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@ ✉ Correspondence author
M. M. Radomska
m.m.radomskaya@gmail.com

M. M. Radomska, Ya. Yu. Bogomazyuk
National Aviation University, Kyiv, Ukraine

THE ALTERNATIVE GREENIZATION OF THE RESIDENTIAL AREA IN KYIV CITY

Green infrastructure of modern cities is an essential element of city planning, which provides recreational facilities and performs environmental functions, namely climate regulation, pollution and noise retention, ecological networks support, humidity retention etc. The analysis of the studies shows that green plantations are able to mitigate the negative impacts of climate changes and provide more comfortable microclimate within the city. The provision of Kyiv residents with green areas is sufficient, but mostly outside the city, while many central areas like Solomyansky and Svyatoshynsky districts lack the necessary volume of greenery. To provide the maximal environmental efficiency it is necessary to improve the species and geometrical structure of green plantations, provide efficient maintenance and employ alternative greenization for the expansion of green plantations area. The conducted experiments of plants stability to physical (low and high temperature, dusting, substrate salination) and chemical (gaseous pollution) factors showed that species with the highest resistance are poplar, birch and lilac. The creation of the system of voids within the rows of green plant improves their capturing efficiency for dust and soot. To expand the area of green plantations we offer to create extensive green roof on multi-storeyed buildings, for which the most appropriate plant species are offered. The choice of plants is based on their tolerance to low humidity and poor substrate; these are perennial grasses with developed foliation to provide maximal capacity of oxygen production and carbon capturing. In order to support the functionality of green plantations we recommend conducting phytomonitoring and using the data for prevention of environment quality degradation. It must cover the following issues: the state of green infrastructure and its decorative quality, entomologic and phytopathological condition of arboreal plantations, air quality with determination of basic phytotoxic substances quantity and total volume of industrial and transport emissions, soil condition analysis and phytotoxicity of precipitations.

Keywords: climate change; environmental functions; green infrastructure; green roof.

Introduction. Modern urban ecosystem is made mostly of artificial components, created by humans for their comfort and living activity support. However, the higher the share of man-made components in the surroundings is, the stronger the resident seeks for recreation among elements of natural environment. Not in vain, the most expensive apartments in major cities are located in close proximity to parks and squares. The famous American biologist Edward Wilson introduced the concept of "biophilia" in the 1980's. His hypothesis suggests that humans cannot be separated from nature and that being connected to nature is the quintessence for psychological well-being (Wilson, 1984). Apart from this, green islands of cities are the most efficient and practically the only regulators of air quality at the territory of any city. Therefore it is necessary to find the ways of maximizing the area of green plantations in cities accounting the limits of territory and technical feasibility of any modifications of city planning.

The value of green infrastructure for urban ecosystem stability. The urban plants associations have importance from few points of view: direct social and psychological value and indirect value due to performance of environmental functions. First of all, urban and semi-urban green space systems provide a range of non-consumptive benefits, namely health strengthening and social connection. Analysis of related studies shows that parks have the ability to increase physical and mental health of those who live around and utilize them (Thomson et al., 2003; Townsend & Weerasuriya, 2010). This is especially true concerning children and the senior population (Herzog et al., 2003). The study by Penn State University has showed strong correlation between reduced stress manifestations and lowered blood pressure and duration of park visits (Chiesura, 2004).

Urban green infrastructure is also the necessary and integral component of sustainable urban communities. X. Zhou and M. Parves Rana have studied the efficiency of social communication under urban conditions. Their findings clearly show that high density of facilities separates residents, resulting in social disengagement (Zhou & Rana, 2012). The crowded urban environment makes it difficult to interact with residents and inhibits productive social communications. But parks can cause a significant rise in social connection in communities they are located in, increase the sense of community and feeling of involvement, which is especially important for senior people and education of youth (Zhou & Rana, 2012). It is crucial for organization of public activity aimed at street cleaning, energy conservation and amenities maintenance under the conditions of limited financial support from the state authorities.

Інформація про авторів:

Радомська Маргарита Мирославівна, канд. техн. наук, доцент кафедри екології. **Email:** m.m.radomskaya@gmail.com
Богомазюк Яна Юріївна, магістрант кафедри екології. **Email:** yanabogomazyuk1995@gmail.com

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From the economic point of view parks have influence on local budgets, giving additional incomes from the specific services provided by private entrepreneurs who take territories and facilities within parks on lease (mostly, entertainment and food facilities). In those countries which have developed system of private property taxation, consolidated green areas play an important role in improving the local tax base and increasing property values by 9-11 % over the average price, but better living conditions still attract educated and skilled workers (Benfield, 2014). Well planned green infrastructure is also the way to increase the tourist potential of a city both for residents and for visitors.

The indirect benefits from green plantations in cities are indirect by human perception: residents normally do not consider the value of ecological functions (ecosystems services) performed by plants. The most obvious ecosystem services are air and noise pollution control: air pollutant particles are retained by vegetation, while noise pressure is reduced as plants play the role of green screens, reflecting the sound from transport, construction and industrial facilities depending on their quantity, density and location. Green plantations improve water quality by protecting groundwater and prevent flooding, provide vegetative buffers between residents and hazardous facilities. At the same time they perform even more important, but not visible functions: preserve biodiversity by providing habitat for wildlife, and regulate urban climate. The last issue is especially valuable taking into account the global climate trends and the need to adapt urban conditions to higher summer temperatures.

The minimum surface temperature is typical for park/woodland zones due to natural evaporation and the absence of artificial coatings, while an abnormally high surface temperature is observed over large traffic junctions, main avenues and areas with limited air ventilation, increased areas of heat absorbing structures (Kazantsev et al. 2016). This creates threats for the health and life of city dwellers. Abnormal temperatures cause pressure on the cardiovascular system, respiratory tract, and contribute to the development of infectious diseases.

However, the average air temperature inside the parks is lower by 2 °C and relative humidity is higher by about 4 % than in the city center (Georgi & Tzesouri, 2008). The results of research 3 have confirmed the ability of people to adapt to the climatic conditions within the green areas of the city, as they rarely come out from the "comfortable" temperature range of 21-39 °C, defined as a result of the survey. Another study has showed that the presence of trees has a slight effect on the air temperature (-1.1 °C), but provides significant cooling effect on the surface temperature (-12 °C). Also, trees reduce the wind speed by 45 % (Spangenberg et al. 2008). All these meteorological parameters could be adjusted with the help of green zones design.

The transformations of the Kyiv city microclimate. According to studies by the Center for Aerospace Studies of the Earth of the NAS of Ukraine, from 2003 to 2011 the surface temperature in some areas of Kyiv increased by 7-10 °C (Kazantsev et al., 2016). Taking into account the considerable industrial pressure on the capital and rapid development rates, there is a risk of a sharp decrease of the city's thermoregulation potential due to the reduction of green areas.

Based on the correlation between natural, that is, unaltered or non-polluted zones of city area (areas under plantations, which have positive effect on the landscape: forests, green islands, meadows, gardens, protected sites and cultivated land used for growing perennial grasses), and those, which undergo anthropogenic stress (annually cultivated soil, unstable soil, areas under buildings and roads, reservoirs with signs of eutrophication and sedimentation, mining and chemical enterprises and other lands affected by anthropogenic influence), the index of environmental stability of the Kyiv urban ecosystem equals 1.6 (Radomska & Yurkiv, 2016), which corresponds to the lower boundary of the relative stability of the ecosystem, hence there is a need to increase the positive elements of the urban landscape to support the environmental balance.

The analysis of Kyiv green infrastructure quality. The territory of Kyiv, covered with green plantations of all types (including summer cottage buildings), is almost 50 thousand hectares, or 58.80 % of the city's area. Totally there are 122 parks, 379 squares, 80 boulevards, as well as a unique hydrophytic complex of the Dnipro, 30 km long and 1.5-5.0 km wide, which includes the Dnieper with the islands, coastal parks and meadows, which together provide ecological and recreational functions (Kazantsev et al., 2016). If the European standard is 20 m^2 of green plantations per a city resident, each resident of Kyiv is provided with 19 m^2 of parks and squares and 124 m^2 of forests and forest plantations. About half of the parks in Kiev (2670.57 hectares) belong to the state protected areas, 12 objects of which are of national importance and 14 are of local importance (Lesnik & Hirs, 2015). The provision of residents with green public areas is different in different administrative districts of Kyiv: the maximum provision of greenery is characteristic for the Podilsky and Holosiivsky districts, and the least greened are Solomyansky and Svyatoshinsky districts (Lesnik & Hirs, 2015).

Even if the area of green infrastructure is sufficient for the provision of city residents, their functionability is not defined only by the number of plants and area occupied. The efficiency of environmental functions performance depends on their quality. The condition of trees is determined visually by the sum of basic biomorphological signs: density of crown, foliation level, size and color of leaves (needles), presence or absence of deviations and deformations in the structure of trunk, crown and sprouts, presence and share of dry sprouts in the crown or dry top, integrity and state of bark. The survey conducted during the summer-early autumn period in 2015-2017 included districts of Kyiv provided with green areas to less than 20 m^2 per resident (Solomyansky, Svyatoshynsky, Pechersky, Obolonsky and Dniprovsky). It has shown that the arboreal plantations condition can be classified as satisfactory. Trees are relatively healthy and specimens with insufficient foliation or deformed in some way are not abundant, while the degradation processes are not developed yet, so the situation can be improved.

However, detailed study has shown that roughly 43 % arboreal plantations are weakened: leaves on the trees are often lighter than ordinary; crown is not evenly foliated; growth processes are not stable; crowns contain up to 15 % dry escapes; the signs of local damage are possible. At the same time the share of healthy, normally developed trees with thickly leaves, without mechanical damages and diseases over 37 %. So, green plantations of the studied districts could be considered relatively normal, but growing anthropogenic pressure gradually leads to deterioration of their quality. The potential negative influence is caused by air, soils and water pollution, constructional and recreational activity of citizens, improper maintenance and management of green plantations. Unfavorable conditions of urban environment depress growth of plants or lead to premature aging, as well as reduce their viability.

The improvement of green infrastructure environmental functionality. This task of the given research has been divided into three components, which must work together on maintaining safe environment in the city: study and improvement of green plantations species and structural composition, expansion of plantations area and development of recommendations for the improvement of the existing green areas condition.

The first task involved the evaluation of typical arboreal plants tolerance to urban conditions. The species composition of green plantations in Kyiv is quite diverse, but the dominant species are linden (39.0 %), bitter chestnut (22.2 %), Italian poplar (20.8 %), which stand for 82.6 % all plantations. The next by quantity are maples (sharp-leaved (4.0 %) and sugar (3.8 %)) and poplar delta- leaved (5.1 %). The last 7 species represent 4.5 % (Lesnik & Hirs, 2015).

Kazantsev T. et al. have conducted the research to define the tolerance of these plants to hot weather by measuring the intensity of consumption and release of CO_2 by the leaves of these trees (photosynthesis and breezing), which reflects physiological activity of a plant during hot (Kazantsev et al., 2016). The study was conducted in July 2016 under the temperature 30-35 °C. The results have showed, that all species of trees have negative ratio of CO_2 released to consumed, in other words they absorb more carbon dioxide, than release, which is good for thermal regulation in the city. However, the most efficient absorption of carbon dioxide is performed by black poplar, and a bit lower efficiency is typical for bitter chestnut ordinary and acacia white; the heart-shaped linden is of low efficiency and the least CO_2 is absorbed by maple. Thus, the structure of green plants in Kyiv (with domination of linden) is not the most efficient in terms of adaptation to climate changes.

We have also conducted the additional research and determined plants stability to the negative factors of urban environment, including imitation of thermal pollution with temperatures over those typical for climate maximum, early frosts, dusting, salination of soils and ground waters, influence of gaseous pollutants. Thermal pollution with temperatures close to 50 °C is the major problem in cities due to emissions of cars and heating facilities functioning. Sudden drops of temperature are possible due to irregular air circulation and problematic insolation in the city. Dusting of plants is a major negative impact produced by traffic and power generating facilities emissions. Salination of soils and ground waters is produced by treatment of roads with de-icing agents, application of detergents and other chemical reagents in municipal services provision, acid rains and industrial emissions. The major air pollutants considered in the study was SO_2, ammonia, toluene, petrol and alcohol.

The research included the dominant arboreal species and a range of decorative plants: poplar, linden, chestnut, acacia, birch, maple, lilac, jasmine, cherry and apple-tree. The results have proved the maximal stability of poplar to the above mentioned factors. But birch and lilac have turned to be among the most tolerable as well. Good resistance to salination and temperature fluctuations has been demonstrated by acacia, while linden seems to be one of the most vulnerable species. The highest variety of the results was established in the experiment with plants leaves exposure to airborne pollutants. Each specimen gave different combination of reactions to the substances in the artificial air environment; nevertheless, it is possible to conclude that poplar, birch and linden posses the highest resistance to air pollution, as well as cherry-tree, while lilac shows vulnerability to the influence of all chemical pollutants. These results must be taken into account in planning new elements of city green infrastructure, but it is also necessary to consider existing hygienic limitations: poplar is a source of allergenic fluff, while lilac is not able to create efficient protective boundaries due to low height.

The structure of green areas could be also improved geometrically. Thus, Sheludchenko L. and Voznyuk S. have offered to create the labyrinth and lacunas within the existing green belts. They have defined, that phytocenotic niches (artificial void) are able to trap mineral dust particles much more efficiently as compared to traditional protective green formations: modified forest belts retain at least 66 % solid particles in winter and 99 % in summer, or 70 % along the roads of the 3rd, 98 % along the roads of the 2nd and over 99 % along the 1st category roads (Sheludchenko & Voznyuk, 2014). It is also possible to provide protection from the gaseous pollutants with the help of the voids system by 28-51 % in relation to CO_2 volumes produced by city traffic (Sheludchenko & Voznyuk, 2014).

The most radical contribution to the improvement of green infrastructure is the expansion of their area. Currently it is very complicated and in most case impossible under the conditions of modern cities densely occupied with buildings and elements of infrastructure. Under these conditions it is possible to involve the available surfaces for the creation of alternative green spots: roofs, building walls and parking areas. Accounting active character of the city it is not efficient to create green spots on parking areas actively used and on pedestrian zones as well. The structure of residential buildings in Kyiv have left not much for the creation of wall phytocenosis due to presence of windows and balconies, or intensive renovation in some way (heat insulation, murals etc.). So, the most perspective feature for Kyiv center (lacking vegetation) is creation of green roofs, which is partially or fully covered by plants. The main function of this type of alternative green plantations is stormwater reduction, retention and filtration, moderation of the urban heat island effect, and production of oxygen with as well as carbon dioxide capturing. They are also able to provide habitat for local plants and birds (Ignatieva, 2008).

Modern green roofs have been categorised as extensive, semi-intensive or intensive. Intensive and semi-extensive green roofs consist of irrigated containers with deep soils, which require intensive maintenance. Extensive green roofs feature drought-tolerant plants growing in a thin layer (50-150 mm) of lightweight soil (<150 kg/m2). They are too fragile to be accessible to the public, but the most easily created. As most of the roofs are not open for public, but accessible for the representatives of municipal authorities, they are the best option for Kyiv city.

There are some limitations on the efficiency of these structures formation: the surfaces must be flat to provide reliable accommodation of substrate and securely isolated from interior environment of the building to prevent propagation of mold and humidity. The choice of plants must undergo rigorous selection to be able to perform ecological functions under the conditions of anthropogenic pressure and reduced nutrition from the artificial substrate. The possible examples are: for relatively moist northern roofs with well drained substrate – representatives of the Crassula genus (*Cotyledon ovata* Mill., *Crassula argentea* Thunb., *Crassula obliqua* Aiton, *Crassula portulacea* Lam.), Oxalis genus (*Oxalis acetosella* L., *Oxalis pes-caprae, Oxalis stricta* L., *Oxalis tetraphylla, Oxalis triangularis*), Epilobium and Chamérion genus (*Epilobium angustifolium* L., *Chamérion angustifólium*, *Epilóbium montánum*); Geranium genus (*Geranium pratense* L., *Geranium palustre* L., *Geranium sanguineum* L., *Geranium cinereum*), Stellaria genus (*Stellaria holostea*, *Stellaria graminea*, *Stellaria media*), Helichrysum genus (*Helichrysum araxinum* Takht. ex Kirp., *Helichrysum arenarium* (L.) Moench), Chenopódium genus (*Chenopodium album, Chenopódium foliósum*) Festuca genus (*Festuca rubra*, *Festuca beckeri*, *Festuca pratensis* Huds., Festuca ovina L., *Festuca valesiaca*, *Festuca rupicola*); for soil protection and retention – *Dichondra argentea*, *Dichondra repens*, *Lysimachia nummularia*, *Cotula coronopifolia* and *Acaena microphylla Hook.f.* These sample plants are tolerant to shade and sun, temporary draughts and frosts, will be able to survive at least 2 years at minimum substrate depth of about 100 mm. The range of plants can be increased by increasing substrate depth, providing afternoon shade, or gently sloping the roof to the south. It is necessary to account that increasing the pitch of a roof beyond 5 degrees increases stress for plants near the ridgeline.

The environmental functions of existing green plantations must be supported by in-time efficient maintenance (watering, fertilizing, covering, spraying crowns, fertility maintenance, weed control, etc.), which is balanced in favor of environmental function provision, instead of aesthetic, organizational or economic. It is especially important for in case of circumcision planning: dust retention, oxygen and humidity provision, carbon dioxide assimilation and other environmental functions performance depends directly on the volume of tree crown and area of leaves.

In order to control the state of urban green plantations special course of full monitoring must be conducted twice a year – spring and autumn, – when all elements of green infrastructure are examined.

Conclusions. The results of the given research have showed that green infrastructure of Kyiv municipal area needs improvement in order to make it more resistant to growing environment pollution, to adapt to climate changes and to prevent degradation and reduction of area due to planning changes and construction plans. Although the condition of arboreal plants is satisfactory, there is demand for the improvement of environmental functions efficiency performance. For this, we have offered to improve the species and geometrical structure of the existing plantations, improve the maintenance and care about tree in the city as well as to expand the area occupies by vegetation at the cost of alternative green formations, namely, green roofs.

A range of experiments and literature analysis was conducted to define the most appropriate species of plants to implement the recommendations, including the determination of the most tolerable to pollution, temperature and humidity fluctuations plants, as well as those able to grow on the roofs of buildings in the central and least vegetated districts of Kyiv under the conditions of bad aeration, watering and insolation.

The efficient functioning of green infrastructure in Kyiv can be also provided with the help of municipal green areas monitoring. The system of "greenery" monitoring under the specific environmental conditions of Kyiv urban ecosystem must address the following issues: the state of green infrastructure and its decorative quality, entomologic and phytopathological condition of arboreal plantations, air quality with determination of basic phytotoxic substances quantity and total volume of industrial and transport emissions, soil condition analysis and phytotoxicity of precipitations. In order to improve the condition of the green areas of Kyiv city a set of research, social-economic and planning activities is necessary.

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М. М. Радомська, Я. Ю. Богомазюк

Національний авіаційний університет, м. Київ, Україна

АЛЬТЕРНАТИВНЕ ОЗЕЛЕНЕННЯ ЖИТЛОВОЇ ЗОНИ МІСТА КИЄВА

Розглянуто засоби підтримки екологічної функціональності зелених насаджень Києва. Проаналізовано основні екосистемні послуги зеленої інфраструктури міста та умови їх ефективного забезпечення. Встановлено, що присутність зелених насаджень пом'якшує негативні наслідки кліматичних змін, зокрема обмежує прояв таких небажаних явищ, як формування островів та хвиль тепла. Оцінено стан зелених насаджень міста та виявлено, що при задовільному стані насаджень рівень догляду і благоустрою на території місць їх зростання не є достатнім. Виконано низку експериментів, що встановлюють стійкість основних порід дерев, типових для Києва, до таких екологічних факторів, як підвищені та понижені температури, пилове та газоподібне забруднення, засолення субстрату. Запропоновано перебудову геометрії зелених насаджень з метою створення системи лакунарних порожнин для ефективного утримання пилу. Розроблено схему створення "зелених" дахів на території районів Києва з найменшою кількістю зелених насаджень. Виділено види рослин, які за своїми властивостями (витривалість за умов нерегулярного поливу, стабільного затінення або підвищеної інсоляції, збідненого субстрату) можуть підтримувати нормальний рівень життєдіяльності та забезпечувати продукцію кисню і фіксацію діоксину карбону. Запропоновано програму спостережень за станом зелених насаджень для прогнозування їх функціональності і виявлення загроз для мешканців міста.

Ключові слова: зміни клімату; екологічні функції; зелені насадження; зелений дах.

М. М. Радомская, Я. Ю. Богомазюк

Национальный авиационный университет, г. Киев, Украина

АЛЬТЕРНАТИВНОЕ ОЗЕЛЕНЕНИЕ ЖИЛОЙ ЗОНЫ ГОРОДА КИЕВА

Рассмотрены средства поддержки экологической функциональности зеленых насаждений Киева. Проанализированы основные экосистемные услуги зеленой инфраструктуры города и условия их эффективного обеспечения. Установлено, что присутствие зеленых насаждений смягчает негативные последствия климатических изменений, в частности ограничивает проявление таких нежелательных явлений, как формирование островов и волн тепла. Оценено состояние зеленых насаждений города и обнаружено, что при удовлетворительном состоянии насаждений уровень ухода и благоустройства на территории мест их произрастания не являются достаточными. Выполнен ряд экспериментов, устанавливающих устойчивость основных пород деревьев, типичных для Киева, к таким экологическим факторам, как повышенные и пониженные температуры, пылевое и газообразное загрязнения, засоления субстрата. Предложена перестройка геометрии зеленых насаждений с целью создания системы лакунарных полостей для эффективного удержания пыли. Разработана схема создания "зеленых" крыш на территории районов города Киева с наименьшим количеством зеленых насаждений. Выделены виды растений, которые по своим свойствам (устойчивость в условиях нерегулярного полива, стабильного затенения или повышенной инсоляции, обедненного субстрата) могут поддерживать нормальный уровень жизнедеятельности и обеспечивать продукцию кислородом и фиксацию диоксина карбона. Предложена программа наблюдений за состоянием зеленых насаждений для прогнозирования их функциональности и выявления угроз для жителей города.

Ключевые слова: изменения климата; экологические функции; зеленые насаждения; зеленая крыша.