, reduces operating costs by up to 30-37% and contributes to an increase in the market value of real estate. In Azerbaijan, the key economic constraints include limited access to green financing tools, high capital intensity of projects, and a relatively low level of development of tax incentives in this area. "Eco—friendly buildings are an investment opportunity that shows that the higher the quality and environmental friendliness of a project, the more profitable the investment can be." [44] At the same time, significant energy-saving potential remains due to the high proportion of energy consumption in buildings: according to the International Energy Agency [2023], this sector forms a significant part of final energy consumption, reaching about 37-39%. The implementation of the Building Energy Efficiency Directive [EPBD] is monitored by the European Commission through regular reports that assess national progress towards near-zero energy consumption buildings [nZEB].

3. Organizational aspects

The organizational aspects of green building are related to the need to change the structure of construction project management.

Effective implementation requires: interdisciplinary collaboration [architects, engineers, environmentalists]; implementation of international standards for sustainable construction; development of professional training.

An important role is played by international organizations such as the World Green Building Council - WorldGBC [2025-2027], which form global standards

for green building. The latest strategic program of the World Green Building Council [2025-2027] defines a global path for decarbonizing the environment, improving energy efficiency and promoting sustainable buildings.

In Azerbaijan, organizational constraints are manifested in: insufficient coordination between institutions; limited practice of applying international standards; weak integration of environmental requirements into construction processes.

The implementation of green building projects requires changes in the organizational structure and approaches:

- integration of interdisciplinary teams [architects, engineers, environmentalists];
- Implementation of international standards [for example, IFC, World Green Building Council]; [45]
- development of educational and training programs;
- Creating an institutional framework to support green initiatives.

Organizational barriers are often associated with insufficient coordination between project participants and lack of experience.

4. Management aspects

Green building management typically encompasses strategic planning, life cycle control of facilities, and the implementation of sustainable project management principles. At the same time, certain limitations remain in a number of countries related to the availability of financing and the effectiveness of monitoring mechanisms for the implementation of relevant initiatives. In this context, the development of a regulatory framework and the formation of so-called "road maps" focused on the principles of sustainable development and the introduction of environmentally oriented building standards is of particular importance [Zuo & Zhao, 2014; Darko & Chan, 2017].

The enforcement mechanism, which ensures compliance with established requirements and norms, deserves special attention. The scientific literature notes that its effectiveness may vary depending on the institutional environment, the level of development of the public administration system and the quality of control [World Bank, 2020; Organization for Economic Co-operation and Development, 2018]. At the same time, it is emphasized that existing restrictions are often associated not only with financial resources, but also with insufficient effectiveness of monitoring mechanisms and compliance with regulatory requirements, which may hinder the implementation of green building principles in practice [Darko & Chan, 2017].

Key management problems: weak environmental standards monitoring system; lack of uniform KPIs for assessing project sustainability; insufficient development of digital construction management tools.

Effective management of green construction involves: strategic planning and development of road maps; building lifecycle management; implementation of

principles of sustainable project management; monitoring and control of environmental indicators.

Effective risk management in construction, including financial, technological and regulatory aspects, is of particular importance in the context of the active phase of reconstruction and integrated development of the territories of Karabakh and Eastern Zangezur. In this regard, modern building codes and standards focused on sustainability and energy efficiency play an important role, which in international practice are divided into prescriptive and performance-based. While a prescriptive approach ensures ease of control and compliance by establishing clear requirements for materials and technologies, a results-based approach creates the conditions for the introduction of innovative solutions and improving the overall efficiency of buildings.

The year 2026 in Azerbaijan has been officially designated as the Year of Urban Planning and Architecture, reflecting the strategic priority of the state in the field of sustainable territorial development, restoration of liberated territories and the introduction of modern urban approaches.

An important confirmation of this course is the holding of the World Urban Forum WUF13 in Baku, one of the largest global events in the field of urbanism organized under the auspices of the United Nations [UN—Habitat], which will be held on May 17-22, 2026.

The forum will bring together tens of thousands of participants from different countries [about 25,000 people are expected] and will become a platform for discussing key issues of sustainable urban development, including affordable housing, climate sustainability, smart cities and effective urban governance.

The theme of the forum — "Housing the World: Safe and Resilient Cities and Communities" — reflects the global transition to urban development models focused on sustainability, inclusivity and security.

In addition, Azerbaijan plans to present at WUF13 its own experience in the restoration and integrated urban development of Karabakh and Eastern Zangezur, which underlines the practical importance of the forum for the exchange of international cases.

The holding of WUF13 in Baku reflects Azerbaijan's desire to integrate international best practices into national urban planning policy, especially in the context of post-war reconstruction of territories. An important element of this process is the participation of international development institutions such as IFC, which contribute to the introduction of green financing mechanisms, the development of energy-efficient construction standards and the reduction of operating costs of facilities. Thus, the synergy of national reconstruction priorities and international initiatives in the field of sustainable development forms the basis for creating a competitive, environmentally oriented and investment-attractive urban environment in Azerbaijan.

Environmental-friendly building codes and regulations continue to be developed and implemented abroad, which seek to raise standards for the design

and construction of buildings to a new level of sustainability and efficiency. Norms in construction aimed at ensuring the sustainability and energy efficiency of buildings are usually divided into two main types: prescriptive and performance-based, while in some cases a hybrid approach combining elements of both types is also used.

The prescriptive approach is a fast and well-regulated way to comply with building regulations based on the use of pre-established requirements for materials, technologies and structural elements, which ensures a high level of reliability and simplifies the control of compliance with established standards.

Results-based standards are designed to achieve specific results, not to meet prescribed requirements for individual building components. For example, results-based standards set a target energy consumption level and provide for the measurement and reporting of energy consumption to ensure that the completed building meets the target level [45]

5. Problems and prospects (using the example of Azerbaijan)

In Azerbaijan, the development of green construction is progressive: modern technologies aimed at improving energy efficiency and environmental sustainability of buildings are being actively introduced with the support of government initiatives; at the same time, the process is limited by insufficient funding, imperfect institutional environment and mechanisms for implementing green policy.[46] Despite the existence of initiatives and cooperation with international organizations, the following problems remain: gaps in project financing; insufficient monitoring of compliance with environmental standards; limited regulatory framework; lack of qualified personnel. Although green buildings are a relatively new phenomenon in Azerbaijan, the growing interest in environmental friendliness and energy efficiency, as well as government support, make this area one of the most promising in the country's construction sector. An important step in the development of green construction in Azerbaijan was the holding of the "Green Building Initiative in Azerbaijan" seminar in September 2024, organized by the State Committee for Urban Planning and Architecture of the Republic of Azerbaijan jointly with IFC. This event was aimed at discussing the implementation of sustainable building standards, the development of the institutional environment and the expansion of international cooperation in this field. As a member of the World Bank Group, IFC plans to strengthen cooperation with Azerbaijan in the coming years by supporting investments in key sectors of the economy. Special attention is paid to green finance, the construction of energy-efficient buildings and support for small and medium-sized businesses.

At the same time, the prospects are related to: the development of a "green" economy; the introduction of sustainable building standards; the implementation of pilot projects; integration into international environmental initiatives. [47]

6. Comparative analysis and international experience

The development of green construction in modern conditions is considered as one of the key factors for improving energy efficiency and ensuring sustainable

development of the national economy. In Azerbaijan, this sector is in its infancy and is characterized by the gradual introduction of energy-efficient technologies, environmentally friendly building materials and elements of renewable energy with a significant role of government initiatives.

However, for a deeper understanding of the existing problems, it is advisable to turn to a comparative analysis with developed countries. Comparison of Azerbaijan with the countries of the European Union shows significant differences in the level of energy efficiency of buildings. With a comparable share of buildings in the structure of final energy consumption, energy intensity in Azerbaijan remains significantly higher compared to EU countries, which is largely due to outdated building standards and insufficient pace of modernization of the existing stock. According to the European Commission, green financing mechanisms and mandatory energy efficiency standards are being actively implemented in the EU countries, which contributes to an accelerated transition to sustainable construction.

Thus, the revealed differences indicate that there is a significant potential for improving the energy efficiency of buildings in Azerbaijan. This, in turn, necessitates the improvement of the regulatory framework, the expansion of green financing tools and the activation of modernization processes of the existing building stock, which is an important condition for scaling green construction practices in the country.

7. Discussion

The results of the study show that the development of green construction in Azerbaijan is at the stage of formation. Despite integration into the global environmental agenda, the following limitations remain: gaps in financing; weak institutional coordination; insufficient enforcement; limited dissemination of energy efficiency technologies.

At the same time, there are positive trends, including the development of pilot projects and cooperation with international organizations.

8. Conclusion

Green building is an important tool for achieving sustainable development. Despite the existing economic and institutional barriers, its implementation provides long-term benefits for both the economy and the environment. For the successful development of this area, an integrated approach is needed, including financial support, management improvement and organizational infrastructure development.

Green building is an important tool for sustainable development, providing economic, environmental and social benefits.

To increase the effectiveness of its implementation in Azerbaijan, it is necessary to: expand the mechanisms of green financing; strengthen regulatory regulation; improve the quality of construction project management; and develop the institutional environment.

An integrated approach will significantly increase the energy efficiency of the construction sector and reduce the environmental burden. [46]

REFERENCES

1. International Energy Agency. Energy Efficiency in Azerbaijan. Paris, 2023.
2. International Finance Corporation. Green Building Market Transformation Program. Washington, 2023.
3. World Green Building Council. Global Status Report. London, 2022.
4. European Commission. Energy Performance of Buildings Directive. Brussels, 2023.
5. World Bank. Azerbaijan Energy Sector Review. Washington, 2023.
6. United Nations Environment Programme (UNEP). Global Status Report for Buildings and Construction. Nairobi, 2022.
7. Ministry of Energy of the Republic of Azerbaijan. Energy strategy and sustainable development. Baku, 2023.
8. Kubba, S. Green Construction Project Management and Cost Oversight. – Elsevier, 2010.
9. Yudelso, J. Green Building A to Z: Understanding the Language of Green Building. – New Society Publishers, 2007.
10. Yudelso, J. Reinventing Green Building. – New Society Publishers, 2016.
11. Hosey, L. The Shape of Green: Aesthetics, Ecology, and Design. – Island Press, 2012.
12. Kibert, C. J. Sustainable Construction: Green Building Design and Delivery. – Wiley, 2016.
13. Jørgensen, B. N., & Ma, Z. (2025). Energy efficiency and decarbonization strategies in buildings. *Applied Sciences*, 15(21).
14. Junhong Liu, Shufan Zhang, Minda Ma, Show all 5 authors, Bo Wang (2025). From Energy Efficiency to Carbon Neutrality: A GlobalBibliometric Review of Energy Conservation and EmissionReduction in Building Stock. *Buildings* 15(12)
15. Madadzadeh, A., Siddiqui, K., & Aliabadi, A. A. (2024). Review: The economics landscape for building decarbonization. *Sustainability*, 16(14), 6214.
16. Karimi, H., et al. (2023). Energy efficiency and environmental impacts of green buildings. *Energies*, 16(9).
17. Green building research—current status and future agenda: A review Zuo, J., & Zhao, Z.-Y. (2014). Green building research: Current status and future agenda. *Renewable and Sustainable Energy Reviews*, 30, 271–281. <https://doi.org/10.1016/j.rser.2013.10.021>
Review of barriers to green building adoption Darko, A., & Chan, A. P. C. (2017).

Review of barriers to green building adoption. Sustainable Development, 25(3), 167–179. <https://onlinelibrary.wiley.com/doi/abs/10.1002/sd.1651>

18. World Bank. (2020). Worldwide Governance Indicators. Washington, DC: Regulatory Enforcement and Inspections Toolkit (2018)

19. Chegut, A., Eichholtz, P., Kok, N. Supply, Demand and the Value of Green Buildings. – Urban Studies. 51(1):22-43

20. Bilotil, V. Green building as a direction of sustainable development: essence, tasks, principles, benefits, prospects– URL: http://nbuv.gov.ua/UJRN/Zp_2021_2_10.

21. World Green Building Council. The Business Case for Green Building. – 2013.

22. UNEP. Buildings and Climate Change: Summary for Decision-Makers. – 2020.

23. Solanki, A., Nayyar, A. (eds.) Green Building Management and Smart Automation. – IGI Global, 2020. <https://www.asau.ru/files/pdf/2166049.pdf>

24. Zaman, B., Sedera, D. Green Information Technology as Administrative innovation - Organizational factors for successful implementation: Literature Review https://www.researchgate.net/publication/305881125_Green_Information_Technology_as_Administrative_innovation_-_Organizational_factors_for_successful_implementation_Literature_Review

25. Tushar, W. et al. IoT for Green Building Management. https://www.researchgate.net/publication/325414824_IoT_for_Green_Building_Management– 2018.

26. Rutkowska, M., Sulich, A. The Green Management Towards a Green Industrial Revolution https://www.researchgate.net/publication/351885435_The_Green_Management_Towards_a_Green_Industrial_Revolution

27. Burdenko, E., Khasanova, A. Standards of Green Technologies in Construction. – Standards and quality journal, 2025.

28. STO NOSTROY 2.35.4-2011 "Green construction" https://www.abok.ru/for_spec/norm_doc/norm/sto-nostroy-2-35-4.pdf.

29. Astafyeva, N. Tendencies of “green” construction in the world and modern RUSSIA, 2019 <https://journals.eco-vector.com/2542-0151/article/view/51418/34880>

30. Lekareva, N. Green Standards and Development of Green Building. Urban planning and architecture. № 1 journal – 2011.

31. Li, Y., Neffke, F. Green building blocks reveal the complex anatomy of climate change mitigation technologies.

32. https://www.researchgate.net/publication/390639434_Green_building_blocks_reveal_the_complex_anatomy_of_climate_change_mitigation_technologies – 2025.

33. Aliyeva, R. Principles and Directions of Green Construction Development in Azerbaijan. *Construction economics and management, journal* – 2025.
34. Mammadova, A. Features and Advantages of Green Construction in Azerbaijan. – Conference: CV International correspondence scientific and practical conference «international scientific review of the problems and prospects of modern science and education» (Boston. USA. May 13-14, 2025) 2025.
35. Azerbaijan's State Committee on Urban Planning and Architecture signs MoU with IFC <https://www.trend.az/business/3951178.html>
36. Ahmed, A., et al. (2022) Assessment of renewable energy generation towards net-zero energy buildings *Energy and Buildings*, 256, 111755 <https://doi.org/10.1016/j.enbuild.2021.111755>
37. Renewable energy integration in buildings: A review *Energy Reports*, 2025 <https://doi.org/10.1016/j.egy.2025.10.046>
38. Darko, A., & Chan, A. P. C. (2017) Review of barriers to green building adoption *Sustainable Development*, 25(3), 167–179 <https://doi.org/10.1002/sd.1651>
39. Integrating renewable energy into building energy systems: a systematic review of strategies, barriers, and policy interfaces. *Discover Sustainability*, 2025 <https://doi.org/10.1007/s43621-025-01966-4>
40. Green construction for low-carbon cities: a review *Environmental Chemistry Letters*, 2023, 21, 1627–1657 <https://doi.org/10.1007/s10311-023-01657-0>
41. Zuo, J., & Zhao, Z.-Y. (2014) Green building research: current status and future agenda *Renewable and Sustainable Energy Reviews*, 30, 271–281 <https://doi.org/10.1016/j.rser.2013.10.021>
42. Advancing Net Zero Status Report 2023 <https://globalabc.org/resources/publications/worldgbc-advancing-net-zero-status-report-2023>
43. Bridging the Gap to Decarbonization: Evaluating Energy Renovation Performance and Compliance. Stegnar, G. (2025). *Energy Efficiency Centre, Jožef Stefan Institute. Energies* 2025, 18(5), 1146. <https://doi.org/10.3390/en18051146>
44. https://www.ifc.org/en/stories/2010/gb-business-case?utm_source=chatgpt.com
45. <https://www.wbdg.org/resources/green-building-standards-and-certification-systems>
46. Modern green technologies of safety and security in the field of architecture and construction applied in Azerbaijan in recent years, <https://voeninvestnik.ru/PDF/45ES625.pdf>
47. <https://media.az/society/goskomitet-i-ifc-prodvigayut-zelenye-innovacii-v-stroitelstve>

SUSTAINABLE SMART HOMES IN THE CONTEXT OF ENVIRONMENTAL SAFETY AND SUSTAINABLE DEVELOPMENT

Viktor Mozdolevskyi,

Kyiv National University of Construction and Architecture, mozdolevskyi_vo-2024@knuba.edu.ua

Contemporary global environmental challenges associated with climate change, depletion of natural resources, increasing waste generation, and ecosystem degradation necessitate the transformation of approaches to the organization of human living environments. One of the key sectors influencing the environment is the residential sector, which consumes a significant share of energy and natural resources and generates a substantial portion of anthropogenic pressure. In this context, the concept of sustainable smart homes, combining environmental principles with the capabilities of modern information and communication technologies (ICT), is becoming increasingly relevant.

From an ecological perspective, residential buildings represent complex technogenic-natural systems interacting with environmental components such as the atmosphere, hydrosphere, lithosphere, and biota. Traditional approaches to housing construction and operation often ignore these interconnections, resulting in excessive energy consumption, environmental pollution, and disruption of natural cycles. Therefore, the formation of an environmentally safe residential environment should be based on the principles of sustainable development, including resource conservation, waste minimization, the use of renewable energy sources, and the restoration of natural processes.

The concept of a sustainable smart home involves the integration of two complementary approaches: the ecological optimization of housing and the implementation of intelligent management technologies. On the one hand, this implies the creation of buildings with minimal environmental impact through the use of environmentally friendly materials, optimization of energy consumption, and implementation of closed-loop resource cycles. On the other hand, ICT provides opportunities for real-time monitoring, analysis, and management of environmental parameters within residential environments. Through the use of sensors, mobile applications, and voice assistants, users can remotely control their homes. Such technologies not only enhance comfort but also significantly reduce energy consumption, which is particularly important under current energy challenges in Ukraine [1].

Smart home technologies are part of the broader concept of a smart city. Smart City involves the implementation of digital technologies in transportation, housing and communal services, healthcare, education, governance systems, and public safety. This model is based on efficient resource utilization, process automation, and continuous interaction between authorities and citizens. E-governance plays an important role by ensuring accessibility of administrative

services and transparency in urban management. At the same time, the development of these technologies requires substantial investments, legislative improvements, and an adequate level of personal data protection. For Ukraine, the implementation of intelligent technologies is strategically important, as it contributes to infrastructure modernization, digital economy development, and improvement of citizens' quality of life [2].



Fig. 1. General concept of smart home technology in the context of the Sustainable Development Goals

From an environmental standpoint, particular importance is attached to the implementation of circular resource-use models that oppose the traditional linear model of “extraction – consumption – waste.” In sustainable smart homes, this is realized through systems for water collection and reuse, composting of organic waste, and the use of solar, geothermal, and other renewable energy sources. Such an approach reduces pressure on natural ecosystems and promotes the formation of closed ecological cycles [3].

Another important aspect is the selection of construction materials. The use of renewable, non-toxic, and recyclable materials reduces the environmental footprint of housing construction and operation. At the same time, modern technologies enable the development of materials with enhanced thermal insulation and energy-saving characteristics, contributing to reduced energy consumption and lower greenhouse gas emissions.

Information and communication technologies play a crucial role in ensuring the environmental efficiency of residential systems. Monitoring systems make it possible to track energy and water consumption, air pollution levels, temperature, and humidity, thereby creating conditions for optimizing resource use. The implementation of sensor networks and automated control systems ensures the

adaptation of building operations to external conditions and user needs, minimizing resource losses.

However, the implementation of ICT in the residential sector is accompanied by several environmental risks. In particular, the production of electronic devices involves the use of rare and toxic materials and leads to the generation of significant volumes of electronic waste. Moreover, the operation of smart systems requires additional energy resources, which may reduce the overall environmental benefits of their application. According to recent studies, the share of household electronics in global energy consumption is steadily increasing, placing additional pressure on energy systems and the environment.

In this context, it is essential to consider the entire life cycle of technologies — from raw material extraction and production to disposal or recycling. The transition to the principles of a circular economy, particularly the reuse of components and materials, makes it possible to reduce environmental risks and improve resource efficiency. The development of modular systems, which allow individual components to be upgraded without replacing the entire system, is also considered promising.

From an ecological perspective, humans constitute the central element of the “smart home – environment” system. The behavior of residents determines the level of resource consumption and the effectiveness of technology use. Therefore, an important direction is the formation of environmental awareness and responsible attitudes toward natural resources. Feedback technologies providing information on resource consumption contribute to increasing environmental awareness and encourage behavioral changes among users [4].

Special attention should also be paid to integrating residential systems into a broader environmental context at the community, city, and regional levels. Sustainable smart homes can become components of larger “smart city” systems that ensure efficient resource management, emission reduction, and improvement of the population’s quality of life. In this regard, coordination among different governance levels and integration of local solutions into broader environmental strategies are of particular importance.

In conclusion, the development of sustainable smart homes represents an important direction in the ecological transformation of the residential sector and the transition toward sustainable development. At the same time, achieving a real environmental effect is possible only through a comprehensive approach that considers not only technological capabilities but also environmental constraints, economic factors, and social aspects. Further research in this field should focus on the development of integrated management models for residential systems, assessment of their environmental efficiency, and implementation of innovative solutions ensuring a balance between human needs and environmental preservation.

REFERENCES

1. Riabchun, Y. V., Sereda, D. E., Kokhan, V. R., & Dolya, O. V. (2023). Opportunities and advantages of the Ukrainian smart home technology market. *Management of Development of Complex Systems*, 56, 181–187. <https://doi.org/10.32347/2412-9933.2023.56.181-187>
2. Strzelecki, A. (2024). Smart homes as catalysts for sustainable consumption. *Sustainability*, 16(11), Article 4676. <https://doi.org/10.3390/su16114676>
3. Li, W. (2025). Responsible smart home technology adoption: Exploring sustainability, privacy and ethical challenges. *Smart Cities*. <https://doi.org/10.1016/j.scs.2025.105692>
4. Komninos, N., Kakderi, C., Panori, A., & Tsarchopoulos, P. (2019). Smart city planning from an evolutionary perspective. *Journal of Urban Technology*, 26(2), 3–20. <https://doi.org/10.1080/10630732.2018.1485368>

ENERGY-EFFICIENT INDOOR CLIMATE CONTROL USING A VAV VENTILATION SYSTEM AND A GREEN WALL

Anna Moskvitina

*Kyiv National University of Construction and Architecture,
moskvitina.as@knuba.edu.ua*

Modern indoor climate control systems in spaces with dynamic changes in pollutant levels must account for the system's response time to changes in parameters. Changes in CO₂ levels and humidity in such facilities are a non-stationary stochastic process, which makes it difficult to obtain accurate statistical characteristics due to the probabilistic nature of the process and measurement errors. The use of green walls to reduce the load on the ventilation system during the workday requires the use of variable air volume (VAV) ventilation and air conditioning systems. The plant life cycle phases of “oxygen release” and “respiration/CO₂ release” also require the use of modern ventilation and air conditioning control systems to ensure the system remains energy-efficient and uses the necessary amount of air at any given moment according to demand. The aim of this work is to develop a comprehensive method for studying the dynamics of these changes and to implement an intelligent control system based on fuzzy logic to ensure comfort and energy efficiency [1].

For controlling cooling (air treatment in a central ventilation unit or central air conditioner), the application of “neurotechnology and fuzzy logic” control principles is a promising approach. The control criterion is a set of parameters that determine comfort for three components: people ($m = 2$) — highest priority; equipment ($m = 1$) — reliable equipment safety; and the room itself ($m = 3$) — compliance with the room's operating standards. The assessment is based on the discomfort index D_n , which integrates the effects of temperature, humidity, and

airflow velocity.

The advantage of a fuzzy logic controller (FLC) is the absence of the need for an exact mathematical model of the object and its resistance to changes in its parameters. It is proposed to use discomfort indices for system development. The combined effect of temperature and humidity on a person is evaluated using the formula:

$$D_n^{(1)} = 0,72_1 \cdot (t_{\text{dry}} - t_{\text{wet}}) + 40,6, \quad (1)$$

where t_{dry} — the dry-bulb temperature, °C; t_{wet} — is the wet-bulb temperature, °C.

The effect of the air flow velocity v_a is determined as:

$$D_n^{(2)} = 37,5 \cdot v_a + 66,25 \quad (2)$$

where v_a — the air mass flow velocity, m/s.

Table 1 presents the levels of discomfort for humans, determined by parameters (1) and (2), which account for the combined effect on the human body of the three main factors that determine the comfort of staying in a given room: temperature, humidity, and airflow velocity [2].

Table 1

Levels of discomfort for people

Discomfort index $D_n^{(1)}, D_n^{(2)}$	Ступінь дискомфорту
≤ 70	Комфортно
70 ... 75	Some people feel uncomfortable
75...80	50% of people feel uncomfortable
80... 85	Everyone feels uncomfortable
≥ 85	Intense discomfort

Given the difficulty of determining optimal parameters in the “people–equipment–premises” system in real time, the use of fuzzy logic is a promising approach. This approach allows for the use of fuzzy concepts and expert knowledge in decision-making.

Structure of the fuzzy inference system:

- input – analog signals for temperature, humidity, and air velocity;
- fuzzification – conversion of signals into input fuzzy variables;
- logical inference – formation of an output fuzzy variable (index or degree of discomfort) based on a rule base;
- defuzzification – formation of an analog signal for the actuators of the air conditioning system.

The synthesis of the fuzzy controller is based on maintaining the discomfort index within acceptable limits for each system component. Three main linguistic variables are used:

- temperature is determined based on the intersection of the “low,” “medium,” and “high” temperature ranges (conventionally 16 °C to 30 °C);

- air velocity for human comfort must be within the range $v_a=0.1\ldots0.5$;
- humidity is based on readings from a “wet-bulb” thermometer; due to its wide range of variation, it has more linguistic terms: from “very low” to “very high.”

To assess the generalized discomfort index, the weight and priority of local criteria are taken into account based on expert evaluations of the “people–equipment–premises” system.

$$D_{nj}^{(gen)} = \sum_{i=1}^3 \lambda_i \cdot D_{ni}^{(j)}, i = \overline{(1,3)}, j = (1,2), \quad (3)$$

here, $D_{ni}^{(j)}, i = \overline{(1,3)}$, denote the discomfort indices for people, equipment, and the room, respectively.

The output of the fuzzy logic controller is a control action on the refrigerant compressor, which is assigned the following terms: “large negative” (NB), “negative” (N), “zero” (ZE), ‘positive’ (P), “large positive” (PB). That is, under comfortable conditions, there is no control action, and the compressor operates at a set power. In the event of deviations from comfortable conditions, the fuzzy logic controller generates a control action to increase or decrease the compressor power until the negative disturbance of the room microclimate and the entire system as a whole is compensated. Table 2 presents the rule base of the fuzzy logic controller for maintaining the indoor microclimate.

Table 2

Rule base for a fuzzy logic controller

$\{t_{dry}, ^\circ\text{C};\}$ $\{v_a, \text{M/C}\}$	“Wet” bulb temperature, $^\circ\text{C}$					
	Very low (6-11)	Low (12-14)	Satisfactorily low (15-18)	Satisfactory (19-21)	High (22-25)	Very high (26-29)
Low $\{16 - 21;\}$ $\{0,1 - 0,2\}$	N	N	ZE	ZE	-	-
Medium $\{22 - 25;\}$ $\{0,21 - 0,4\}$	N	ZE	ZE	P	P	-
High $\{26 - 30;\}$ $\{0,41 - 0,5\}$	ZE	ZE	P	P	P	PB

The system, equipped with a FLC, continuously adjusts the microclimate parameters, reducing energy consumption by eliminating unnecessary actions in response to small deviations. The use of a generalized discomfort index allows for simultaneously meeting the needs of visitors and the operational requirements of the equipment. Despite its “coarser” control compared to PID controllers, the system is robust and effective under conditions of uncertainty. The proposed method allows for the identification of CO_2 and humidity changes with an accuracy of 10%.

REFERENCES

1. TRČKA, Marija; HENSEN, Jan LM. Overview of HVAC system simulation. Automation in construction, 2010, 19.2. P.93-99.
- 2 . Babak V.P., Khandets'kyi V.S., Shryufer E. Obrobka syhnaliv [Tekst]: pidruchnyk. K.:Lybid', 1999. – 496 s. {in Ukrainian}

PROSPECTS FOR THE USE OF CELLULOSE-CONTAINING FIBER WASTE AND GLASS WASTE AS COMPONENTS IN MIXTURES FOR 3D CONCRETE PRINTING

Maryna Sukhanevych¹, Olga Bondarenko¹, Dmytro Samchenko¹, Oles Lastivka¹, Oleksii Tsapko¹, Volodymyr Chakhoian¹

¹Kyiv National University of Construction and Architecture,
sukhanevych.mv@knuba.edu.ua

The construction industry is one of the largest sources of waste: in Ukraine alone, millions of tons of construction and industrial waste are generated annually, a significant portion of which consists of organic agricultural residues (stems of grains, flax, and corn) and glass processing waste [1].

3D concrete printing technology (3DCP) offers a unique opportunity to integrate this waste directly into the production chain: the waste becomes a functional component of the mixture, reducing material costs and the carbon footprint of construction [2,3].

Cellulose-containing materials (discrete fibers, micro- and nanocellulose) influence the rheology and structure formation of cementitious systems through micro-reinforcement, thixotropy, and the nucleation effect [4, 5]. After grinding, glass cullet acquires pozzolanic properties (powder < 0.14 mm) or can serve as a filler (sand 0.14–4 mm) [6,7,8]. The combined use of both groups of waste in 3DCP remains poorly studied, which determines the relevance of this research.

Three types of *cellulose-containing waste* (Table 1) were investigated for use in 3D printing:

- discrete natural fibers of corn (CF) and flax (FL) — initially ground to 10–15 mm, dried, and added in an amount of 1.5% above 100% of the component mass;

- organosolvent microcellulose — obtained from wheat, flax, and corn stalks by delignification with isobutyl alcohol and KOH in an autoclave (160°C / 240 min or 180°C/90 min) followed by thermochemical purification with CH₃COOH+H₂O₂ (70:30) at 97°C;

- nanocellulose — obtained from purified microcellulose by acid hydrolysis with 64% H₂SO₄ (v:w = 44:1, 20–60°C, 60 min) followed by centrifugation at 8000 rpm and ultrasonic homogenization at 24 kHz (UZDN-1200M); the product is a stable 1% gel.

Glass waste is generated during the production of glass products, during building demolition work, and in everyday life. Glass is virtually non-biodegradable, so its recycling in the construction industry is a priority area of the circular economy. Processing includes: collection and sorting by color and type, removal of metal and ceramic inclusions, washing, crushing, and fractionation.

For use in 3DCP, glass cullet (Table 2) should be used in two particle size fractions:

– glass powder (< 0.14 mm) — obtained by fine grinding in ball or vibratory mills. The amorphous structure of SiO₂ confers pozzolanic activity to the material: SiO₂(glass) + Ca(OH)₂ + H₂O → C-S-H.

Table 1

Comparative characteristics of organosolvent microcellulose and nanocellulose derived from plant waste

Parameter	Organosolvent cellulose	Nanocellulose (acid hydrolysis)
Raw materials	Wheat, flax, corn (stems, 2–5 mm)	Pre-cleaned cellulose
Delignification	Isobutyl alcohol + KOH; autoclave at 160°C for 240 minutes (hydrazine) or 180°C for 90 minutes (anthraquinone)	64% H ₂ SO ₄ ; v:w = 44:1; 20–60°C, 60 min; neutralization: 10-fold volume of water
Purification	5% KOH (30 min) + hot water; CH ₃ COOH+H ₂ O ₂ (70:30) at 97°C, 120 min	Centrifugation at 8,000 rpm (10 min); ultrasound at 24 kHz (UZDN-1200M); 1% gel
Particle size	µm (microfibers)	nm (nanocrystals/nanofibers)
Effect in 3DCP	Micro-reinforcement, early strength, water retention	Thixotropy, nano-reinforcement of the C-S=H matrix
Environmental friendliness	High (sulfate-free; alkali regeneration)	Needs to be neutralized H ₂ SO ₄

The degree of pozzolanic activity approaches that of Class F fly ash, but depends on the fineness: at a specific surface area > 400 m²/kg, the effect is comparable to that of metakaolin.

– Glass sand (0.14–4 mm) — obtained by grinding and screening. It is used as a partial substitute for natural sand in 3DCP mixtures up to 20% without significantly impairing rheology. It provides a decorative effect and reduces the consumption of natural resources.

Alkali-silica reaction (ASR). The main risk when adding glass to cement concrete is the reaction between the amorphous SiO₂ in the glass and the alkalis in the cement paste (Na₂O, K₂O), which can lead to the formation of a gel that expands when absorbing moisture and causes cracks in the structure.

- Measures to prevent the reaction from occurring include the following steps:
- the use of active mineral admixtures that bind $\text{Ca}(\text{OH})_2$ and lower the pH of the pore solution (microsilica, metakaolin, fly ash);
 - fine grinding of glass (< 0.14 mm), during which SiO_2 undergoes a pozzolanic reaction (a beneficial reaction) rather than ACR;
 - control of alkali content in cement ($< 0.6\%$ Na_2O -eq.).

The mechanism by which plant fibers influence the hydration processes of the Portland cement matrix is as follows:

1. micro-reinforcement—sealing microcracks in the early stage;
2. nucleation effect — the fiber surface acts as a center for C-S-H crystallization;
3. water retention — slowing down the diffusion of free water.

Table 2

**Classification of cullet waste by processing method
and potential in the 3DCP**

Type of waste	Size after crushing	Replacement in the 3D database	Main effect	ACR risk
Finely ground glass powder (< 0.14 mm)	$< 0,14$ mm	5–15% cement	Puzzolan activity, $\downarrow$ permeability	Low
Glass sand (0.14–4 mm)	0,14–4 mm	10–20% natural sand substitute	$\downarrow$ sand consumption, decorative effect	Moderate
Glass chippings (4–8 mm)	4–8 mm	5–10% decorative aggregate	Decorative surface, gloss	Moderate
Chopped glass fiber (< 0.14 mm, $L=6$ –20 mm)	$< 0,14$ mm (d)	0.5–1.5% reinforcing aggregate	$\uparrow$ crack resistance, $\uparrow$ impact strength	Low

Organosolvent microcellulose is a promising next step: its fibrous structure increases the mixture's thixotropy—the ability to be liquid when pumped and to solidify at rest (yield shear stress $t_0 = 0.5$ –2.5 kPa).

Nanocellulose (1% gel) has the potential to increase the density of C-S-H phases (similar to nanoclay) and is an environmentally friendly alternative to synthetic thickeners.

Glass cullet is a promising resource for 3D-printed concrete in two ways. First, as a pozzolanic mineral additive: finely ground glass powder (< 0.14 mm, specific surface area 400–600 m^2/kg) undergoes a pozzolanic reaction with $\text{Ca}(\text{OH})_2$ in the cement paste, forming additional C-S-H gels that densify the microstructure, reduce permeability, and enhance the chemical resistance of

concrete. Adding 5–15% glass powder instead of cement can reduce the binder's CO₂ footprint by 5–15%.

Second, as a fine aggregate: glass sand (0.14–4 mm) is close in particle size distribution to the requirements of 3DDB (maximum particle size not exceeding 4 mm). Replacing 10–20% of natural sand with glass sand reduces the consumption of natural resources and provides a decorative effect (transparency, surface gloss of the layers). To prevent ASR, it is recommended to combine glass sand with microsilica (5–10%) or metakaolin (5–10%).

An important advantage of glass powder for 3D printing is its stable chemical composition (unlike industrial waste such as fly ash), which simplifies the prediction of the mixture's properties and is essential for automated production. An additional benefit is the ability to adjust the surface color of 3DCP structures by varying the color of the glass aggregate.

Effective realization of the potential of both waste groups requires their organic integration into the 3DCP production cycle. The proposed *integration model* is presented in Table 3.

Table 3

Integrated model for the simultaneous use of cellulose-containing waste and cullet in the 3DCP cycle

Step	Cellulose-containing waste	Glass cullet
1. Collection and preparation	Wheat, flax, and corn stalks; particle size 2–5 mm	Color sorting; metal removal; washing
2. Processing	Organosolvent delignification → microcellulose; acid hydrolysis → nanocellulose (1% gel)	Grinding → screening: powder < 0.14 mm (pozzolan) or sand 0.14–4 mm
3. Quality control	Degree of polymerization, pH, gel concentration, suspension viscosity	Particle size distribution, alkali-silica reaction (ASR), impurity content
4. Entry into the 3D database	VK/VL 1.5% + nanocellulose 0.5–1% → early strength + thixotropy	Glass powder 5–15% as a cement substitute or sand 10–20%
5. Result	R1 +11.4%, R7 +6.5%; thixotropy; CO ₂ footprint of materials –5–10%	Recycling of cullet; ↓ cement or sand consumption; pozzolanic activity

The expected benefits of using waste materials are as follows:

- early strength will increase by 8–12% due to the addition of waste materials;
- the thixotropy of the mixture will improve due to the presence of nanocellulose;

- the pozzolanic activity of the glass powder will be accelerated, leading to a 5% reduction in CO₂ emissions;
- up to 15–20% of waste will be recycled in 1 m³ of the mixture.

Validation of this composition is the subject of the next stage of research.

The estimated environmental benefit for a typical 200 m² house is achieved through the recycling of 50–70 kg of cellulose-containing waste (0.3–0.5 ha of agricultural land) and 80–120 kg of cullet; a 10–18% reduction in the CO₂ footprint of materials; and a 15–25% reduction in the cost of aggregate and binder due to the partial replacement of primary materials with waste.

Conclusions. Organosolvent cellulose (isobutyl alcohol + KOH, 160–180°C, two-stage purification with CH₃COOH/H₂O₂) is a promising micro-reinforcing and thixotropic component for 3DCP mixtures. Nanocellulose (64% H₂SO₄, w:v = 44:1, 24 kHz ultrasound, 1% gel) is a promising nano-additive for nano-reinforcement of the CSH matrix and thixotropy.

Finely ground glass powder (< 0.14 mm, specific surface area 400–600 m²/kg) exhibits pozzolanic activity and can replace 5–15% of the cement in 3DCP without compromising the technological properties. A key requirement is control of ASR: combination with microsilica or metakaolin (5–10%) and grinding to a particle size below 0.14 mm.

Glass sand (0.14–4 mm) is suitable for replacing 10–20% of natural fine aggregate in 3DCP and serves as a decorative element on the structure's surface. The stable chemical composition of the glass simplifies the prediction of the mixture's rheological properties.

The proposed integration model for combining cellulose-containing waste and cullet in the 3DCP production cycle allows for the utilization of up to 15–20% of waste in 1 m³ of the mixture, with an expected reduction in the carbon footprint of 10–18% and a 15–25% reduction in material costs. Validation of the combined composition is the subject of further research.

REFERENCES

1. Ministry of Regional Development of Ukraine (2023). Assessment of Construction Waste Volumes Resulting from the Demolition of Construction Sites. Kyiv: Ministry of Regional Development.
2. Buswell R.A. et al. (2018). 3D printing using concrete extrusion: A roadmap for research. *Cement and Concrete Research*, 112, 37–49.
3. Rahul A.V. et al. (2019). 3D printable concrete: Mixture design and fresh properties. *Cement and Concrete Composites*, 97, 13–23.
4. Nechyporchuk O. et al. (2016). Production of cellulose nanofibrils: A review. *Industrial Crops and Products*, 93, 2–25.
5. Pickering K.L. et al. (2016). A review of natural fibre composites. *Composites Part A*, 83, 98–112.

6. Shao Y., Lefort T., Moras S., Rodriguez D. (2000). Studies on concrete containing ground waste glass. *Cement and Concrete Research*, 30, 91–100.
7. Wang H.Y. (2011). The properties of high-strength concrete using ground waste glass as fine aggregate. *Construction and Building Materials*, 25, 4286–4290.
8. Islam G.M.S., Rahman M.H., Kazi N. (2017). Waste glass powder as partial replacement of cement for sustainable concrete practice. *International Journal of Sustainable Built Environment*, 6, 37–44.

THE USE OF INDUSTRIAL CONSTRUCTION WASTE IN CONCRETE FOR 3D-PRINTED BUILDINGS

Maryna Sukhaneych¹, Oles Lastivka¹, Olga Bondarenko¹, Dmytro Samchenko¹, Oleksii Tsapko¹, Artem Smoglii¹

¹*Kyiv National University of Construction and Architecture,
sukhaneych.mv@knuba.edu.ua*

The widespread destruction of buildings resulting from armed aggression has led to the generation of hundreds of millions of tons of construction waste in Ukraine [1]. At the same time, the growing need for rapid and affordable housing reconstruction highlights the importance of applying advanced construction technologies, particularly 3D concrete printing (3DCP) [2, 3, 4]. This technology reduces labor costs by 50–80%, material waste by 40–60%, and construction time by 50–65% [5]. The combination of recycling construction and demolition waste as a substitute for aggregate in 3DCP introduces the concept of a closed-loop resource cycle, which aligns with the principles of the circular economy [6].

However, standard mixtures for 3DCP impose specific rheological requirements (open time, early strength, thixotropy), which complicates the direct use of concrete demolition waste (CDW) [7].

The aim of this study is to investigate the effect of two types of recycled concrete waste (DW and BW), agricultural by-products and superplasticizers on the properties of cementitious systems for 3DCP and to determine the optimal mix design.

Portland cement CEM II/B-S 42.5 R was used as the binder. Dnipro sand with a particle size modulus $M_k = 1.3$ served as the aggregate.

Recycled concrete waste was obtained from demolished buildings and structures using two technologies that differ in the type of fuel used during grinding:

- waste obtained using diesel fuel during grinding (DFW);
- waste obtained using biofuel during grinding (BFW).

Key difference: the fraction < 0.14 mm is 18.0% in DFW and 22.8% in BW, indicating a finer particle size distribution in BFW.

The following agricultural byproducts were used:

- corn waste fibers (CWF);
- flax waste fibers (LWF).

The chemical modifiers and plasticizers used in the mixtures were the superplasticizers Sika ViscoCrete-225 P (polycarboxylate ester) and Sika Plast 2410W in amounts of 0.5–1.5% of the cement mass.

The research was conducted in two stages. In the first stage, the influence of DS and BS (10–30% sand replacement) and CWF and LWF fibers (1.5%) on the properties of “cement–sand–waste” model systems was studied at a specified slump of 140 mm. In the second stage, 8 BFW-based mixtures with superplasticizers were optimized. The following parameters were monitored: water demand, slump (mm), cone penetration (mm—immediately, after 30 and 60 min), setting times (min), and compressive strength R1, R7, R28 (MPa).

The results of the model system tests are presented in Table 1. The control mixture is No. 1 (25% cement + 75% sand, 12.5% water, R1 = 12.3 MPa, R7 = 36.8 MPa, R28 = 56.6 MPa).

Table 1

Compositions and results of the “cement–sand–concrete demolition waste” model systems

№	Component content, wt. %							Cone spread, mm	Compressive strength at age, MPa		
	Cement	Sand	DFW	BFW	CWF	LWF	Water		1 day	7 days	28 days
1	25	75	—	—	—	—	12,5	140	12,3	36,8	56,6
2	25	65	10	—	—	—	13,5	140	11,1	35,2	54,2
3	25	55	20	—	—	—	14,25	140	9,8	34,1	52,5
4	25	45	30	—	—	—	15,0	140	8,0	32,6	50,2
5	25	55	—	20	—	—	13,0	140	10,9	34,9	53,7
6	25	45	—	30	—	—	14,0	140	9,7	33,8	52,0
7	25	75	—	—	1,5	—	12,5	140	13,7	39,2	60,3
8	25	75	—	—	—	1,5	12,5	140	12,9	38,5	59,2

The addition of concrete waste (CDW) increases water demand: by 10%—to 13.5%, by 20%—to 14.25%, and by 30%—to 15.0%. This leads to a decrease in early strength: R1 decreases from 12.3 to 8.0 MPa (–35%), R7 — from 36.8 to 32.6 MPa (–11%), R28- from 56,6 MPa to 50,2 MPa (–13%). Mechanism: the increased porosity of the residual cement paste on the surface of the aggregate particles absorbs free water from the mixture, increasing the effective W/C ratio.

Concrete waste (CDW), which has a finer particle size distribution (22.8% passing through 0.14 mm versus 18.0%), demonstrates a significantly smaller negative effect. With 20% BFW, water demand is only 13.0% (compared to 14.25% for FCM), R1 = 10.9 MPa, R7 = 34.9 MPa—a decrease of only 5.2% and 5.2%, respectively. At 30% BFW: water demand 14.0%, R7 = 33.8 MPa — a decrease in R7 of only 8.2% compared to 11.4% for the control.

The addition of 1.5% corn plant fibers (CWF) does not change water demand (12.5%) while increasing early strength: R1 = 13.7 MPa (+11.4% compared to the control), R7 = 39.2 MPa (+6.5%). The effect of flax fibers (LWF) on the mixture's properties is slightly smaller: R1 = 12.9 MPa (+4.9%), R7 = 38.5 MPa (+4.6%). Increased early strength is critically important for concrete mixtures used in 3D printing—it enhances the layers' self-supporting capacity.

Based on the results of the first stage of research, concrete waste (BFW and corn fiber (CWF) were selected as the most promising materials for further optimization. Eight mixtures with varying component contents and superplasticizers were tested. The results are presented in Table 2.

Table 2

Compositions and results of optimized concrete mixtures for 3D printing with superplasticizers

№	Component content, wt. %						Cone flow,		Set time, min	Compressive strength R28, MPa
	Cement	Sand	BFW	CWF	Plastis. V-225P, %	Plastis. P-2410W, %	0 min	60 min		
1	25	45	20	1,5	—	—	65	—	105	45,1
2	25	45	30	1,5	—	—	50	—	120	42,0
3	25	45	20	1,5	0,5	—	70	10	115	47,2
4 *	25	45	30	1,5	1,0	—	80	50	125	49,5
5	25	55	30	1,5	1,5	—	90	90	150	47,4
6	25	45	20	1,5	—	0,5	65	—	100	45,9
7	25	75	30	1,5	—	1,0	70	—	110	46,6
8	25	75	30	1,5	—	1,5	80	30	120	44,2

*- optimal composition

Mixture No. 1 (20% BFW) yields a cone penetration of 65 mm, but after 30 minutes, the flowability drops to 20 mm—the mixture becomes unsuitable for extrusion. Increasing the water content to 30% (mixture No. 2) reduces

workability to 50 mm and R28 strength to 42.0 MPa. Without a plasticizer, neither mixture meets the 3DCP requirements for maintaining workability.

The addition of 0.5% ViscoCrete-225 P superplasticizer (mixture No. 3) increases workability to 70 mm with slight retention (10 mm after 60 min). The optimal dosage of 1.0% (mixture No. 4, 30% water) provides a slump of 80 mm with a slump retention of 50 mm after 60 min, a setting time of 125 min, and the highest R28 = 49.5 MPa among all tested mixtures. A dosage of 1.5% (mixture No. 5) results in excessive slump (90 mm) and its complete retention—the mixture does not acquire the required thixotropy for self-supporting layers.

When dosing the superplasticizer Sika-Plast 2410W at 0.5% (mixture No. 6), the slump of 65 mm without retention is insufficient for 3DCP. The best result in the series is composition No. 7 (1.0%, 30% BFW): 70 mm with no retention after 60 min, setting time 110 min, R28 = 46.6 MPa. This additive is inferior to ViscoCrete-225 P in terms of effectiveness at the same dosage and waste content.

Thus, the optimal mix is No. 4: cement CEM II/B-S 42.5R — 25%, sand (Mk = 1.3) — 45%, BFW — 30%, CWF — 1.5%, Sika ViscoCrete-225 P — 1.0%. This mix meets all the technical requirements of 3DCP: slump ≥ 70 mm, slump retention after 60 min ≥ 30 –50 mm, setting time > 90 min, R28 > 40 MPa, while containing recycled waste and natural fibers.

Based on the results obtained, a conceptual model of a closed-loop resource cycle “Demolition → Recycling (BFW) → 3D Construction” was developed, integrating both phases of the research (Fig. 1).

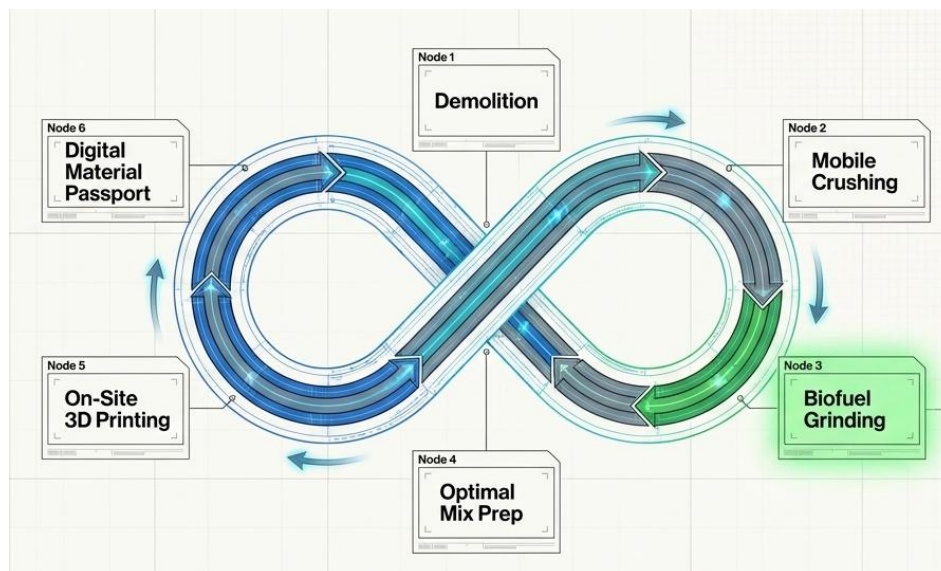


Fig. 1. Conceptual model of a closed-loop resource cycle for producing 3D concrete from construction demolition waste

A key difference from general approaches is the inclusion of a grinding operation for construction and demolition waste using biofuel (instead of traditional diesel fuel)—which produces a better particle size distribution of the

aggregate (a higher proportion of the <0.14 mm fraction) and improves compatibility with the cement system.

The cycle includes:

1. crushing with separate collection of fractions;
2. mobile crushing + grinding with biofuel;
3. quality control (particle size distribution, Cl^- , SO_4^{2-});
4. preparation of a mixture with optimal composition;
5. on-site 3D printing;
6. digital material passport.

Estimates for a typical 200 m² house: 40–45 tons of construction and demolition waste diverted from landfills; a 12–18% reduction in the carbon footprint of materials; a 30–40% reduction in aggregate costs.

Thus, construction waste (ground material with biofuel) outperforms natural aggregate in 3D concrete mixes due to its finer particle size distribution (22.8% vs. 18.0% passing through 0.14 mm): with 30% sand replacement, water demand is 1.0% lower, and the reduction in R28 is 8.2% versus 11.4% for conventional waste.

The Sika ViscoCrete-225 P superplasticizer is more effective than Sika Plast 2410W when used with waste materials: at a dosage of 1.0%, it maintains a slump of 50 mm after 60 minutes and achieves the highest R28 value of 49.5 MPa among the mixtures tested.

Optimal mix No. 4 (cement 25% + sand 45% + recycled aggregate 30% + corn waste fibers 1.5% + ViscoCrete-225 P 1.0%): slump 80 mm, setting time 125 min, R28 = 49.5 MPa — meets the technical requirements for 3D concrete and includes 30% recycled waste.

The proposed conceptual model of a closed-loop system involving the grinding of construction and demolition waste with biofuel is technically sound and suitable for implementation in the context of post-war infrastructure reconstruction in Ukraine.

REFERENCES

1. Ministry of Regional Development of Ukraine (2023). Assessment of Construction Waste Volumes Resulting from the Demolition of Construction Sites. Kyiv: Ministry of Regional Development. 48 pp.
2. Buswell R. A., Leal de Silva W. R., Jones S. Z., Dirrenberger J. (2018). 3D printing using concrete extrusion: A roadmap for research. *Cement and Concrete Research*, 112, 37–49. <https://doi.org/10.1016/j.cemconres.2018.05.006>
3. Rahul A. V., Santhanam M., Meena H., Ghani Z. (2019). 3D printable concrete: Mixture design and fresh properties. *Cement and Concrete Composites*, 97, 13–23.

4. Silva R. V., de Brito J., Dhir R. K. (2019). Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete. *Journal of Cleaner Production*, 183, 1–13.

5. Chen Y., Romero Rodriguez C., Li Z., Chen B., Copuroglu O., Schlangen E. (2021). Effect of different grade levels of calcined clays on fresh and hardened properties of limestone calcined clay cement mortar. *Cement and Concrete Composites*, 115, 103862.

6. Wang L., Tian Z., Ma G., Zhang M. (2020). Interlayer bonding improvement of 3D printed concrete with polymer modified mortar. *Cement and Concrete Composites*, 110, 103571.

7. European Environment Agency (2022). Construction and demolition waste: challenges and opportunities in a circular economy. EEA Report No 2/2022.

INFLUENCE OF BIOMASS CONCENTRATION ON FORMATION BIOFILM THICKNESS

Serhii Telyma

*Institute of Hydromechanics of the National Academy of Sciences of Ukraine,
sertelyma @ gmail . com*

Let us consider a complex mathematical model of biofilm which takes into account on the dynamic of biomass forming along the thickness of the biofilm and which is described by the following equations [1,2-4]:

1. The equation for substrate transport and its consumption within the biofilm :

$$\frac{\partial L}{\partial t} = D_L \frac{\partial^2 L}{\partial x^2} - \frac{\mu_{\max}}{Y} \frac{L X_L}{K_{mL} + L}, \quad (1)$$

with initial condition: at $t = 0$ $L = L_0$ (2)

and boundary conditions:

$$\text{at } x = 0 \quad -D_L \frac{dL}{dx} = K_L (L_e - L), \quad (3)$$

$$\text{at } x = \delta \quad \frac{dL}{dx} = 0. \quad (4)$$

where t is time, s,

x - spatial coordinate, m,

$L = L(x, t)$ - concentration of liquid contaminants in the biofilm , g/m³,

L_e - concentration of dissolved pollutants in wastewater, g/m³,

$X_L(x, t)$ – concentration of microorganisms in the biofilm , g/m³,

Y - mass of oxygen consumed per unit mass of consumed substrate ,

$\mu_{\max}$ - maximum recycling rate , S⁻¹,

K_{mL} - concentration of pollutants at which the conversion rate is 50% of the maximum, g/m³,

D_L - diffusion coefficient, m²/s,

K_L – organic pollution transfer coefficient, m/s.

2. The biomass balance equation:

$$\frac{\partial X_L}{\partial t} = \mu_{\max} \frac{L}{K_{mL} + L} X_L - bX_L^2, \quad (5)$$

with the initial condition: at $t=0$ $X_L = X_{L0}$

where b - experimental parameter, m³/g s,

3. The equation describing biofilm growth :

$$\frac{d\delta}{dt} = \frac{\mu_{\max}}{\rho_b} \int_0^{\delta} \frac{LX_L}{K_{mL} + L} dx - r\delta. \quad (6)$$

with the initial condition: at $t=0$ $\delta = \delta_0$

where δ –biofilm thickness, m,

r –intensity of substrate detachment from biofilm, S⁻¹,

ρ_b – biofilm density, .

The system of equations (1), (4)-(6) is solved with initial and boundary conditions (2)-(4), as well as (7):

$$L(0, x) = L_0, \quad X_L(0, x) = X_{L0}, \quad \delta(0) = \delta_0. \quad (7)$$

The functions sought are the concentrations $L(x, t)$, $X_L(x, t)$ and biofilm thickness $\delta(t)$.

That to solve the system of equations (1)-(7), the method of successive changes of stationary states was used, that is, at each moment of time t with appropriate film thickness δ concentration distribution $L(\delta)$ and $X_L(\delta)$ is found from solving the steady-state equations of substrate transport and biomass balance [5,7].

The system of equations (1)-(7) in dimensionless form will be as follows:

$$\frac{\partial \bar{L}}{\partial \bar{t}} = \frac{\partial^2 \bar{L}}{\partial \bar{x}^2} - \alpha \frac{\bar{L} \bar{X}_L}{\bar{K}_{mL} + \bar{L}}, \quad (8)$$

$$\text{at } \bar{x} = 0 \quad \frac{d\bar{L}}{d\bar{x}} = \beta(\bar{L} - 1), \quad (9)$$

$$\text{at } \bar{x} = \bar{\delta} \quad \frac{d\bar{L}}{d\bar{x}} = 0. \quad (10)$$

$$\frac{\partial \bar{X}_L}{\partial \bar{t}} = \gamma \frac{\bar{L}}{\bar{K}_{mL} + \bar{L}} \bar{X}_L - \bar{b} \bar{X}_L^2, \quad (11)$$

$$\text{with the initial condition: at } \bar{t} = 0 \quad \bar{X}_L = \bar{X}_{L0} \quad (12)$$

$$\frac{d\bar{\delta}}{d\bar{t}} = \lambda \int_0^{\bar{\delta}} \frac{\bar{L}\bar{X}_L}{\bar{K}_{mL} + \bar{L}} d\bar{x} - \bar{r}\bar{\delta} \quad (13)$$

$$\text{with initial condition: at } \bar{t} = 0 \quad \bar{\delta} = 1. \quad (14)$$

$$\text{where } \bar{L} = \frac{L}{L_e}, \bar{X}_L = \frac{X_L}{X_{L0}}, \bar{K}_{mL} = \frac{K_{mL}}{L_e}, \bar{L}_0 = \frac{L_0}{L_e}, \bar{x} = \frac{x}{\delta_0}, \bar{t} = \frac{D_L}{\delta_0^2} t,$$

$$\begin{aligned} \bar{\delta} &= \frac{\delta}{\delta_0}, \quad \alpha = \frac{\mu_{\max} \delta_0^2 X_{L0}}{Y D_L L_e}, \quad \beta = \frac{K_L \delta_0}{D_L}, \quad \gamma = \frac{\mu_{\max} \delta_0^2}{D_L}, \\ \lambda &= \frac{\mu_{\max} \delta_0^2 X_{L0}}{D_L \rho_b}, \quad \bar{b} = \frac{b \delta_0^2 X_{L0}}{D_L}, \quad \bar{r} = \frac{r \delta_0^2}{D_L}. \end{aligned} \quad (15)$$

To take into account the influence of biomass on the thickness of the biofilm we consider the boundary value problem (8)-(14) which takes the following form:

$$\frac{\partial^2 L}{\partial x^2} - \alpha \frac{L X_L}{K_{mL} + L} = 0, \quad (16)$$

$$\text{at } x=0 \quad \frac{dL}{dx} = \beta(L-1), \quad (17)$$

$$\text{at } x=\delta \quad \frac{dL}{dx} = 0. \quad (18)$$

$$\gamma \frac{L}{K_{mL} + L} - b X_L = 0, \quad (19)$$

$$\text{with initial condition: at } t=0 \quad X_L = X_{L0} \quad (20)$$

$$\frac{d\delta}{dt} = \lambda F(\delta) - r\delta \quad (21)$$

$$F(\delta) = \int_0^{\delta} \frac{L X_L}{K_{mL} + L} dx$$

$$\text{with the initial condition: at } t=0 \quad \delta = 1 \quad (22)$$

From the biomass balance equation (19) we find the relationship between the desired functions $L(x, t)$ and $X_L(x, t)$

$$X_L = \frac{\gamma}{b} \frac{L}{K_{mL} + L}, \quad (23)$$

It is obvious that the concentration distribution functions L and X_L there are also functions (through $\alpha = \frac{\mu_{\max} \delta_0^2 X_{L0}}{Y D_L L_e}$ and $\beta = \frac{K_L \delta_0}{D_L}$) from the thickness of the biofilm, i.e., $L = L(x, \delta)$ and $X_L = X_L(x, \delta)$.

At this the following boundary value problem was solved [1,3,8]:
equation of substrate transport and its consumption within the biofilm taking into account the biomass balance:

$$\frac{\partial^2 L}{\partial x^2} - \alpha_1 \left(\frac{L}{K_{mL} + L} \right)^2 = 0, \quad (24)$$

where

$$\alpha_1 = \frac{\mu_{\max}^2 \delta_0^2}{b Y D_L L_e}$$

$$\text{at } x=0 \quad \frac{dL}{dx} = \beta(L-1), \quad (25)$$

$$\text{at } x=\delta \quad \frac{dL}{dx} = 0. \quad (26)$$

and the equation describing biofilm growth :

$$\frac{d\delta}{dt} = \lambda F(\delta) - r\delta \quad (27)$$

$$\text{where } F(\delta) = \frac{\gamma}{b} \int_0^\delta \left(\frac{L}{K_{mL} + L} \right)^2 dx$$

$$\text{with the initial condition: at } t=0, \delta=1 \quad (28)$$

It is obvious that the solution of equation (24) of substrate transport and its consumption within the biofilm with the corresponding biomass balance does not depend on the parameter X_{L0} .

The boundary value problem (24)-(28) was solved using the finite difference method.

Below are graphs of changes in biofilm thickness over time at different parameter values. $r = 0.005-0.030 \text{ h}^{-1}$ and $X_{L0} = 18000 \text{ g/m}^3$. The graphs are plotted with and without biomass component in general balance equation..

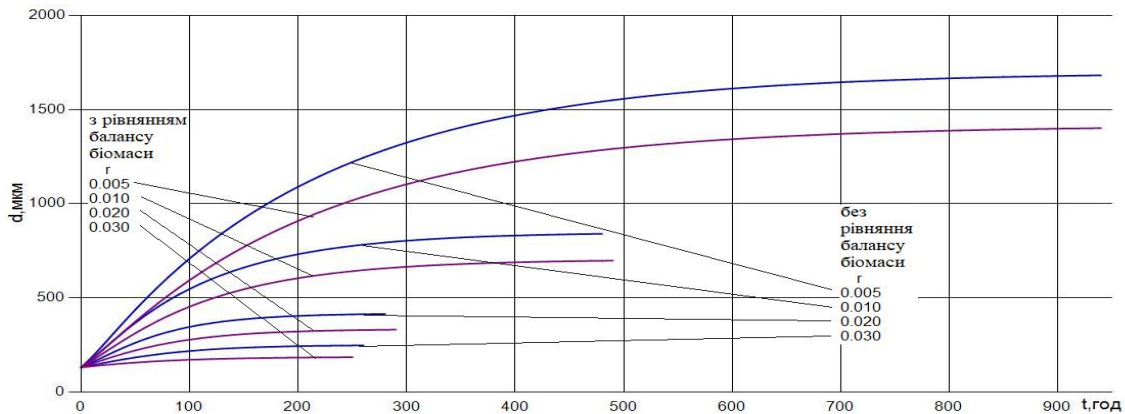


Fig. 1. Change in biofilm thickness over time at $r = 0.005 \div 0.030 \frac{1}{\text{год}}$ and

$$X_{L0} = 18000 \frac{\text{г}}{\text{м}^3}$$

As shown by the calculation data and the constructed graphs the influence of biomass concentration significantly affects on the thickness of the biofilm. Taking into account the biomass balance component reduces the thickness of the biofilm at an intensity of detachment of more than 0.01 h^{-1} to optimal values of less than $500 \text{ }\mu\text{m}$ and thus at the stage of design and operation of treatment facilities there is an opportunity to plan different modes and regulate the treatment process and increase the efficiency of bioreactors based on predictive calculations and modeling.

REFERENCES

1. Henze M., M van Loosdrecht M.E, Ekama G.A, Brdjanovic D. (2008). Biological Wastewater Treatment. IWA Publishing, London, 511p.
2. Moira Alvi et al . (2023). Deep learning in wastewater treatment: a critical review. Water Research, vol.245.pp.1-15.
3. Boltz J., Morgenroth C., Dipankar S. (2010). Mathematical modeling of biofilms and biofilm reactors. Water Science and Technology, vol.62(8). pp.1821-1836.
4. Levandowsky Z., Beynal H. (2014). Fundamentals of biofilm research. CRC Press. 157 p.
5. Elenter D., Milferstedt K., Zhang W., Hausner M., Morgenroth E. (2007). Influence of detachment on substrate removal and microbial ecology in a heterotrophic / autotrophic biofilm. Water Res., 41. pp. 4657-4671.
6. Telyma S.V. (2025). On the formation of the structure of a fixed biocenosis In bioreactors at wastewater treatment. Materials of 1Y International scientific and practical conference “Green Construction” .Kyiv , KNUBA, 14-15 of May 2025. pp.292-297.
7. Laspidou C. S. , Rittman B. F. (2004) . Modeling the development of biofilm density including active bacteria , inert biomass and extracellular polymer substances . Water Research , vol.38 . pp .3349-3361 .
8. Ohi Leon A., Horn H., Hemper DC . (2004). Behavior of biofilm systems under varying hydrodynamic conditions. Water Science and Technology. vol.49, no.11. IWA Publishing. pp.345-351 .

ASSESSMENT OF THE SOLAR ENERGY POTENTIAL OF KIROVOHRAD REGION FOR IMPROVING THE ENERGY EFFICIENCY OF CONSTRUCTION PROJECTS

Mariia Tyemchenko

*Ivano-Frankivsk National Technical University of Oil and Gas,
mariia.tiemchenko-ekom251@nunge.edu.ua*

The energy efficiency of construction projects is an important component of green building and the sustainable development of modern territories. In the

context of rising costs of traditional energy resources, the use of renewable energy sources, particularly solar energy, is becoming one of the most effective ways to reduce building energy consumption.

The purpose of this article is to assess the solar energy potential of Kirovohrad Oblast and Kropyvnytskyi in order to substantiate the feasibility of implementing solar photovoltaic systems in construction projects within the region.

The study was conducted based on data from the international platform Global Solar Atlas [1]. The following key indicators were analyzed: photovoltaic power potential (PVOUT), direct normal irradiation (DNI), global horizontal irradiation (GHI), diffuse irradiation (DIF), global tilted irradiation (GTI), the optimal tilt angle of photovoltaic modules (OPTA), and air temperature. A spatial analysis of cartographic information was carried out to identify the most promising areas of the region.

Results and discussion. The solar energy indicators of Kirovohrad Oblast are presented in Table 1.

Table 1

Helioenergetic Characteristics of Kirovohrad Oblast (Average Daily Values)

Indicator	Value
Specific photovoltaic power output (PVOUT), $\text{kBt} \cdot \text{год} / \text{kBтп}$	3.30 – 3.42
Direct normal irradiation (DNI), $\text{kBт} \cdot \text{год} / \text{м}^2$	3.22 – 3.42
Global horizontal irradiation (GHI), $\text{kBт} \cdot \text{год} / \text{м}^2$	3.39 – 3.52
Diffuse horizontal irradiation (DIF), $\text{kBт} \cdot \text{год} / \text{м}^2$	1.52 – 1.62
Global tilted irradiation (GTI), $\text{kBт} \cdot \text{год} / \text{м}^2$	3.96 – 4.12
Optimum tilt of PV modules (OPTA), °	34 – 36
Air temperature, °C	8.9 – 10.1
Terrain elevation (ELE), м	-

The average daily photovoltaic power output (PVOUT) is 3.30–3.42 kWh/kWp, the global horizontal irradiation (GHI) is 3.39–3.52 kWh/m², and the global tilted irradiation (GTI) is 3.96–4.12 kWh/m².

The spatial distribution of global horizontal irradiation (GHI) is presented in Figure 1.



Fig. 1. Global Horizontal Irradiation (GHI) of Kirovohrad Oblast

According to the results of the spatial analysis, 97.9% of the oblast's territory has a GHI value greater than 3.40 kWh/m^2 . The annual GHI value across most of the territory is approximately 1300 kWh/m^2 .

The distribution of global tilted irradiation (GTI) and the optimal tilt angle of the modules also indicate the high suitability of the territory. 80% of the oblast's area has a GTI value exceeding 4 kWh/m^2 .

The solar energy indicators of the city of Kropyvnytskyi are presented in Table 2.

Table 2

Helioenergetic Characteristics of the City of Kropyvnytskyi (Average Daily Values)

Indicator	Value
Specific photovoltaic power output (PVOUT), кВт*год/кВтп	3.34 – 3.37
Direct normal irradiation (DNI), кВт*год/м^2	3.32 – 3.34
Global horizontal irradiation (GHI), кВт*год/м^2	3.44 – 3.45
Diffuse horizontal irradiation (DIF), кВт*год/м^2	1.58 – 1.58
Global tilted irradiation (GTI), кВт*год/м^2	4.02 – 4.03
Optimum tilt of PV modules (OPTA), °	35 – 36
Air temperature, °C	9.6 – 9.8

The city of Kropyvnytskyi has slightly higher indicators compared to the oblast average: GHI is $3.44\text{--}3.45 \text{ kWh/m}^2$, GTI is $4.02\text{--}4.03 \text{ kWh/m}^2$, and PVOUT is $3.34\text{--}3.37 \text{ kWh/kWp}$.

The spatial distribution of global horizontal irradiation for the city of Kropyvnytskyi is presented in Figure 2.

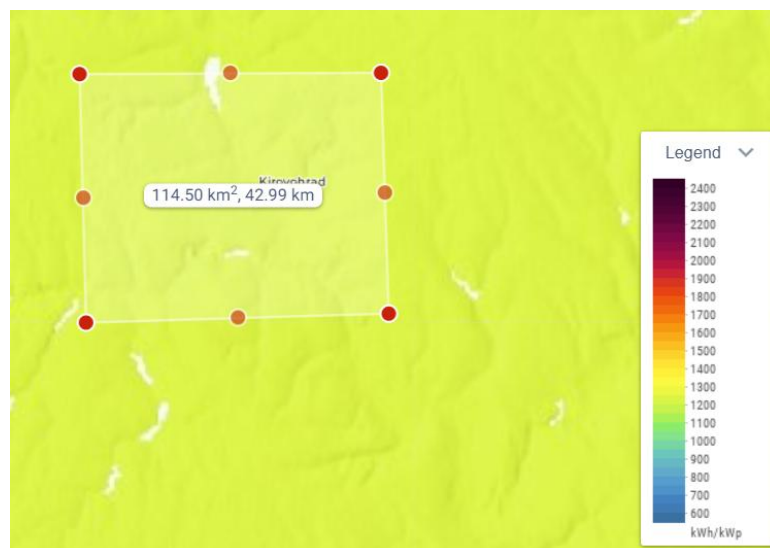


Fig. 2. Global Horizontal Irradiation (GHI) of the city of Kropyvnytskyi



Fig. 3. Map of the city of Kropyvnytskyi

The elevation of the city's terrain ranges from 106 to 183 m, which is a favorable factor for the installation of solar panels.

The obtained results (Tables 1, 2 and Figures 1–3) confirm the high solar potential of Kirovohrad Oblast. The integration of solar photovoltaic systems into construction projects will significantly improve building energy efficiency, reduce the consumption of conventional energy resources, and decrease the carbon footprint. Such implementation complies with the current legislation of Ukraine [2] and state building regulations on energy efficiency [3].

Particularly promising is the use of solar energy in new construction and the reconstruction of facilities in the central and southern parts of the oblast.

Conclusions. Kirovohrad Oblast has a high solar energy potential (annual GHI of approximately 1300 kWh/m²), which significantly exceeds the minimum feasibility threshold (1100 kWh/m²). More than 97% of the oblast's territory and

almost the entire area of the city of Kropyvnytskyi are suitable for the efficient use of solar panels.

The integration of solar technologies into construction projects in the region is a promising direction for improving their energy efficiency.

REFERENCES

1. Global Solar Atlas [Electronic resource]. – Access mode: <https://globalsolaratlas.info>
2. Law of Ukraine “On Alternative Energy Sources” dated 20.02.2003 No. 555-IV.
3. DBN V.2.5-56:2014 Engineering Equipment of Buildings and Structures. Power Supply Systems.

SMART HOMES AND NEXT-GENERATION SHELTERS UNDER CONDITIONS OF ENVIRONMENTAL SUSTAINABILITY

Olha Chencheva,

*Kremenchuk Mykhailo Ostrohradskyi National University,
chenchevaolga@gmail.com*

The modern world faces large-scale environmental, energy, and security challenges. Climate change, urbanization, resource shortages, and military threats require new approaches to the formation of residential and protective infrastructure. This issue has become particularly relevant for Ukraine under wartime conditions, when population safety, energy independence, and infrastructure resilience have acquired strategic importance. Under such circumstances, smart homes and next-generation shelters, combining advanced digital technologies, autonomy, energy efficiency, and principles of sustainable development, become increasingly significant as the foundation of the “Fortress Country” concept [1].

This concept acquires particular importance in the context of modern military and technological threats. Its primary idea is the formation of resilient state infrastructure capable of ensuring public safety even during prolonged crisis situations. Within this framework, a key role is assigned to the development of a network of autonomous next-generation shelters integrated into the “smart city” system and equipped with smart technologies. Such facilities must provide autonomous power supply, air purification, water supply, digital monitoring, and communication systems. The combination of energy efficiency principles, environmental sustainability, and advanced technologies makes it possible to create adaptive security infrastructure that meets the requirements of civil protection and the strategic objectives of Ukraine’s post-war modernization [2].

The concept of a smart home is based on the use of automated management systems controlling lighting, heating, ventilation, water supply, and security

systems. These solutions are founded on the technologies of the Internet of Things (IoT), sensor networks, monitoring systems, and elements of artificial intelligence. Through automation, buildings can adapt to residents' needs, regulate resource consumption, and minimize energy losses. For example, smart systems automatically switch off lighting in empty rooms, control temperature, or regulate ventilation depending on the number of occupants [3].

An important direction in smart home development is the use of renewable energy sources. Solar panels, heat pumps, energy storage systems, and heat recovery technologies ensure the energy autonomy of buildings and reduce dependence on centralized networks. For Ukraine, this is particularly important under conditions of damaged energy infrastructure and unstable power supply. Furthermore, the use of environmentally friendly materials and modern thermal insulation structures contributes to reducing heat losses and greenhouse gas emissions [4].

Particular attention today is focused on the development of next-generation shelters. Recent events have demonstrated that traditional protective structures often fail to meet modern requirements regarding safety, autonomy, and the long-term accommodation of people. New shelters should function not only as temporary protective spaces but also as multifunctional facilities capable of ensuring human life support during prolonged emergencies [5].



Fig. 1. Concept of modern smart shelters with internal environmental parameter control

One of the key characteristics of a modern shelter is autonomy. In the event of emergency power outages, the facility must have backup energy sources such as batteries, generators, solar panels, and energy storage systems. This ensures the uninterrupted operation of lighting, ventilation, communication, and other critically important systems. The use of alternative energy sources not only increases the level of safety but also complies with the principles of environmental sustainability.

Equally important are air purification and ventilation systems. Next-generation shelters are equipped with automated microclimate control systems that monitor temperature, humidity, oxygen levels, and concentrations of harmful substances. Intelligent systems can automatically regulate ventilation depending on the number of occupants and external conditions. This is especially important in cases of prolonged stays in enclosed spaces.

Another essential component of modern shelters is autonomous water supply and resource-saving systems. Water storage tanks, purification systems, and resource reuse technologies enable life support even in the absence of external infrastructure. Some projects also implement rainwater collection systems and circular economy technologies, contributing to the reduction of environmental impact.

Smart monitoring and warning technologies also play a significant role. The integration of shelters into the digital “smart city” system enables centralized monitoring of technical conditions, coordination of evacuation procedures, and оперативне informing of the population about threats. The use of mobile applications, geoinformation platforms, and automated management systems significantly improves the efficiency of emergency response.

A particularly promising direction is the development of modular autonomous shelters that can be rapidly installed near residential buildings, educational institutions, or critical infrastructure facilities. Such structures are equipped with autonomous power supply systems, ventilation, air purification, and digital control technologies. The modular principle ensures mobility, rapid installation, and adaptability to different operational conditions.

For Ukraine, the development of smart homes and next-generation shelters is of strategic importance. The restoration of infrastructure after destruction requires the implementation of modern energy-efficient and safe solutions. The integration of smart technologies, autonomous life-support systems, and renewable energy will make it possible to establish a new level of civil protection and ensure urban resilience to modern challenges.

Thus, smart homes and next-generation shelters are becoming an important component of an environmentally sustainable and secure environment. They combine energy efficiency, autonomy, digital technologies, and a high level of public protection. In the future, such structures may become the basis for the modernization of urban infrastructure and the formation of a safe living environment under conditions of global crises and military threats.

REFERENCES

1. Koval M. V., Koval V. V., Kotsiuruba V. I., Bilyk A. S. Organizational and technical principles for constructing an engineering protection system for critical energy infrastructure facilities of Ukraine // Science and Defense. 2022. No. 3. P. 11–16. DOI: 10.33099/2618-1614-2022-20-3-4-11-16.
2. Wang L., Zhao H., Li X. Sustainable underground infrastructure and smart shelter design in resilient cities // Tunnelling and Underground Space Technology. 2023. Vol. 140. DOI: 10.1016/j.tust.2023.105321.
3. Li W. Responsible smart home technology adoption: exploring sustainability, privacy and ethical challenges // Smart Cities. 2025. DOI: 10.1016/j.scs.2025.105692.

4. Riabchun Yu. V., Sereda D. E., Kokhan V. R., Dolya O. V. Opportunities and advantages of the Ukrainian smart home technology market // Management of Development of Complex Systems. 2023. No. 56. P. 181–187. DOI: 10.32347/2412-9933.2023.56.181-187.
5. Ahmed M., Hassan R., Gupta N. Energy-efficient autonomous shelter systems integrating renewable energy and IoT technologies // Energy and Buildings. 2024. Vol. 315. DOI: 10.1016/j.enbuild.2024.114320.

INFLUENCE OF MULTIFUNCTIONAL ADDITIVES ON THE STRENGTH OF ALKALI SLAG PORTLAND CEMENT

Olga Bondarenko¹, Konstantin Kaverin¹

*¹Kyiv National University of Construction and Architecture,
bondolya3@gmail.com, 1krik.1k1@gmail.com*

The aggravation of economic and environmental problems in Ukraine, which is observed in our time, requires the development of new low-energy technologies for processing waste from the heat and power industry and metallurgy, which would ensure the maximum degree of their utilization and guarantee the possibility of obtaining building materials that are safe for human health [1]. Experience in using waste shows that binders that contain them in their composition are characterized by low construction and technological properties, including slow hardening, low hardening rate in the early stages, and concretes based on them have low performance characteristics, in particular frost and corrosion resistance [2]. To prevent these phenomena, complex additives of multifunctional action are introduced into the concrete mixture, which determine not only the kinetics of strength gain, but also the formation of the corresponding structure of the material, which has a significant impact on the properties and durability of the resulting artificial stone. At the same time, it is relevant to develop a concept for maximum use of the potential of waste as raw materials for obtaining such building materials and products that are not inferior in their properties to traditional ones, but are more effective from an environmental and economic point of view [3].

The aim of the work was to study the effect of multifunctional additives, which contain an alkaline component – a plasticizer, on the synthesis of the strength of artificial stone based on alkaline slag Portland cement.

Analysis of the obtained results of the study of the strength characteristics of the developed binder compositions shows that co-grinding has a positive effect on the processes of structure formation in alkaline slag Portland cement systems and allows you to accelerate the process of gaining compressive strength both at the early and later stages of hardening (Fig. 1, a). Thus, when using, in addition to sodium metasilicate, the plasticizing additives “Neoplast 500” and “Coral N – 4”, the strength of slag Portland cement compositions increases by 15...20% on day

2, compared to unmodified slag Portland cement, and is 10.6 and 10.8 MPa, and on day 28 – by 20...25% and reaches 45.5 and 45.7 MPa, respectively; when using “Neoplast 700” and “Neoplast 1000”, the strength of modified slag Portland cement increases by 20...25% on day 2 and reaches 14.7 and 14.6 MPa, and on day 28 – by 25...30% and is 49.5 and 46.5 MPa, respectively.

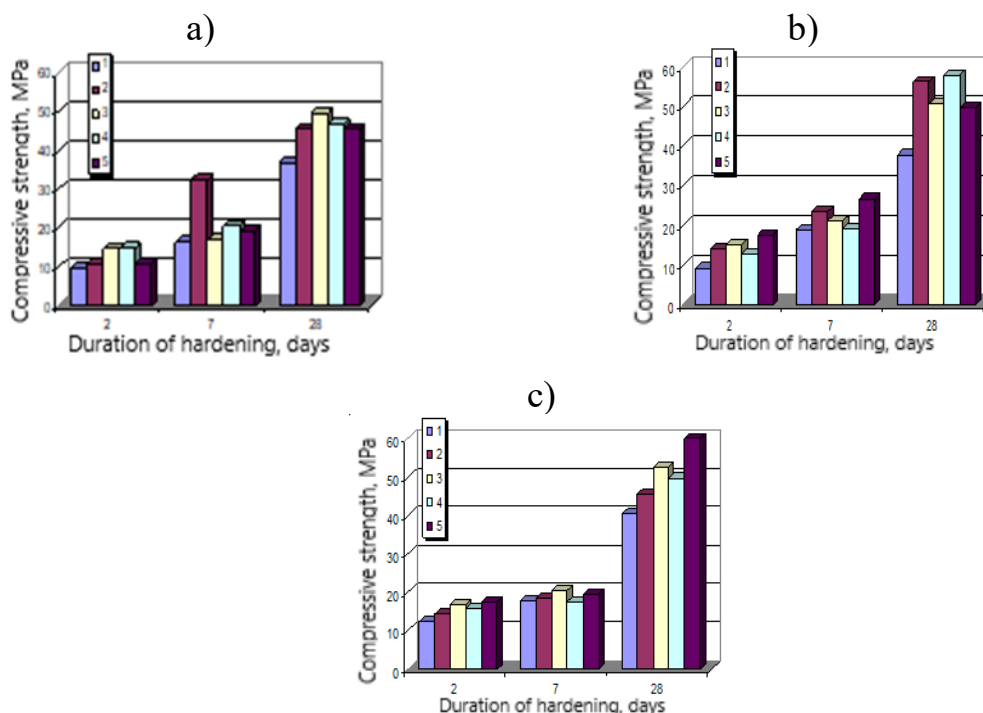


Fig. 1. Kinetics of compressive strength gain of slag Portland cement containing 60% slag (1), modified with sodium metasilicate (a), soda ash (b), sodium metasilicate and soda ash (c) and additives: “Neoplast 500” (2), “Neoplast 700” (3), “Neoplast 1000” (4), “Coral N – 4” (5)

The introduction of soda ash in a complex with "Neoplast 700" and "Coral N – 4" provides the highest results of strength increase at the initial stages of hardening. Thus, at 2 days it increases by 23...28% and is 15.0 and 17.5 MPa. At later stages of hardening, the highest strength indicators are achieved when using "Neoplast 500" and "Neoplast 1000". Thus, at 28 days they increase by 25...30% and are 57.8 and 56.1 MPa, respectively (Fig. 1, b). The complex use of sodium metasilicate, soda ash and plasticizing additives provides the highest strength indicators in the case of using "Neoplast 700" and "Coral N - 4" (for 2 days – 17 and 17.5 MPa and for 28 days – 52.5 and 60 MPa) (Fig. 1, b).

In the course of further studies, the phase composition of new formations of slag Portland cement binder compositions was established, which is represented mainly by low-basic calcium hydrosilicates (CSH (B), scoutite, afvilite, pictolite) and X-ray amorphous hydroaluminosilicate phases.

It is shown that the activation of slag Portland cement with the alkaline component and plasticizing additive "Neoplast 700" provides a decrease in the

basicity of the formed hydration products (CaO/SiO_2) to 1.1...1.2 when using sodium metasilicate (Fig. 2, b), to 1.3...1.4 (Fig. 2, c) when using soda ash, and to 1.25...1.35 when using sodium metasilicate and soda ash in a complex, while for slag Portland cement without additives the CaO/SiO_2 ratio is 2.1...2.5 (Fig. 2, a).

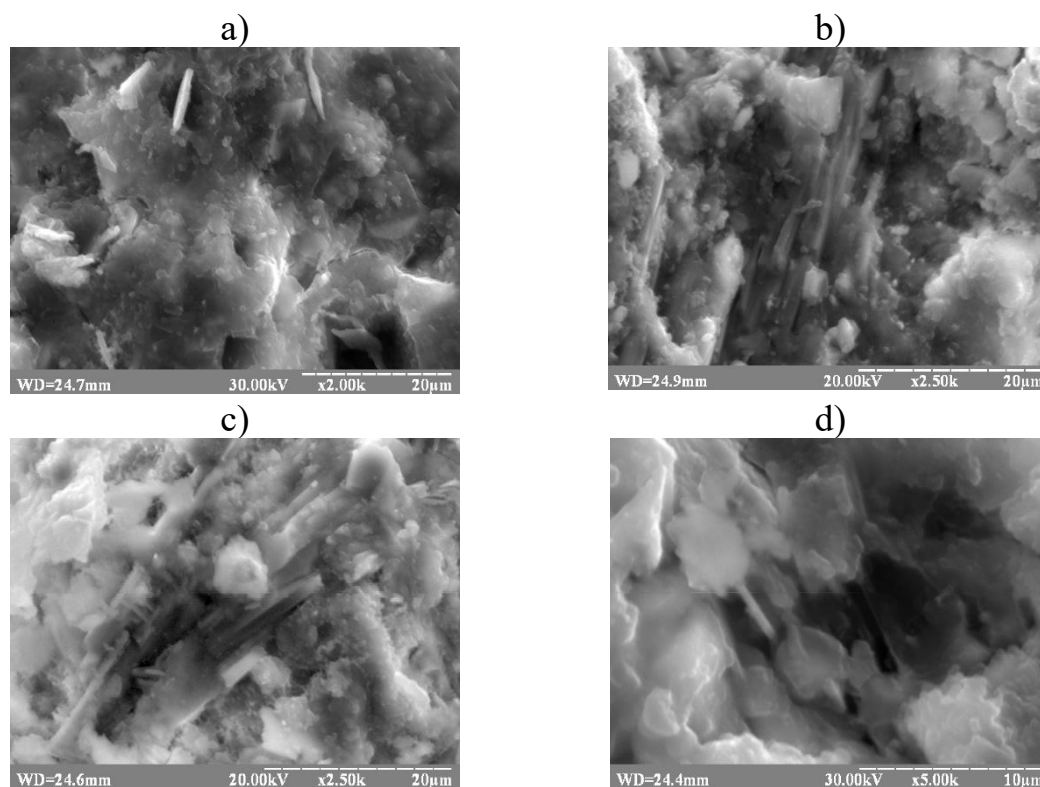


Fig. 2. Electron microscopic photographs of the surface of a chipped cement stone based on slag Portland cement containing 60% slag (a), modified with sodium metasilicate (b), soda ash (c), sodium metasilicate and soda ash (d) and the plasticizing additive “Neoplast 700” after hardening under normal conditions for 28 days

Thus, as a result of the conducted research, it was established that the formation of low-basic calcium hydrosilicates and X-ray amorphous hydroaluminosilicate phases in the composition of cement stone hydration products has a positive effect on the physical and mechanical performance of the obtained binder compositions based on alkaline slag Portland cement modified with polyfunctional additives.

REFERENCES

1. Krüger S., Gluth J.G., Watolla M.B., Morys M 1. Kryvenko P.V., Pushkareva E.K., Gots V.Y., Kovalchuk G.Yu. Cements and concretes based on fuel ashes and slags: Monograph – K.: Publishing House "Express-Polygraf", 2012. 258 p.
2. Kryvenko P.V., Pushkareva E.K. Durability of slag-alkaline concrete. K.:

Budivelnik, 1993. 224 p.

3. Pushkareva K.K., Bondarenko O.P., Nesenyuk V.G. Concretes based on slag Portland cements modified with water-reducing additives. Collection. "Building materials, products and sanitary ware". K., NIBMV, 2011. Issue 39. P. 74-77.

ADVANCED MULTILAYER FIRE-PROTECTIVE TEXTILES: MATERIALS, HYBRID ARCHITECTURES, AND INTELLIGENT FUNCTIONALIZATION

Oksana Kasianova

*Kyiv National University of Construction and Architecture,
kasianova_om@knuba.edu.ua*

As of early March 2026, according to the Ministry of Internal Affairs of Ukraine, since the beginning of the full-scale invasion (from February 24, 2022), 114 rescuers of the State Emergency Service of Ukraine (SESU) have been killed, and more than 500 SESU personnel have been injured while performing their duties. The highest number of fatalities occurs during repeated strikes (when rescuers arrive at the site of the first attack), as well as during demining operations. In addition to professional rescuers, more than 100 volunteers working alongside SESU in hazardous areas have also been killed.

Key causes of losses:

- Repeated strikes are the most common cause of death and injury. After the first shelling of a civilian or industrial facility, rescuers arrive at the site to extinguish fires and clear debris. The enemy deliberately delivers a second strike at the same coordinates when SESU units are already operating there.
- Mine hazard and demining – SESU sappers and pyrotechnicians work daily in de-occupied territories. Injuries occur due to detonations of anti-personnel mines, booby traps, and unexploded ordnance contaminating over 133 thousand km² of Ukraine's territory.
- Shelling during evacuation and firefighting – rescuers are often subjected to artillery fire, MLRS, or attack drones directly during firefighting operations in frontline zones or while evacuating civilians from dangerous areas.
- Specific risks of rescue operations – in addition to military factors, emergency personnel suffer injuries due to structural collapses of damaged buildings, high temperatures, and toxic combustion products during large-scale fire suppression [1].

The problem of protecting SESU personnel as well as workers in gas extraction and metallurgical industries is becoming increasingly acute and requires more advanced solutions in the field of fire-resistant materials used in personal protective equipment (PPE). A separate domain includes construction materials and structural systems aimed at enhancing fire resistance of buildings

and structures.

In recent years, research in fire-protective textiles has shifted from optimization of single fibers to integrated multilayer systems combining thermal resistance, mechanical strength, and thermo-physiological comfort. Particular attention is paid to hybrid composite architectures and the trade-off between thermal protection and user comfort. Emerging research topics include migration of flame retardants (FR) [2], material ageing [3 - 5], and limited representativeness of laboratory testing.

Fire-protective clothing plays a critical role in ensuring the safety of personnel operating in high-temperature and hazardous environments. Traditionally, research in this field focused on the development of inherently flame-resistant fibers such as aramids and polybenzimidazole. However, recent studies demonstrate a paradigm shift toward multilayer composite systems, where overall performance is determined by structural configuration rather than individual material properties.

The core challenge lies in resolving the intrinsic contradiction between thermal protection and physiological comfort. Increasing thermal resistance typically reduces moisture permeability and increases heat stress, leading to decreased operational efficiency and increased risk for the user. Therefore, modern research emphasizes multi-objective optimization integrating thermal insulation, air permeability, and ergonomic characteristics.

Recent reviews confirm that fire-protective performance is governed by the interaction of multiple layers, including: an outer shell providing flame resistance, a moisture barrier, and a thermal liner enhancing insulation properties.

Heat transfer mechanisms include conduction, radiation, and convection within air gaps. Advanced modeling approaches incorporate transient heat transfer equations and empirical indices such as TPP and THL.

A 2021 study [5] highlights the growing reliance on empirical and semi-empirical models for predicting thermal performance, while another 2021 study presents the design and fabrication of an aerogel-based nonwoven material for multilayer protective clothing systems [6]. The authors note that the developed aerogel nonwoven composite exhibits nearly equivalent resistance to dry and radiant heat, but lower resistance to contact heat compared to commercial aerogel nonwovens. It demonstrates high air and moisture vapor permeability and provides thermal comfort in hot and humid environments. Overall thermal resistance characteristics, combined with high flexibility, make aerogel nonwoven materials a promising alternative to commercial nonwovens for thermal protective clothing systems where fabric flexibility and thermal comfort are critical requirements.

Common materials include: aramids (e.g., Kevlar, Nomex), PBI and PBO, modacrylic and FR-viscose, as well as inorganic fibers (carbon, silica, basalt).

However, recent research indicates a clear shift toward hybrid systems, where different fiber types are combined to balance thermal stability, flexibility,

and moisture management. Hybridization enables the tailoring of functional gradients across layers, improving both protection and comfort.

Phase change materials (PCMs) are increasingly investigated for reducing heat transfer in firefighter protective clothing. However, these materials are typically hydrocarbons and therefore flammable. It has been shown that incorporating silica aerogel into PCM-based fabric coatings reduces flammability (i.e., enhances heat resistance, increases ignition temperature, and slows flame propagation) [7]. This reduction in flammability is likely associated with PCM retention on aerogel particles after melting due to the extremely high specific surface area of aerogels. Consequently, recent developments focus on flexible aerogel composites, integration of aerogel with nonwoven materials, and mechanically reinforced aerogels. Despite their advantages, challenges remain in terms of brittleness, dust release, and integration into textile systems, limiting their application range.

PCM technologies enhance thermo-physiological comfort by absorbing and releasing latent heat during phase transitions. Their integration into protective clothing helps stabilize body temperature under thermal exposure.

Key advancements include microencapsulation, shape-stabilized PCMs, and fiber-level integration.

However, limitations related to leakage, cyclic stability, and limited heat storage capacity persist [8, 9]. Considering these factors, a major trend in recent years is the development of intelligent PPE systems integrating temperature sensors, gas detectors, and physiological monitoring systems for operation in extreme environments involving high-temperature exposure.

The use of phase change materials is associated with several challenges. For instance, the incorporation of PCM into textiles requires the development of new testing methods and standards. Application techniques represent the most complex aspect of PCM textile system development. A common solution is encapsulating PCM within polymer shells, although this increases material weight. Technological challenges include encapsulation efficiency, yield, stability during use, and integration of capsules into textile structures. Another significant issue is the durability of PCM-integrated fabrics under repeated use.

These systems enable real-time risk assessment and enhance operational safety. However, challenges related to power supply, durability, and thermal resistance of embedded electronics remain substantial. The analysis presented in [10] demonstrates that no single material can simultaneously satisfy all PPE performance requirements. Instead, a systems engineering approach is essential, emphasizing the transition to multifunctional layered architectures, integration of adaptive thermoregulation systems, development of intelligent monitoring capabilities, and increased focus on environmental safety and durability. A critical limitation of current research is the reliance on laboratory testing, which does not fully replicate real-world conditions. Future studies should prioritize full-scale wear trials, thermal manikin testing, and long-term ageing analysis [11].

Conclusions. The evolution of fire-protective textiles demonstrates a clear transition from material-oriented approaches toward system-oriented design paradigms, in which overall performance is governed by the interaction of multiple functional layers rather than by the properties of individual components. Contemporary advancements are increasingly based on hybrid multilayer architectures integrating aerogels, phase change materials (PCMs), and intelligent monitoring technologies, enabling enhanced thermal protection while maintaining acceptable levels of thermo-physiological comfort.

A fundamental challenge remains the inherent trade-off between thermal insulation and physiological comfort, which necessitates the application of multi-objective optimization strategies in the design of personal protective equipment. In this context, hybridization and functional gradation across layers emerge as key engineering principles for achieving a balanced performance profile.

Despite significant progress, several critical limitations persist, including insufficient long-term durability of advanced materials, unresolved issues related to the integration and stability of PCM systems, and challenges associated with the incorporation of smart components under extreme thermal conditions. Furthermore, the reliance on laboratory-scale testing continues to constrain the reliability of performance assessment, as such conditions do not fully replicate real operational environments.

Future research should therefore prioritize the development of adaptive and intelligent protective systems with enhanced durability and environmental safety. Particular emphasis should be placed on full-scale experimental validation, long-term ageing studies, and the implementation of advanced modeling approaches capable of capturing coupled heat and mass transfer processes under realistic exposure conditions.

Overall, the advancement of fire-protective textiles is expected to be driven by interdisciplinary integration, combining materials science, textile engineering, and systems engineering to achieve next-generation protective solutions suitable for increasingly complex and hazardous operational scenarios.

REFERENCES

1. Kostenko T.V. Features of injuries of personnel of rescue units of the State Security Service of Ukraine in conditions of martial law / T.V. Kostenko // Current issues of occupational safety, civil and technogenic safety. No. 1(1), 2025. [https://doi.org/10.36910/3083-6255/1\(1\).2025](https://doi.org/10.36910/3083-6255/1(1).2025).
2. Effects of ageing on the fire behavior of flame retarded polymers: A review. Henri Vahabi, Rodolphe Sonnier, Laurent Ferry // *Polymer International* / Volume 64(3), November 2014. DOI: 10.1002/pi.4841.
3. Physico-chemical mechanism of extinguishing and preventing fires using means based on highly porous media / Elagin G. I., Kryshchal D. O., Tyshchenko E. O. et al. // *TECHNICAL SCIENCES «Colloquium-journal»* № 11(204), 2024. P. 36-39. URL: <http://repositsc.nuczu.edu.ua/bitstream/>

123456789/21994/1/Colloquium-journal-2024-204-1%20%281%29.pdf.

4. Flame retardancy evolution behavior and molecular mechanism of polyvinyl chloride under the action of damp heat aging / Ke Xu, Chenyu Gao, Xin Liu et al. // *Polymers* // Volume 17. Issue 6. DOI: 10.3390/polym17060794.

5. Characterization and Modeling of Thermal Protective and Thermo-Physiological Comfort Performance of Polymeric Textile Materials-A Review / Sumit Mandal, Nur-Us-Shafa Mazumder, Robert J. Agnew et al. // *Materials (Basel)*. 2021 May 5;14(9):2397. DOI: 10.3390/ma14092397.

6. Aerogel incorporated flexible nonwoven fabric for thermal protective clothing / Abu Shaid, M.A. Rahman Bhuiyan, Lijing Wang // *Fire Safety Journal*. Volume 125, October 2021. <https://doi.org/10.1016/j.firesaf.2021.103444>.

7. Emerging applications of aerogels in textiles / Steven J. McNeil, Honey Gupta // *Polymer Testing* // Volume 106, February 2022, 107426. URL: <https://doi.org/10.1016/j.polymertesting.2021.107426>.

8. An overview of phase change materials, their production, and applications in textiles / Anik Das, Md.Mehedi Hasan Apu, Asma Akter et al. // *Results in Engineering* // Volume 25(8):103603, December 2024. DOI: 10.1016/j.rineng.2024.103603.

9. A review on volatilization of flame retarding compounds from polymeric textile materials used in firefighter protective garment / Obikwelu Raphael Okonkwo, Vincent Mokoana, Joseph K. O. Asante // *Journal of Fire Sciences* // Volume 41(8):073490412311713, May 2023. DOI: 10.1177/07349041231171349.

10. Thermal Protective Performance of Firefighters' Clothing Under Low-Intensity Radiation Heat Exposure / Hualing He, Zhicai Yu, Chunbo Zhang, Minhua Li // *Autex Research Journal* // Volume 21(3), May 2020. DOI: 10.2478/aut-2020-0018.

11. Flammability and Thermoregulation Performance of Multilayer Protective Clothing Incorporated with Phase Change Materials / Muhammad Shoaib, Hafsa Jamshaid, Rajesh Mishra et al. // *Materials* // Volume 17(23):5826, November 2024. DOI: 10.3390/ma17235826.

PROBLEMS OF HOUSING RENEWAL FOR SUSTAINABLE DEVELOPMENT OF THE URBAN ENVIRONMENT

Maryna Kravchuk¹, Tetiana Kryvomaz¹

*¹Kyiv National University of Construction and Architecture,
zaxra@ukr.net, kryvomaz.ti@knuba.edu.ua*

The relevance of housing stock renewal is increasing worldwide against the backdrop of ecological, social, and economic challenges of sustainable urban development. In particular, research conducted by the Oxford University Institute for Environmental Change forecasts the necessity of demolishing approximately

three million buildings by 2050 to achieve energy consumption reduction targets. However, such approaches require comprehensive consideration of the full life cycle of buildings, including embodied carbon costs, resource use, and impacts on the urban environment [3].

As result of the ongoing war, Ukraine's housing stock is experiencing significant destruction and degradation, which exacerbates the problems of urban functioning and intensifies the need for comprehensive housing renewal. At the same time, the issue of modernizing the outdated housing stock existed even before the full-scale invasion, since a considerable share of residential buildings constructed during the era of mass industrial housing development is characterized by low energy efficiency and non-compliance with contemporary requirements of safety, comfort, and environmental resilience. Consequently, Ukraine adopted a number of legislative and regulatory acts aimed at stimulating reconstruction, renovation, and integrated renewal of residential areas. Yet, the practical implementation of such programs is accompanied by numerous technical, economic, social, and ecological challenges. Studies of housing reconstruction indicate that in Ukrainian cities the problem of housing renewal is complicated by the high level of physical deterioration of buildings (50–70%), the significant share of privatized housing (up to 92%), and limited financial capacity of the population, which hinders the realization of comprehensive renovation programs [2].

Contemporary research demonstrates that demolition of buildings entails considerable ecological, socio-economic, and cultural consequences, whereas preservation and modernization of existing housing may have a more positive environmental impact compared to complete dismantling and new construction [1]. International experience shows that for five-storey panel buildings of the first period of mass housing construction, the most effective approach is renovation, which should combine modernization of the residential environment, improvement of energy efficiency, and respect for property rights of residents [2]. Scholarly literature emphasizes the necessity of comprehensive evaluation of decisions regarding demolition or preservation of buildings at the level of urban policy, planning, and real estate management, which underscores the relevance of housing renewal studies for sustainable urban development [1].

Comparative analysis of the economic efficiency of housing of different storeys indicates that maintenance of five-storey “Khrushchev-era” buildings is less profitable compared to modern multi-storey residential complexes. Many of these buildings were designed as temporary housing with a limited service life; therefore, further extension of their life cycle requires disproportionately high expenditures on repairs and modernization of engineering systems. For two buildings with identical land plot areas, the difference between five-storey and sixteen-storey housing generates additional monthly revenues of approximately 155,000 UAH, even without accounting for electricity costs and elevator maintenance. Under conditions of equal adjacent territory and basement areas,

low-rise housing demonstrates lower economic efficiency in the use of land resources and communal infrastructure. In the long-term perspective, demolition of Khrushchev-era housing is an objectively necessary process, determined by physical and moral depreciation of the housing stock, low energy efficiency of buildings, high maintenance costs, and non-compliance with modern requirements of safety, comfort, and sustainable urban development.

The demolition process of a five-storey Khrushchev-era apartment block (commonly known as «Khrushchyovka») with five entrances and a total area of approximately 3,500–4,500 m² constitutes a complex engineering and technological project. It includes not only dismantling of above-ground structures but also disassembly of foundations, sorting of construction waste, and organization of subsequent removal and recycling. The estimated cost of such works in 2026 ranges from 10 to 20 million UAH and may increase depending on structural type, density of development, and logistical conditions. For preliminary calculations, demolition costs are usually determined per square meter of building area. The average turnkey demolition price, including waste removal, is about 2,500–4,500 UAH per m². Brick buildings are more expensive to dismantle compared to panel ones due to higher labor intensity. The largest share of costs is formed by waste removal and recycling, which may account for up to 40–50% of total demolition expenses.

Analysis of demolition practices shows that the duration of works is significantly influenced by logistical, natural-climatic, and urban planning factors. In densely built-up areas, limited access of construction machinery to inner courtyards may substantially slow down the pace of works and increase organizational costs. Adverse weather conditions, particularly heavy precipitation, complicate the operation of heavy machinery and increase risks of soil damage and temporary road deterioration. Additional restrictions arise when neighboring buildings are located in close proximity, requiring slower demolition and additional measures to minimize vibration, noise, and dust pollution.

The active demolition phase usually lasts three to five weeks and is characterized by the most intensive technogenic load on the environment and urban infrastructure. The main volume of works is performed using specialized machinery, particularly demolition excavators, which carry out mechanized collapse of structures directly on site. For a multi-entrance medium-rise building, the duration of such works may amount to 15–20 working shifts depending on structural condition, density of development, and organization of the construction process. At this stage, monitoring of noise, dust, and vibration levels is of particular importance, as their excess may negatively affect adjacent buildings and the comfort of nearby residents. Simultaneously, primary sorting of construction waste should be carried out directly on site. Separation of metal elements and reinforcement enhances recycling efficiency and reduces the volume of waste destined for landfilling. This approach corresponds to the

principles of circular economy and allows reduction of demand for primary raw materials in subsequent construction.

The waste recycling and crushing stage lasts approximately four to six weeks. Modern demolition practices increasingly employ mobile crushing plants, which enable recycling of concrete structures into secondary aggregate directly on site. Processing large volumes of construction material requires about one month of stable operation of a mobile crusher. Use of secondary aggregate reduces environmental load associated with extraction of natural non-metallic materials, as well as transportation costs and waste volumes. Simultaneously, materials unsuitable for reuse or recycling, such as insulation, timber, and mixed waste, are removed.

The final demolition stage, lasting about two to three weeks, involves dismantling of foundation structures, crushing of concrete blocks, and preparation of the site for subsequent use. If provided by the project, backfilling of the excavation and preliminary site leveling are performed. At this stage, the final condition of the territory is formed and readiness for new construction or reclamation is assessed. To minimize negative impacts on residents and infrastructure, phased demolition with concentration of works on a limited number of sites is advisable. Excessive demolition intensity within one neighborhood may cause local overload of the transport system and sharp growth of cumulative environmental impacts, including dust, noise, traffic congestion, and waste accumulation. Optimal organization involves demolition of no more than one or two buildings per street section simultaneously.

On the site of a demolished Khrushchyovka of about 4,000 m², construction of a modern sixteen-storey residential building with a total area of 12,000–18,000 m² is typically feasible. The average construction cost of “comfort class” housing in Kyiv in 2025–2026 is 600–850 USD per m² of gross floor area. Accordingly, construction of a residential complex of about 15,000 m² requires a minimum budget of approximately 9 million USD, while the average project budget may reach 12–13.5 million USD. This sum usually includes costs of monolithic frame, external and internal walls, façade systems, glazing, engineering networks, and finishing of common areas.

At the same time, renovation of outdated housing areas entails significant additional expenditures, which may increase the overall project budget by 20–30%. These include design and permitting documentation costs (about 15–25 USD per m²), as well as connection of the new building to engineering networks. A modern sixteen-storey building requires 4–5 times greater electricity and water supply capacity compared to a Khrushchyovka, which may increase infrastructure costs to 0.5–1.5 million USD per project. Additional expenditures include landscaping, playgrounds, guest or underground parking facilities in accordance with modern urban planning standards.

One of the key challenges is social resistance of residents, associated with distrust of relocation mechanisms and risks of losing familiar living

environments. Overcoming this problem requires legislative consolidation of transparent relocation guarantees, provision of equivalent or improved housing, and creation of mechanisms for resident participation in planning of neighborhood renovation. In most cases, relocation is carried out with provision of housing in a new building with an area coefficient of 1.2–1.5 compared to the previous dwelling. For a Khrushchyovka of about 4,000 m², this implies free transfer of approximately 5,000–6,000 m² of residential area in the new building. In practice, this reduces potential developer profit by 30–40%. Under such conditions, one newly built multi-storey building can accommodate relocation of residents from approximately three five-entrance Khrushchyovkas, which necessitates a comprehensive block-level approach to housing stock renovation. An important direction is phased relocation within one district, which minimizes social disintegration and preserves accessibility of social infrastructure. To ensure economic feasibility of renovation, models of public-private partnership must be implemented, international financial organizations engaged, and special state programs for comprehensive housing renewal established. An effective instrument may be the use of green financing mechanisms, which enhance investment attractiveness of projects and integrate energy efficiency, ecological safety, and social responsibility criteria into the renovation process.

Among the principal challenges of housing stock renewal are the considerable costs of demolition and new construction, the complexity of resident relocation, the imperfection of financing mechanisms, the high level of housing privatization, and the risks of negative impacts on the environment and urban infrastructure. This process is not merely a matter of physical housing renewal but simultaneously represents a large-scale transformation of the urban environment, which requires a balanced integration of economic efficiency, social equity, and ecological safety. Only a comprehensive approach, grounded in the principles of sustainable development and long-term urban planning, can ensure the successful implementation of renovation programs and the formation of a qualitatively new built environment in Ukrainian cities.

REFERENCES

1. Huuhka, S. (2023). Understanding demolition. *Buildings & Cities*, 4(1), 927–937. <https://doi.org/10.5334/bc.398>
2. Pleshkanovska, A., & Biriuk, S. (2021). «Outdated housing stock» as an object of complex reconstruction programs and projects: challenges for Ukraine. *Journal of Urban & Regional Analysis*, 13(2), 257–280. <https://doi.org/10.37043/JURA.2021.13.2.4>
3. Power, A. (2008). Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability? *Energy policy*, 36(12), 4487–4501. <https://doi.org/10.1016/j.enpol.2008.09.022>

LABOUR SAFETY UNDER THE CONDITIONS OF GREEN CONSTRUCTION

Roman Katsan

*Kyiv National University of Construction and Architecture,
romakatsan4107@gmail.com*

Green construction is a strategic guideline for the development of the modern construction industry, as it combines the efficient use of resources, careful treatment of the environment, and orientation toward human needs in the formation of living space. Its main principles предусматривают the rational use of natural resources, the reduction of negative impact on the environment, and the provision of comfortable and safe conditions for life and activity.

At the same time, the expansion of the implementation of environmental standards into construction practice determines the necessity of updating approaches to the organization of the occupational safety system. The active implementation of innovative technological solutions, the use of new materials, and the transformation of organizational and production processes within green construction are accompanied by the emergence of atypical occupational hazards. Under such conditions, comprehensive research into occupational safety issues aimed at the identification, assessment, and minimization of occupational risks in this dynamic field acquires particular importance.

Working conditions in the field of green construction are distinguished by a number of specific features caused by the nature of the applied materials, technologies, and technical means. The use of environmentally safe materials, the implementation of energy-saving solutions, and the involvement of modern equipment form a new production environment that requires the corresponding adaptation of approaches to occupational safety.

Workers under such conditions are affected by a complex of multidirectional factors. In particular, chemical factors are associated with the action of components of the latest materials; physical factors manifest themselves through the level of noise, vibration, and temperature fluctuations; biological factors are conditioned by the possible development of mold and microorganisms in a humid environment; psychophysiological factors arise as a result of increased work intensity and responsibility during the performance of complex production operations.

At the same time, the integration of innovative technologies, in particular smart house systems, solar panels, and air recuperation installations, puts forward additional requirements for the qualifications of personnel. This determines the necessity of special training for workers and strict observance of enhanced safety measures during their operation.

Green construction, having significant environmental advantages, is accompanied by the emergence of specific occupational risks caused by the use of new materials, technologies, and engineering systems [1].

Table 1

Hazardous factor	Possible consequences	Safety measures
Chemical substances	Poisoning, allergic reactions	Use of personal protective equipment, ventilation
Dust	Respiratory diseases	Respirators, air humidification
Work at height	Falls, injuries	Safety systems, safety instruction
Electrical installations	Electric shock injury	Insulation, equipment inspection, safety instruction
Fire hazard	Fires, explosions	Control of materials, fire safety measures
Machines and mechanisms (cranes, lifting devices)	Injuries of varying degrees of severity	Safety instruction, protective barriers, technical inspection, personnel training

In the practice of occupational health and safety risk assessment, there is a consistent identification of hazardous factors, an analysis of the cause and effect relationships of their occurrence, and the subsequent organization of the labor process according to the level of risk for their effective management [2]. Such an approach allows consideration of the systemic impact of occupational hazardous factors rather than separate influencing factors individually.

The main occupational risks of green construction are presented in the table1.

The system for ensuring occupational safety under the conditions of green construction is formed on the basis of modern approaches to the management of occupational risks and integrates environmental, technological, and organizational aspects of production activity. In accordance with international standards, in particular DSTU ISO 45001:2019, an effective occupational safety system must be based on the principles of risk-oriented management [3].

The organization of occupational safety in green construction is characterized by a number of advantages resulting from the implementation of energy-efficient solutions, innovative technologies, and the use of materials inherent to this field of construction activity [1; 4]. At the same time, the adaptation of existing labor protection systems to the specificities of the modern technological process in construction remains a pressing issue.

To minimize occupational risks, it is necessary to implement a comprehensive system of measures that combines technical, organizational, and individual components of occupational health and safety in accordance with DSTU ISO 45001:2019 [3].

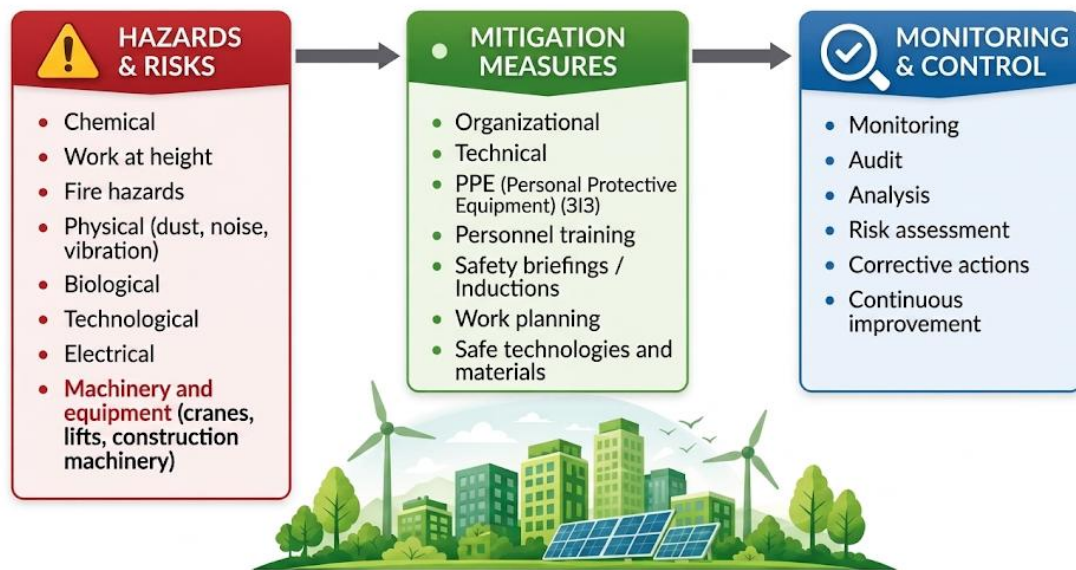


Fig. 1 Occupational safety system in green construction

Technical measures are aimed at creating an inherently safe production environment. They involve the extensive application of modern certified equipment with a high level of automation, reliable ventilation systems, and local exhaust systems for hazardous substances, as well as automated dust extraction, air humidification, and continuous real-time monitoring of microclimate parameters. Particular attention is paid to ensuring electrical safety during the installation of solar panels, 'smart home' systems, and other energy-efficient equipment, as well as the use of materials with reduced fire hazards [4].



Figure 2. Classification of occupational safety assurance measures in construction

Organizational measures form the foundation of effective safety management. They include the regular updating of occupational safety instructions, taking into account the specifics of green technologies and materials, conducting all types of safety briefings, systematic training, and professional development of employees. A vital role is played by the optimization of technological processes, rational work planning, and constant monitoring of compliance with labor protection requirements. A significant component is the active formation of a safety culture through seminars, workshops, and the involvement of employees in hazard identification [2; 5].

Individual measures directly ensure the health protection of each employee. They encompass the provision of modern personal protective equipment adapted to the conditions of green construction, conducting mandatory medical examinations, training in the correct use of protective gear and safe working methods, as well as involving employees in risk assessment at their workplaces [1].

The integrated application of technical, organizational, and individual measures allows not only for a significant reduction in the level of occupational risks but also for the creation of comfortable working conditions that fully align with the philosophy of green construction — preserving human health and maintaining a stewardship of the environment [4].

Effective risk management is a fundamental component of the occupational health and safety system and the assurance of workplace safety. According to modern approaches, this process is systemic and continuous in nature, comprising interrelated stages aimed at reducing the probability of accidents and occupational diseases [3].

The first stage of risk management is hazard identification, which involves detecting potential sources of harm to the lives and health of workers. This process encompasses a detailed analysis of production processes, applied technologies, equipment, working conditions, and consideration of the human factor. The results of identification serve as the basis for subsequent risk assessment and the prioritization of safety measures [2].

Modern research in the field of labor protection emphasizes that the effectiveness of hazard identification largely depends on the application of a risk-oriented approach. Such an approach allows for the adaptation of the safety system to the conditions of digitalization and the active implementation of innovative technologies in construction, facilitates the timely detection of new types of risks, and enhances the quality of management decisions [1].

The next stage is risk assessment, which consists of determining the probability of hazardous events and the severity of their potential consequences. Conducting a high-quality assessment makes it possible to establish the risk level, prioritize threats, and reasonably allocate resources for their mitigation. Modern methods for assessing occupational risks, combining qualitative, quantitative, and hybrid approaches, allow for the consideration of the frequency of hazard

occurrence, the probability of their realization, and the seriousness of the consequences. The application of these methods fully complies with the principles of risk-oriented management enshrined in international and national labor protection standards [3]. Following the risk assessment, control measures are implemented. This stage involves the development and realization of technical, organizational, and individual solutions aimed at eliminating or significantly reducing risk levels. The effectiveness of these measures increases substantially when they are integrated into a single occupational health and safety management system of the enterprise [2].

The final and, at the same time, ongoing stage is risk monitoring and control. It ensures the evaluation of the effectiveness of implemented measures, the timely detection of new hazards, and the adaptation of the safety system to changes in working conditions. Regular analysis of the production environment, conducting audits, and updating risk management procedures allow for maintaining the high efficiency of the labor protection system in the dynamic conditions of green construction [1].

Green construction, as a leading direction in the modern development of the building industry, opens new opportunities for creating an environmentally safe and comfortable living environment. At the same time, the transition to green technologies and materials is accompanied by the emergence of specific occupational risks, which necessitates a substantial update of approaches to the organization of labor protection.

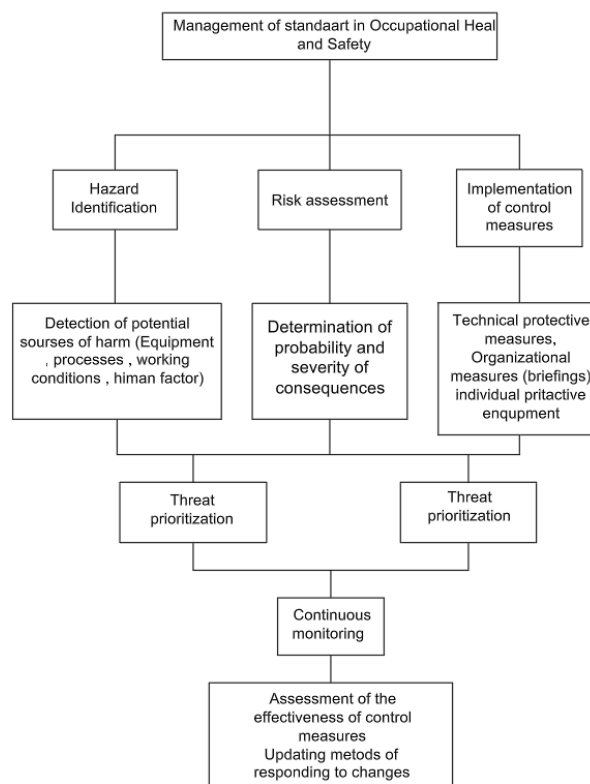


Fig. 3. Occupational health and safety risk management scheme

As a result of the conducted research, it has been established that working conditions in green construction are characterized by the complex influence of chemical, physical, biological, and psychophysiological factors. Ensuring effective employee safety is possible only through the implementation of risk-oriented management in accordance with the requirements of DSTU ISO 45001:2019. A comprehensive approach to occupational risk management—which includes systematic hazard identification, assessment, implementation of control measures, and continuous monitoring—allows for a significant reduction in the rates of industrial injuries and occupational diseases. Particular importance is attached to the integration of technical, organizational, and individual labor protection measures, taking into account the specifics of innovative technologies and materials used in green construction.

Promising directions for further research include the development of industry-specific methodologies for occupational risk assessment specifically for green construction sites, the improvement of the regulatory framework, and the creation of specialized training and professional development programs for employees that address new challenges.

Thus, ensuring occupational safety in green construction is not only a mandatory requirement but also a vital element in realizing the concept of sustainable development, which combines concern for human health, environmental preservation, and increasing the efficiency of the construction industry.

REFERENCES

1. Adesoji, T., Pearce, A., Kleiner, B., & McGinnis, S. (2025). Occupational health and safety in green construction. *Journal of Cleaner Production* (In press). Available at: <https://surl.lt/ivysgo> (Accessed: 10 May 2026).
2. Kovalchuk, O. Yu. (2020). *Occupational Health and Safety in Construction: A Study Guide*. Kyiv: Kondor. [In Ukrainian].
3. State Standard of Ukraine (2019). *DSTU ISO 45001:2019. Occupational health and safety management systems. Requirements and guidelines for use*. Kyiv: SE "UkrNDNC". [In Ukrainian].
4. Kibert, C. J. (2016). *Sustainable Construction: Green Building Design and Delivery* (2nd ed.). Hoboken: Wiley.
5. Kibert, C. J. (2022). *Sustainable Construction: Green Building Design and Delivery* (5th ed.). Hoboken: Wiley. Available at: <https://surl.li/vxxops> (Accessed: 10 May 2026).

INTEGRATED FOUNDATION DRAINAGE AND SUSTAINABLE STORMWATER MANAGEMENT: COMPARATIVE ANALYSIS OF CANADIAN AND UKRAINIAN SYSTEMS

Svitlana Abu Deeb,
EPt (ECO Canada), lanaabudeeb@gmail.com

1. Introduction

Water around building foundations creates several major risks: basement flooding, foundation cracking, hydrostatic pressure, mold growth, soil instability, and structural degradation.

Historically, most countries attempted to solve this problem by removing water as quickly as possible. However, climate change, urbanization, and increasing storm intensity have forced engineers to rethink traditional drainage concepts.

Canada developed highly efficient drainage systems focused on rapid evacuation, underground piping, sump pumping, and municipal storm sewer integration. Ukraine, especially after increasing integration with European environmental engineering practices, increasingly explores “green infrastructure” systems that imitate natural hydrology. The key difference is philosophical (Table 1).

Table 1

Comparing Canadian and Ukrainian drainage systems

Canadian System	Ukrainian Green System
Water is a threat to remove	Water is a resource to manage
Mechanical evacuation	Natural infiltration
Impermeable urban design	Permeable ecological design
Centralized infrastructure	Decentralized retention

2. Canadian Underground Foundation Drainage Systems

2.1 Purpose of the Canadian System

Canadian homes face extreme environmental conditions like: snow accumulation, spring melt, frozen soils, deep frost penetration, heavy rainfall, and large groundwater fluctuations.

Because many Canadian houses include deep basements, underground hydrostatic pressure becomes a major structural concern. The Canadian drainage model therefore prioritizes keeping foundations dry, rapid groundwater evacuation, preventing basement flooding, protecting structural integrity [1, 8, 10].

3. Main Components of Canadian Drainage Systems

3.1 Weeping Tile (Perimeter Drain)

The weeping tile is the core element. It is a perforated pipe installed around the perimeter of the foundation below footing level. Functions: collect groundwater, relieve hydrostatic pressure, direct water toward sump systems. Modern systems use: perforated PVC pipes, gravel filtration layers, geotextile membranes.

Government of Canada guidance explains that weeping tile systems help reduce water pressure around foundations and direct groundwater away from homes [7].

3.2 Gravel Drainage Bed

Gravel layers surround the pipe. Advantages: prevent soil clogging, improve permeability, create drainage voids, increase water collection efficiency. Typical gravel sizes: $\frac{3}{4}$ inch crushed stone, washed aggregate, rounded drainage rock.

4. Canadian Sump Pump Systems

4.1 Sump Pit Groundwater collected by weeping tiles enters a sump pit. The pit acts as: temporary storage, sediment collection, pumping station.

4.2 Sump Pump Operation When water reaches a certain level a float switch activates, the pump ejects water outside, water enters storm drainage systems (Fig. 1).

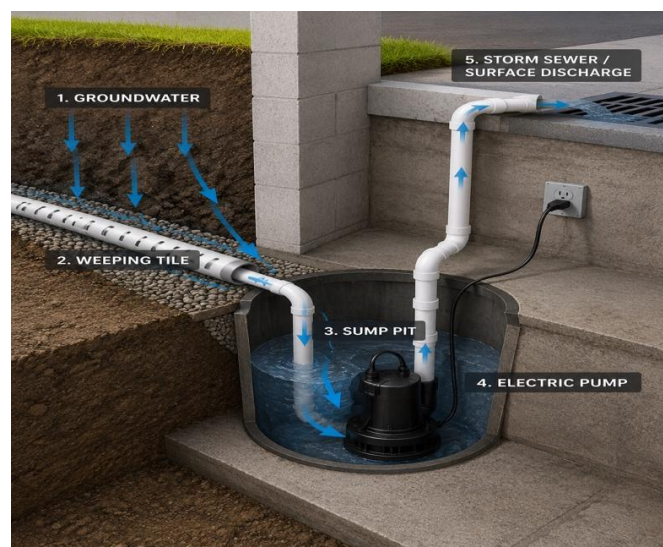


Fig.1. Simplified Flow Diagram

According to Canadian flood-prevention guidance, sump pumps are considered essential in many flood-prone regions [8, 9].

5. Canadian System Advantages

5.1 High Flood Protection Canadian systems are extremely effective in severe storms, spring melt, high groundwater conditions.

5.2 Basement Suitability Canada has one of the world's highest percentages of homes with basements and deep drainage systems are therefore essential.

5.3 Winter Performance The systems are designed specifically for frozen soils, snowmelt surges, ice conditions.

6. Weaknesses of Canadian Drainage Systems

6.1 High Energy Dependence The system depends heavily on electricity, during power outages, severe storms, or freezing rain events, sump pumps may fail. This creates catastrophic flooding risk. Many municipalities now recommend to use backup pumps, battery systems, or emergency generators [2].

6.2 Urban Impermeability Canadian suburban development often includes asphalt, concrete, compacted soil, impermeable surfaces. This reduces natural infiltration and increases storm runoff, sewer overload, flash flooding.

6.3 Ecological Impact Rapid water removal disrupts natural hydrology by groundwater recharge decreases, rivers receive sudden surges, ecosystems become destabilized.

7. Ukrainian Green Drainage Technologies

7.1 Conceptual Philosophy Modern Ukrainian sustainable drainage systems are strongly influenced by Germany, Netherlands, Scandinavia, EU ecological engineering. Instead of exporting water rapidly, these systems attempt to slow water, filter water, infiltrate water, store water naturally [3].

8. Biowales Biowales are vegetated shallow drainage channels. They serve to slow stormwater, absorb pollutants, increase infiltration, reduce erosion[4, 5].

8.1 Environmental Benefits Biowales improve biodiversity, urban cooling, pollutant filtration, ecological aesthetics. Unlike concrete channels, they imitate natural ecosystems (Fig.2)

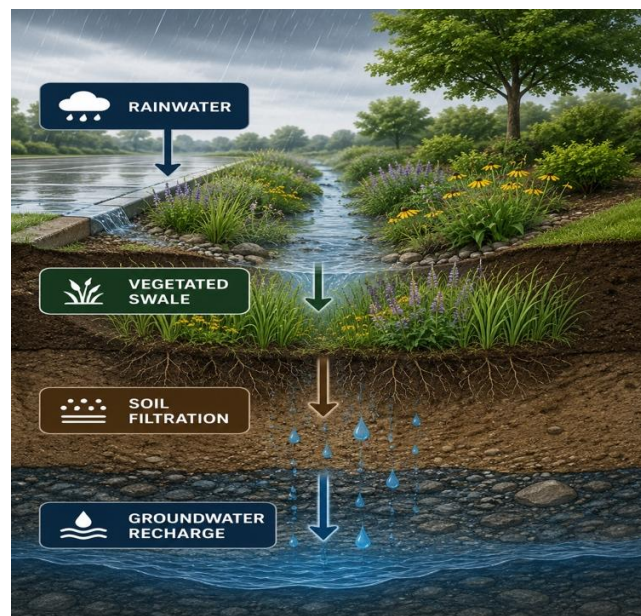


Fig 2. Biowales diagram

9. Permeable Pavement Systems

Traditional pavement prevents infiltration. Permeable pavements allow water to pass through surface layers into underground storage systems. Common

materials that are used: porous concrete, permeable pavers, gravel grids, reinforced grass systems [3]. The advantages are shown in table 2.

Table 2

Advantages of Permeable Pavement Systems

Benefit	Impact
Reduced runoff	Less flooding
Groundwater recharge	Sustainable hydrology
Lower heat island effect	Cooler cities
Less sewer pressure	Infrastructure savings

10. Retention Trenches

Retention trenches are underground stone-filled structures. Their purpose is for temporary water storage, delayed release, infiltration enhancement (Fig.3).



Fig. 3. Retention trenches structure

11. Rain Gardens

Rain gardens are landscaped depressions designed to capture runoff. They reduce stormwater volume, support native vegetation, improve filtration. Typical Plants that used are: sedges, grasses, wetland flowers, deep-rooted native species [6].

12. Ukrainian Green Technology Advantages

- Lower Operational Cost as most systems use gravity, infiltration, passive flow. This minimizes electricity use, mechanical maintenance, pumping requirements.
- Climate Sustainability Green systems improve urban cooling, drought resistance, ecological resilience.
- Carbon Footprint Reduction Compared to mechanical pumping systems an energy demand is much lower, and infrastructure emissions decrease.

13. Challenges of Ukrainian Green Systems

13.1 Frozen Soil Limitations In colder climates infiltration becomes difficult when soil freezes. This reduces effectiveness during severe winter events, rapid snowmelt.

13.2 Design Sensitivity Green systems require proper soil analysis, hydrological planning, vegetation management. Poor design may lead to oversaturation, standing water, mosquito problems.

14. Comparison of Canadian and Ukrainian drainage systems (Fig.4)

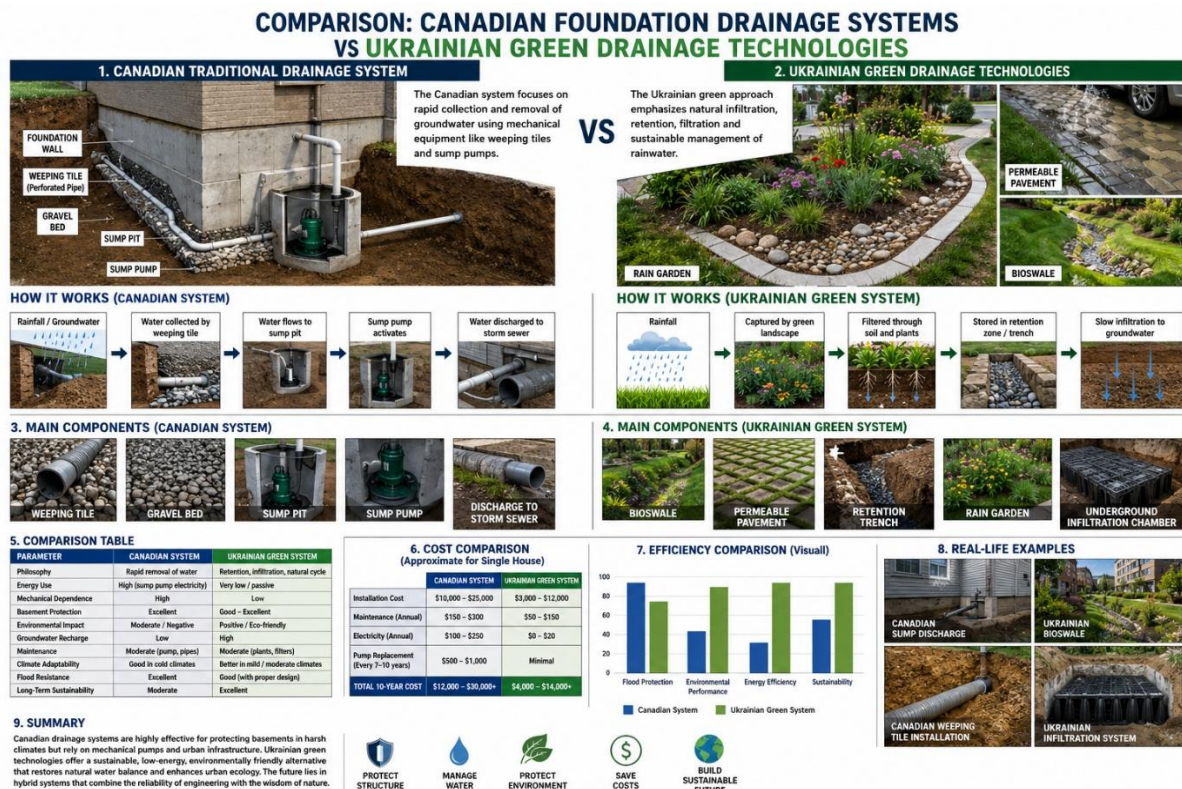


Fig.4. Comparison of Canadian and Ukrainian drainage systems

17. Climate Change Adaptation

Current climate change increases heavy rainfall, flash flooding, sewer overloads, and groundwater instability. Traditional Canadian systems alone may become insufficient because storm sewer networks can overload. Green systems help by slowing runoff, reducing peak flow, increasing infiltration. This is why many Canadian cities are now adopting: Low Impact Development (LID), biowales, permeable surfaces, stormwater retention landscapes.

18. Hybrid Future Systems

The future of drainage engineering is hybridization. Modern systems increasingly combine weeping tiles, sump systems, infiltration trenches, permeable pavements, biowales, smart stormwater controls. This hybrid approach offers strong basement protection, ecological sustainability, lower infrastructure stress, improved climate resilience (Fig.5).



Fig.5 Visual Comparative Diagram

20. Conclusion

Canadian underground drainage systems are highly engineered solutions optimized for cold climates, severe freeze-thaw conditions, and deep basement flood protection. Their greatest strengths are in reliability, rapid evacuation, strong flood resistance. However, these systems are energy dependent, infrastructure intensive, and ecologically disruptive.

Ukrainian green drainage technologies provide a fundamentally different philosophy focused on sustainability, infiltration, ecological restoration, and decentralized stormwater management. These systems reduce energy use, improve groundwater recharge, enhance biodiversity, and increase long-term environmental resilience.

The future of urban water management can be improved by combining Canadian engineering reliability with Ukrainian-European ecological sustainability. Hybrid systems represent the most adaptive and climate-resilient solution for modern cities.

REFERENCES

1. Canadian Geotechnical Society. (2006). *Canadian foundation engineering manual* (4th ed., pp. 312–348). Richmond, BC: Canadian Geotechnical Society.
2. Chen, X., Davitt-Liu, I., Erickson, A. J., & Feng, X. (2023). Integrating the spatial configurations of green and gray infrastructure in urban stormwater networks. *Water Resources Research*, 59(12). <https://doi.org/10.1029/2023WR034796>
3. Dmitrieva, O., & Teliura, N. (2018). Implementation of environmentally safe wastewater technologies as an element of sustainable human settlements development in Ukraine. *Municipal Economy of Cities*, 73–82.

4. Khoruzhyi, P. D., & Levytska, V. D. (2016). Complex use of infiltration waters in flooded zones of the Dnipro reservoir cascade. *Problems of Water Supply, Sewerage and Hydraulics*, 27, 400–407.
5. Kononenko, O., & Dronova, O. (2022). Urban metabolism as a background for the development of circular cities in Ukraine. *Ukrainian Geographical Journal*, 1, 36–46.
6. Kravchenko, M., Tkachenko, T., & Mileikovskiy, V. (2023). Modification of green roofs using technical solutions to reduce the negative impact of stormwater in urban conditions. *Problems of Water Supply, Sewerage and Hydraulics*, 43, 16–28. <https://doi.org/10.32347/2524-0021.2023.43.16-28>
7. Li, J., & Burian, S. J. (2023). Evaluating real-time control of stormwater drainage network and green stormwater infrastructure for enhancing flooding resilience under future rainfall projections. *Resources, Conservation and Recycling*, 1–18.
8. Marsalek, J., & Schreier, H. (2009). Innovation in stormwater management in Canada. *Water Quality Research Journal of Canada*, 44(1), 5–15.
9. Muma, M., & Chu, A. (2014). Review of performance of urban stormwater management practices in cold climate regions. *Journal of Hydrologic Engineering*, 19(5), 102–118.
10. National Research Council Canada. (2020). *National Building Code of Canada 2020: Part 9 – Housing and small buildings* (pp. 892–915). Ottawa, ON: National Research Council Canada.

DYNAMICS OF PHYSICO-CHEMICAL PARAMETERS DURING ANAEROBIC COMPOSTING OF BIOWASTE USING THE EM–PREPARATION BOKASHI

Liya Kuznetsova¹, Alona Perebynos¹

¹*Kyiv National University of Construction and Architecture,
perebynos.ar@knuba.edu.ua*

The problem of rational management of municipal waste remains one of the most pressing environmental challenges of our time [1]. According to the legislation of Ukraine, a significant share of municipal waste (up to 40%) is biowaste [2]. The traditional management model of «collection – disposal» leads to the fact that organic residues in landfills become a source of methane, which is a powerful greenhouse gas. The transition to a circular economy requires the introduction of methods for local treatment of biowaste, among which the use of “effective microorganisms” (EM) occupies a special place.

The relevance of this study is due to the need to find affordable and effective ways to reduce the load on landfills. Home treatment of food waste using EM–preparations allows not only to minimise methane emissions, but also to obtain organic fertiliser. Understanding the dynamics of fermentation and the role of

microbiological additives is one of the key factors for popularising this method among the citizens.

The object of the study was kitchen waste, which was subjected to anaerobic fermentation using the EM preparation Bokashi. The methodology included the following stages:

1. Layering biowaste into an EM–container with a double bottom to collect the liquid produced during the fermentation process.
2. Application of Bokashi (a mixture of bran inoculated with photosynthetic, lactic acid bacteria and yeast).
3. Monitoring of organoleptic indicators (smell, colour, structure) for 6 weeks.
4. Control of physicochemical parameters (Table 1):
 - The temperature was measured using a laboratory thermometer;
 - pH was determined in EM fluid using a pH meter and in compost using indicator test strips;
 - moisture content was determined by the gravimetric (weight) method, which involves determining the difference in mass between wet and dried material.

During the experiment, the temperature of the compost mass initially increased to a maximum of 20 °C on the 14th day, after which its gradual decrease to 18 °C was observed. Such dynamics may indicate the passage of an active thermal phase of decomposition and subsequent stabilisation of the fermentation process.

Table 1

Physico-chemical parameters of the fermentation process

Parameter	Research stage (day)					
	7	14	21	28	35	42
Temperature, °C	17	20	19	18	18	18
Humidity, %	85,5	81,4	80,4	80,3	66,6	–
Compost pH value	7,5	6,5	5	5	6,5	6,5
pH value of compost liquid	-	5,1	4,02	5,97	4,5	5

The pH level of the compost tended to decrease (from 7.5 on day 7 to 5 on day 21–28), indicating active acid fermentation under the influence of the Bokashi EM preparation. At the same time, on day 35, an increase in pH to 6.5 was recorded, which may indicate the completion of the active acid phase and the transition to the stage of compost maturation.

The pH of the compost liquid (filtrate) also demonstrated the dynamics characteristic of fermentation processes. The highest acidity was recorded on the 21st day (pH 4.02), which is fully synchronised with the peak acidity of the compost mass itself. On the 28th day, a decrease in the acidity of the liquid was noted (the pH increased to 5.97), which further confirms the gradual stabilisation

of microbiological processes.

The moisture content of the compost mass gradually decreased from 85.5% (on the 7th day) to 66.6% (on the 35th day), which may be due to the formation and release of filtrate, the intensity of which is related to the moisture content of the biowaste itself.

During the study, visual observations of the condition of the compost mass were also carried out; in particular, structural changes, the appearance of fungi, and the intensity of the odour at each stage of fermentation were assessed (Table 2).

Table 2

Results of monitoring the food waste fermentation process

Observation stage	Odor intensity	Organoleptic indicators	EM fluid output, ml
Week 1	High	The smell is sharp, unpleasant; fermentative; notes of hydrogen sulfide and cabbage odor. White-blue mold.	0
Week 2	Medium	The smell in the bucket is rotten; the compost tea is sweet and earthy. Reduction of blue mold; dominance of white mold in compost.	30
Week 3	High	The smell is sharp; fermentative, and pronounced sweet-sour profile. Only white mold; the blue mold is gone.	140
Week 4	Medium	The smell is intense, sweet-sour and fermentative; compost tea has a more pungent smell. Increase in white mold on the surface of the compost.	76
Week 5	Very high	Sharply unpleasant, acrid, putrid; pronounced sour and fermentative profile. The amount of white mold has decreased.	98
Week 6	Very high	The smell is putrid, rotten, pungent; the sour tone is retained. The amount of white mold is unchanged.	15

In addition to the physical and chemical parameters and organoleptic indicators, the formation of compost liquid (filtrate) was recorded, the amount of which changed during the experiment. The beginning of liquid release was

recorded on the 14th day (30 ml), and the maximum value was observed on the 21st day (140 ml), after which a sharp decrease in volume to 76 ml on the 28th day and a subsequent slight increase to 98 ml on the 35th day were noted. In the final 7th week (42nd day), a significant drop in the volume of the formed filtrate was recorded to a minimum of 15 ml.

Conclusions

1. The use of EM preparation ensures a stable course of anaerobic fermentation of food waste without the onset of putrefaction processes.
2. The optimal fermentation period at home is 4–6 weeks, after which the substrate is ready for mineralisation in the soil.
3. The pH indicator is a reliable indicator of the success of the process: a drop in pH below 4.5 guarantees the absence of pathogens.

REFERENCES

1. On waste management: Law of Ukraine dated 20.06.2022 No. 2320–IX. URL: <https://zakon.rada.gov.ua/laws/show/2320–20#Text>
2. National Waste Management Plan until 2033: Order of the Cabinet of Ministers of Ukraine dated 27.12.2024 No. 1353–r. URL: <https://zakon.rada.gov.ua/laws/show/1353–2024–%D1%80#Text>

RESEARCH OF PARAMETERS OF DECENTRALISED COMPOSTING OF BIOWASTE USING LIQUID EM PREPARATIONS

Elizaveta Getman¹, Mariia Nosach¹, Alona Perebynos¹

*¹Kyiv National University of Civil Construction and Architecture,
perebynos.ar@knuba.edu.ua*

At the current stage of civilisation development, the problem of municipal waste management has transformed from a purely technological issue into a critical challenge for environmental safety. For Ukraine, where a linear management model consisting of waste collection and disposal in landfills has long dominated, the transition to the principles of sustainable management according to the waste management hierarchy [1] is not only a requirement of European integration, but also a necessity for preserving the viability of local ecosystems.

According to the Law of Ukraine «On Waste Management», the key priority is to prevent waste generation and its recycling [2]. A special place in the morphological composition of household waste is occupied by biowaste, which makes up about 40 % of the average citizen's waste container [3]. The problem is that, when disposed of in landfills, organic residues become a source of methane and leachate emissions, which leads to an increase in the greenhouse effect and groundwater pollution in the absence of protective engineering structures at landfills.

The relevance of the topic is due to the need to find effective solutions for decentralised biowaste management in dense urban areas. The use of biotechnological methods, in particular effective microorganisms (EM) technologies, proposed by Japanese professor Teruo Higa, allows not only to accelerate the destruction of organics, but also to direct the process through fermentation, rather than rotting.

EM technology is based on the coexistence of lactic acid bacteria, yeast, and photosynthetic bacteria. This allows food waste to be converted into fertiliser (fermented mass) and EM liquid, which minimises the negative impact on the environment and contributes to the restoration of biogeochemical cycles.

The study was conducted by a team of students to assess the practical potential of the liquid EM preparation "Emochka" for home composting.

Research object: the process of fermentation of kitchen biowaste.

Toolkit afterding: specialised household EM composter with a sealed lid, double bottom and drain tap; EM preparation "Emochka" (activated solution of effective microorganisms), laboratory scales (accuracy 1 g), laboratory thermometer, pH meter, universal indicator paper, measuring containers.

The research algorithm involved performing a series of repetitive procedures:

1. Preparation: grinding and weighing organic waste (residues of vegetables, fruits, coffee grounds, etc.).
2. Stacking: layering biowaste into a composter.
3. Inoculation: spraying each layer with a solution of EM preparation (1:100).
4. Exposure: exposure under anaerobic conditions for seven days.
5. Monitoring: sampling and measuring the volume of the formed EM liquid, determining physicochemical parameters (Table 1), as well as recording organoleptic parameters.

Table 1

Physico-chemical indicators of the fermentation process

Parameter	Research stage (day)					
	7	14	21	28	35	42
Temperature, °C	19,5	20	19,5	17	17	18
Humidity, %	91,5	78	83,7	75	78,3	–
Compost pH value	8,5	6,5	5	5	5	5
pH value of compost liquid	5	5	4,51	4,28	4	–

During the experiment, a gradual decrease in the temperature of the compost mass from 20 °C to 17 °C was observed, which indicates the stabilisation of the fermentation process. The pH level tended to decrease (from 6–7 to 5), which indicates the active course of acid fermentation under the influence of the EM

preparation. The humidity of the compost mass gradually decreased, which may be due to the evaporation of the liquid and the course of biochemical processes of decomposition of organic matter, as well as the low humidity of biowaste.

During six visits, consistent changes in the appearance and smell of the compost mass were recorded, reflecting the typical course of anaerobic fermentation under the influence of the liquid EM preparation “Emochka”. In the initial stages (week 1), the compost consisted of fresh organic waste with a well-preserved structure, and mixed mold was observed on the surface — white, grey, and a small amount of blue. The smell was sharp, pungent and sour, which corresponded to the high content of cabbage components and the beginning of acid-forming processes.

In the following weeks of fermentation, the structure of the waste gradually changed: more mucus appeared, the amount of white mold increased, and the mass itself darkened and became softer. At the same time, the smell lost its sharpness and acquired a more stable sour-fruity character. Observations indicated the activation of fermentative microorganisms, which suppressed the development of undesirable microbial groups, in particular those that cause rot.

Table 2

Results of monitoring organoleptic indicators of the biowaste fermentation process

Research stage	Appearance of compost mass	Mildew	Scent	EM fluid output, ml
Week 1	Fresh organic waste with a clear structure; beginning of decomposition	White, gray, blue (very little)	Sharp, unpleasant, caustic, sour	—
Week 2	Increased mucus; waste darkened	Only white	Stable, less harsh; fruity aroma with a sour note; liquid odor is sweet and sour, not harsh	140
Week 3	Moistened mass, presence of liquid fraction; individual spots of white mold; the structure of waste is disturbed	White (isolated spots)	Less pronounced, sour	137
Week 4	Significant spread of white mold; intense decomposition; homogeneous mass	White (active surface coating)	Strongly acidic, no signs of rot	127

Research stage	Appearance of compost mass	Mildew	Scent	EM fluid output, ml
Week 5	Mold evenly distributed; deep decomposition; soft, uniform structure	White (a significant amount)	Stable acidic, typical of anaerobic fermentation	92
Week 6	Significant volume reduction; significantly degraded structure	White (even top coat coverage)	Weakly pronounced, sweet and sour; no signs of rot; sign of stabilisation of fermentation	44

The middle of the experiment was characterised by intensive decomposition of organic residues, which was manifested in the overmoistening of the mass, a decrease in its structural integrity and the dominance of white mold, evenly distributed over the surface. The smell during this period was predominantly sour, typical of anaerobic fermentation, but without signs of rotting, which indicated the stability of the process and the effective operation of the EM culture.

At the final stage, the compost mass significantly decreased in volume and acquired a homogeneous, degraded structure - individual wastes no longer retained their original form. The upper layer was completely covered with white mold, which corresponds to a healthy fermentation process. The smell became weakly pronounced, sweet-sour and stable, which indicates the completion of the active fermentation phase and the transition of the compost to the stabilisation stage.

Based on the research conducted, the following conclusions can be formulated:

1. Efficiency of the method: the use of liquid EM preparations is a highly effective way of treating biowaste in city apartments. The method allows you to avoid rotting and the formation of unpleasant odours.

2. Resource potential: the process provides two types of biofertilizers: a solid fermented substrate and a liquid concentrate rich in amino acids and antioxidants.

3. Climate significance: local organic recycling is a direct contribution to the fight against climate change, as it prevents the formation of methane in landfills.

4. Social aspect: popularising EM technologies among the population can be a key factor in the transition to a "zero waste" culture. The absence of odours and ease of use make this method accessible to a wide range of citizens.

To further scale up the technology, it is advisable to recommend the development of municipal programs to support home composting and the inclusion of relevant courses in environmental education for youth.

REFERENCES

1. Waste Framework Directive : [electronic resource] / European Commission; Directorate-General for Environment. URL: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en(date of application: 07.05.2026).
2. On waste management: Law of Ukraine dated 20.06.2022 No. 2320–IX. URL: <https://zakon.rada.gov.ua/laws/show/2320–20#Text> (in Ukrainian).
3. National Waste Management Plan until 2033: Order of the Cabinet of Ministers of Ukraine dated 27.12.2024 No. 1353–r. URL: <https://zakon.rada.gov.ua/laws/show/1353–2024–%D1%80#Text> (in Ukrainian).

TRENDS AND PROSPECTS FOR THE DEVELOPMENT OF THE GREEN BUILDING PROJECTS MARKET IN THE CONTEXT OF CLIMATE CHANGE

Ruslana Zadorozhna¹, Tetyana Dyman¹, Nataliya Dyman¹

*¹Bila Tserkva National Agrarian University,
ruslana.zadorozhna@btsau.edu.ua*

Construction, as one of the fundamental sectors of the economy, provides the material foundation for society's functioning and creates the necessary basis for the development of other sectors. In the face of the growing adverse effects of climate change, the role of green construction as a tool for reducing human impact on the natural environment is becoming increasingly important.

Green construction involves a comprehensive approach to the design, construction, and operation of buildings that minimizes environmental impact, ensures the rational use of resources, and promotes a high quality of life for the population [1, p. 81].

“Green” buildings are designed, constructed, and operated in such a way as to minimize the impact on the natural environment while maximizing the well-being of residents and the efficient use of resources. They utilize energy-efficient systems, environmentally friendly materials, water-saving technologies, and low-emission construction methods [2, p. 205]. As a result, the carbon footprint is reduced, operating costs are lowered, indoor environmental quality is improved, and long-term environmental sustainability is maintained.

Green construction makes extensive use of innovative solutions, including modular prefabricated construction, smart sensors, building automation based on the Internet of Things, and energy consumption optimization using artificial intelligence.

Building efficiency is improving thanks to advanced thermal insulation, energy-efficient glazing, and modern composite materials. These technologies make “green” buildings more technologically advanced, while reducing emissions throughout their entire life cycle and lowering operating costs.

Increased comfort for residents also makes green building projects more attractive to residential real estate buyers.

Guided by the principles of sustainable development, national governments and developers are supporting environmentally focused construction projects, leading to the rapid growth of the global green building market (Fig. 1).

According to Global Market Insights Inc., if the market maintains its average annual growth rate of 10.2 %, its value is expected to reach USD 1.39 trillion by 2034 [3].

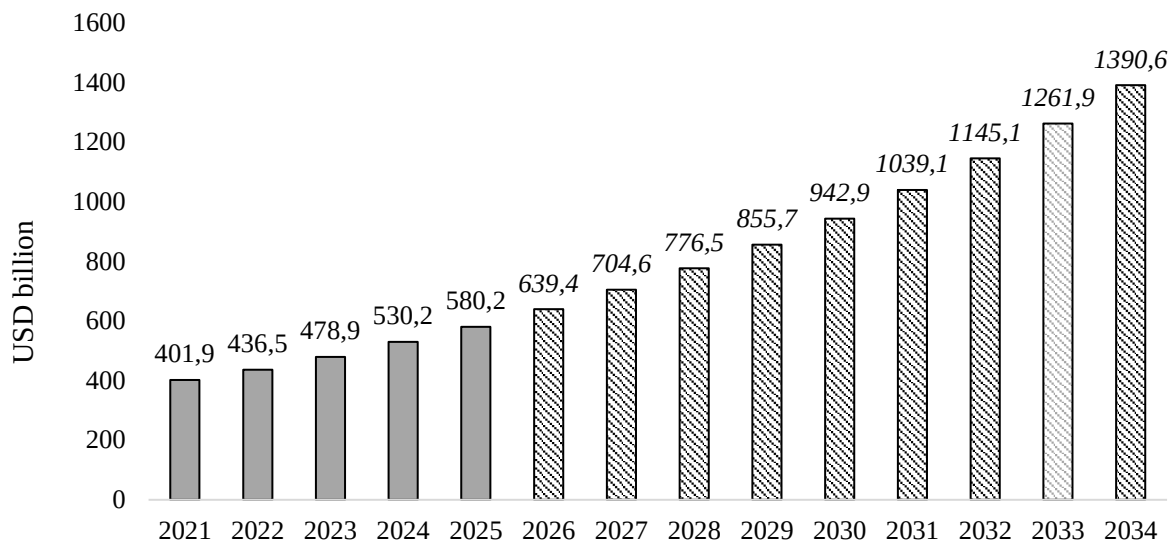


Fig. 1. Green construction market size in 2021-2025 and forecast for 2026-2034
Source: Compiled by the authors based on [3]

The green construction market is segmented based on several criteria:

- by end use – residential, commercial, and industrial real estate;
- by project type – new construction, renovation;
- by product – interior, exterior, other;
- by material type – structural, insulation, finishing, glass, and glazing sectors;
- by sales channels – online, offline.

In 2024, the residential segment accounted for approximately 45% of the market volume, equivalent to USD 238.5 billion; industrial real estate accounted for USD 94.8 billion.

The commercial segment is expected to exceed USD 450 billion by 2034. This sector is growing rapidly as companies seek to create energy-efficient facilities that reduce operating costs and contribute to achieving corporate sustainability goals [3].

According to forecasts, the green building market in North America will reach USD 400 billion by 2034. The United States holds a leading position in this

market: in 2024, its share was approximately 80%, and the revenue of American companies was nearly USD 132 billion.

The green building market in Latin America is the fastest-growing segment of the global market [4].

The European market is shaped by government institutions' strict approaches to climate policy and compliance with energy efficiency regulations. For example, in May 2024, the European Union reported on the progress of the "Renovation Wave" initiative, under which member states presented revised long-term renovation strategies in accordance with the updated Energy Performance of Buildings Directive. These strategies outline pathways to achieving net-zero emissions from buildings by 2050, with interim targets for 2030 and 2040 [3].

At the individual company level, the leaders in the green building industry are BASF, IBM, General Electric Company, Siemens, and Schneider Electric. Collectively, they accounted for approximately 40% of the market in 2024.

The chemical company BASF supplies construction chemicals, insulation materials, coatings, and eco-friendly solutions for buildings. The company's portfolio includes polyurethane insulation systems, concrete additives, and external insulation cladding systems.

IBM specializes in solutions for smart buildings, Internet of Things platforms, artificial intelligence for building optimization, and data analytics. Its Maximo suite of applications includes building management capabilities, while Watson IoT provides predictive maintenance and energy consumption optimization.

General Electric offers comprehensive solutions covering building automation and management, energy-efficient lighting, heating, ventilation, and air conditioning (HVAC) equipment, renewable energy systems, energy storage, and digital platforms for building energy management. This comprehensive approach makes General Electric a preferred partner for large-scale commercial and institutional green building projects.

The technology company Siemens provides services in building automation, fire safety, and heating, ventilation, and air conditioning (HVAC) systems management. The company's platform provides integrated building management, while its smart infrastructure division focuses on the electrification, automation, and digitalization of buildings.

Schneider Electric is a recognized leader in sustainable development, developing comprehensive solutions for zero-emission buildings. The company specializes in energy management and automation. Its EcoStruxure platform offers Internet of Things-based solutions, including building management systems, power distribution, lighting control, and energy analytics.

Thus, the key drivers of the green building market are growing awareness of environmental sustainability and the economic benefits associated with implementing green building principles.

It is advisable to draw on global experience in implementing green building projects during Ukraine's post-war reconstruction. This will make it possible to achieve three important outcomes: first, to ensure the efficient use of energy resources; second, to reduce the negative impact on the natural environment; and third, to create comfortable living conditions for society.

REFERENCES

1. Hlushchenko, R. (2025). Challenges of green construction in Ukraine at the stages of regulatory implementation and practical realization. *Environmental Safety and Natural Resources*, 57(1), 79-94. <https://es-journal.in.ua/article/view/358129>
2. Vranayova, Z., Tkachenko, T., Lis, A., Savchenko, O., Vranay, F. (2023). Green Buildings in Pursuit of Healthy and Safe Human Living Environment. *System Safety: Human – Technical Facility – Environment*, № 5(1), 204-211. <https://doi.org/doi:10.2478/czoto-2023-0022>
3. Green Building Market Size & Share 2025-2034. <https://www.gminsights.com/industry-analysis/green-building-market>
4. Commercial Green Construction Market (2025-2030). <https://www.grandviewresearch.com/industry-analysis/commercial-green-construction-market-report>.

USE OF RECYCLED PLASTICS FROM CONSTRUCTION WASTE FOR 3D PRINTING OF NON-STANDARD FASTENERS FOR ENGINEERING SYSTEMS: FROM BIM MODEL TO PRODUCT

Dmytro Kryshchuk

*Kyiv National University of Construction and Architecture,
kryshchuk_ds-2024@knuba.edu.ua*

Introduction and problem statement. The modern construction industry constantly faces unprecedented environmental and logistical challenges. On the one hand, the global transition to the "Green Construction" concept requires minimizing the carbon footprint and radically reducing the volume of construction waste. On the other hand, in the context of Ukraine's post-war recovery and the active development of civil infrastructure, there is an urgent need for fast, efficient, and adaptive engineering solutions.

According to statistics, a significant share of construction waste on sites consists of polymer material residues: offcuts of water supply and drainage pipes, elements of plastic permanent formwork, protective corrugations of cable routes, packaging materials, and insulation. Traditionally, these materials are classified as illiquid waste and transported to domestic solid waste landfills, where their natural decomposition period can last hundreds of years.

At the same time, the active implementation of Building Information

Modeling (BIM) technologies has radically changed the approach to designing engineering networks. Modern BIM complexes (e.g., Autodesk Revit, ArchiCAD) allow designing ventilation, water supply, and electrical cable routes with extremely complex spatial geometry, bypassing load-bearing structures and architectural elements. However, at the stage of physical installation of such networks, a significant problem arises: standard factory fasteners (metal clamps, traverses, consoles) have a fixed geometry. To install them in cramped technical rooms or at reconstruction facilities, builders often have to modify parts on site (bend, weld, use an excessive number of adapters), which leads to time losses, reduced node reliability, and increased project costs.

Justification of the chosen direction. The focus of this study is specifically on engineering systems and non-standard (custom) parts, which is due to clear technological and economic factors. Firstly, the physical and mechanical limitations of recycled polymers do not allow their use for printing large-sized load-bearing structures (walls or floors). Still, they perfectly withstand local loads from engineering systems. Secondly, the economy of mass production makes 3D printing of standard, typical fasteners (which are produced in millions of copies by injection molding) absolutely unprofitable. The main advantage of additive technologies lies precisely in the speed of response to unpredictable spatial collisions. The ability to design a unique part and print it directly on the construction site within a few hours eliminates the need for "artisanal" welding or for weeks of waiting for specific factory-made elements.

Aim of the study. Development and justification of a closed technological cycle (within the framework of the circular economy) for recycling polymer construction waste into secondary filament for subsequent 3D printing of custom (non-standard) fasteners of engineering systems directly on the construction site based on spatial data of the BIM model.

Methodology and technological cycle. The proposed solution combines recycling, parametric design, and additive manufacturing (Fused Deposition Modeling - FDM). The process consists of four consecutive stages.

Stage 1. Recycling of construction waste and filament manufacturing.

The process begins with sorting plastic scrap on the construction site by polymer labeling (mainly PET, PP, ABS, or PLA). The selected material is cleaned of construction dust and mortar residues using hydrocyclone units. Next, the clean plastic is crushed in an industrial shredder to a granule fraction (3-5 mm). A critical stage is the dehydration (drying) of granules, since most engineering polymers (especially PETG and ABS) are hygroscopic, and moisture leads to defects during extrusion. The dried granules are loaded into a local extruder, which melts the material and forms a secondary thread (filament) of standardized diameter (1.75 mm or 2.85 mm) with constant thickness control using laser micrometers.

At the sorting stage, it is critical to separate chlorine-containing polymers (in particular PVC, from which sewer pipes are made), since their thermal extrusion

releases toxic gases, making them unsuitable for local 3D printing without specialized chemical equipment. Therefore, the main source of raw materials will be PETG, PP, and ABS waste. And it is advisable to recycle PVC by hot-pressing it into large-sized landscaping elements or using it as an inert filler in building mixtures.

Stage 2. Analysis of the BIM model and parametric design of the node.
During the installation preparation stage, a specialist (BIM coordinator) analyzes the consolidated building information model in Autodesk Navisworks or an equivalent program. Upon detecting a spatial collision or a non-standard intersection (for example, the need to bypass a column with a bundle of cable trays at an angle of 37 degrees, Fig. 1), the basic coordinates of the attachment points are calculated. This geometry is imported into an engineering modeling environment (e.g., Autodesk Fusion 360). The engineer creates a basic (blank) of the future fastener, sets the points of fixation to the wall/ceiling, and the points of support of the engineering network. Then, boundary conditions are introduced: load vectors (pipe weight with water), vibration directions, and permissible stresses.

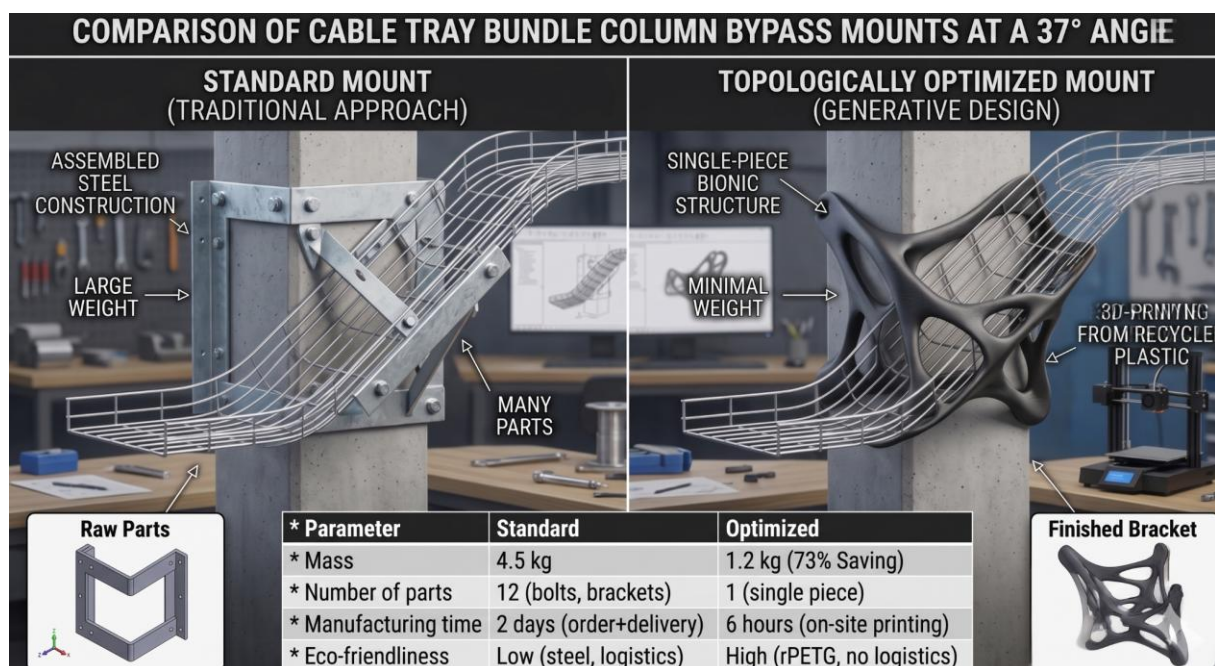


Fig. 1 Bracket comparison

Stage 3. Topology optimization (Generative design).

The most important innovation of the proposed method is the application of topology optimization algorithms. The software uses the finite element analysis (FEA) to analyze the stress-strain state of the base model under a given load. The algorithm iteratively removes material from those zones of the part that do not experience significant loads, leaving only those "stiffening ribs" that ensure force transmission. As a result, a part of a complex, bionic shape is generated. This approach reduces the mass of the part (and hence the consumption of recycled

plastic) by 30-45% compared to monolithic cast analogs, while fully maintaining the necessary load-bearing capacity and safety factor.

Stage 4. Additive manufacturing (3D printing) on-site.

The generated 3D model is converted into G-code format using a slicer (e.g., Ultimaker Cura), where print parameters are set: layer thickness (usually 0.2-0.3 mm for engineering parts), infill percentage (from 50% to 100% depending on the load), number of wall perimeters, and temperature conditions. Printing is carried out on a local 3D printer (desktop- or industrial-grade) directly in a mobile workshop on the construction site. This allows obtaining a finished part of a complex shape in just a few hours after a collision is detected in the BIM model.

Results of the study of physical and mechanical properties.

To confirm the feasibility of using secondary polymers, an analysis of their physical and mechanical properties was conducted. Experimental data indicate that the use of recycled plastics is fully justified for elements of engineering systems that operate in normal operating conditions (not exposed to temperatures above 70-80 °C and aggressive chemical environments). Comparative characteristics of the most common recycled polymers are presented in Table 1.

Table 1

Comparative characteristics of recycled polymers for 3D printing of engineering fasteners

Polymer Type	Typical Source on Construction Site	Tensile Strength , MPa	Recommended Application Scope in Systems
rPETG (Polyethylene Terephthalate Glycol)	Offcuts of plastic pipes, strong packaging, and containers	45-50	Fasteners for lightweight ventilation air ducts, cable trays, and suspensions for low-voltage networks
rABS (Acrylonitrile Butadiene Styrene)	Residues of plastic permanent formwork, equipment casings	40-42	Fixation nodes for cold water supply pipes, rigid distance clamps
rPP (Polypropylene)	Packaging containers, offcuts of polypropylene pipes and fittings	25-30	Flexible clips, insulating inserts, and gaskets for pipe vibration isolation

The table shows that secondary PETG (rPETG) demonstrates the highest tensile strength and high interlayer adhesion during 3D printing, making it a universal material for most suspension systems. Secondary ABS (rABS) is characterized by better impact resistance, but requires the use of 3D printers with a closed thermal chamber to prevent temperature deformations (shrinkage) during printing.

Economic and environmental efficiency.

The application of the proposed concept has a dual positive effect. From an economic point of view, decentralized manufacturing ("on-site production") completely eliminates the costs of complex logistics, ordering small batches of custom parts from factories, and waiting time for delivery (which can take weeks). This is critically important in the reconstruction of hospitals, shelters, or critical infrastructure facilities.

From an environmental point of view, this approach is a perfect illustration of the principles of sustainable development. First, the load on landfills is reduced. Second, plastic recycling and its 3D printing require significantly less energy than primary injection molding at large enterprises. By eliminating the "factory - warehouse - construction site" logistics chain, the overall carbon footprint of the process of providing the facility with fasteners is reduced by 40-60%.

Conclusions.

1. Integration of BIM design technologies, topology optimization, and construction 3D printing opens up fundamentally new opportunities for solving complex engineering tasks of network installation at non-standard facilities.

2. Construction polymer waste is a valuable resource. Processing PETG, ABS, and PP directly on site allows obtaining a filament with sufficient physical and mechanical characteristics for the manufacture of fasteners and auxiliary structures.

3. Topology optimization compensates for the slight decrease in the strength of secondary plastics (compared to primary ones) by rationally distributing the mass in the part, while saving significant amounts of material.

4. Further prospects for the development of this direction lie in the development of mobile automated complexes (container type) that would combine a shredder, an extruder, and an industrial 3D printer for quick deployment at large construction sites. Also, a necessary step is to conduct large-scale tests of printed elements for durability and fire resistance with a view to their future standardization in the State Building Norms (DBN) of Ukraine.

REFERENCES

1. Cruz Sanchez F. A., Boudaoud H., Camargo M., Pearce J. M. Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy. *Journal of Cleaner Production*. 2020. Vol. 257. P. 120–149.

2. Liu J., Gaynor A. T., Chen S., Kang Z., Suresh K., Takezawa A., ... & To A. C. Current and future trends in topology optimization for additive manufacturing. *Structural and Multidisciplinary Optimization*. 2018. Vol. 57, Issue 6. P. 2457–2483.

3. Zander N. E., Gillan M., Burckhard Z., Gardea F. Recycled polymer feedstocks for 3D printing of thermoplastic materials. *Additive Manufacturing*. 2018. Vol. 21. P. 34–41.

4. Woern A. L., Byard D. J., Oakley R. B. Fused Filament Fabrication 3D Printing Using Recycled Materials. *Resources, Conservation & Recycling*. 2018. Vol. 128. P. 37–44.
5. DSTU ISO 14040:2013. Environmental management. Life cycle assessment. Principles and framework (ISO 14040:2006, IDT). Kyiv: Ministry of Economic Development of Ukraine, 2014. 24 p.
6. European Commission. A new Circular Economy Action Plan – For a cleaner and more competitive Europe. Brussels: European Union, 2020. URL: https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

BACKGROUND ENVIRONMENTAL MONITORING AS A TOOL FOR ENSURING SUSTAINABLE GREEN BUILDING

Khrystyna Diachenko¹, Yuliia Bereznytska¹

¹Kyiv National University of Construction and Architecture

1. Introduction

Modern cities are developing very rapidly, and construction plays a key role in this process. However, along with development, the pressure on the environment is also increasing: air quality deteriorates, noise levels rise, and the microclimate of territories changes. In response to these challenges, the concept of green building has emerged, which involves creating buildings with minimal impact on the environment. However, for a building to truly be “green,” it is not enough to simply use modern materials or energy-efficient technologies. It is important to take into account the initial condition of the territory.

This is where background environmental monitoring plays an important role. It makes it possible to determine the baseline environmental indicators before construction begins and later assess whether the situation has improved or, on the contrary, worsened.

The purpose of this paper is to show how background monitoring affects the quality of green building and why it should be integrated into modern construction projects.

2. Theoretical Aspects of Background Environmental Monitoring

Environmental monitoring is a system for observing the state of the environment. Its main task is to identify changes and assess the impact of various factors.

Background monitoring is an important part of this system. It makes it possible to determine the state of the environment before any activity begins, for example construction.

Its specific feature is that it provides a “starting point” with which all subsequent changes can be compared.

During monitoring, the following parameters are assessed:

- air quality;
- noise level;
- soil condition;
- water resources;
- microclimate.

This approach makes it possible to comprehensively assess the studied territory [1].

3. The Role of Monitoring in Green Building

Background environmental monitoring is one of the key elements of green building. It forms the basis for making justified environmental decisions at all stages of the implementation of a construction project. The use of background monitoring makes it possible to assess the suitability of a territory for development more accurately, identify possible environmental risks in a timely manner, and take them into account during the design process. This makes it possible to adapt construction solutions to the specific environmental conditions and reduce the negative impact on the environment. For example, if there is an increased noise level or atmospheric air pollution on the territory, these factors should be taken into account at the design stage through the application of appropriate architectural and technical solutions.

Thus, green building should be considered not only as the implementation of modern technologies, but also as a process based on an in-depth analysis of the state of the environment and its specific features [2].

4. Key Environmental Indicators of Background Monitoring

Table 1 [5] presents the main indicators of background environmental monitoring according to which control is carried out.

Table 1

Main Monitoring Indicators

Indicator	What is Assessed	Importance for Construction
Air	PM2.5, CO ₂	Impact on health
Noise	dB	Living comfort
Soil	pollution	Safety of the territory
Water	quality	Environmental stability
Microclimate	temperature	Energy efficiency

5. Modern Technologies and the Smart Approach

In modern conditions, environmental monitoring is reaching a new level of development due to the introduction of innovative technologies. Air quality sensors, CO₂ concentration control systems, automated ventilation systems, as well as IoT solutions that ensure data collection and processing in real time, are actively used.

The concept of “smart buildings” is becoming especially widespread. In such buildings, the parameters of the indoor environment are regulated automatically depending on the current state of the environment. Such systems make it possible to respond quickly to changes in environmental indicators and maintain optimal conditions for people.

The use of modern technologies in the field of environmental monitoring helps reduce energy consumption, increase comfort levels, and improve the quality of life of the population. In addition, it ensures more efficient resource management and reduces the negative impact of buildings on the environment [3-5].

6. Comparison of Environmental Monitoring in Ukraine and the EU

A comparative analysis of approaches to environmental monitoring was conducted and is presented in Table 2.

Table 2

Comparison of Environmental Monitoring

Indicator	Ukraine	EU
Background monitoring	used partially; it has a branched multi-component structure, the functioning and effectiveness of which are difficult to track	mandatory
Technologies	partly limited due to insufficient state funding	modern (smart)
Implementation control	periodic	continuous
Certification	currently not systematic; it is rarely used for residential and industrial buildings with a long service life	actively used for buildings of all service-life periods

It was established that in EU countries environmental monitoring is a mandatory element of construction and is carried out using modern technologies. In Ukraine, this system requires further development, particularly in the direction of digitalization and integration into the design process.

An important feature is the widespread use of automated monitoring systems that ensure continuous control of the main environmental indicators, such as atmospheric air quality, noise level, temperature conditions, and humidity. The use of such technologies makes it possible to quickly identify deviations from standard values and promptly implement measures to eliminate them.

In addition, environmental certification systems for buildings, in particular LEED and BREEAM, play a significant role in EU countries. They establish clear requirements for taking environmental indicators into account at all stages of construction project implementation. This helps increase the level of

environmental responsibility of developers and ensures a comprehensive approach to assessing the impact of construction on the environment.

In Ukraine, the environmental monitoring system is still at the stage of development and is characterized by an insufficient level of integration into the design and construction process. In most cases, monitoring is episodic and does not ensure continuous control of environmental parameters, which reduces the effectiveness of environmental protection measures.

Thus, in order to increase the level of sustainability of the construction industry in Ukraine, it is advisable to introduce modern digital monitoring technologies, develop automated control systems, and expand the use of international environmental certification standards [3-4].

7. Conclusions

The study established that background environmental monitoring is an important tool for assessing the state of the environment and ensuring the environmental safety of construction. Its use makes it possible to make justified design decisions and minimize negative impact on the environment. The comparison with EU countries showed a higher level of integration of monitoring into construction practice, which is achieved through the use of modern technologies and certification systems.

Thus, the implementation of comprehensive environmental monitoring is a necessary condition for the development of green building in Ukraine.

REFERENCES

1. Bobrovskiy O.O. Environmental Monitoring of the Environment. - Kyiv: Lybid, 2020.
2. European Commission. Level(s): A common EU framework for sustainable buildings. - Brussels, 2022.
3. World Green Building Council. Global Status Report for Buildings and Construction. - 2023.
4. European Environment Agency. Air Quality in Europe Report. - 2023.
5. DBN V.2.6-31:2021. Thermal Insulation of Buildings.

MEASURES TO IMPROVE THE ENERGY EFFICIENCY AND ECOLOGICAL COMPATIBILITY OF IN-BUILDING GAS SUPPLY SYSTEMS

Kostiantyn Predun¹, Vitalii Eismont¹,

*¹Kyiv National University of Construction and Architecture
predun.km@knuba.edu.ua, eismont_vs-2024@knuba.edu.ua*

The theory of ‘sustainable development’ [1] is regarded as one of the most promising ideologies of the 21st century. The ideas of sustainable development were officially proclaimed at the International Conference on Environment and

Development in Rio de Janeiro (Earth Summit) in 1992 [2]. It was there that the environment and socio-economic development were considered for the first time as interrelated and interdependent areas.

The concept of sustainable development comprises 17 Global Goals, adopted at the UN Summit on Sustainable Development, which took place during the 70th session of the UN in New York in 2015 [1]. Among these, the following are worth noting:

- Goal 7 «Affordable and Clean Energy», the aim of which is to ensure that humanity has access to affordable, reliable, sustainable and modern, environmentally friendly sources of energy;
- Goal 12 «Responsible Consumption and Production» aims to ensure a transition to sustainable consumption and production patterns;
- Goal 13 «Mitigating the effects of climate change» involves developing and implementing urgent measures to combat climate change and its consequences.

By signing the Association Agreement with the European Union [3], Ukraine has taken a historic decision regarding its development priorities. This decision not only entails a number of obligations that must be fully reflected in the country's socio-economic development priorities, but also necessitates a change in our state's approach to shaping its energy policy, which is designed to meet the needs of society and the economy for fuel and energy resources in a technically reliable and safe, economically efficient, and environmentally acceptable manner, thereby ensuring improved living conditions for its citizens.

The Law of Ukraine «On the Energy Efficiency of Buildings» [4] has established the priority of measures to ensure the energy efficiency of buildings:

- 1) improving the thermal performance of building envelopes;
- 2) installing meters and controls for energy consumption;
- 3) implementing automated monitoring and control systems;
- 4) modernising heating, ventilation, hot water supply and lighting systems;
- 5) using renewable and/or alternative energy sources and/or types of fuel (using engineering equipment located within the building, in annexed premises and on the adjacent site);
- 6) installation of electric storage heating systems;
- 7) implementation of other measures to improve the energy efficiency of buildings.

To improve the energy efficiency and environmental compatibility of in-building gas supply systems—as one of the key elements of the engineering energy infrastructure in built-up areas—the following measures can be proposed:

1. Additional thermal insulation of a building's external envelope to increase the thermal resistance of the existing external envelope to the level required by DBN V.2.6-31:2021 'Thermal Insulation and Energy Efficiency of Buildings' [5]
 - will ensure a reduction in the thermal output of heat-generating installations

installed to maintain standardised indoor air conditions in buildings and structures of various purposes during the cold season, and consequently in natural gas consumption for heating purposes.

Table 1

Trends in changes to the thermal insulation properties of external envelopes in Ukraine (using Temperature Zone I as an example)

Type of external fencing	Values of heat transfer resistance coefficients, $\text{m}^2\cdot\text{K}/\text{W}$ per year:				Dynamics of change
	1990	2006	2016	2022	
External walls	0,75	2,80	3,30	4,00	5,33
Light openings	0,34	0,60	0,75	0,90	2,65
Attic floor	1,01	4,95	4,95	6,00	5,94
Basement ceiling	1,68	2,80	3,75	5,00	2,98
Doors	0,45	0,60	0,6	0,70	1,56

An analysis of the results shown in Table 1 indicates that, over the last 35 years in Ukraine, improvements to regulatory documents governing the thermal insulation requirements for external building envelopes have enabled heat loss to be reduced by a factor of between 1.56 and 5.94, which significantly exceeds the corresponding trend in Finland. Moreover, the main reduction was achieved in external walls (by a factor of 5.33), as the structural element of a building's external envelope with the largest surface area, as well as in roof structures (by a factor of 5.94), as the envelope structure with the highest heat loss emissions.

2. The installation of smart meters to measure fuel consumption in units of energy, which eliminates any external interference in data collection and transmission (there is no longer any need for monthly adjustments to meter readings by applying coefficients whose values depend on the average monthly outdoor temperature), i.e. the accuracy of readings is ensured. The proposed meters can be easily integrated into the overall natural gas metering systems in the settlement [6].

3. Replacement of existing heating boilers/appliances with modern ones, thereby increasing the natural gas utilisation rate (improving energy efficiency), reducing emissions of combustion products (pollutants – carbon and nitrogen oxides, greenhouse gases – nitrogen dioxide, methane, nitrous oxide) into the atmosphere (making the energy supply system more biosphere-compatible).

The use of alternative fuels – such as waste from agribusinesses, timber processing plants and similar sources – is possible, but requires appropriate

justification (involving the replacement of a settlement's centralised gas supply system with an autonomous/individual system using non-conventional fuels) for use in each individual home [7]. Such a replacement is relevant for municipal heating companies, agricultural enterprises, and others.

4. Replacement of existing domestic gas cookers (efficiency – efficiency – not exceeding 60%), installed to meet the domestic needs of residents, with induction electric cookers (efficiency – not less than 90%). The advantages of the latter include a reduction of approximately 50% in energy consumption, as the energy is used directly to heat the food rather than raising the ambient temperature (of the kitchen), thereby reducing environmental pollution. Especially if the energy is generated from alternative sources [8]. Furthermore, electric hobs are significantly more environmentally friendly – they do not consume oxygen (burning 1 m³ of natural gas requires approximately at least 9 m³ of outside air [9]).

The auto-off function makes the hob safe to use and saves energy. This feature automatically switches off the hob when it has not been used for a certain period of time, helping to prevent potential accidents and excessive energy consumption. A similar function in domestic gas hobs is provided by a 'gas control' safety feature.

The automatic operation of an induction hob (unlike a gas hob), utilising the heat retention properties of the cookware, hob surface and so on, also helps to reduce energy consumption by approximately half.

5. Replacement (where justified) of the existing water-based heating system, typically featuring natural circulation of the heat transfer fluid and metal-bodied radiators – with cast-iron sectional gas radiators, and the installation in each room of gas convectors with a sealed combustion chamber for fuel combustion, increases the energy utilisation factor, facilitates better regulation of heat output, and maintains the operational capability and reliability of the heating system.

Implementing the proposed measures will therefore improve the operational reliability, cost-effectiveness and environmental safety of domestic gas supply systems.

REFERENCES:

1. Stalyy rozvytok [Sustainable development]. URL: https://uk.wikipedia.org/wiki/Сталий_розвиток (accessed: 20.04.2026).

2. Tsili staloho rozvytku [Sustainable Development Goals]. URL: https://uk.wikipedia.org/wiki/%D0%A6%D1%96%D0%BB%D1%96_%D1%81%D1%82%D0%B0%D0%BB%D0%BE%D0%B3%D0%BE_%D1%80%D0%BE%D0%B7%D0%B2%D0%B8%D1%82%D0%BA%D1%83 (accessed 08.05.2026).

3. Uhoda pro Asotsiatsiyu mizh Ukrayinoyu ta Yevropeys'kym soyuzom [Association Agreement between Ukraine and the European Union].

URL: https://uk.wikipedia.org/wiki/Угода_про_асоціацію_між_Україною_та_Європейським_Союзом (accessed: 08.05.2026).

4. Pro enerhetychnu efektyvnist' budivel': Zakon Ukrayiny [On the Energy Efficiency of Buildings: Law of Ukraine No. 2118-VII. – Kyiv: VVR, 2017, No. 3, p. 5, Article 359].

5. DBN «Teplova izolyatsiya ta enerhoefektyvnist' budivel'» [State building standards «Thermal insulation and energy efficiency in buildings»]. – Kyiv: Ministry of Regional Development of Ukraine, 2022. – 23 p.

6. Predun K., Obodyanska O., Franchuk U. Principal content and methodology modernization of organizational and engineering design and exploitation regulations for locality GDS // Paradigm of Knowledge. Multidisciplinary Scientific Journal. – No. 2 (34), 2019. – P. 74-92.

7. Predun K.M. Innovatsiyni tekhnolohiyi proektuvannya ta ekspluatatsiyi system enerhopostachannya v konteksti svitovykh ekolohichnykh problem [Innovative technologies for the design and operation of energy supply systems in the context of global environmental issues] // Environmental Sciences: Scientific and Practical Journal. – Kyiv, 2019. – No. 3(26). – pp. 125-131.

8. Pro vnesennya zmin do deyakykh zakoniv Ukrayiny shchodo zabezpechennya konkurentnykh umov vyrobnytstva elektrychnoyi enerhiyi z al'ternatyvnykh dzherel enerhiyi: Zakon Ukrayiny [On Amendments to Certain Laws of Ukraine Concerning the Ensuring of Competitive Conditions for the Production of Electricity from Alternative Energy Sources: Law of Ukraine]. – Bulletin of the Verkhovna Rada (VVR), 2019, No. 23, p. 89.

9. Tkachenko V.A., Sklyarenko O.M. Hazopostachannya: pidruchnyk [Gas Supply: A Textbook]. – Kyiv: IVNVKP 'Ukrheliotech', 2012. – 588 p.

MEASURES TO IMPROVE THE ENERGY EFFICIENCY AND ECOLOGICAL COMPATIBILITY OF GAS DISTRIBUTION SYSTEMS IN POPULATED AREAS

Kostiantyn Predun¹, Olha Pochka¹

*¹Kyiv National University of Construction and Architecture
predun.km@knuba.edu.ua, pochka.ob@knuba.edu.ua*

Throughout human history, our interaction with the environment has been characterised by the use of natural resources and, consequently, environmental pollution. The relationship between society and nature is a constant process of resolving the dilemma between the need to conserve natural resources and the need to consume them in order to ensure our continued existence. Sustainable use of natural resources is intended to ensure the development of modern society whilst maintaining a high quality of the human environment [1].

Gas supply systems [2] are a vital component of the engineering infrastructure in populated areas. A significant proportion of existing gas

distribution networks require modernisation due to the physical and obsolescence of the equipment. At the same time, there is a pressing need to reduce the negative impact of these systems on the natural environment [3].

To improve the energy efficiency and environmental compatibility of gas distribution systems in rural settlements, the following solutions can be proposed:

1. Replacement of gas pipeline materials

The existing gas distribution system [2] is generally a two-stage system: medium- and low-pressure gas pipelines made of steel electric-welded straight-seam pipes. The main method of laying pipes within a settlement – underground – requires protection of the networks and structures on them against corrosion, both passive (application of a protective coating) and active (using instrumental methods to direct the flow of electric current). Replacing steel pipes with polyethylene (PE) pipes makes these measures unnecessary. As a result, the guaranteed service life of gas distribution networks made from polyethylene pipes – 50 years – is approximately twice that of steel pipes, which is 20–25 years before major repairs are required.

Furthermore, the equivalent absolute wall roughness of a PE pipe $n_{PE}=0.002$ cm is approximately five times lower than that of steel pipes: $n_{ST}=0.01$ cm [4]. Over time, the wall roughness of a PE pipe decreases, whilst that of a steel pipe increases. Thus, the flow capacity of a PE pipe compared to a steel pipe of the same diameter is slightly higher (up to 10%) under all other equal conditions – pressure drop at the pipe inlet/outlet, pipe length, etc.

An analysis of the technical and economic indicators for pipes used in the construction of external gas distribution networks has shown that a system using polyethylene pipes with a diameter of up to 100 mm is cheaper than a comparable steel system (taking into account the cost of materials and construction and installation works) [3].

2. Abandoning the two-stage gas distribution system and replacing it with a single-stage medium-pressure system, with the installation of domestic gas pressure regulators [2].

In rural areas, when designing natural gas distribution networks, the maximum hourly fuel flow rates in the design sections are typically low, despite the pipelines being of considerable length. The maximum diameter of gas pipelines, as a rule, based on the results of hydraulic calculations performed using the ‘HYDRA’ software package, does not exceed 100 mm for both low-pressure and medium-pressure gas systems. Consequently, replacing a two-stage gas distribution system with a single-stage one will allow its material consumption to be reduced by almost half. Operating costs are also reduced. Furthermore, the manufacture of materials and equipment is inextricably linked to energy consumption in production and, consequently, to environmental pollution from waste.

3. The use of alternative fuels.

Biogas has been known to humankind since ancient times. It has been used, and continues to be used today, primarily in densely populated countries with warm climates, particularly in China and India. More recently, it has also been used in European Union member states. Biogas is a renewable energy source; therefore, with the depletion of natural organic fuels – natural gas, oil, coal, etc. – the production and use of synthetic combustible gases is a pressing issue of our time.

In Ukraine, according to statistical data [5], of the approximately 13.5 million tonnes of agricultural waste generated annually, the most common types are:

- 1) plant-based waste (7,742,000 tonnes or 57%);
- 2) animal excrement, urea and manure (4,938 thousand tonnes or 37%);
- 3) animal waste and mixed food waste (897 thousand tonnes or 6%).

If one compares the physicochemical properties of biogas with the quality requirements for natural gas set out, for example, in the Gas Transmission System Code [6], it is clear that, without further purification, biogas is unsuitable both for transmission via existing networks and for use in conventional gas equipment. Internationally, various methods of utilising such biogas are known, ranging from simple flaring directly at the point of generation without utilising the heat from the combustion products, to substantial purification bringing the methane content up to 90-95% (so-called biomethane) or the production of commercial carbon dioxide [7]. Currently, in Ukraine, given the partial destruction of the gas infrastructure, the use of biogas purified to the level of biomethane will help avoid emergency shutdowns of the gas transmission and distribution systems and ensure that end consumers are supplied with natural gas.

In Ukraine, electricity from biogas is currently generated by 73 plants with a combined capacity of 124 MW (according to the Bioenergy Association of Ukraine [8]). The feed-in tariff for electricity is approximately 12.4 euro cents per kWh. Since the start of the full-scale war with the Russian Federation, the state has not been paying producers in full – only around 40% of the pre-war tariff. The money received is not enough to cover the cost of raw materials, repay loans, and so on. Consequently, the only way forward is to switch to biomethane production as quickly as possible. Unlike electricity generated from biogas, the price of biomethane is not regulated by the state but is equal to the price of natural gas, which is at a record high.

According to the Bioenergy Association of Ukraine, the cost of a new plant with a capacity of 10 million m³ of biomethane per year is up to €16 million. The cost of retrofitting an existing biogas plant of similar capacity with a biomethane production module is significantly lower – approximately €5 million.

Overall, Ukraine's potential for biomethane production stands at around 10 billion m³ per year. This represents one-third of Ukraine's pre-war gas consumption. The most promising regions are Vinnytsia, Kyiv, Cherkasy,

Poltava, Dnipropetrovsk and Donetsk. Ukraine will be able to realise this potential, but only in the long term, not before 2030 [8].

Once the war ends, analysts predict a boom in the construction of new biomethane production facilities, similar to what is currently being seen in Europe. For example, in France, a new biomethane plant is commissioned every week.

By the end of 2025, a total of approximately 0.1 billion m³ of biomethane will have been produced in Ukraine. The use of fuel obtained in this way allows, with appropriate justification, for the full or partial coverage of the demand for grid natural gas, for example, during the warmer months for certain categories of consumers. Furthermore, biomethane plants represent a decentralisation of fuel supply sources. Consequently, this enhances the operational reliability of energy supply to both settlements and individual facilities [9].

At present, despite the full-scale aggression by the Russian Federation, Ukraine is pursuing its strategic course – achieving full membership of the European Union, which, amongst other things, involves decarbonising the economy (improving energy efficiency, recycling accumulated waste, the development of renewable energy sources and the circular economy, and alignment with the ‘European Green Deal’ initiative). By declaring its commitment to the principles of sustainable development, Ukraine has recognised that the development of renewable energy sources, the reduction in the consumption of traditional fossil fuels, and so on, are important factors in enhancing energy security and reducing the economy’s anthropogenic impact on the natural environment.

REFERENCES

1. Stalyy rozvytok [Sustainable development]. URL: https://uk.wikipedia.org/wiki/Сталий_розвиток (accessed: 20.04.2026).
2. Yenin P.M., Shyshko H.H., Predun K.M. Hazopostachannya naselenykh punktiv i ob’yektiv pryrodnyim hazom [Gas supply of settlements and facilities with natural gas]. – Kyiv: Lohos, 2002. – 198 p.
3. Pohani novyny. Bil’shist’ klimatohiv prohnozuyut’, shcho tempy hlobal’noho poteplinnya perevyshchat’ tsili Paryz’koyi uhody [Bad news. Most climate scientists predict that the rate of global warming will exceed the targets set out in the Paris Agreement]. URL: <https://techno.nv.ua/ukr/popsceince/unayblizhchi-20-rokiv-70-naselennya-planeti-vidchuye-na-sobi-zmini-klimatu-50451143.html> (accessed: 12.04.2026).
4. DBN V.2.5-20:2018. Hazopostachannya. Z urakhuvannyam zminy № 1. [State building codes V.2.5-20:2018. Gas supply. Taking into account amendment No. 1.] – Kyiv: Ministry of Regional Development of Ukraine, 2019. – 109 p. – Effective from 01.06.2020].
5. Natsional’na stratehiya upravlinnya vidkhodamy v Ukrayini do 2030 roku [National Waste Management Strategy for Ukraine up to 2030: approved by

Cabinet of Ministers of Ukraine Order No. 820-r of 8 November 2017 – Revised version of 17 September 2020, reference No. 826-2020-p]. URL: <https://zakon.rada.gov.ua/laws/show/820-2017-%D1%80/print> (accessed: 10.04.2026).

6. Kodeks hazotransportnoyi systemy. Dokument z1378-15, chynnyy, potochna redaktsiya. – Redaktsiya vid 15.09.2025, pidstava - v1182874-25. [Gas Transmission System Code. Document z1378-15, current, current edition. – Edition dated 15.09.2025, basis - v1182874-25]. URL: <https://zakon.rada.gov.ua/laws/show/z1378-15#Text> (accessed on 20 November 2025).

7. P"yatnychko O.I., Zhuk H.V., Hrytsenko A.V. et al. Dosvid utylizatsiyi zvalyshchnoho hazu v enerhetychnykh ustanovkakh v Ukrayini: Monohrafiya [Experience in the utilization of landfill gas in power plants in Ukraine: Monograph]. – Kyiv: Ahrar Media Hrup, 2015. – 126 p.

8. Zamina pryrodnomu hazu. Khto i yak buduyut' biometanovi zavody v Ukrayini i chy varto investuvaty tsey biznes [A substitute for natural gas. Who is building biomethane plants in Ukraine, how are they doing it, and is it worth investing in this business]. URL: <https://forbes.ua/money/v-ukraini-zyavlyayutsya-persh-biometanovi-zavodi-chi-varto-investuvati-v-tsey-biznes-i-skilki-mozhna-zarobiti-30092022-8713> (accessed: 20.03.2026).

9. Kostiantyn Predun, Svitlana Rubtsova, Olha Pochka, Vitalii Eismont Increasing the reliability of energy supply in Ukraine. Ventilation, Illumination and Heat-Gas Supply. – 2025. – Vol. 55. – P. 66-78. DOI: <https://doi.org/10.32347/2409-2606.2025.55>.

ENERGY EFFICIENT MULTILAYER SYSTEMS FOR THERMAL CAMOUFLAGE AND REGULATION OF THERMAL CONTRASTS IN GREEN BUILDING AND CIVIL PROTECTION

Liliya Popova¹, Serhii Skochko²

*¹“The Ukrainian-British Academic Partnership” CIC
(liliya.popova.prof@gmail.com)*

² International EcoSocial Innovative Foundation (fsahi84@gmail.com)

Abstract

The article presents a comprehensive engineering approach to managing thermal visibility and reducing thermal contrasts of construction facilities, temporary structures, shelters, and mobile modules. A method of infrared camouflage is proposed, implemented through a three-layer adaptive envelope incorporating an intermediate low-emissivity layer. The thermophysical properties of the envelope materials are analysed, and their effectiveness is mathematically substantiated based on the Stefan–Boltzmann law.

The integration of the proposed technical solution (formalised as a patent application) into a modern digital engineering environment is examined through

the use of the software system “Digital Engineering Platform.” The implementation of this method enables improved energy efficiency of buildings [1], minimisation of local heat island formation, and a significant enhancement of safety and protection levels within the framework of green building and civil protection concepts.

Keywords: thermal contrast, multilayer structure, low-emissivity materials, infrared camouflage, digital engineering platform, green building, civil protection, temporary structures.

Introduction and Relevance of the Study

Current conditions characterised by military challenges, infrastructure destruction, and the need to ensure the safety of civilian populations and personnel require a fundamental reassessment of approaches to the design of construction facilities and temporary shelters. Traditional engineering approaches have predominantly focused on mechanical strength, durability, and conventional thermal insulation of building envelopes [2]. However, the parameter of thermal visibility (surface thermal contrast) of external structures remains largely overlooked.

High heat flux and uneven surface heating lead to the formation of local thermal contrasts, which make objects easily detectable by modern infrared surveillance systems [3] and thermal imaging devices. Furthermore, within the context of *green building*, excessive thermal radiation and surface overheating contribute to the formation of local heat islands, adversely affecting the overall environmental and energy efficiency of the built environment.

Therefore, the management of emissivity characteristics of building envelopes is no longer merely a component of camouflage but represents a critical interdisciplinary engineering parameter, integrating thermophysics, materials science, civil protection, and digital engineering.

Analysis of Factors Influencing the Thermal Field of an Object

To develop effective protection measures, it is essential to recognise that the thermal field of a structure is dynamic rather than static. It is formed under the influence of a combination of factors:

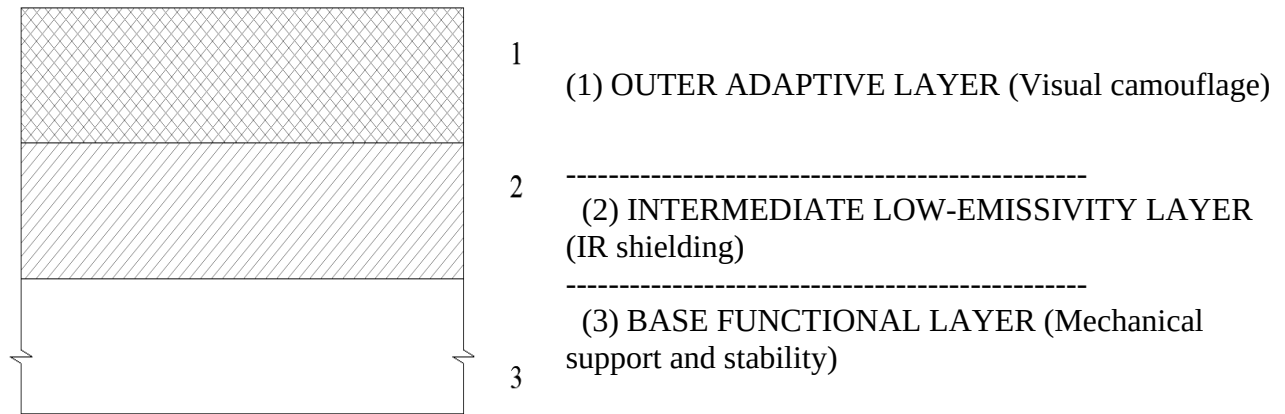
- External climatic factors: uneven surface heating due to solar radiation, fluctuations in air temperature, wind speed, and ambient humidity.
- Internal factors: heat emissions from internal sources (heating systems, equipment operation, presence of personnel or occupants).
- Structural characteristics: the presence of joints, connections, and thermal bridges, which create pronounced temperature inhomogeneities on external surfaces.

Even when high-quality conventional insulation is used, the outer layer of a building, influenced by solar radiation and wind, generates a thermal contrast with the surrounding environment. The aim of this study is to substantiate the application of an adaptive multilayer envelope capable of mitigating such contrasts.

Structure and Functionality of the Multilayer Adaptive Envelope

The technical solution proposed by the authors is based on a multilayer system that can be installed as a covering, shielding, or temporary external envelope on construction facilities, modular hospitals, humanitarian units, or equipment elements. The structure consists of three main layers (Fig. 1).

[ENVIRONMENT / LANDSCAPE]



[OBJECT SURFACE / LOAD-BEARING STRUCTURE]

Fig. 1. Schematic of the operating principle of the multilayer structure

Each layer of the system performs a strictly defined thermophysical and structural function, a detailed description of which is provided in Table 1.

Table 1

Functional Characteristics of System Components

System Element	Structural Purpose	Thermophysical Function	Significance for Green Building and Civil Protection Objects
Outer Adaptive Layer	Forms the external surface of the envelope	Partially stabilises external heat exchange and provides visual integration	Enhances the structure's adaptability to landscape, construction site, or urban environment conditions
Intermediate Low-Emissivity Layer	Located between the outer and base layers	Reduces surface emissivity and decreases radiation intensity	Lowers thermal visibility, reduces local thermal contrasts, and enhances object protection

Base Functional Layer	Interfaces with the core structure or load-bearing base	Ensures system stability and structural compatibility	Enables integration of the envelope into shelters, temporary structures, modular units, and reconstruction projects
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Physical and Mathematical Justification of the Method

The key role in reducing thermal contrast is played by the intermediate layer (2). The physical validity of its application is described by the Stefan–Boltzmann law of thermal radiation for surface heat flux density:

$$Q = \varepsilon \cdot \sigma \cdot A \cdot (T^4 - T_s^4) \quad (1)$$

where:

Q — heat flux of the object (W);

ε — surface emissivity;

$\sigma = 5.670 \cdot 10^{-8} \text{ W/m}^2\text{K}^4$ — Stefan–Boltzmann constant;

A — object area (m²);

T — object temperature (K);

T_s — ambient temperature (K).

Analysis of the equation shows that if the object temperature (T) or ambient temperature (T_s) cannot be significantly altered, the only effective engineering parameter is the reduction of surface emissivity (ε). The use of low-emissivity interlayers reduces the intensity of infrared radiation even at high internal temperatures.

During the study, the effectiveness of various materials for forming the intermediate low-emissivity layer was evaluated (Table 2).

Table 2

Efficiency of Heat Flux Reduction Depending on Material

Intermediate Layer Material	Emissivity (ε)	Heat Flux Reduction, %
Ceramic composite	0.25	30%
Polymer composite	0.12	45%
Foil-coated textile layer	0.08	60%

As demonstrated by experimental data, the use of a foil-coated textile interlayer with a low emissivity coefficient ($\varepsilon = 0.08$) provides shielding of up to 60% of the heat flux [4], representing an optimal performance indicator for protective camouflage systems.

Integration with the Digital Engineering Environment

The proposed multilayer envelope is considered not merely as a passive coating, but as a high-technology element integrated into a “Digital Engineering Platform.”

In modern practice of designing eco-buildings and civil protection facilities, the parameters of this envelope are incorporated into the relevant engineering data model already at the 3D modelling stage. This enables, in real time:

1. To model future thermal fields of the object, taking into account geographical location, solar insolation, and wind loads.
2. To automatically determine the optimal thickness and type of low-emissivity layer for specific climatic conditions.
3. To assess the overall energy efficiency of the structure (minimisation of non-productive heat losses through walls and roofs) and to predict its level of protection against thermal imaging monitoring.

Conclusions

1. The implementation of multilayer adaptive envelopes with an intermediate low-emissivity layer represents a promising and highly effective direction in the development of engineering solutions for civil protection, shelter construction, and the preservation of critical infrastructure.
2. Through the use of low-emissivity materials (in particular, foil-coated textile layers), it is possible to reduce the surface heat flux density by up to 60%, effectively eliminating local thermal contrasts in the thermal imaging spectrum.
3. From a green building perspective, adaptive envelopes stabilise surface heat exchange, mitigate the “heat island” effect, and reduce energy consumption for cooling and heating.
4. The integration of the physical parameters of the structure into the “Digital Engineering Platform” software enables automated calculations, systematic data management, and rapid adaptation of protective technologies to real reconstruction and recovery projects.

REFERENCES

1. DBN V.2.6-31:2021. Thermal Insulation and Energy Efficiency of Buildings. Kyiv: Ministry for Communities and Territories Development of Ukraine; 2022.
2. DSTU B V.2.6-189:2013. Methods for Selecting Thermal Insulation Materials for Building Insulation. Kyiv: Ministry of Regional Development of Ukraine; 2014.
3. Ivanenko O., Petrenko M. Methods of Object Camouflage in the Visible and Infrared Spectra. *Journal of Military Technologies*. 2022;3:45–52.
4. Landau L.D., Lifshitz E.M. *Course of Theoretical Physics: Heat Transfer*. Nauka; 2019.

LICHEN INDICATION AS A METHOD FOR ASSESSING AIR POLLUTION UNDER WAR CONDITIONS

Tetiana Tkachenko¹, Viktor Mileikovsky¹, Alisa Chzhan¹, Yurii Tsiuriupa¹

¹Kyiv National University of Construction and Architecture,
tkachenko.tm@knuba.edu.ua, mileikovskiy.vo@knuba.edu.ua, chzhan_al-
2025@knuba.edu.ua, tsiuriupa_yv@knuba.edu.ua

Lichens are living indicators that react sensitively to the composition of the environment (particularly to the presence of sulphur dioxide and heavy metals in the air). Their species composition is used to determine the so-called 'air purity index' (lichen indication).

Lichen indication, as a method of assessing the state of the environment using lichens, originated in 1866. It was then that the Finnish botanist Vilhelm Nylander first drew attention to the fact that the mass disappearance of lichens in Paris was linked to air pollution, and proposed calling them 'hygienometers' [1].

In general, the reaction of lichens to changes in air quality can be divided into several time stages:

1. Physiological response (from a few hours to a few days). This is the fastest stage. It cannot be detected with the naked eye. At high concentrations of SO₂ or NO_x, the processes of photosynthesis and respiration are disrupted. Chlorophyll in algae (the lichen's symbionts) is destroyed, which can be detected through analysis (for example, by changes in chlorophyll fluorescence).

2. Morphological changes (from several weeks to several months). If pollution is chronic, visible signs of damage appear: colour change (whitish, brownish, yellowish), indicating chlorosis and necrosis; deformation, where the edges of the thallus begin to curl, it becomes brittle and loses its grip on the tree bark or rock.

3. Population response and degradation (1 to 5 years). This is the stage typically recorded during environmental monitoring: species extinction, changes in structure [2].

Specificity and relevance of the method. In conditions of armed conflict, traditional instrumental air monitoring is often impossible due to infrastructure destruction and risks to personnel. Lichens, as long-lived organisms with an adsorptive mode of nutrition, act as natural accumulators of pollutants. They enable retrospective analysis of the ecological state of territories, in particular recording the consequences of shelling and fires even after a significant period of time [2–7].

The response of lichen biota to war-related pollution. Emissions from the detonation of munitions and the combustion of missile fuel create specific chemical stress.

Example: High concentrations of nitrogen oxides (NO_x) lead to the disappearance of sensitive bushy species, such as *Usnea hirta* (rough usnea). In

contrast, nitrophilic species, particularly *Xanthoria parietina* (wall lichen), may exhibit abnormal thallus growth (hypertrophy) in blast zones, which serves as a marker of nitrogen oversaturation.

Morphological changes as rapid indicators. Fires at critical infrastructure sites (oil depots, factories) are accompanied by emissions of soot and aerosols, which cause mechanical blockage of the lichen's respiratory pores.

Example: Under the influence of sulphur dioxide (SO₂), lichens of the genus *Physcia* exhibit marginal necrosis of the thalli and depigmentation (whitening) of the thallus, indicating the destruction of chlorophyll and the degradation of the photobiont under the action of toxic haze.

Heavy metals as markers of weapons use. Lichens effectively accumulate metals found in munitions (lead, antimony, copper, cadmium).

Example: Analysis of the lichen *Parmelia sulcata* (grooved parmelia), collected in active combat zones, often shows levels of chromium (Cr) and nickel (Ni) several times higher than background values, which is a direct consequence of the destruction of metal structures and the detonation of shells [2–7].

Conclusion. The use of the Atmospheric Purity Index (IAP) and the mapping of 'lichen deserts' around the epicentres of military operations allows for an objective assessment of the scale of ecocide. Lichenological data serve as a significant evidential tool for assessing long-term environmental damage and planning the subsequent restoration of territories.

REFERENCES

1. Encyclopaedia of Modern Ukraine. – Online resource. – URL: <https://esu.com.ua/article-55887>
2. Boiko T., Vinogradova O. Anthropogenic transformation of lichen flora under the influence of military actions: case studies from Eastern Ukraine. Ukrainian Botanical Journal. 2023. Vol. 80, No. 2. pp. 112–125.
3. Garkot S., Kondratyuk S. Lichen-based air quality assessment in post-war recovery conditions: monitoring of urban ecosystems in Ukraine. International Journal of Environmental Research. 2024. No. 12. pp. 45–58.
4. Dimitrova L. Biomonitoring of atmospheric deposition of heavy metals using epiphytic lichens as a tool for assessing environmental damage during armed conflicts. Environmental Pollution and Management. 2023. Issue 15. pp. 201–214.
5. Kashubina, Yu., Sokolov, V. Post-fire recovery of lichens and chemical fingerprinting of soot-contaminated areas. Journal of Applied Ecology and Nature Conservation. 2025. No. 7. pp. 88–102.
6. Malysheva N. V. Modern methods of lichen indication under conditions of complex technogenic and military stress: textbook. Kyiv: KNUBA Publishing House, 2025. 160 pp.

7. Methodological recommendations for determining environmental damage caused by military aggression using bioindicators / Ministry of Environmental Protection and Natural Resources of Ukraine. Kyiv, 2024. 42 pp.

ENVIRONMENTAL AND GEOPOLITICAL CHALLENGES OF THE FORMATION OF THE GREAT PACIFIC GARBAGE PATCH

Tetiana Tkachenko¹, Viktor Mileikovskiy¹, Yurii Tsiuriupa¹, Sofia Moroz¹

*¹Kyiv National University of Construction and Architecture,
tkachenko.tm@knuba.edu.ua, mileikovskiy.vo@knuba.edu.ua,
tsiuriupa_yv@knuba.edu.ua, moroz_sv-2025@knuba.edu.ua*

Introduction. The problem of pollution of the World Ocean by plastic waste has become critical in the 21st century. The largest manifestation of this crisis is the Great Pacific Garbage Patch (GPGP), located between 135°–155° west longitude and 35°–42° north latitude. This phenomenon is not a solid island in the usual sense, but forms a zone of extremely high concentration of micro- and macroplastics, held by the North Pacific current system. The relevance of the study is due to the transboundary nature of the problem and the lack of effective legal mechanisms for its elimination.

1. Hydrodynamic factors in the formation of the Great Pacific Garbage Patch

The formation of the patch is directly related to ocean circulation systems (eddies). The North Pacific Subtropical Patch forms a convergence zone where the speed of currents slows down, which contributes to the accumulation of floating debris. Mathematically, the concentration of debris in the centre of the vortex can be described through the balance of advection and diffusion forces. The main role is played by the Coriolis force, which directs the debris towards the centre of the system.

According to the latest data, the mass of plastic in GPGP is estimated at 80,000 tons, consisting of approximately 1.8 trillion fragments. It is important to note that the dynamics of the patch are not static: seasonal fluctuations in currents can lead to temporary shifts in the boundaries of pollution, which complicates monitoring using satellite systems. Ocean gyres act like giant centrifuges, concentrating plastic in a relatively stable centre.

2. Structural composition and morphology of plastic waste

Research by The Ocean Clean-up expeditions has shown that the structure of pollution is heterogeneous. About 92 % of the mass is made up of objects larger than 0.5 cm, but microplastics (< 5 mm) dominate in terms of particle size. A significant proportion (up to 46 %) is made up of so-called "ghost nets" – remnants of fishing gear made of synthetic polymers (nylon, polypropylene).

The degradation process of plastic in oceanic conditions occurs mainly through photodegradation under the influence of ultraviolet radiation. This leads

to the fragmentation of large objects into microparticles that adsorb persistent organic pollutants (POPs) on their surface. Thus, each particle of plastic turns into a highly toxic "time bomb" for marine ecosystems. Chemical analysis shows the presence of high-density polyethylene (HDPE) and polypropylene as the main components.

3. Ecological consequences and biological invasion

The impact of GPGP on marine biota is classified into three areas: mechanical damage (entanglement), ingestion (eating) and chemical poisoning. Seabirds, in particular albatrosses, mistakenly eat bright plastic fragments for food, which leads to physical blockage of the gastrointestinal tract. This causes chronic malnutrition and the death of entire populations.

Of particular scientific interest is the phenomenon of the "plastisphere" – a new ecosystem that forms on the surface of plastic. Plastic serves as a substrate for microorganisms and small invertebrates, allowing them to travel thousands of kilometres. This creates the threat of biological invasion: species native to the coastal waters of one continent reach the shores of another, which radically disrupts the local biological balance and biodiversity.

4. Legal and technological aspects of cleaning

The main problem with cleaning up the spill is its legal status. Since the GPGP is located on the High Seas, under the United Nations Convention on the Law of the Sea (UNCLOS), no state is directly responsible for cleaning it up. This creates a "tragedy of the commons," where the costs of clean-up are common and the benefits are diffuse. No international fund currently has sufficient authority to finance a full-scale operation.

The most promising technological approach is a passive collection system that uses the energy of ocean currents to concentrate plastic in special traps. However, the problem of microplastic removal remains critical, as methods of filtering large volumes of water inevitably lead to the capture of mesoplankton, which can have catastrophic consequences for the ocean food chain. Current research is focused on the development of selective membranes capable of separating harmful particles.

Conclusions

The Great Pacific Garbage Patch is a marker of the Anthropocene and evidence of the inefficiency of the current model of plastic use. Solving this problem requires not only technological innovations in the field of cleaning, but also a global reform of waste management (circular economy) and strengthening international maritime law. The priority should be to prevent plastic from entering the ocean through river arteries. Only an integrated approach that combines engineering solutions with political desire will allow preserving the integrity of ocean ecosystems for future generations.

REFERENCES

1. Evidence that the Great Pacific Garbage Patch is rapidly accumulating

plastic / L. Lebreton, B. Slat, F. Ferrari and others. Scientific Reports. 2018. Vol. 8, No. 1. P. 4666. DOI: 10.1038/s41598-018-22939-w.

2. Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea at One Time / M. Eriksen, LC Lebreton, HS Carson and others. PLOS ONE. 2014. Vol. 9, No. 12. P. e111913. DOI: 10.1371/journal.pone.0111913.

3. Jambeck JR, Geyer R., Wilcox C. Plastic waste inputs from land into the ocean. Science. 2015. Vol. 347, No. 6223. P. 768–771. DOI: 10.1126/science.1260352.

4. Geyer R., Jambeck JR, Law KL Production, use, and fate of all plastics ever made. Science Advances. 2017. Vol. 3, No. 7. P. e1700782. DOI: 10.1126/sciadv.1700782.

5. Law KL, Thompson RC Microplastics in the seas. Science. 2014. Vol. 345, No. 6193. P. 144–145. DOI: 10.1126/science.1254052.

6. Moore CJ Synthetic polymers in the marine environment: A rapidly expanding common responsibility. Environmental Research. 2008. Vol. 108, No. 2. P. 131–139. DOI: 10.1016/j.envres.2008.07.025.

7. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre / CM Boerger, GL Lattin, SL Moore, CJ Moore. Marine Pollution Bulletin. 2010. Vol. 60, No. 12. P. 2275–2278. DOI: 10.1016/j.marpolbul.2010.08.007.

8. Kaiser J. The Dirt on Ocean Garbage Patches. Science. 2010. Vol. 328, No. 5985. P. 1506–1506. DOI: 10.1126/science.328.5985.1506.

IMPACT OF NANOPLASTICS ON AQUATIC ECOSYSTEMS: ASSESSMENT OF ENVIRONMENTAL RISKS AND CHALLENGES FOR ECOLOGICAL SECURITY

Vadym Khodakovskiy¹, Yuriy Tsyuryupa¹, Tetiana Tkachenko¹, Viktor Mileikovskiy¹

*¹Kyiv National University of Construction and Architecture
khodakovskyy_vo-2025@knuba.edu.ua, tsiuriupa_yv@knuba.edu.ua,
tkachenko.tm@knuba.edu.ua, mileikovskiy.vo@knuba.edu.ua*

Today, pollution of the hydrosphere with synthetic polymers has reached global scale, turning from a purely aesthetic problem into a systemic threat. Nanoplastics are a particular danger to environmental safety – a heterogeneous group of particles with a size of 1 to 100 nm. They are formed mainly as a result of secondary fragmentation of macro- and microplastics (high and low density polyethylene, polystyrene, polypropylene) under the influence of solar radiation (UV-A and UV-B ranges) and hydrodynamic and mechanical abrasion in the coastal zone. Due to colloidal behavior, extremely small size and exponentially high specific surface area ($10^2 - 10^3 \text{ m}^2/\text{g}$), these particles acquire unique kinetic properties, which determines their abnormal bioavailability and pronounced

cytotoxicity for aquatic organisms.

Mechanisms of impact on aquatic biota and cellular targets. Unlike microplastics, which mostly cause mechanical damage to the digestive tract, nanoparticles are able to overcome the most resistant protective barriers of organisms, in particular the gill epithelium, the blood-brain barrier, and the plasma membranes of cells by endocytosis.

At the level of primary producers (phytoplankton), experiments on model organisms *Chlorella vulgaris* and *Scenedesmus obliquus* show that polystyrene nanoparticles adsorb to the cell walls of algae through electrostatic interactions. This causes mechanical shading, which reduces the efficiency of photosynthesis by 25-40 %, initiates lipid peroxidation (LPO) of membranes and leads to electrolyte leakage.

At the level of first-order consumers (zooplankton), in the classic test object *Daphnia magna*, the effect of nanoplastics leads to immobilization of the filtration apparatus, a sharp decrease in intestinal enzymatic activity, and embryotoxicity (a 2–3-fold decrease in fertility).

The Trojan Horse effect (co-transport of toxicants) is that, due to the high hydrophobicity of the surface, nanoplastics act as an effective vector (carrier) in the aquatic environment for persistent organic pollutants (POPs), such as polycyclic aromatic hydrocarbons (PAHs), dichlorodiphenyltrichloroethane (DDT), as well as heavy metal ions Cd^{2+} , Pb^{2+} , Cu^{2+}). Accumulating on the plastic matrix, these ecotoxicants enter cells in concentrations that are tens of times higher than their dissolved background level in water.

Nanoplastics are actively involved in food chains. They demonstrate a high potential for biomagnification along the chain: “microalgae - zooplankton (*Daphnia*) - small consumers (*Danio rerio*) - predatory fish”. When studying fish (for example, *Danio rerio* and *Carassius auratus*), the accumulation of nanoparticles in the tissues of the liver, gills and brain was revealed. This results in pronounced neurotoxicity: inhibition of the activity of the enzyme acetylcholinesterase (AChE), which causes systemic disorders of behavioral reactions, a decrease in swimming speed and disorientation in space. This significantly weakens the adaptive capabilities of populations and creates a threat of upward transfer of plasticizers (phthalates, bisphenol A) to humans as the final consumer of seafood.

Ensuring the ecological safety of the hydrosphere is currently blocked by two critical factors:

1. Analytical dead end of detection. Isolation of nanofractions from real natural matrices (sea and fresh water, silts, tissues of aquatic organisms) is an extremely difficult task. Traditional methods (FTIR and Raman spectroscopy), effective for microplastics, have a physical resolution limit of about 1 μm . Identification of nanoparticles requires extremely expensive and difficult-to-prepare methods: transmission electron microscopy (TEM), scanning electron microscopy (SEM), inductively coupled plasma mass spectrometry in the single

particle analysis mode (sp-ICP-MS) and pyrolysis gas chromatography-mass spectrometry (Py-GC-MS).

2. Legislative vacuum. Neither the Ukrainian legal framework (Water Code, environmental standards) nor the EU directives (in particular, the Water Strategy Framework Directive) currently have approved maximum permissible concentrations (MPCs) for nanoplastics. Since there is no standard, there is no official state monitoring of this threat.

Conclusions. Nanoplastics are a hidden, but extremely aggressive factor in the degradation of aquatic ecosystems. To minimize environmental risks and form an effective environmental safety strategy, it is necessary to immediately join the efforts of fundamental science and regulatory authorities. Priority steps should be: development and unification of interstate express methods for detecting nanoplastics, conducting long-term chronic low-dose toxicological tests, and legislatively enshrining standards for the content of artificial nanoparticles in natural and drinking waters.

REFERENCES

1. Hnatyuk N. V., Kovalchuk O. V. Ecological risks of contamination of aquatic ecosystems with micro- and nanoplastics. Ecological safety and balanced use of nature. 2024. No. 2 (30). Pp. 45–52.
2. Tkachenko T. M. Modern challenges for the ecological safety of the hydrosphere under conditions of technogenic loading. Scientific Bulletin of Construction. 2025. Vol. 114, No. 3. Pp. 112–118.
3. Alimi OS, Farner Budarz J., Chae Y. et al. Microplastics and Nanoplastics in Aquatic Environments: Aggregation, Deposition, and Enhanced Contaminant Transport. Environmental Science & Technology. 2022. Vol. 56, No. 11. P. 7441–7455.
4. Chae Y., An YJ Current research trends on plastic pollution and ecological impacts on the soil ecosystem: A review. Environmental Pollution. 2023. Vol. 284. Art. 117451.
5. Kögel T., Büsler O., Monteleone A. et al. Micro- and nanoplastics in aquatic organisms: Toxicity, tissue distribution, and trophic transfer. Environmental Sciences Europe. 2024. Vol. 36, No. 1. P. 12–29.
6. Mitrano DM, Wohlleben W. Microplastic and nanoplastic in the environment: Research challenges and milestone analytical developments. Communications Earth & Environment. 2025. Vol. 6, No. 2. Art. 89.

SPEEDING UP THE TIGHTNESS TESTING OF HIGH-RISK FACILITIES USING THE ABSOLUTE PRESSURE METHOD

Serhii Tsybytovskiy¹, Tatiana Tkachenko¹

1. ¹Kyiv National University of Construction and Architecture,
serhii.uaror@gmail.com, tkachenkoknuba@gmail.com

Nuclear energy safety is a priority task in the field of decarbonisation and environmental transformation of the energy sector. One of the issues of nuclear safety is the tightness of the containment system (CS) of a nuclear facility. Tests [1] are performed by the absolute pressure method. Air is pumped into the CS up to a pressure of 169 kPa. Then, tightness is assessed by the pressure drop over time. The main problem of the tests is the long duration of air pumping into the CS, up to 25 hours. To speed up the process, the use of an ejector was proposed in work [1]. Calculations were performed in work [2].

In this work, the mathematical model of the installation with an ejector was improved. First, the characteristic of the compressor performance G [kg/s] – pressure p [bar] was approximated. Up to 4.73 kPa, the compressor TSK135/8 has an almost linear characteristic $G = 3.44669 - 0.04554 \cdot p$ [kg/s]. Next, the operation without an ejector is considered. The differential equation of the filling process, together with the Clapeyron equation and the compressor characteristic, allows calculation of the filling time of the CS – 3.965 hours.

Next, a mathematical model of the ejector is developed (Fig. 1 a). Unlike traditional approaches [3], we will optimise not the ejector efficiency, which varies with pressure, but the CS filling time. The mathematical model assumes the continuity equation, conservation of angular momentum, and equality of pressures in the flow from the nozzle and the flow of ejected air at the inlet to the mixing chamber.

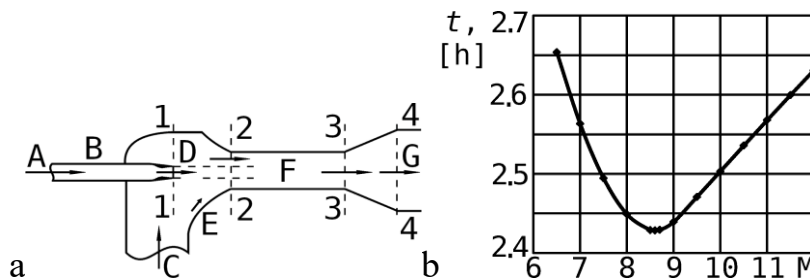


Fig. 1. Ejector: a – diagram; b – dependence of the CS filling time t on the ejector module M : A – flow from the compressor; B – nozzle; C – inlet of ejected air; D – flow at the nozzle outlet; E – flow of ejected air; F – mixing chamber; G – outlet to the CS

In the author's calculations, the adiabatic processes were assumed, and the compressibility of the air was taken into account, since the velocity at the nozzle exit is supersonic. When calculating the characteristics of the ejector, the ejection

coefficient u is usually set, and the compression ratio ε is calculated. However, with such a calculation sequence, it is difficult to determine the maximum value of the ejection coefficient, which significantly reduces the accuracy of calculating the CS filling time. In this work, the calculation method is improved, and it is proposed to set the compression coefficient ε and calculate the ejection coefficient u . In this case, the convergence of the results is significantly improved.

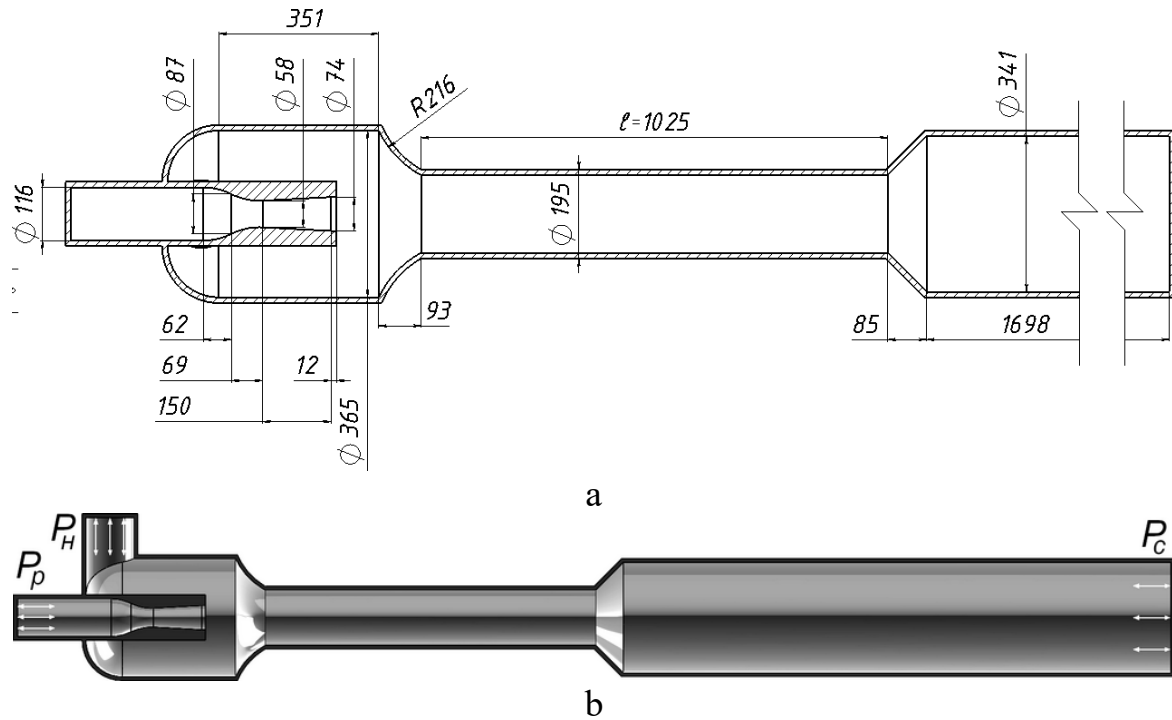


Fig. 2. Ejector model: a – drawing; b – general view with pressure boundary conditions: $P_p = 500000$ Pa (abs.); $P_H = 101325$ Pa (abs.); $P_C = 136325$ Pa (abs.)

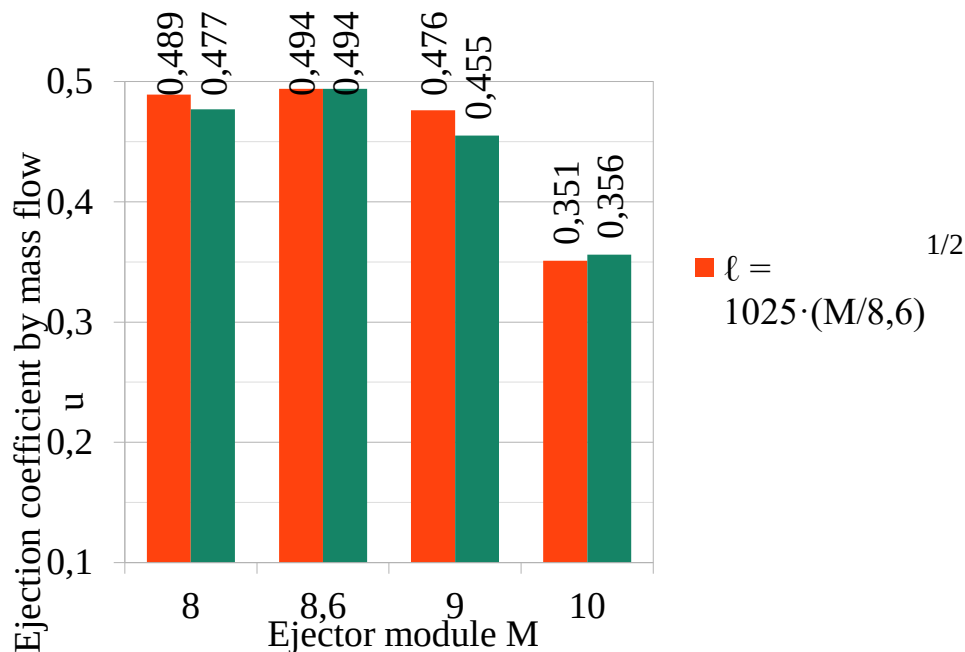


Fig. 3. Dependence of the ejection coefficient u on the ejector module M

As a result (Fig. 2), it was found that the dependence of the CS filling time t [h] on the ejector module M (the ratio of the cross-sectional area of the mixing chamber to the narrowest nozzle cross-section) has a minimum at $M = 8.6$, which is the optimal value for design.

Due to the impossibility of taking into account all the effects, CFD simulation was performed using the k - ε model. The injection calculation will take a very long time, so a pressure of 0.35 bar was simulated. A three-dimensional model was built (Fig. 2), and the geometric shape was optimized, which confirmed $M = 8.6$. The ejector module was changed in two ways: by scaling the mixing chamber or by increasing its diameter without changing the length. Fig. 3 confirms the optimal value of the module $M = 8.6$.

More detailed results can be found in the publication [4].

REFERENCES

Kravchenko, V., A. Vlasov, A. Golovchenko, A. Mazurenko, V. Dubkovskyi, O. Chulkin. "State and Prospects of Containment Tightness Tests for VVER-1000 Reactor Installations." Nuclear and Radiation Safety, no. 2(98), June 2023, pp. 53–60. [https://doi.org/10.32918/nrs.2023.2\(98\).05](https://doi.org/10.32918/nrs.2023.2(98).05).

Kravchenko V., Vlasov A., Andryushchenko A., Vlasov D., Golovchenko A., Gavrilo P., "Reduced air injection time during containment testing due to the use of an ejector." Odes'kyi Politechnichnyi Universytet Pratsi, vol. 1, no. 65, 2022, pp. 62–69. <https://doi.org/10.15276/opu.1.65.2022.07>.

Butenko, O., S. Smyk. "Improvement of the central ejector efficiency under nonoptimal operating modes." Naukovyi Visnyk Natsionalnoho Hirnychnoho Universytetu [Dnipropetrovsk], vol. 2, 2015, pp. 57–61, <https://nvngu.in.ua/index.php/en/archive/on-the-issues/1072-2015/contents-no-2-2015/geotechnical-and-mining-mechanical-engineering-machine-building>

Tsybytovskyi S. Simulation of the ejector in the system for testing the tightness of high-risk facilities. Ventilation, Illumination and Heat-Gas Supply. 2026. Vol. 56. P. 131-152. <https://doi.org/10.32347/2409-2606.2026.56.131-152>

CHANGES IN THE MECHANICAL PARAMETERS OF CEMENT MORTARS DUE TO THE ADDITION OF ASH AND SLAG FROM MUNICIPAL SOLID WASTE

Alina Pietrzak,
CZESTOCHOWA UNIVERSITY OF TECHNOLOGY,
ALINA.PIETRZAK@PCZ.PL

Abstract

This study investigates the potential use of fly ash and slag derived from the thermal treatment of municipal solid waste as additives in cement mortars. The

waste materials were incorporated as partial replacements of sand in amounts ranging from 5% to 30% of the cement mass. Sixteen different mortar mixtures, including a reference mix without additives, were prepared and tested. The experimental program included evaluations of fresh and hardened mortar properties, such as consistency, water absorption, frost resistance, and flexural and compressive strength after 7 and 28 days of curing. The results showed that increasing the content of waste materials negatively affected workability and reduced flowability. Additionally, an increase in water absorption of approximately 15–20% compared to the control mix was observed. All modified mortars exhibited a reduction in compressive strength at both curing ages. The most favorable performance was obtained for the mixture containing 5% ground slag, which was the only modified composition that met the strength requirements for CEM I 42.5R cement after 28 days of curing. Furthermore, mixtures containing slag showed improved frost resistance compared to the reference mortar.

The findings indicate that municipal solid waste incineration residues may have potential for use in cement-based composites; however, further research is required, particularly regarding their long-term durability and performance.

THEORY OF IMPLEMENTING GREEN BUILDING IN THE NATURE RESERVE FUND OF UKRAINE

Yuliia Bereznytska¹, Oleksandr Lytovchenko¹

*¹Kyiv National University of Construction and Architecture
bereznytska.iuo@knuba.edu.ua*

1. Introduction. Today, in the context of the world in general, and Ukraine in particular, the issue of preserving natural and natural-technogenic complexes and present and future generations is particularly relevant. A promising and effective direction of sustainable development of the state is not only the support of existing nature reserves and objects, but also the design, implementation and effective use of the latest technologies, one of the directions of which is green building technologies.

The purpose of the work is to analyze the effectiveness of the implementation of green building technologies in the nature reserve fund of Ukraine, as well as to identify critical points of slowing down this process.

2. Theoretical principles of green building and its main technologies for implementation in the territories and objects of the nature reserve fund

According to [1], green building is a set of works on the creation of new urban green spaces and the reconstruction of existing ones. However, today this term includes a much broader and more meaningful list of design, construction and reconstruction solutions that significantly improve the impact of buildings on the environment, the microclimate in the premises themselves and create

biologically diverse urban ecocenoses, which also improve the aesthetic appearance of buildings. Table 1 shows the main tasks that green building technologies set themselves in terms of objects of the nature reserve fund.

Table 1

The main tasks that green building technologies set for themselves in terms of nature reserve objects

No.	Objective	Ways to Achieve the Objective	Protected Area Category Suitable for Implementation
1	Improving the efficiency of the use of natural and renewable resources (solar and wind energy, water resources)	Installation of photovoltaic power plants, heat pumps, and autonomous energy supply systems	Particularly relevant for protected areas with large territories and functional zoning (biosphere reserves, national nature parks)
2	Reducing the negative impact on natural ecosystems during the construction and arrangement of buildings required for the operation of protected area institutions	Use of environmentally friendly construction materials, minimization of soil disturbance, limitation of the construction footprint	Nature reserves (Zakaznyks), natural monuments, parks-monuments of landscape gardening
3	Improving the energy efficiency of administrative and recreational buildings	Application of thermal insulation materials, energy-efficient lighting systems, and automated energy management systems	Nature reserves (Zakaznyks), botanical gardens, dendrological parks, zoological parks
4	Rational use of water resources	Installation of rainwater harvesting and reuse systems, water-saving equipment	Hydrological nature reserves and protected areas with large surface runoff
5	Reducing construction waste generation	Application of modular construction technologies, reuse of construction materials, waste sorting and recycling	Applicable to all categories of protected areas
6	Creating an accessible and inclusive ecological environment	Development of inclusive ecological trails, energy-efficient visitor centers, and environmentally friendly recreational areas	Applicable to all categories of protected areas
7	Climate change adaptation of infrastructure	Use of climate-resilient construction materials, nature-based solutions, landscape greening, and green roofs	Applicable to all categories of protected areas

No.	Objective	Ways to Achieve the Objective	Protected Area Category Suitable for Implementation
8	Environmental education and promotion of sustainable development	Establishment of modern environmental education centers based on green building principles	Applicable to all categories of protected areas
9	Achieving carbon neutrality of protected area facilities	Construction of low-carbon buildings, application of natural materials, compensatory greening, and implementation of energy-efficient technologies	Applicable to all categories of protected areas

Thus, we can argue that the existing territories of the nature reserve fund have significant potential for the implementation of a wide range of green building technologies in the performance of their functions.

3. The main problems of implementing green building technologies in the territories of the nature reserve fund and ways to solve them

The main problems of implementation include the prohibition of any type of economic activity in the territories of the nature reserve fund except for the types of activities provided for by the performance of the functions assigned to them [4]. Other problems of implementing green building technologies in the territories of the nature reserve fund and ways to solve them are given in Table 2.

Table 2

Problems of implementing green building technologies in the territories of the nature reserve fund and ways to solve them

No.	Challenge	Causes	Proposed Solutions
1	Imperfection of the regulatory and legal framework	Lack of specific requirements for the application of green building technologies within protected areas of the Nature Reserve Fund	Development of sector-specific regulatory documents and harmonization of national legislation with European standards
2	Limited funding for protected area management institutions	Insufficient public funding and the high cost of green technologies	Attraction of grants, public-private partnerships, and environmental fund
3	Lack of integrated planning	Insufficient integration of environmental, economic, and social aspects in planning processes	Application of sustainable development principles, Building Information Modeling (BIM), and spatial planning
4	Insufficient use of renewable energy sources (RES)	High cost of renewable energy equipment	Installation of photovoltaic power plants and heat pump systems

No.	Challenge	Causes	Proposed Solutions
5	Risk of ecosystem disturbance	Failure to consider the natural characteristics and ecological sensitivity of protected areas	Environmental Impact Assessment (EIA), implementation of Nature-based Solutions (NbS), and environmentally responsible design
6	Insufficient environmental competence	Shortage of qualified specialists in green building and environmental protection	Professional development, specialized training, and capacity-building programs
7	Lack of environmental monitoring	Inadequate monitoring of environmental conditions	Implementation of automated environmental monitoring systems, Geographic Information Systems (GIS), and Internet of Things (IoT) technologies
8	High carbon footprint of construction materials	Predominant use of conventional construction materials	Application of low-carbon and recycled construction materials
9	Underdeveloped environmental infrastructure	Lack of modern visitor centers and ecological routes	Construction of energy-efficient environmental facilities and visitor infrastructure
10	Impacts of climate change	Rising temperatures and an increasing frequency of extreme weather events	Climate adaptation measures, implementation of Nature-based Solutions (NbS), and enhancement of infrastructure resilience

3. Conclusions

The study found that green building technologies are an important tool for improving the general condition of nature reserves. In particular, using modern technologies, it is possible to reduce the negative impact on the environment from farm buildings during their construction and operation. Green technologies have a wide potential for implementation in protected areas. The implementation of green building has a number of obstacles on the way to implementation, and therefore this issue requires further in-depth study.

REFERENCES

1. Pro zatverdzhennia Pravyl utrymannia zelenykh nasadzen u naselenykh punktakh Ukrainy [On Approval of the Rules for the Maintenance of Green Plantations in Settlements of Ukraine]: Order of the Ministry of Construction, Architecture and Housing and Communal Services of Ukraine No. 105 of April 10, 2006 (as amended). Available at: <https://zakon.rada.gov.ua/laws/show/z0880-06>
2. Bilotil, V. (2021). Green building as a direction of sustainable

development: essence, tasks, principles, benefits, prospects. Zbalansovane pryrodokorystuvannia (Balanced Nature Management), 2, 64–71. Available at: http://nbuv.gov.ua/UJRN/Zp_2021_2_10

3. Kryvomaz, T. I., & Savchenko, A. M. (2021). Znyzhennia vplyvu budivelnoi haluzi na klimatychni zminy shliakhom vprovadzhennia pryntsyviv zelenoho budivnytstva [Reducing the impact of the construction industry on climate change through the implementation of green building principles]. Ekolohichna bezpeka ta pryrodokorystuvannia (Environmental Safety and Natural Resources), 1(37), 55–68. <https://doi.org/10.32347/2411-4049.2021.1.55-68> Available at: <http://es-journal.in.ua/article/view/228419>

4. Zvit pro stratehichnu ekolohichnu otsinku proiektu Planu zakhodiv z realizatsii Onovlenoho Natsionalno vyznachenoho vnesku Ukrainy do Paryzkoï uhody do 2030 roku [Report on the Strategic Environmental Assessment of the Draft Action Plan for the Implementation of the Updated Nationally Determined Contribution of Ukraine to the Paris Agreement until 2030]. Kyiv: Ministry of Environmental Protection and Natural Resources of Ukraine, 2023. 216 p. Available at: <https://mepr.gov.ua/wp-content/uploads/2023/07/Zvit-pro-strategichnu-ekologichnu-otsinku.pdf>

5. Mashchenko, S. O., Vovk, M. S., & Aliiev, R. A. (2016). Teoriia ta metodolohiia "zelenoho budivnytstva" [Theory and methodology of green building]. Ekonomichnyi prostir (Economic Space), 113, 220–230. Available at: http://nbuv.gov.ua/UJRN/ecpros_2016_113_23

6. Tkachenko, T., & Mileikovskiy, V. (2025). Pershi ukrainski standarty zelenoho budivnytstva [The first Ukrainian green building standards]. In Proceedings of the IV International Scientific and Practical Conference "Green Construction" (Kyiv, May 13–14, 2025) (pp. 297–302). Kyiv: Kyiv National University of Construction and Architecture. Available at: https://www.researchgate.net/publication/391850615_Materiali_IV_Miznarodno_i_naukovo-prakticnoi_konferencii_Green_Construction_Zelene_budivnictvo_Kiiv_13-14_travna_2025_r

OVERVIEW OF POSSIBILITIES FOR IMPLEMENTING ESG APPROACHES IN OCCUPATIONAL SAFETY AND HEALTH MANAGEMENT IN GREEN BUILDING

Yuliia Bereznytska

*¹Kyiv National University of Construction and Architecture
bereznytska.iuo@knuba.edu.ua*

1. Introduction

The implementation of ESG principles, as a set of environmental, social and state branches of management, in the activities of the Ukrainian construction

industry is an important step towards sustainable development of society and improving the level of occupational safety and health management in the construction sector. Today, ESG principles have reached the level of a global standard for many areas of business and economy, in particular for the construction industry, increasing social responsibility, as well as contributing to the growth of financial and environmental responsibility of construction companies.

However, despite global development trends, the construction sector of Ukraine is only mastering and getting acquainted with the implementation of the ESG system, especially in the context of the occupational safety and health management system. Insufficient attention from the state and the lack of specialized tools for assessing and monitoring risks associated with sustainable development complicate the integration of these principles. In addition, the specifics of the construction sector, in particular the dependence on private investment and state financing of development programs in Ukraine, as well as the limited share of construction companies working with green technologies, create additional limitations on the way to implementing the ESG approach in the occupational safety management system.

Therefore, there is a need to study how global trends in the integration of ESG principles can be implemented in the occupational safety management system in green construction, as well as to identify particularly valuable factors of favorable influence for social and environmental safety.

The purpose of the work is a general overview of the possibilities of the ESG approach in improving the occupational safety management system in green construction, which would lead to the successful modernization of the green construction sector, contribute to the stabilization of the state economy by reducing social payments and increasing the level of environmental safety through the use of the principles of rational nature management.

2. The essence of the ESG approach and its possibilities in the green construction sector

The structure of the ESG approach consists in assessing a construction company or sector not only from the perspective of financial indicators of costs and profits, but also in terms of its impact on environmental parameters, society or the social environment and the quality of corporate governance.

Such a principle is the basis of sustainable development of society, which can help the Ukrainian construction sector manage risks, in particular in occupational safety and health management, and create long-term value for society.

Fig. 1 shows a general scheme of the environmental component of ESG for green construction, taking into account sustainable development goals and environmental factors that can ensure them.

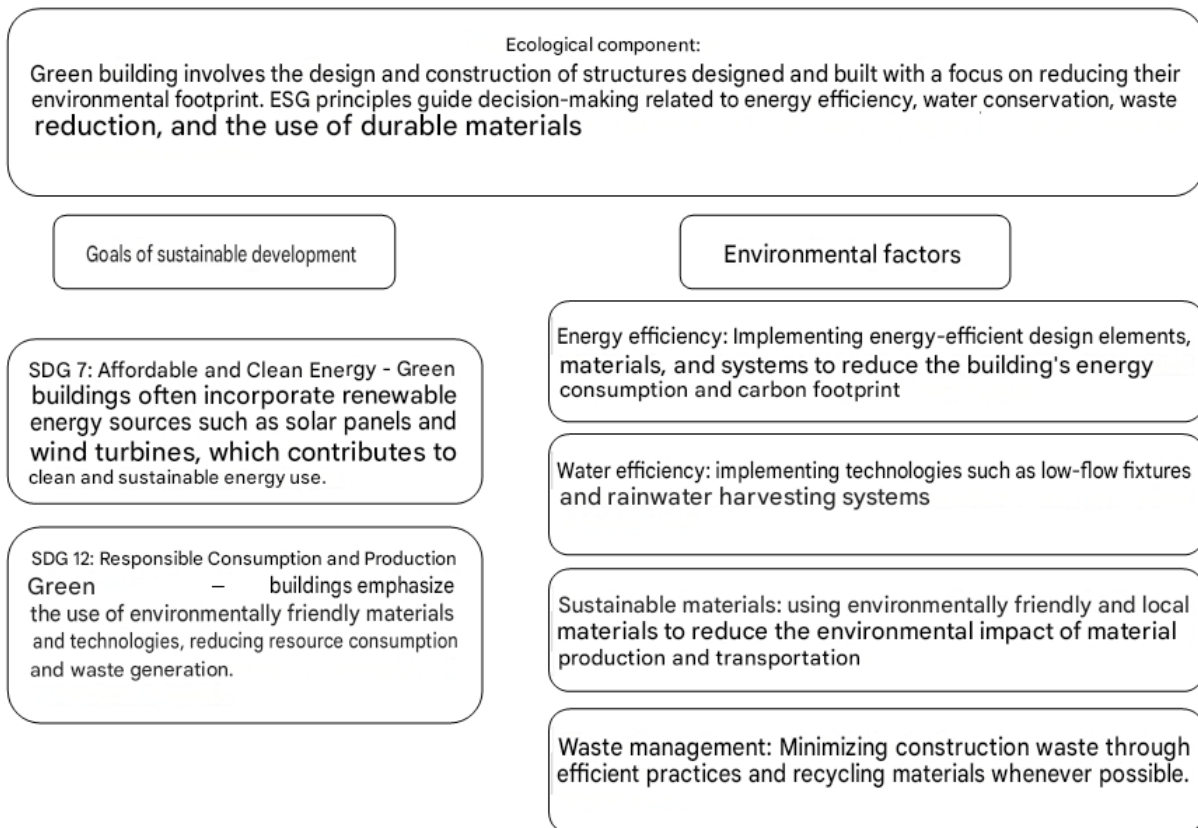


Fig. 1. General scheme of the environmental component of ESG for green construction
Formulated by the author based on [3]

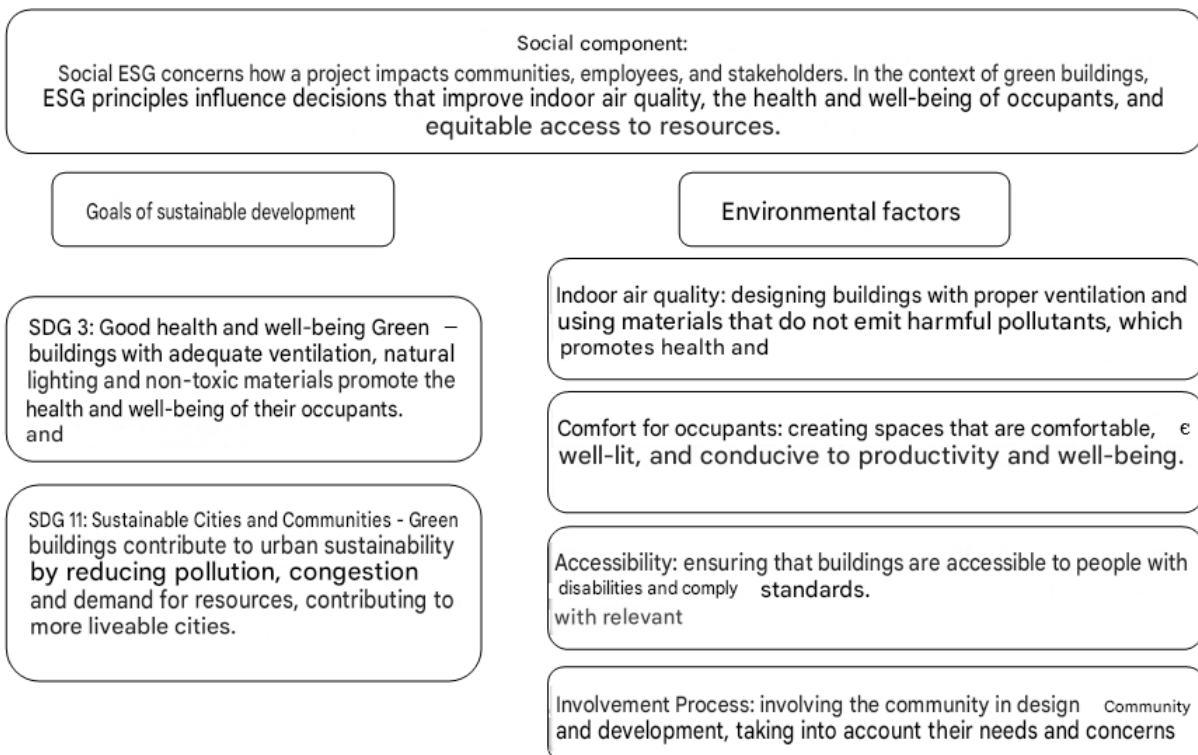


Fig. 2. General scheme of the social component of ESG for green construction

Formulated by the author based on [3]

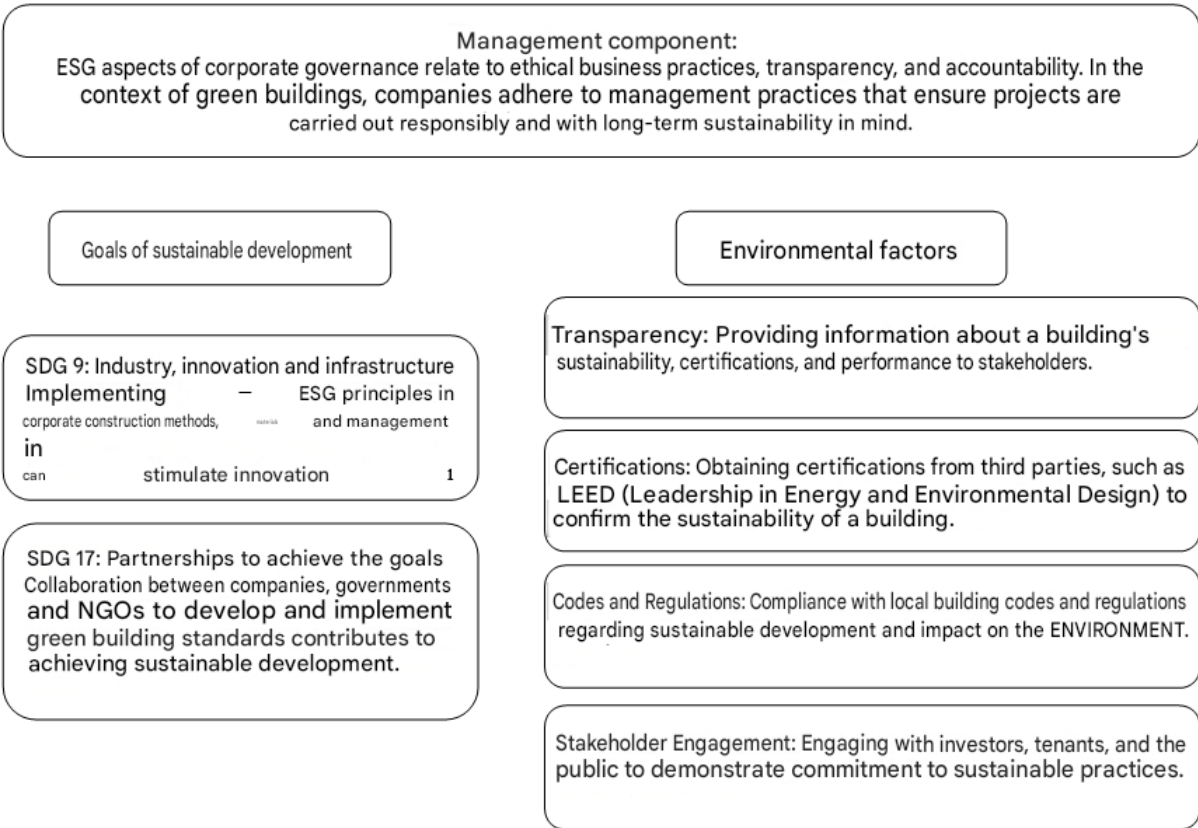


Fig. 3. General scheme of the ESG management component for green construction

Formulated by the author based on [3]

Fig. 2 shows a general scheme of the social component of ESG for green construction, taking into account sustainable development goals and social instruments that can ensure their achievement.

The general scheme of the ESG management component for green construction, taking into account sustainable development goals and management tools that can ensure their achievement, is shown in Fig. 3.

Thus, it can be argued that in the field of green construction there is a wide range of environmental, social and management factors that can serve as a powerful and promising tool for achieving many sustainable development goals.

At the same time, the state system of labor protection management in the construction sector lacks a single mechanism for assessing environmental, social and management decisions to ensure the life, health and working conditions of workers.

In our opinion, the management system of any construction organization should include not only approved state norms and standards, but also constantly develop, seek new prospects for implementation to achieve the goals of sustainable development of society.

3. Conclusions

During the study, it was found that ESG criteria are an effective tool for achieving many sustainable development goals. The ESG approach has a number of implementation options using environmental, social and management factors in green construction. The possibilities of implementing such a comprehensive approach to the construction sector's occupational health and safety management system require further detailed study in order to identify the prospects, critical points of implementation and implementation of such a modern approach, which will not only improve the working conditions of workers, but also provide a future springboard for attracting investments from stakeholders and international partnerships in the construction sector.

REFERENCES

1. Opalchuk, R., Chornovol, A., & Popliuiko, Ya. (2025). Intehratsiia ESG-pryntsypiv u diialnist ukrainskykh strakhovykh kompanii: hlobalni trendy ta mistsevi osoblyvosti [Integration of ESG Principles into the Activities of Ukrainian Insurance Companies: Global Trends and Local Features]. *Ekonomika ta suspilstvo (Economy and Society)*, 72. <https://doi.org/10.32782/2524-0072/2025-72-113>
2. Kryvomaz, T. I., Chalyi, I. H., Hamotskyi, R. O., Ilchenko, I. S., & Tsyba, A. M. (2023). Kryterii ESG u zelenii vidbudovi Ukrainy [ESG Criteria in the Green Reconstruction of Ukraine]. *Ekolohichna bezpeka ta pryrodokorystuvannia (Environmental Safety and Natural Resources)*, 4, 5–20. Available at: <http://jnas.nbu.gov.ua/article/UJRN-0001465328>
3. ESG in the Design, Construction, and Operation of Green Buildings, and the Relation to SDGs. (2023). Trium Limited Consulting Engineers. Available at: <https://www.linkedin.com/pulse/esg-design-construction-operation-green-buildings/>