UDC 692.43+711

THE INFLUENCE OF GREEN STRUCTURES OF BLUE INFRASTRUCTURE ON THE LOAD OF BUILDING STRUCTURES

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DOI: 10.32347/2410-2547.2025.114.135-144

The paper considers the place of green structures in the blue infrastructure of cities. A scheme of integrated rainwater management using green structures is built. The combination of different green structures allows to creation of a unified and effective rainwater management system. The impact of green building structures on their supporting structures plays an important role. The loads from green roofs have two components: the load from structural elements and plants, including wind loads, and the load from precipitation-retained rainwater and snow. The first group of loads is constant, except for periodic wind loads, but its peak values vary little during rain and snow. It is impractical to consider snow load management. It can be reduced by snow removal. However, this will lead to a high risk of improper performance of snow removal duties with overloading of the supporting structures. Therefore, for safety reasons, the calculation is based on the maximum load. The load from rainwater depends on the runoff coefficient, which can be changed. Therefore, the paper underestimates the snow load for different snowy regions and average recurrence periods. The critical water retention of rainwater with the same load as the snow cover was determined. In the worst-case scenario of the first snow region and an average recurrence period of 10 years, we have a critical water retention of 56.2 dm^3/m^2, which is significantly higher than the intensity of precipitation.

This means that the load of retained rainwater will be less than that of snow. Therefore, it's necessary to ensure maximum water retention by the amount of precipitation. This cannot affect the bearing capacity of structures, which will be determined by the snow load. The possibility of utilising melt water for household needs is shown. The tasks for future research have been set.

Keywords: blue infrastructure, green structures, green pavement, rain garden, load, runoff coefficient, bearing capacity.

Introduction. The rapid pace of development with the expansion and densification of cities globally is causing serious problems for modern cities, such as increased risk of flooding, air pollution, deterioration of water quality and the formation of urban heat islands [1]. These problems, in addition to negatively affecting the health and comfort of urban residents, reduce the productivity and service life of buildings.

To effectively address the problems and improve the quality of urban construction, it is important to comprehensively understand the complex interactions between elements of the urban environment, among which buildings are one of the main ones as a complex system of building, envelope and life support systems. Cities are complex systems with unique characteristics, such as population density, buildings, land use and climatic conditions, which have a significant impact on their condition.

Taking into account the interaction of these factors, it is necessary to implement comprehensive and integrated approaches to the design of new buildings and the renovation of existing ones, using technology to create a sustainable, safe and efficient urban environment that can meet the needs of both current and future generations. Such a comprehensive solution that simultaneously addresses technical, environmental, economic and social issues is green building, which combines building structures and living plants.

Recently, the use of green construction has increased significantly worldwide due to government incentives and demand for methods and processes that support sustainable development. This type of design is seen as both a concept and a process. As a concept, green design influences urban planning and development, in particular by promoting the integration of green spaces with engineering solutions and creating a new type of infrastructure - blue-green. As a process, green design aims to maximise the benefits of green spaces by identifying their potential ecosystem services, one of which is urban stormwater management.

Excessive runoff, which leads to urban flooding, is most pronounced in densely built-up central areas, where limited available space and high land values prevent the introduction of natural structures such as lawns, green spaces or parks. As building coverings can account for half of an impermeable urban area [2], the use of this largely unused space has gained attention.

Green roofs are a type of green structures that provides a greened building covering on artificial substrates and gives numerous technical, environmental, economic and social benefits through interaction with buildings, the microclimate of the premises and surrounding areas, and urban ecosystems [3]. Technical solutions for the construction of green pavements are divided into three main types: intensive, semi-intensive and extensive [4]. The difference between them is mainly in the thickness of the substrate, the purpose of the coating and the maintenance costs.

Intensive green roofs are thick and heavy systems that require significant maintenance efforts but allow for the creation of additional functional spaces – places for recreation, study, business, etc. Extensive green roofs are lightweight, thin systems that usually do not require maintenance and are not intended for human access. Semi-intensive solutions are a compromise between these two types of green structures.

One of the main benefits of green roofs is improved stormwater management [5, 6]. They are the first stage of absorbing rainwater before it reaches the ground. Therefore, this solution reduces the amount of stormwater and delays the runoff with a decrease in peak flow. Precipitation that falls on green surfaces is partially retained in the substrate due to the sponge effect, absorbed by plants, evaporates into the atmosphere and is partially discharged as runoff [7]. The proportion of precipitation that does not go out as runoff is called retention.

Maintenance is affected by the complex interaction between the components of green pavements and their physical environment. In addition, the winter season in cold temperate regions, such as Ukraine, also affects the annual maintenance performance. In winter, in cold climates, soil environments for plant growth usually freeze, and snow accumulates on the structure for up to several months, which leads to additional stresses on the building.

The greatest risk to the long-term integrity of the building envelope is moisture penetration [8]. Moisture can promote the biological growth of microorganisms, which deteriorates the quality of structures and affects indoor air quality. It can act as a solvent that changes the properties of materials, causes corrosion creates mechanical failure due to expansion from frost, and also causes additional loads due to its weight [9].

The weight of green roofing is the most discussed quality risk issue in the research presented in the scientific literature. Adding additional weight to the pavement, especially during retrofitting, requires verification of the adequacy of the load-carrying capacity of the structures. Therefore, it is important to consider the expected load from green pavement, including retained water and snow cover, from the early stages of design.

Thus, the problem arises of assessing the impact of green pavements on the load-bearing capacity of building structures depending on the rain and snow conditions of the area. This is necessary to ensure the efficiency and cost-effectiveness of such innovative solutions in construction, as well as to ensure their practical usefulness for construction professionals.

Analysis of recent research and publications. Research on green coatings is biased towards environmental and hydraulic effects, with a significant lag in studies of mechanical impacts.

Numerous studies have experimentally evaluated the ability of green pavements to retain rainwater runoff. The recorded cumulative percentage of runoff retention varied from 50 % to 90 % [10-12].
It has been noted that green roofs can significantly reduce the snow load on wastewater management systems by retaining part of the snow in the substrate and its gradual melting [13]. However, a review of the literature shows a lack of research on the practical aspects of green roofs and their impact on the load-bearing capacity of structures [14].

Even though technical risks and problems associated with green roofs are discussed in scientific papers, this topic is not the main object of research. For example, the authors of [15] analysed the life cycle cost of green coatings and expressed some concerns about their durability and service life, but did not delve into the details of defects. Other authors [16] investigated the impact of green coatings on the durability of roofing membranes but focused only on ageing and material degradation.

Wilkinson et al. [17] reviewed the technical aspects of green roofs in Australia and identified the perceived risks at the conceptual level as «barriers to implementation».

An analysis of the cases of collapse of green roofs [18,19] showed that the collapse did not occur during normal operation, but due to exceeding the design loads due to unforeseen circumstances. The main causes of the collapse were not related to structural engineering deficiencies but were caused by improper drainage or insufficient quality of joints in the supporting structures.

This analysis has confirmed that the lack of scientifically based characteristics and detailed design guidelines for green pavements, in particular in terms of water retention and the corresponding load on the substructure, means that the implementation of these technologies is often based on experience alone. This can make the use of green pavements inefficient.

The only regulatory document that mentions these aspects is the German FLL guidelines for green pavements [20]. They note that the main variations in the ability of these systems to retain water depend on the depth of the growing medium.

Annual water retention can range from 40 % for a large green roof with 20 mm of substrate to over 90 % for an intensive green roof with 500 mm of substrate. The maximum annual water retention for large and semi-intensive green surfaces is about 60 %, as the substrate depth should not exceed 200 mm to avoid overloading the building support structure [20].

Formulation of the purpose of the article. The purpose of this paper is to identify the place of green structures in the city’s blue infrastructure and to optimise their effect, taking into account the load on buildings.

1. Place and interaction of green structures in the city’s blue infrastructure. In 2005, the Indian expert Van Roijen introducted the term «Sponge City». This concept was officially adopted in China in 2013, and since then, China has become a leader in its implementation, having developed the state programme «Sponge City Concept».

The Chinese central government selected 30 pilot cities with different natural and social conditions (each with an average built-up area of 31.3 km²) to test the concept in 2015 and 2016. The performance evaluation was completed at the end of 2019 [21]. In 2021, based on the experience of the pilot projects, China began to systematically implement the sponge city concept at the national level.

The sponge city concept envisages sustainable urban development, including flood control, water conservation, water quality improvement, and protection of the natural ecosystem. Such a city has a rainwater drainage system that functions like a sponge. Sponge facilities absorb, store, infiltrate and purify rainwater, which can be reused as needed [22].

The main objectives of sponge cities are:

- retaining 70-90 % of the average annual rainwater on-site by applying the concept of green structures;
- eliminating waterlogging and preventing urban flooding;
- improving the quality of stormwater;
- mitigating the impact on natural ecosystems;
- reducing the effect of urban heat islands.

An important method for creating sponge cities is to integrate grey infrastructure with green spaces to form a new blue-green infrastructure (Figure 1). A grey drainage system is designed to collect and drain stormwater. It should provide a safe level of traffic service through a stormwater conveyance network, storage systems and pumping stations [23].

Green infrastructure is designed to take advantage of the filtration capacity of plants, soils and sand filters to dispose of surface water runoff. It includes green structures such as rain gardens, green roofs and green walls.

Integrated blue-green infrastructure is a modern approach that allows solving several urban problems simultaneously. It can effectively combat flood risk, pollution, and the urban heat island effect, as well as provide water treatment and reuse, promote biodiversity conservation, and create blue-green recreational spaces.

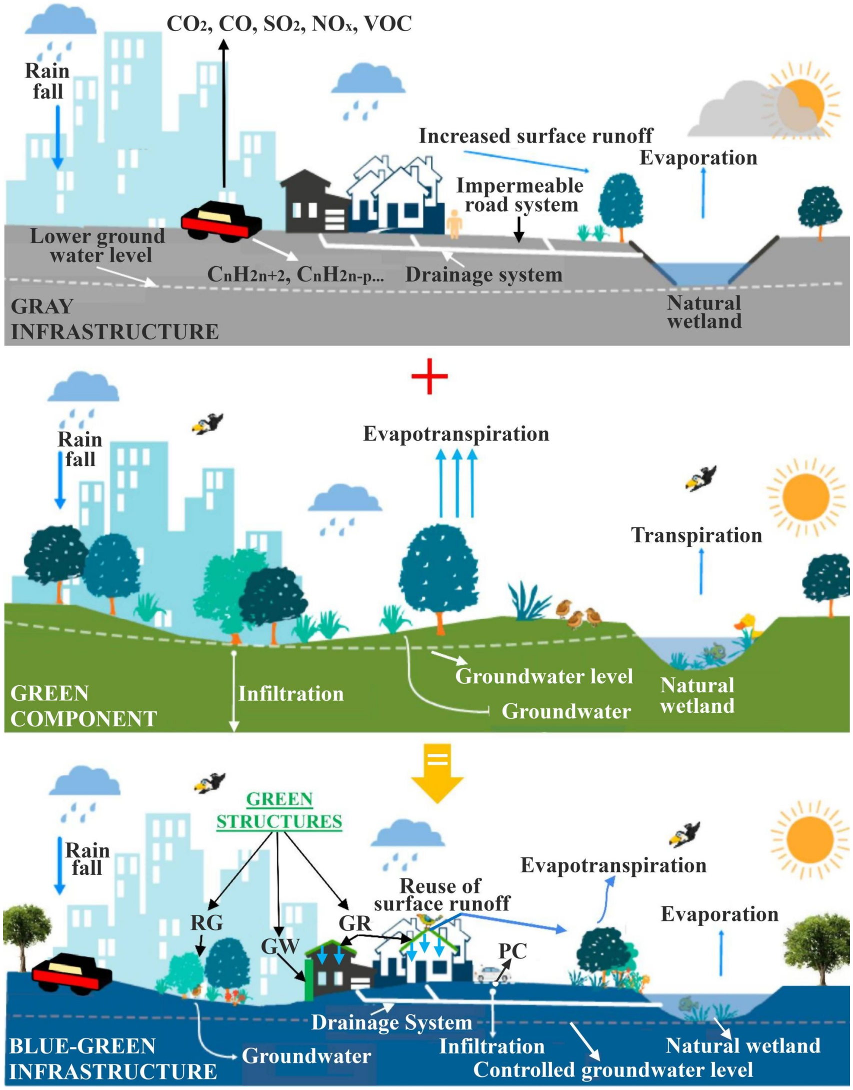

Fig. 1. Place and interaction of green structures in the blue infrastructure of the city:
RG – rain garden; GW – green wall; GR – green roof; PC – permeable coating

«Grey+green» approaches help to mitigate or compensate for the negative effects of grey infrastructure. At the same time, the economic uncertainty that can arise when using exclusively green solutions is reduced.

The first link in the chain of rainwater capture is green pavements. They are the first stage to absorb and retain rainwater along the route. The remainder is partially absorbed by the green walls, especially in oblique rains. Even though the amount of retained rainwater is lower, wall systems and materials that fulfil this function are being actively developed. An example is the latest development of moss concrete [24], which can retain 5 dm^3/m^2 of wall water. The remaining water falls on the ground and road surfaces and must be absorbed by green areas, pervious pavement for eco-parking, roads and pavements, and rain gardens. In the absence of a stormwater system, these sponge facilities form the last stage in stormwater management. In the presence of engineering systems, they become the last stage.

Despite the growing interest in blue-green infrastructure among researchers, engineers, and landscape designers, its widespread implementation remains limited. This is due to the interdisciplinary design requirements, lack of confidence and knowledge on the part of engineers, and insufficient understanding of the interaction of these structures with buildings and structures.

2. Loads from green roofs on the building's supporting structures. The load from green roofs can be divided into two components:

- permanent load from structural elements and plants;
- temporary load from retained rainwater and snow.

The first type of load can be considered constant except for the wind load on plants, which is periodic. However, its peak values differ little during rain and snow. Therefore, it can be added to the constant load.

Precipitation loads have two components:

- rainwater retention after precipitation;
- snow load.

The total weight of rainwater per unit area of green roof after a single rain event can be determined by the formula [N/m^2]:

$$m_A = \frac{\rho \cdot g \cdot \min\left(h_0 + (1-K)\cdot h, H\right)}{1000}, \tag{1}$$

where K is the runoff coefficient, which indicates the proportion of rainwater that flows off the pavement; ρ is the density of water [kg/m^3]; g is the acceleration of free fall [m/s^2]; h_0 is the amount of moisture required for plants [mm]; h is the amount of precipitation in a rain event [dm^3/m^3]; H is the maximum area-averaged water retention capacity of the pavement [dm^3/m^3]; min is a function whose value is equal to the smaller of the listed argument values.

Formula (1) has the following physical meaning. Before the rainfall event, the substrate is moistened by previous rainfall events or by the irrigation system to the state required by the plants and contains moisture at the level h_0 [dm^3/m^3]. At the start of the rain event, water accumulates and is retained by the substrate layer. During the rainfall event h [mm] of moisture fell. If the rainfall event is not strong enough to saturate the substrate, it will store a fraction of the moisture received, which adds up to the runoff coefficient. Thus, the total amount of moisture is $h_0 + (1 - K) - h$ [mm]. If the rain event is sufficiently heavy, the substrate will eventually be saturated with moisture, after which all excess moisture will drain away. Therefore, the substrate will accumulate an amount of moisture H [dm^3/m^3].

Thus, to accurately calculate the loads from a green surface, it is important to have an understanding of the rainfall regime and runoff coefficient. Today, the city's blue infrastructure tries to create reserves of water-holding capacity so that the substrate is not completely saturated during the largest rain event. However, if we take into account possible future climate change, the calculation is often based on the maximum water-holding capacity without taking into account actual rain events. This value is also controllable and depends on the substrate and the area of waterproof paths on the pavement.

A different situation arises with snow cover, prevalent throughout Ukraine. Most green roofs are designed to be flat or have a slight slope, which helps to retain snow.

The load from the snow cover can be reduced by snow removal. However, this would lead to a high risk of improperly performing the snow removal duties and overloading the support structures. Therefore, for safety reasons, the calculation is performed on the limit design value. Paper [25] states that maintaining snow cover helps to reduce temperature fluctuations and improve the survival of perennial plants due to better temperature conditions.

Thus, the snow load is a limiting factor below which it is impossible to reduce the temporary load from precipitation. For conventional roofs with an angle of no more than $5\cdot\pi/36$, this load corresponds to the limit design value according [26] to DBN B.1.2-2:2006 [N/m^2]:

$$S_m = \gamma_{fm} \cdot S_0 \cdot C, \tag{2}$$

where γ_{fm} is the reliability factor for the limiting value of the snow load, which can be determined by the author's formula, which repeats all the signs of Table 8.1 in [26]:

$$\gamma_{fm} = \begin{cases} 0{,}23996 + 0{,}195444 \cdot \ln(\mathrm{T}), & \mathrm{T} \le 136, \\ 0{,}8071 + 0{,}016281 \cdot \ln^2(\mathrm{T}), & \mathrm{T} > 136; \end{cases} \tag{3}$$

S_0 is the characteristic value of snow load [N/m^2], which is 800...1800 [N/m^2] depending on the snowy region, [N/m^2]:

$$S_0 = 600 + 200 \cdot No \ \ [\text{N/m}^2]; \tag{4}$$

No = 1...6 is the number of the snowy region; T is the average recurrence period [years]; C is the coefficient defined as a product:

$$C = \mu \cdot C_e \cdot C_{alt}\,; \tag{5}$$

μ is a coefficient that depends on the shape of the roof and is equal to 1 for roofs with an angle of up to 5-π/36, and if the roof has a blind parapet with a height of χ [m] then at a distance x from the nearest such parapet:

$$\mu = \max\left(\max\left(\min\left(2 \cdot \frac{\chi}{S_0}, 3\right), 1\right) \cdot \left(1 - \frac{x}{2 \cdot \chi}\right) + \frac{x}{2 \cdot \chi}, 1\right); \tag{6}$$

two at χ/S_0 is the dimensional coefficient [N/m^3]; C_e is the coefficient of the impact of operation, for example, snow sweeping, for green roofs we take one; C_{alt} is the correction for altitude Alt [km] above sea level according to the formula [26]:

$$C_{alt} = \max(1{,}4 \cdot Alt + 0{,}3, 1)\,; \tag{7}$$

1.4 is the dimensional coefficient [km^{-1}]; max is a function whose value is the largest of the arguments.

With temperature fluctuations, the snow melts, and the pores become saturated with water, after which the snow freezes and significantly compacts - up to 3.5...4 times. On a green surface, the substrate can act as a sponge. When melting, part of the water will saturate the substrate, not the pores between the snowflakes. This will lead to a decrease in snow compaction. However, the overall weight will deviate from the weight of an ungreened pavement minimally and only because of the possible absorption of some of the water that runs off on standard pavements.

To date, no such studies have been conducted. To calculate the snow load on green pavements, it is possible not to introduce correction factors or to introduce a safety factor C_e of the order of 1.05...1.1. From formulas (1-5), we have a general formula for estimating the snow load in [N/m^2]:

$$S_m = \max(1{,}4 \cdot Alt + 0{,}3, 1) \times \left[\max\left(\max\left(\min\left(2 \cdot \frac{\chi}{S_0}, 3\right), 1\right) \cdot \left(1 - \frac{x}{2 \cdot \chi}\right) + \frac{x}{2 \cdot \chi}, 1\right)\right] \times$$
$$\times (600 + 200 \cdot No) \cdot \begin{cases} 0{,}23996 + 0{,}195444 \cdot \ln(\text{T}), & \text{T} \le 136, \\ 0{,}8071 + 0{,}016281 \cdot \ln^2(\text{T}) & \text{T} > 136, \end{cases} \tag{8}$$

where the expression in square brackets is taken into account only if there is a continuous parapet without a gap in the pavement.

3. Results and discussion. Building structures should be designed to withstand a greater load from precipitation, whether snow or rain. Therefore, if water retention by green pavement provides less additional load than snow load ($m_A \le S_m$), it will not lead to the need to strengthen the bearing capacity of structures, and therefore will not increase their cost. Therefore, let us consider the estimate of S [N/m^2], of the snow load from below, which will depend only on the snow region according to [26] and the average recurrence period:

$$S_m \ge S = (600 + 200 \cdot No) \cdot \begin{cases} 0{,}23996 + 0{,}195444 \cdot \ln(\text{T}), & \text{T} \le 136, \\ 0{,}8071 + 0{,}016281 \cdot \ln^2(\text{T}) & \text{T} > 136. \end{cases} \tag{9}$$

According to formula (1), the permissible water retention, so as not to affect the bearing capacity of the structure, is [dm^3/m^2]:

$$\min(h_0 + (1 - K) \cdot h, H) \le \frac{1000 \cdot S}{\rho \cdot g}\,. \tag{10}$$

For the six snowy regions defined in [26] and several recurrence periods within up to 50 years ($\gamma_{fm} \le 1$), we have an estimate of the snow load using formula (7) and the corresponding estimate of the maximum water retention using formula (8) in Fig. 2. The water density is assumed to be the highest — 1000 kg/m^3 at an outside air temperature of 277 K.

Fig. 1, b shows that even when calculated for T = 10 years in the first snow region, we have a critical water retention of 56.2 mm, which is 1.5 times higher than the amount of precipitation of a volley rainstorm [5] in Kyiv (fifth snow region). Other values of water retention are unattainable for the Ukrainian climate. Thus, the water retention of green pavements, even with a zero runoff coefficient, will not create a significant rain load compared to snow. Therefore, it is advisable to ensure the highest possible water retention by green surfaces by the city's rain regime to reduce the load on the subsequent stages of rainwater management - road pavements, eco-parking spaces and rain gardens.

Figure 1b has another physical meaning. It shows the approximate values of maximum water retention by green pavements required for meltwater disposal in spring. It is more correct to calculate this using the formulae (6) and substituting the result into the formula similar to (11) [dm^3/m^2]:

$$H_m = \frac{1000 \cdot S_m}{\rho \cdot g}, \tag{11}$$

where the density of water ρ should be taken at a lower value at a snowmelt temperature of 273.15 K, i.e. 999.87 kg/m^3.

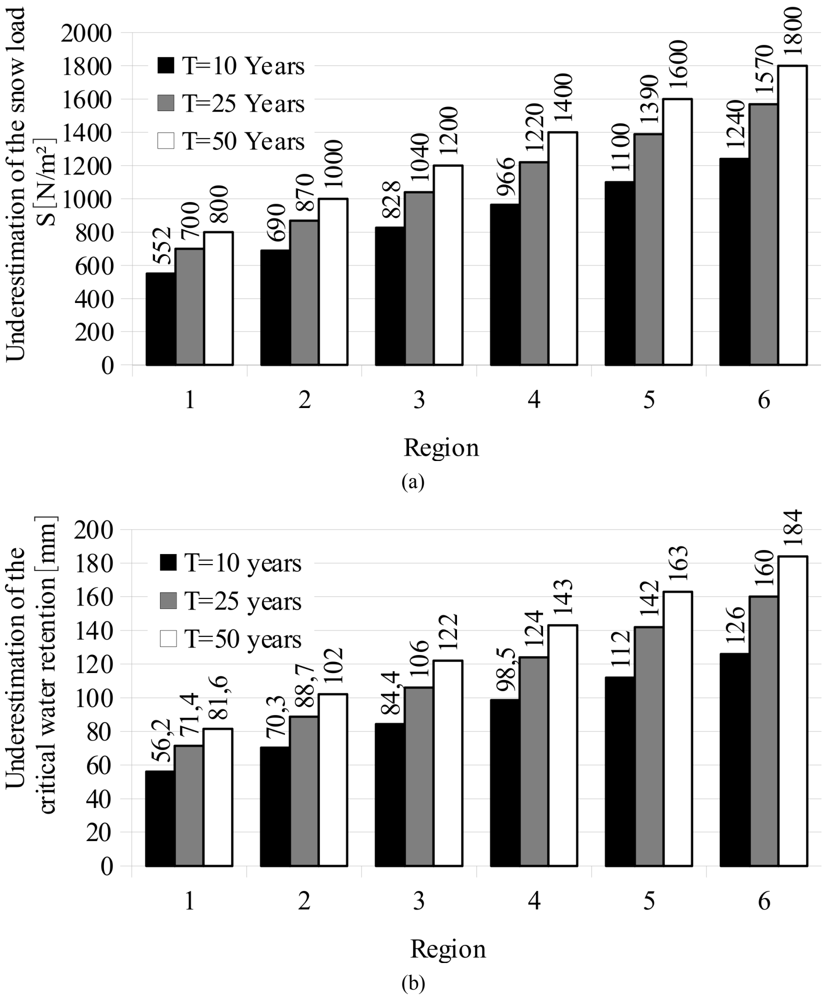

Fig. 2. Calculation results: (a) - assessment of snow load, (b) - assessment of critical water retention

However, this leads to a deviation from the result at a density of 1000 kg/m^3 of only 0.013 %, which is within the error of the data taken from [26]. Therefore, ρ = 1000 kg/m^3 should be accepted.

At present, the utilisation of meltwater by green pavements for water supply purposes is considered very poorly because such water is formed only a few times during the winter-spring period. However, at this time, it can meet the needs for process water for a sufficient number of sanitary appliances, much more than rainwater.

Conclusions. The developed conceptual schemes have shown a close interaction between green structures in multi-stage rainwater management. From the point of view of this management, it is advisable to capture rainwater as much as possible at the first stage - green roofs. And, as calculations have shown, such a strategy will not lead to an increase in the requirements for the bearing capacity of building structures. After all, it is not the impact of rainwater that is decisive, but the snow load. For the rainwater load to be equal to the snow load, even in the first snowy region, 56.2 mm of rainwater must be retained for an average recurrence period of only 10 years, which is significantly higher than the corresponding rainwater resources in the Ukrainian climate. Therefore, this strategy is recommended for Ukrainian conditions. A dependence for calculating the amount of meltwater that can be utilised from green roofs for household needs is proposed.

Prospects for further research. As this analysis has shown, the impact of snow on green surfaces has not been sufficiently investigated. For example, the effect of water absorption and water retention of the substrate on snow load has not been considered, nor have the possibilities of meltwater disposal been studied. These issues will be addressed in future research.

REFERENCES

1. *Yu B.* Ecological effects of new-type urbanization in China // Renewable and Sustainable Energy Reviews. – 2021. – Vol. 135. – P. 110239. https://doi.org/10.1016/j.rser.2020.110239.
2. *Stovin V., Vesuviano G., Kasmin H.* The hydrological performance of a green roof test bed under UK climatic conditions // Journal of Hydrology. – 2012. – Volumes 414–415. P. 148–161. 10.1016/j.jhydrol.2011.10.022.
3. *Kravchenko M.V., Tkachenko T.M.* Problems of improving the terminology and modern classification of "green" constructions for the creation of ukrainian "green" standards // Collection of Scientific Publications NUS. – 2023. – Vol. 493. P. 194–204. 10.15589/znp2023.4(493).26.
4. *Palla A., Gnecco I., Lanza L.* Hydrologic Restoration in the Urban Environment Using Green Roofs // Water. – 2010. – Vol. 2. – P. 140–154. 10.3390/w2020140.
5. *Kravchenko M., Trach Y., Trach R., Tkachenko T., Mileikovskyi V.* Improving the Efficiency and Environmental Friendliness of Urban Stormwater Management by Enhancing the Water Filtration Model in Rain Gardens // Water. – 2024. – Vol. 16, Iss. 10. – P. 1316. 10.3390/w16101316.
6. *Kravchenko M., Trach Y., Trach R., Tkachenko T., Mileikovskyi V.* Behaviour and Peculiarities of Oil Hydrocarbon Removal from Rain Garden Structures // Water. – 2024. Vol. 16, Iss. 13. – P. 1802. 10.3390/w16131802.
7. *Kuoppamäki K.* Vegetated roofs for managing stormwater quantity in cold climate // Ecological Engineering. – 2021. – Vol. 171. – P. 106388. 10.1016/j.ecoleng.2021.106388.
8. *Andenæs E., Time B., Muthanna T., Asphaug S., Kvande T.* Risk Reduction Framework for Blue-Green Roofs // Buildings. – 2021. – Vol. 11. – P. 185. 10.3390/buildings11050185.
9. *Berdahl P., Akbari H., Levinson R., Miller W.A.* Weathering of roofing materials – An overview // Construction and Building Materials. – 2008. – Vol. 22. – P. 423–433. 10.1016/j.conbuildmat.2006.10.015.
10. *Liu W., Engel B.A., Feng Q., Li R.* Simulating annual runoff retention performance of extensive green roofs: A comparison of four climatic regions in China // Journal of Hydrology. – 2022. Vol. 610. – P. 127871. 10.1016/j.jhydrol.2022.127871.
11. *Sims A.W., Robinson C.E., Smart C.C., Voogt J.A., Hay G.J., Lundholm J.T., Powers B., O'Carroll D.M.* Retention performance of green roofs in three different climate regions // Journal of Hydrology. – 2016. – Vol. 542. – P. 115–124. 10.1016/j.jhydrol.2016.08.055.
12. *Graceson A., Hare M., Monaghan J., Hall N.* The water retention capabilities of growing media for green roofs // Ecological Engineering. – 2013. – Vol. 61. P. 328–334. 10.1016/j.ecoleng.2013.09.030.
13. *Braskerud B.C., Paus K.H.* Retention of snowmelt and rain from extensive green roofs during snow-covered periods // Blue-Green Systems. – 2022. – Vol. 4. – P. 184–196. 10.2166/bgs.2022.011.
14. *Andenæs E., Kvande T., Muthanna T., Lohne J.* Performance of Blue-Green Roofs in Cold Climates: A Scoping Review // Buildings. – 2018. – Vol. 8. – P. 55. 10.3390/buildings8040055.
15. Porsche U., Köhle M. Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazi // Krauter S.C.W., Rosa L. P., Landsberg P. T. (Eds). RIO 3 - World Climate & Energy Event 1-5 December 2003, Rio de Janeiro, Brazil: Proceedings of the international conference. Rio de Janeiro: S. C. W. Krauter, 2003. P. 461-467.
16. *Tabatabaee S., Mahdiyar A., Durdyev S., Mohandes S.R., Ismail S.* An assessment model of benefits, opportunities, costs, and risks of green roof installation: A multi criteria decision making approach // Journal of Cleaner Production. – 2019. – Vol. 238. – P. 117956. 10.1016/j.jclepro.2019.117956.
17. *Wilkinson S., Lamond J., Proverbs D.G., Sharman L., Heller A., Manion J.* Technical considerations in green roof retrofit for stormwater attenuation in the Central Business District // Structural Survey. – 2015. Vol. 33. – P. 36–51. 10.1108/SS-07-2014-0031.
18. Fotball tettet sluk – skoletak raste sammen [Electronic Resource] / Stor-Oslo. - Access mode: https://www.nrk.no/stor-oslo/fotball-tettet-sluk-_-skoletak-raste-sammen-1.15114526. - Access date 03.08.2024.
19. Final investigation report on the collapse of roof structure of Chan Tai Ho multi-purpose hall of Hu Fa Kuang Sports Centre of City University of Hong Kong Tat Chee Avenue, Kowloon: The Redacted Version [Electronic Resource] / Buildings Department. - Access mode: https://www.bd.gov.hk/doc/en/resources/codes-and-references/notices-and-reports/reports/CityUReport_201705e.pdf. - Publication date May 2017.

20. FLL 2018. - Guidelines for the Planning, Construction and Maintenance of Green Roofs; Landscape Development and Landscaping Research Society e.V.: FLL standard. - Valid from 2018. - Bonn: FLL, 2018. – 156 p.
21. *Jia H., Yin D.* Green Infrastructure for Stormwater Runoff Control in China // Oxford Research Encyclopedia of Environmental Science. – 2021. – ISBN 978-0-19-938941-4. 10.1093/acrefore/9780199389414.013.765
22. *Li H., Ding L., Ren M., Li C., Wang H.* Sponge City Construction in China: A Survey of the Challenges and Opportunities // Water. – 2017. – Vol. 9. – P. 594. 10.3390/w9090594.
23. *Yin D., Chen Y., Jia H., Wang Q., Chen Z., Xu C., Li Q., Wang W., Yang Y., Fu G.* Sponge city practice in China: A review of construction, assessment, operational and maintenance // Journal of Cleaner Production. – 2021. – Vol. 280. – P. 124963. 10.1016/j.jclepro.2020.124963.
24. Moss concrete [Electronic Resource] / Material District. - Access mode: https://materialdistrict.com/material/moss-concrete/. - Access date 03.08.2024.
25. Lundholm J.T., Weddle B.M., MacIvor J.S. Snow depth and vegetation type affect green roof thermal performance in winter // Energy and Buildings. – 2014. – Vol. 84. – P. 299–307. 10.1016/j.enbuild.2014.07.093.
26. DBN V.1.2-2:2006. Systema zabezpechennia nadiinosti ta bezpeky budivelnykh obiektiv. Navantazhennia i vplyvy. Normy proektuvannia. (System for ensuring the reliability and safety of construction objects. Loads and impacts. Design standards). – Valid from 1 January 2007. – Kyiv: Minbud Ukrainy, 2006. – 75 p.

Стаття надійшла 04.09.2024

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ВПЛИВ ЗЕЛЕНИХ КОНСТРУКЦІЙ БЛАКИТНОЇ ІНФРАСТРУКТУРИ НА НАВАНТАЖЕННЯ КОНСТРУКЦІЙ БУДІВЛІ

У роботі розглянуто місце зелених конструкцій у блакитній інфраструктурі міст. Побудовано схему комплексного керування дощовими стоками за допомогою зелених конструкцій. Показано, що поєднання різних зелених конструкцій дозволяє створити єдину та ефективну систему управління дощовою водою. При цьому виникає потреба оптимізування дії окремих елементів цієї системи. В цьому процесі важливу роль відіграє дія зелених конструкцій будівель на їхні носійні конструкції. Навантаження від зелених покрівель можна розкласти на дві складові: навантаження від конструктивних елементів і рослин, серед яких і вітрове, та навантаження від опадів – утриманої дощової води та снігу. Перша група навантажень є постійною крім періодичного вітрового, але його пікові значення мало відрізняються під час дощів та снігів. Враховувати керування сніговим навантаженням недоцільно. Його можна зменшити прибиранням снігу. Проте це призведе до високого ризику неналежного виконання обов'язків щодо прибирання з перевантаженням носійних конструкцій. Тому з метою безпеки розрахунок виконують на максимальне навантаження. Тому в роботі виконано оцінювання знизу снігового навантаження для різних снігових районів та середніх періодів повторюваності. Визначено критичне водоутримання дощової води, яке має створити таке ж навантаження, що і сніговий покрив. У найгіршому випадку першого снігового району та середнього періоду повторюваності 10 років маємо критичне водоутримання 56,2 дм^3/м^2, що значно перевищує інтенсивність опадів. Це означає, що навантаження від утриманої дощової води буде меншим снігового. Таким чином, необхідно забезпечувати максимальне водоутримання відповідно до обсягу опадів. Це не може вплинути на носійну здатність конструкцій, адже вона визначатиметься сніговим навантаженням. Показано можливість утилізування талої води для господарських потреб. Але цьому питанню на сьогодні приділено недостатню увагу. Поставлено відповідні завдання для майбутніх досліджень.

Ключові слова: блакитна інфраструктура, зелені конструкції, зелене покриття, дощовий сад, навантаження, коефіцієнт стоку, носійна здатність.

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THE INFLUENCE OF GREEN STRUCTURES OF BLUE INFRASTRUCTURE ON THE LOAD OF BUILDING STRUCTURES

The paper considers the place of green structures in the blue infrastructure of cities. A scheme of integrated rainwater management using green structures is built. The combination of different green structures allows to creation of a unified and effective rainwater management system. The impact of green building structures on their supporting structures plays an important role. The loads from green roofs have two components: the load from structural elements and plants, including wind loads, and the load from precipitation-retained rainwater and snow. The first group of loads is constant, except for periodic wind loads, but its peak values vary little during rain and snow. It is impractical to consider snow load management. It can be reduced by snow removal. However, this will lead to a high risk of improper performance of snow removal duties with overloading of the supporting structures. Therefore, for safety reasons, the calculation is based on the maximum load. The load from rainwater depends on the runoff coefficient, which can be changed. Therefore, the paper underestimates the snow load for different snowy regions and average recurrence periods. The critical water retention of rainwater with the same load as the snow cover was determined. In the worst-case scenario of the first snow region and an average recurrence period of 10 years, we have a critical water retention of 56.2 dm^3/m^2, which is significantly higher than the intensity of precipitation. This means that the load of retained rainwater will be less than that of snow. Therefore, it's necessary to ensure maximum water retention by the amount of precipitation. This cannot affect the bearing capacity of structures, which will be determined by the snow load. The possibility of utilising melt water for household needs is shown. The tasks for future research have been set.

Keywords: blue infrastructure, green structures, green pavement, rain garden, load, runoff coefficient, bearing capacity.

УДК 692.43+711
Кравченко М.В., Ткаченко Т.М., Мілейковський В.О., Ткаченко О.А. **Вплив зелених конструкцій блакитної інфраструктури на навантаження конструкцій будівлі** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2025. – Вип. 114. – С. 135-144. – Англ.
Розглянуто розглянуто місце зелених конструкцій у блакитній інфраструктурі міст. Порівняно снігове навантаження та навантаження від утриманої дощової води. Показано, що в умовах України останнє не може наблизитися до значень першої, що дозволяє рекомендувати максимальне водоутримання зеленими покриттями без впливу на носійну здатність конструкцій.
Іл. 2. Бібліогр. 26 назв.

UDC 692.43+711
Kravchenko M.V., Tkachenko T.M., Mileikovskyi V.O., Tkachenko O.A. **The influence of green structures of blue infrastructure on the load of building structures** // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA, 2025. – Issue 114. – P. 135-144. – English
The place of green structures in the blue infrastructure of cities is considered. The snow load and the load from retained rainwater are compared. It is shown that in the conditions of Ukraine, the last one cannot approach the values of the first one, which allows the recommendation of the maximum water retention of green roofs without affecting the bearing capacity of the structures.
Figs. 2. Refs. 26.

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