Vol. 12, 2023, 94-106

DOI: 10.17512/bozpe.2023.12.11

Construction of optimized energy potential

Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Transforming urban areas in accordance with the principles of Nature-Based Solutions

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Abstract: Settlement of the population in large urban centers contributes to the strong urbanization of substantial areas, especially increasing the density of buildings at the expense of green areas. Current trends are focused on sustainable development and the search for ways to ensure the permanent maintenance of the proper function of the ecological system. A sustainable approach is especially important for urbanized areas where nature is losing the fight against "concretosis". The ecological idea, related to the concept of compensating the green space occupied by buildings, comes to the fore here, which provides ecological, economic and social benefits, and supports adaptation to climate change. The article presents the concept of transforming a specific urbanized area in accordance with the principles of Nature-Based Solutions. Detailed solutions on a local scale in Košice (Slovakia) were presented. Obtaining positive results from the applied solutions on a local scale can have positive effects not only for the indicated area or city, but can be adapted in other European cities, which will contribute to the creation of green and resilient urbanscapes.

Keywords: urbanized areas, sustainable development, Nature-Based Solutions, green space compensation, biologically active surfaces

Please, quote this article as follows:

Čákyová K., Vertaľ M., Vargová A., Vranayová Z., Lis A., Transforming urban areas in accordance with the principles of Nature-Based Solutions, Construction of Optimized Energy Potential (CoOEP), Vol. 12, 2023, 94-106, DOI: 10.17512/bozpe.2023.12.11

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Introduction

The concentration of population in a given area creates the need to adapt this space in a specific way. The process of urbanization has transformed green areas into concrete jungles. At the beginning of the 19th century, cities concentrated about 2.4% of the population, these days this number has risen to much more than half. The increase in the population of cities results not only from the percentage increase in people willing to live in their area, but also from the increase in the world population, which in 1900 was about 1.65 billion, in 1950 about 2.55 billion, in 2000 almost 6 billion, and now it has already exceeded 8 billion. It is estimated that over the next 30-40 years, the percentage of the population living in cities will increase to nearly 70%, and the world's population will exceed 10 billion (World, 2019; 2022; 2023).

The growing gray infrastructure in cities reduces the share of biologically active areas and this results in exposed surfaces heating up and then release the heat to the atmosphere. The urban heat island effect contributes to climate change, characterized not only by an increase in temperature, but also disturbances in the hydrological cycle (Kim & Brown, 2021; Salmanian & Bayat, 2023; Stewart & Mills, 2021; You, 2023). Impervious surfaces are a barrier to water infiltration. During heavy rainfall, rainwater flows quickly, which leads to drought, and when the municipal sewage system cannot keep up with water drainage, to flooding. An additional threat is high concentrations of harmful substances related to fuel combustion and traffic volume. The WHO indicates that over 90% of people around the world breathe polluted air, and about 3 million die annually as a result. Over 50% of urban residents are also exposed to traffic noise levels of at least 55 decibels. The European Environment Agency (EEA) estimates that long-term exposure to noise causes 12,000 deaths a year in Europe and contributes to 48,000 new cases of illness (Tian et al., 2022; World, 2019). The urbanization also leads to the degradation of natural habitats and the reduction of biodiversity. The wrong direction of development of the urban tissue and the intensification of extreme phenomena related to climate change have a negative impact on city dwellers, both in terms of discomfort, but also in terms of health and life. Since the process of urbanization is difficult to stop, the search for ways to introduce greenery into urban space has begun. Thanks to the use of Nature-Based Solutions (NBS), many of these problems can be effectively solved, as well as supporting the sustainable development of cities, increasing their resilience and improving the living conditions of residents (Busha & Doyon, 2019; Croci & Lucchitta, 2021). By introducing elements of blue-green infrastructure, such as green roofs and facades or sustainable water management systems, cities can contribute to the reduction of greenhouse gas emissions and mitigate the effects of climate change, while achieving numerous social, economic and environmental benefits (Cai & Pan, 2023; Johnson et al., 2022; Nature, 2020). The potential of NBS for mitigation and adaptation to climate change is still underutilised by cities and there has been a lack of testing. Barriers hindering the dissemination of solutions include insufficient knowledge and experience in their planning and implementation, as well as the shortage of urban management instruments in sectoral and integrated policies (Goličnik Marušić, 2023; Wickenberg et al., 2021).

1. Benefits of NBS as compensation for the area occupied by buildings

Nature-Based Solutions introduce elements and processes occurring in nature to cities through systemic activities adapted to local conditions and efficient in terms of resource use. Nature-inspired and economically viable solutions deliver ecological, economic and social benefits, and support climate change adaptation and resilience to the effects of these changes. Blue and green infrastructure complements or replaces gray infrastructure (Balapgol & Narwade, 2022; Bona et al., 2023; Epelde et al., 2022; Kabisch et al., 2022; Pancewicz et al., 2023). Compensation of green space occupied by buildings is a concept aimed at increasing the amount of greenery in intensively built-up urban spaces without the need to allocate additional areas (World, 2021). Since the roofs and walls of buildings and transport stops, as well as outbuildings occupy a significant part of a city's area, they can supplement the lack of biologically active areas at ground level. Living roofs and walls are green areas that improve the aesthetics, reducing the feeling of being overwhelmed by tall buildings, and play a significant role in restoring local ecosystems. However, it is much more important that they contribute to climate protection, reducing the urban heat island phenomenon and pollution, increase energy savings and limit excessive rainwater runoff (Brázdová & Kupka, 2023; Cakyova et al., 2021a; Vertal' et al., 2018, Vranayová et al., 2023).

In urban conditions, traditional surfaces of roofs and walls reach a temperature of nearly 60°C, and for roofs with bituminous coating even 80°C, which causes the ambient temperature to increase from 8°C to 10°C. Depending on the vegetation used, the surface temperature can be reduced by up to half. With a 5% increase in the biologically active areas, the average summer ambient temperature is decreased by 2.2°C, and the amount of smog by 10% (Huang et al., 2023; Pongkua, 2023). Each green surface is a producer of oxygen. In the process of photosynthesis, 155 m^2 of greenery produces enough O_2 for one person a day. Plants also have a huge share in absorbing gaseous pollutants from the air. A green roof absorbs up to 20% of dust and harmful gases annually. Studies have shown that 1 m^2 of grass on a green roof absorbs 0.2 kg of dust particles from the air per year. A 10 m^2 green wall absorbs the same amount of CO_2 as a 4 m tree. The use of appropriate plant species allows for the reduction of chemical compounds such as NO_x and SO_2. Some plant species can also take up harmful elements and incorporate them into their tissues. Green surfaces stop e.g. heavy metals such as copper, lead, cadmium, and also reduce nitrogen concentrations (Kuok Ho, 2023; Tan et al., 2023, Tkaczenko et al., 2019; Ysebaert et al., 2021).

Green roofs are additionally absorptive surfaces for rainwater, achieved through the process of retention, while also taking an active part in improving the water balance of urbanized areas. The average retention is in the range of 50-60%.

A green roof discharges up to 90% less water into the sewage system, making it an effective flood prevention solution. It stops pollutants and by keeping water, it prevents drought and humidifies the air. Reducing the runoff lowers construction and maintenance costs for the building's installations and stormwater drainage system while also having a higher fire resistance (Cakyova et al., 2021b; Kravchenko et al., 2023; Poorova & Vranayova, 2020). Green surfaces can increase acoustic comfort. The applied layer of the substrate absorbs the range of low-frequency waves, while the higher ones are blocked by vegetation. Studies have shown that a 12 cm layer of the substrate reduces the sound level by 40 decibels, and 20 cm by 50 dB (Besir & Cuce, 2018; Cascone et al., 2018). Green roof layers reduce the risk of breaking the cover by the wind, and doubles the life of the materials and the durability of the structure. They protect against UV radiation, temperature jumps and mechanical damage (service, hail). They also increase the energy efficiency of buildings by providing thermal insulation at both low and high temperatures, which reduces the energy consumption of the buildings (Domanicki et al., 2021; Halaszova & Kozlovska, 2021; Karimi et al., 2023). Solutions based on efficient façade and roof systems are used to generate energy or food. Biophotovoltaic panels obtain energy from natural microbiological processes. Roof and wall surfaces can also be a place to introduce renewable energy sources into urban space. Such infrastructure, of course, does not have the advantages of green infrastructure, but it is a source of green energy that fits into the idea of climate neutrality (Gorás et al., 2021; Idzikowski & Cierlicki, 2021; Lis, 2020; Savchenko & Lis, 2021; Voznyak et al., 2023). Introducing greenery into the built-up area is important not only from the point of view of improving the local microclimate, but also the quality of the indoor environment (Doan et al., 2023; Minova et al., 2019; Poorova et al., 2019; Venuh et al., 2023).

2. Scope and method of the analysis

The subject of the work was the transformation of a selected urbanized area in accordance with the principles of NBS. Nature-inspired solutions on roofs and façades are most common in city centres on new or refurbished residential buildings than in industrial areas. The article focuses on the development of a concept for the transformation of a selected typical industrial zone in the city of Košice (Slovakia). It was assumed that the gray infrastructure would be replaced by compensating the space occupied by buildings with living walls and roofs. The main emphasis was placed on capturing the maximum amount of rainwater. The concept assumes the involvement of the zone owner in the creation and selection of solutions, which can help stimulate the activity of owners of areas and the general public to introduce such solutions in their area and raise awareness of the benefits of using NBS.

The transformation of the selected zone was divided into several stages. After the technical and economic assessment, a project containing optimal NSB for the selected area would be developed. Individual elements of the designed green infrastructure would then be implemented in turn. As part of the venture, it was planned to create a research project consisting of the realization of an experimental roof with various layers and types of vegetation. Sensors would be installed in the structure in two circuits for measuring and recording climate parameters and selected parameters in the test layers. The measured data, from both circuits would be stored in the cloud and available for further analysis. Monitoring the condition of the coating with a layer of vegetation would allow the determining of the optimal procedures and solutions for the entire territory of Slovakia and climatically similar regions of Central Europe. The introduction of green as well as blue infrastructure in industrial zones can create an interesting connection between nature and industry in cities.

3. Subject of the analysis

The selected area is located in the Nad jazerom district and is part of a large industrial complex (Fig. 1).

Fig. 1. Industrial areas in the city of Košice with the selected zone marked (*own research*)

On the area of 3,926 m^2 there is an administrative building, storage sheds, a fire protection tank and parking spaces. The four-storey administrative building with an area of 618 m^2 was erected in a prefabricated structure, the reinforced concrete skeleton was filled with small-sized elements (Fig. 2).

Fig. 2. Administrative building with the adjacent area (*own photo*)

Greenery covers about 14% of the analyzed area, the rest is concrete and asphalt. The terrain is drained by a sewer which passes through an oil separator and then discharges into the city sewer.

4. Applied solutions

In the selected area, various types of green infrastructure were proposed to compensate for the parts occupied by buildings, i.e. green walls, vegetation roofs of various substrate thicknesses, vegetation roofs in symbiosis with photovoltaics, extensive green roofs and wet roofs (Figs. 3 and 4). Part of the parking zone would also be covered with vegetation. There was a proposal to create green sheds over parking spaces and an artificial wetland near the storage hall.

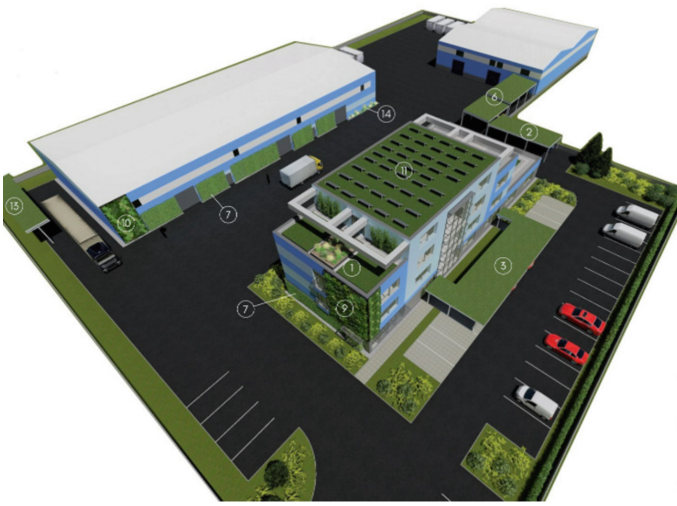

Fig. 3. Nature-Based Solutions in the selected area – front view (*own research*)

Fig. 4. Nature-Based Solutions in the selected area – rear view (*own research*)

The indication of solutions for the transformation of the selected area was preceded by an analysis of technical and economic parameters, as well as their environmental impact. Prior to the development of the project, a static assessment of the buildings to determine the load-bearing capacity of their structures, as well as an assessment of the condition of the asphalt surface was carried out. It was found that the buildings were suitable to support green infrastructure. It was decided to leave the asphalt pavement as it was in good condition and its removal would not bring much economic or environmental benefit. Excess rainwater from vegetation segments and non-absorbent surfaces (asphalt roads and car parks) would be collected and properly cleaned, and then accumulated by infiltration blocks within the zone.

The implementation of the concept included the creation of a research project. On the southern terrace, an experimental roof was designed with continuous recording of selected physical parameters at various layers of the structure. The test roof was divided into three test segments, which are identical in the level of waterproofing. Test segment I was an extensive vegetation roof with a roof substrate height of 120 mm, test segment II was a referential roof with gravel backfill and test segment III was an extensive vegetation roof with a roof substrate height of 240 mm (Fig. 5).

Two measuring circuits were installed. The first circuit measured and recorded relevant atmospheric parameters: temperature and relative humidity, solar radiation intensity, wind direction and speed, total amount and intensity of precipitation and atmospheric pressure. The second circuit with sensors built into the roof structure measured and recorded the effect of rainwater on the temperature in the roof cladding, ability to accumulate precipitation water and its redistribution in the substrate, analyzed the effects of shortwave and long wave radiation, recorded overheating of the roof in long-term dry weather and also the influence of the snow layer on the course of temperatures in the roof cladding. As part of the experiment, it would be possible to create and test different types of green coverings suitable from the point of view of the city's climate.

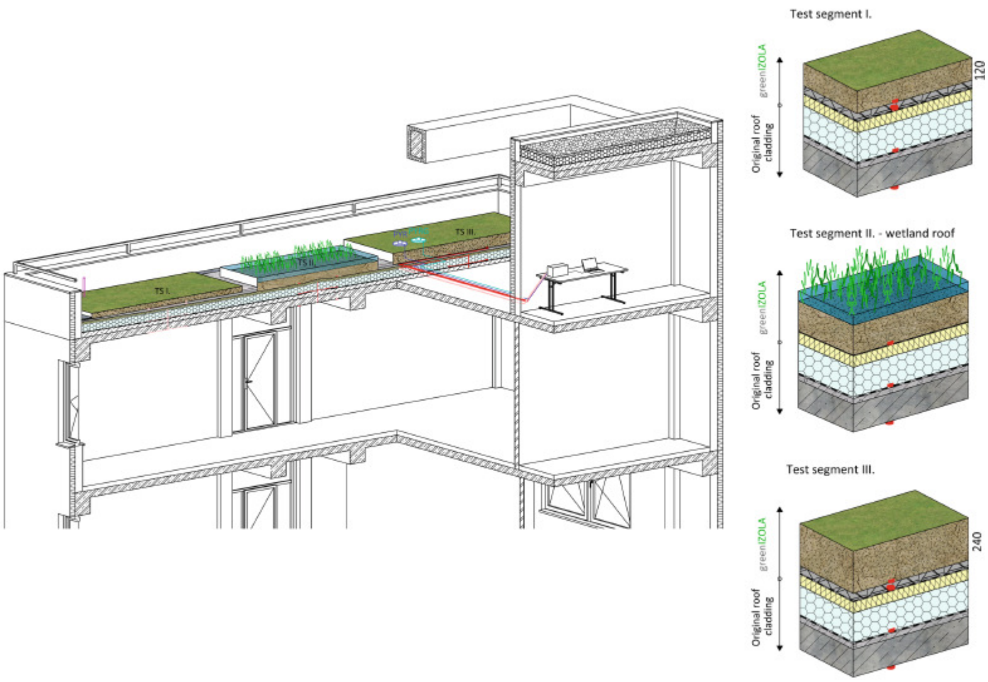

Fig. 5. Types of layers on the experimental roof and location of the sensors (*own research*)

5. Results

The success of the transformation of the selected zone in accordance with the principles of NBS is the obtaining of a space that fits into the concept of sustainable urban development and creates a friendly environment for people. As a result, about 1,025 m^2 of roofs and sheds would be covered with vegetation. Replacing part of the car parking and storing area with vegetation would also reduce the non-absorbent surface from 3,308 m^2 to 2,765 m^2, transforming it into a functional solution for water retention. The area of green infrastructure would increase from 14 to 41%. The construction of sheds over car parking increases the green area, and protects vehicles against adverse weather conditions (overheating, hail). Returning part of the terrain to nature would also lower the ambient temperature, increase the retention of rainwater, create a thermal and acoustic barrier, as well as form specific filter screens and strengthen biodiversity and environmental resilience. Part of the project has already been completed in the form of an experimental roof being built, sensors for measuring parameters in layers and a weather station were installed, and measurements were started. Monitoring the behaviour of test vegetation segments is carried out through long-term in-situ measurements. Figure 6 presents measurement data from three different segments during the summer period.

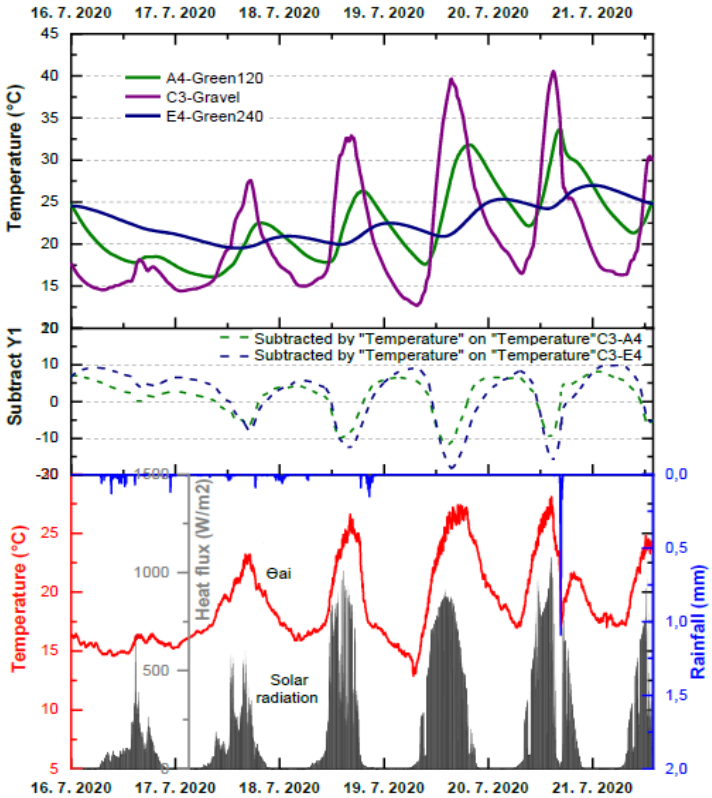

Fig. 6. Presentation of the measurement results for the selected period (*own research*)

The upper part shows the course of temperatures measured under the ground of individual segments. The influence of the substrate and its thickness on the course of temperatures and its maximum value and shift in the presented period is clearly visible. The middle part of the Figure shows the difference between the temperature measured under the gravel roof substrate (C-3) and the temperature measured under the 120 mm thick vegetation roof substrate (A-4) and 240 mm thick vegetation roof substrate (E-4). The climate parameters are shown in the lower part of the Figure.

The use of different types of vegetation on various structures of roofs and walls with different locations in relation to the cardinal compass points enables the collection of information on the behaviour of this type of structure in various atmospheric conditions throughout the year and their impact on the surrounding and internal environment. Connecting the transformation with a research project run by the university will broaden the knowledge on the impact of green infrastructure on the condition of cities and popularize this subject both among the scientific community, the architectural and construction sector and the general public. The project also includes the creation of a training camp to identify the benefits and obstacles of green building.

Conclusions

The effect of transforming the selected industrial zone in accordance with the NBS principles is the obtaining of an attractive, human-friendly ecological area, while maintaining the functionality and requirements that are necessary for this type of zone. The implementation of the project contributes to the creation of approximately 1,025 m^2 of new, diverse plant area on roofs, terraces and sheds, and thus to an increase in the share of vegetation covered areas by nearly 30% without the need to reduce the functional area of the terrain. Also non-absorbent surfaces were reduced by 543 m^2; the filtration of rainwater was increased by 94% thus relieving the sewage system and reducing the risk of terrain flooding; air quality and local climate was improved thus reducing the heat island phenomenon and reducing the amount of pollutants in the air; vehicles were secured against harmful weather phenomena; acoustic comfort inside and outside buildings was improved; the quality of the indoor microclimate and working comfort was increased; the energy expenditure of the buildings was reduced; durability, resilience to climate change, attractiveness and aesthetics of buildings and terrain were improved; and the creation of research potential in the form of an innovative in-situ laboratory was obtained. The current monitoring of the effects of the solutions shows the significant impact of the vegetation layer on the temperature profiles of the roofing and positive changes in the external and internal environment. The presence of vegetation on the ground layer protects the building from overheating in the summer, and through the retention of rainwater in the roof, its thermal capacity is increased. Vegetation is also an effective thermal barrier in winter. The process of evapotranspiration in the layers of vegetation visibly reduces the temperature of the upper layers of the roof, which significantly affects the overall energy balance and ambient temperature.

Well-designed industrial zones in terms of sustainable development and integration with nature are rare not only in Slovakia, but all over the world. Although practice shows that NBS are on average 50% more profitable than their traditional, gray alternatives and provide about 30% more added value, globally they still represent a small percentage of city budgets. The presented example is a unique concept that can be a positive example for the ecological and aesthetic transformation of industrial zones in Central Europe. The use of different types of vegetation on different structures will guarantee the possibility of their universal use to deepen knowledge and transpose the results to cities with a similar climate. The concept of the green industrial zones creates a strong and lasting foundation for building resilient, smart and green cities in the present and in the future. Linking the owner of the selected zone with the university will engage a wider group of potential investors and contractors, and will also be a source of information for both professionals and the public.

Acknowledgements

The authors thank the Ministry for Education of the Slovak Republic for the support within VEGA research grant No. 1/0492/23 "Transformation of existing buildings into sustainable buildings – the ecological potential of flat roofs", and a project run by the Slovak Research and Development Agency APVV-18-0360 Active hybrid infrastructure towards to a sponge city.

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