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THE NBS PROJECT FOR THE ADAPTATION OF THE KYIV OSOKORKY DISTRICT TO CLIMATE CHANGES

Global climate changes have significant impact on cities around the world, although the exact threats can vary significantly depending on the geographic region. Kyiv is a capital city with large population and vast area, which faces different challenges imposed by changing climate. The analysis of climate models demonstrates vulnerability of Kyiv urban infrastructure to heat waves, urban heat island, increasing precipitations and negative weather phenomena. The research was conducted for the Osokorky district of Kyiv to determine its problem points and evaluate the resilience of infrastructure. The results of analysis show that in spite of novelty of the district it lacks sustainability components, has poorly developed green and blue infrastructure, as well as inefficient road network. All these factors combined with dense construction create favorable conditions for the thermal pressure at local population and other biotic components of the district. The suggested approach to the adaptation of Osokorky district to climate changes is through the implementation of nature-based solutions with the aim to expand green infrastructure and increase the volume of ecosystem services provided by urban plants. The green roofs design was developed for 15 sites around the district, based on their location and favorable technical conditions. The economic costs of the project were estimated and the payback period based on the value of ecosystem services provided was defined. In order to strengthen the resilience of the district a complex of additional organizational measures is necessary to support the progress towards safe urban environment.

Keywords: climate change, adaptation, urban ecosystem, nature-based solutions

Introduction. Climate change raises numerous challenges for cities and threatens functionability of municipal infrastructure, human health, urban flora and fauna. So far as we observe limited progress towards the reduction of greenhouse emissions, cities face the need to adapt to the effects of climate changes in the field of infrastructure resilience and population safety.

Problem statement. Methods of adaptation to climate changes in urban ecosystems are divided into urban technology solutions, urban nature-based solutions and urban social solutions [1]. The long – term achievements with moderate monetary investments and limited reconstruction of the existing facilities is provided by nature-based solutions for adaptation. Nature-based solutions (NBS) involve working with nature to solve societal problems and involving the protection, restoration or management of natural and semi-natural ecosystems; or creating new ecosystems in and around cities [2]. The variety of the given solutions has been already developed in many cities of the world, including Belgium, United Kingdom, Poland, Sweden, Denmark, Greece, Italy, Bulgaria, The Netherlands etc. However, the analysis of these cases demonstrates various scale of efficiency and their applicability should be always vigorously considered [3]. Thus, it is important to choose solutions according to the very specific conditions of each municipality and even its parts, since NBS are not fixed and work differently in each case [4]. Moreover, the NBS are able to provide different results in terms of environmental problems and they should be planned to target exactly adaptation to climate changes at first place with possible yield of positive side benefits for the solution of other environmental issues. For example, the NBS could be aimed at improving resources and energy efficiency in cities, thus giving limited effects for climate change adaptation [5]. Another important issue is that flaws in NBS planning can even cause social tension and raise the level of inequality in a city [6]. Thus, collaboration of all interested parties and open access process of planning are key preconditions for effective NBS as a part of urban adaptation to climate changes [7].

The first stage to the development of adaptation plan with nature-based solutions embodied should be the assessment of cities vulnerability, in particular, resilience of its infrastructure and factors contributing to the development of problems [8].

The prominent signs of climate changes in Kyiv will include rising temperature, precipitations and intensity of weather extremes, as it is shown in numerous publications by O.Shevchenko, S. Boichenko, S. Snizhko, Yu. Posudin and others. In particular, the expected temperature rise is up to 0.5-1.5°C [9] and the rainfall is expected to raise by 10-12% according to the estimations [10]. The results of the modeling also predict the extreme weather phenomena, in particular heat waves, to become more severe and frequent for Kyiv by 25% [11].

To approach the problem the city administration has conducted the assessment of Kyiv vulnerability to climate changed in the end of 2021 and the corresponding plan for adaptation has been announced later on (the relevant information is available a the official web-page of the Kyiv city council [12]). However, the final document hasn't been presented yet. The overview of the problem given by the National institute for strategic studies in 2016 included a range of recommendations on institutional and legislative initiatives necessary to enable municipalities to respond to climate change challenges. Unfortunately, adaptation to climate changes is only mentioned as a potential field of actions [13].

Kyiv is also a signatory of the Covenant of Mayors initiative, which aims to engage and support cities and towns to commit to reaching the EU climate mitigation and adaptation targets. Signatory cities pledge action to support implementation of the EU 40% greenhouse gas-reduction target by 2030 and the adoption of a joint approach to tackling mitigation and adaptation to climate change [14]. 310 other cities of Ukraine have joined the Convention, however, only one city has taken commitment to implement adaptation plan and this is not Kyiv, even though it has the biggest resources available. The action plans are developed by 164 cities (53% of signatory cities), but most of these plans (115 cities) are on hold due to insufficient data provided or lack of real actions, instead of declarative formulation. Thus, the task of developing and implementing adaptation strategies in cities of Ukraine is still far from completed.

The city of Kyiv has diverse natural conditions and level of infrastructure development. As a result vulnerability to climate change effects is different depending on the part of city. The aim of the given paper is to evaluate the vulnerability of the sample district of Kyiv to climate changes and develop a project for its adaptation using nature based solution.

Analysis of current situation. Osokorky residential district is the youngest massif in Kyiv - its construction began in 1993 on drained wetlands around the village Osokorky. It is located in Darnytskyi district, between the Dnieper River and Lake Vyrlytsia. Until the 1990s, the Osokorki were mostly floodplain meadows with streams, swamps and lakes. For the construction of the metro and residential facilities the wetlands were drained and alluvium was extracted. This has led to dramatic changes in local landscapes. On the territory of the private sector there is a chain of residual natural lakes, the largest of which are Zaryvakha, Pidbirna, Yaremine.

The transport infrastructure of this area is well developed, it includes subway line and the system of roads. However, their planning is based on the rectangular principles, when all the traffic flows run into one central road and then major avenue of the urban district. This creates continuous traffic complications and contributes to the thermal pollution of the area [15], exacerbated by high-rise buildings into local heat island. It is mostly mitigated by the Dnieper River, but in some areas the canyon effect is very pronounced due to lack of vegetation. The quality of air according to the data from the online monitoring system (Kyiv eco city) usually fluctuates between satisfactory and poor. This is also the result of transport emissions concentrated along the roadways and inefficient aeration in the central part of the district.

The structure of ***residential estate*** is quite diverse. These are mostly densely located high-rise buildings, with lack green elements along them. The eastern part of the district is made of the buildings of the Soviet time, many of which are in unsatisfactory condition. The auxiliary infrastructure includes several shopping malls (Pyramid and Aladdin), two hypermarkets (Epicenter and Metro), several large supermarkets (such as Novus). They are characterized be low level of landscaping and vast areas of parking zones with solid cover, prone to overheating in warm season.

The pressure from local industrial facilities (furniture, textile and automotive services) is not high, as compared with the magnitude of technogenic impact of the Bortnytsia aeration station and the waste incineration plant "Energia" from the neighboring district. Continuous construction also contributes to poor air quality.

Power supply in the district is centralized and almost exclusively electric, while the old-fashion buildings are provided with gas supply. Even though most buildings were constructed in this century the application of sustainable technologies, green architecture principles and alternative sources of power supply is very limited. Thus, only one new building is equipped with solar panels.

The system of water supply and sewerage experience high levels of wearing, since it is based on the initial network, planned for lower-rise buildings of the soviet times. The level of storm waters management is considered unsatisfactory as well and under the threat of growing precipitation levels due to climate changes there is a risk of flooding in the area.

Municipal solid waste management system is still underdeveloped as in all other parts of the city of Kyiv. Waste collection is unsatisfactory and there is no holistic system of separate waste collection. Despite the fact that newer buildings are provided with separate containers for waste sorting, their efficiency is limited by imperfect waste collection.

The land use planning in the district is mostly aimed at maximally dense construction of residential buildings. Such approach restricts the equal expansion of the green infrastructure in the district and further aggravates existing environmental issues and upcoming challenges, posed by climate changes.

Green infrastructure of the district is of limited coverage and lacks well-planned structure. There are no large green areas in the study area, there is only vegetation along the main streets and near houses. However, there are some green belts of the embankment of Lake Teglya, Lake Silver Circle, Lake Vyrlytsia, Lake Nebrezh, Lake Lebedyne and Lake Poznyaki. To the west of the study area there is the private sector with denser vegetation. But we believe that this is not enough to significantly reduce local temperature extremes and heat island expressiveness.

Blue infrastructure of the district is made of waterbodies (natural and artificial) around the district: lakes, ponds and the Dnieper system. However, there are no water bodies within the area. Those water bodies at the borders of the districts are characterized by numerous environmental issues, in particular, insufficient maintenance and waste management; low biodiversity of aquatic species, which makes water ecosystems vulnerable to future climate changes; pollution with urban runoff and industrial discharges; illegal extraction of construction materials; construction in floodplains. These factors considerably reduce the role of blue infrastructure in the improvement of environment condition at the study are.

Results and discussions. Accounting the above presented strengths and weaknesses of the Osokorky municipal facilities, to mitigate the effects of climate changes and to adapt the studied district to growing temperature, a plan of green infrastructure development, using green roofs, is suggested.

Technical solutions. Green roofs are divided into two types: extensive and intensive. **Extensive roofs** are those covered with a relatively thin layer of substrate with hardy plants (sedums, grasses, cereals), which minimizes the necessary care and maintenance of them). **Intensive roofs** ("roof gardens") require a larger layer of substrate, and therefore are suitable for all plants - perennials, shrubs and trees, - arranged playgrounds and recreation facilities. Consequently such roofs need much more intensive care and support.

There is a large number of low-rise buildings with flat roofs in the study area, suitable for alternative greening. We have selected 15 objects, including 5 schools, 2 parking spaces, 2 hypermarkets, 3 supermarkets, 2 shopping malls, and 1 commercial building (Fig. 1), offering specific solutions in terms of green roofs parameters for each site (Table 1).

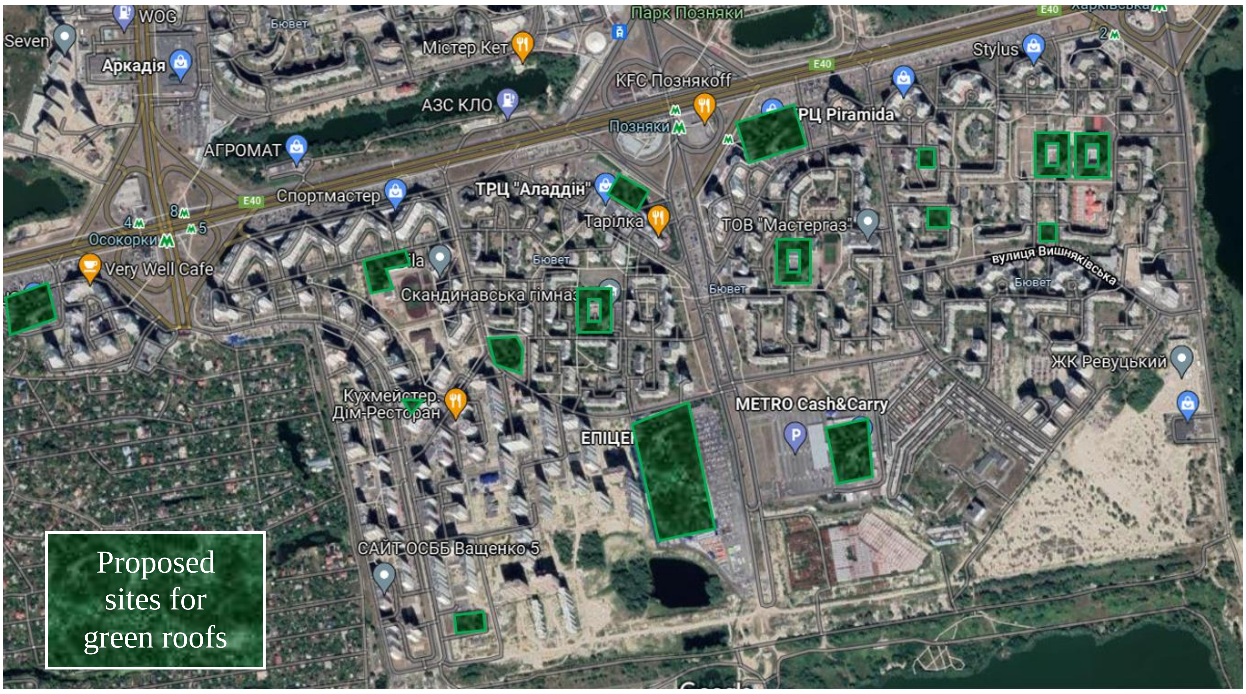

Fig. 1. Location of green roof in project

Table 1

Technical characteristics of the green roofs components

Type of system	Advantages	Recommended plant types	The selected sites on the project
Extensive roofs at 7 buildings			
Economical roof	- classic multilayer structure with drainage and storage element and system filter. - relatively low biodiversity: sedums are mainly used as a plant layer. - the most cost-effective system solution for a green roof. - can be used on inverted roofs, - requires minimal maintenance.	Sedum, Crassulaceae, and any flowering perennials with high tolerance to water and thermal stress.	1. Residence (Hmyria St., 7) 2. Parking (Rudenko St., 17) 3. Velmart (Vyshniakivska St.10) 4. VK Express (Rudenko St., 9) 5. NOVUS (Bazhan Ave, 8) 6. NOVUS (Hryshko St., 3)
Lightweight roof	- the easiest system solution for a green roof. - possibility to install an irrigation system. - can be used on flat roofs (without drainage slopes). - reliable anti-erosion solution; used only with a reliable waterproofing system. - higher maintenance and installation costs compared to the economical roof.	Sedums, Crassulaceae and perennials	7. Multi-storey car park (Chavdar St., 13)
Intensive roofs at 8 buildings			
Garden on the roof	- multilayer system solution with drainage and storage element; - recreational opportunity; - intensive type of landscaping; - automatic watering is possible; - can be used on inverted roofs.	Perennial herbaceous plants, small shrubs, trees with a maximum height of 2-4 meters.	1. Epicenter (Hryhorenko Ave.40)
Roof landscape	- the "greenest" system solution with relatively low weight; - unique landscape design is possible; - can be used on inverted roofs.	Pine-tree, Birch, maple, oak (dwarf subtypes), willow, juniper, honeysuckle, spirea, lilac, brier + lawn (moss, oregano, cloves, lavender)	2. Piramida shopping mall (Myshuhy St., 4) 3. Gymnasium "Kyivska Rus" (Borysa Hmyri St., 2B) 4. Scandinavian Gymnasium (Hmyri St., 3B) 5. Lyceum "Intellect" (Bazhan Ave, 34A) 6. School №316 (Bazhan Ave. 32A) 7. Gymnasium of International Relations №323 (Myshuha St., 5) 8. METRO Cash&Carry (Hryhorenko Ave, 43)

The plants, selected for the given types of roofs, are the general recommendations, as it is impossible to list all candidates. These plants and other potentially suitable species can be found by looking at the microclimate (media depth, solar levels, water availability, etc.) of the green roof in question and comparing it to a plant's native habitat [16]. The other important plants characteristics, taken into account, are rate of establishment, longevity, ground cover density, and disease and pest resistance. The ideal species are long-lived, drought tolerant, self-pollinating or spread vegetatively. However, drought-tolerant species that rely on deep taproots to obtain moisture should be avoided, since such conditions do not exist on shallow green roofs [17].

Additionally we offer to install solar panels at some sites. The modern trends in the sustainability for cities include development of the decentralized power supply sources, including those based on alternative solutions. Since the construction of the district is an ongoing process, wider application of alternative decentralized power supply would provide a range of valuable benefits to the district, including higher energy independence and stability of supply, lower carbon footprint of utilities and additional reserves for local business development.

The pilot facility could be the roof of the Epicenter shopping mall due to its considerable area, availability of resources for in-time maintenance and well regulated power consumption. Growing plants under the solar panels is possible, if the shade tolerant plants are chosen (e.g. woodland bulbs (bluebells, aconites etc), woodland grasses, red or white dead nettle and primrose).

The climate conditions, accounting expected rise in precipitations, are favorable for green roofs, since they need minimal irrigation. The possible drawback is that some of the chosen sites are low buildings and are partially shaded by high rise apartment blocks.

Economic parameters of the project. The cost of a green roof includes: design and project permission acquisition; installation; materials; plants seedlings and seeds; transportation; preparation of the object (repair, if the site needs it); additional materials to create a recreational area. Also, it is important to (take into) account the running costs of the maintenance of green areas, which is also paid. The price also depends on the location, based on research data [18-20] and information from companies providing this type of works in Europe the average cost of roofs can be accepted as follows:

- Economical roof: 14-17 €/m^2;
- Lightweight roof: 17-20 €/m^2;
- Roof landscape and Garden on the roof: 35 €/m^2.

Approximate roof area of objects and price (without additional materials for repairs, cost of maintenance and documentation):

- Epicenter = 37800 m2 = 1970696 € (including solar panels)
- Pyramid shopping mall = 11004 m2 = 385140 €
- Gymnasium "Kyivska Rus" = 5372 m2 = 188020 €
- Scandinavian Gymnasium = 4000 m2 = 140000 €
- Lyceum "Intellect" = 3950 m2 = 138250 €
- School №316 = 3520 m2 = 123200 €
- Gymnasium of International Relations №323 = 5200 m2 = 182000 €
- Multi-storey car park = 1750 m2 = 29720 €
- METRO Cash & Carry = 15200 m2 = 304000 €
- Borys Hmyria St., 7 = 4420 m2 = 61880 €
- Covered parking (Larysa Rudenko St., 17) = 1650 m2 = 23100 €
- Velmart = 1540 m2 = 21560 €
- VK Express = 1820 m2 = 25480 €
- NOVUS (Prospect Mikoli Bazhana, 8) = 9650 m2 = 135100 €
- NOVUS (3 Mykhailo Hryshko St.) = 3260 m2 = 45640 €

This project is designed for the long term perspective. Therefore, the payback will take about 15-20 years on average, depending on the object, but it will be very beneficial in terms of ecosystem resilience and human health. The project is not a platform for direct earnings, but a tool for improving the environment, which in turn will save money in the future. As such the “income” part of the payback period is based on oxygen production, carbon fixation and cooling effect, provided by green roofs in the form of ecosystem services. The period may be reduced, if the entrance to the green zone is charged.

Of course the cost of the projects is quite high and cannot be invested from the city budget, but the given calculations could be used as a reference point for similar projects, as the choice of materials will have a profound effect on the cost of their implementation.

Since the aim of the project is to reduce local temperature and mitigate the effects of climate change, the additional solutions could be recommended:

- landscaping by the principle “15 minutes walk”;
- installation of green fences where possible (for example, the fence of the gymnasium "Kyivska Rus");
- painting "dark" roofs and buildings in light color (almost all buildings in the area are dark, which increases the local temperature when heated. This is a low-cost, but very effective measure);

- allocation of area for blue infrastructure, which will contribute to the reduction of thermal pressure and improve the quality of air;
- distribution of information on the threats from climate change and need for adaptation efforts and investments.

The complex of the suggested solutions will enable adaptation to the adverse effects of climate change and increase district resilience.

Conclusions. The urgency of climate change is raising concerns in cities about their vulnerability and pressing the need for adaptation efforts. Densely build up areas of big cities are the hotspots of climate change effects in terms of urban heat island formation and amplified air pollution.

The Osokorky district is a prominent example of the outlined problem. Its area undergoes thermal pressure and properties of its urban structure reduce its resilience and impose additional threats for the population.

In order to adapt the district to climate changes the pilot project of green roofs on 15 buildings of the district is offered. The technical parameters of the green roofs are tailored to the properties of the chosen objects. The expected benefits from these roofs include reduction of thermal pollution and heat island, additional recreation opportunities and improvement of the overall air quality. The costs of the project by facilities range from almost 2 million to slightly above 20000. The probable payback period is estimated in the range from 15 to 20 years, depending on the type of roof created and changes for roof usage, if implemented. The recommended types of green roofs could be changed to a more cost efficient, but the general idea will be pursued if the district is to respond efficiently to the upcoming exacerbation of climate change effects on urban environment.

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ПРОЕКТ ПРИРОДНИЧИХ РІШЕНЬ ДЛЯ АДАПТАЦІЇ РАЙОНУ ОСОКОРКИ МІСТА КИЄВА ДО ЗМІН КЛІМАТУ

Глобальні кліматичні зміни мають значний вплив на міста в усьому світі, хоча точні загрози можуть значно відрізнятися залежно від географічного регіону. Київ – столиця з великою кількістю населення та величезною територією, яка стикається з різними викликами, пов’язаними зі зміною клімату. Аналіз кліматичних моделей демонструє вразливість міської інфраструктури Києва до хвиль спеки, міського острова тепла, збільшення кількості опадів та негативних погодних явищ. Для району Осокорки м. Києва проаналізовано інформацію щодо основних проблем та оцінки стійкості його інфраструктури в умовах кліматичних змін. Результати аналізу показують, що, незважаючи на новизну району, в ньому відсутні складові стійкості, слабко розвинена зелена та блакитна інфраструктура, а також неефективна мережа доріг. Усі ці фактори в поєднанні з щільною забудовою створюють сприятливі умови для підвищеного теплового навантаження на місцеве населення та інші біотичні компоненти району. Пропонований підхід до адаптації району Осокорки до кліматичних змін полягає у впровадженні природничих рішень з метою розширення зеленої інфраструктури та зменшення передумов для формування острову тепла. Запропоновано створити зелені дахи на 15 об’єктах району, в якому визначені типи дахів, їх технічні характеристики та вартість. Для посилення стійкості району розроблено комплекс додаткових організаційних заходів для підтримки просування району і міста в цілому до створення безпечного міського середовища.

Ключові слова: зміна клімату, адаптація, міська екосистема, природничі рішення.

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