МЕНЕДЖМЕНТ

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MODELING OF LEVEL OF POLLUTION OF CANYONS DURING MANAGEMENT OF THE ECOLOGICAL CONDITION OF THE MEGAPOLIS

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Summary

Introduction. *In the conditions of rapid urbanization, the share of people living in megacities is growing. Urban development creates its own microclimate and its own unique circulation of air masses. Road transport is the biggest polluter of the city, the number of which is growing over the years, especially in the current environment, when it has become more accessible. As a result, its impact on human health is becoming more tangible. Urban canyons are the main functional unit of the metropolis. The study of the impact of urban canyons on the ecological situation in the conditions of dense construction of the metropolis is an extremely urgent task. Simulation divergent wind fields in urban areas is an extremely difficult task, because the structure of urban development is uneven. In this regard, the architectural planning urban piece was presented a set of elementary fragments – street canyons with appropriate spatial and geometric characteristics. The practical significance of the results is to understand the future state of the environment in urban canyons.* ***Purpose.*** *The aim of the work is to model and quickly assess the concentration of pollutants in street canyons in the projects of environmental management of the metropolis.* ***Results.*** *Based on the recommended model, the air dynamics of the level of the transport level of the atmosphere by the main flows, the concentration of the period of the day, the amount of pollutants reaches a critical level, exceeding the maximum allowable values.* ***Conclusions.*** *The proposed model will allow to model the level of pollution of street canyons of cities, as well as to determine the critical values of traffic intensities at which the concentration of pollutants will exceed the maximum allowable values. The obtained results can be used to build a forecast of daily pollution of roadside ecosystems and management of the ecological state of the metropolis.*

Key words: *management, transport, pollution assessment, transport flow, project, modeling of pollution fields.*

МЕНЕДЖМЕНТ МОДЕЛЮВАННЯ РІВНЯ ЗАБРУДНЕННЯ ВУЛИЧНИХ КАНЬЙОНІВ ПІД ЧАС УПРАВЛІННЯ ЕКОЛОГІЧНИМ СТАНОМ МЕГАПОЛІСУ

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Анотація

Вступ. *В умовах швидкої урбанізації зростає частка людей, що живуть у мегаполісах. Міський розвиток створює власний мікроклімат і свою неповторну циркуляцію повітряних мас. Автомобільний транспорт є найбільшим забруднювачем міста, кількість якого з роками зростає, особливо в сучасних умовах, коли він став більш доступним. У результаті цього його вплив на здоров'я людини стає відчутнішим. Міські каньйони є основною функціональною одиницею мегаполісу. Вивчення впливу міських каньйонів на екологічну ситуацію в умовах щільної забудови мегаполісу є надзвичайно актуальним завданням. Моделювання полів забруднення атмосферного повітря урбанізованих територій є надзвичайно складним завданням, оскільки структура міського розвитку нерівномірна. У зв'язку з цим у статті представлено безліч елементарних фрагментів – вуличних каньйонів з відповідними просторово-геометричними характеристиками. Практичне значення результатів полягає в оцінці та прогнозуванні стану атмосферного повітря в міських каньйонах.* ***Мета.*** *Метою роботи є моделювання й оперативна оцінка концентрації забруднюючих речовин вуличних каньйонах у проектах екологічного менеджменту мегаполісу.* ***Результати.*** *На основі запропонованої моделі визначено динаміку рівня забруднення атмосферного повітря міст транспортними потоками, установлено періоди доби, коли концентрація забруднюючих речовин досягає критичного рівня, перевищуючи гранично допустимі значення.* ***Висновки.*** *Запропонована модель дасть змогу моделювати рівень забруднення вуличних каньйонів міст, а також визначати критичні значення інтенсивностей транспортних потоків, при яких концентрація забруднюючих речовин перевищуватиме гранично допустимі значення. Отримані результати можуть бути використані для побудови прогнозу щоденного забруднення екосистем придорожнього простору й управління екологічним станом мегаполісу.*

Ключові слова: *управління, транспорт, оцінка забруднення, транспортний потік, проект, моделювання полів забруднення.*

Introduction. Today, the level of air pollution is one of the key factors determining the quality of living conditions in megacities. In many cities, the concentration of pollutants significantly exceeds the maximum acceptable values [1; 2]. As a result,

the health of the population is deteriorating and there are significant economic losses that are directly related to human health, disease and disability. The main sources of pollution of urban areas are traffic flows, the specificity of which is manifested in their close proximity to residential areas, territorial distribution, ground location. The fields of concentration of pollutants formed in the surface layer of the atmosphere have an spatiotemporal heterogeneity, which is explained by both dynamic (intensity, traffic flow, meteorological conditions) and static (geometric characteristics of street canyons, terrain, the presence of greenery, regulated intersections, spatial orientation of the street, etc.) factors [3; 4].

Assessment of air pollution is conducted in two directions: field observations and mathematical modeling. The construction of mathematical models is based on the results of theoretical and experimental study of the patterns of distribution of pollutants, which allow to build fields of pollution and reflect their spatiotemporal dynamics. Thus, modeling of pollution fields will allow to make operative forecasts of concentration of pollutants in street canyons of cities and by traffic control, to prevent critical situations in which the level of pollution exceeds the maximum allowable values, and thus to manage the ecological state of the metropolis.

Purpose. The aim of the work is to model and quickly assess the concentration of pollutants in street canyons in the projects of environmental management of the metropolis.

Analysis of recent researches and publishing. There are different approaches to solving the problem of scattering of pollutants in the atmosphere and modeling of pollution fields, in particular: analytical solution of the equation of turbulent diffusion, numerical modeling of turbulent flows, Lagrange models, Gaussian models, statistical models, models of urban canyons: STREET (Johnson et al., 1973); Canyon Plum Box Model (Yamartino et al., 1986); Operational Street Pollution Model (Berkowicz, 1996). To date, there is no generally accepted model for the dispersion of pollutants due to its complexity [5].

To determine the level of pollution in cities, there is a class of semi-empirical models based on a priori parameterization of the conditions of transport and scattering of pollutants. Among these models, the most well-known are: California Line Sours Dispersion Model (CALINE-4) and Danish Operational Street Pollution Model (OSPM). The CALINE-4 model was created by the California Department of Transportation, based on the Gaussian torch model. The stability class of the surface layer of the atmosphere is determined using modified Pasquil-Gifford curves. This model requires a small amount of input information, which ensures its simplicity and widespread use. However, the simulation results can be considered only approximate, as this model does not take into account the features of urban development, terrain, meteorological characteristics [6; 7].

The OSPM model is focused on determining the concentration of pollutants from traffic flows in street canyons, taking into account meteorological conditions, geometric characteristics of street canyons: different street configurations, width, height, building density, also the model takes into account mechanical turbulence created by vehicles. The main disadvantage of OSPM is the inability to take into account the deformation of the wind flow depending on the configuration of buildings.

Main material. Determination of the concentration of pollutants in street canyons from traffic flows is proposed to be based on the methodology of the Operational Street

Pollution Model. The model is based on the Gaussian type of scattering of pollutants in combination with the characteristics of the road network of cities [8].

Modeling of pollution fields in cities is a rather difficult task, as the structure of urban development is heterogeneous [9]. Therefore, it is advisable to present an architectural and planning fragment of urban development with a set of elementary street canyons with appropriate spatial and geometric characteristics.

The street canyon is a typical architectural and planning element of the city, which is an elementary area with buildings along the carriageway between the nearest crossroads. The space between buildings is an elementary ecosystem, the level of pollution which determines the level of ecological safety of the canyon. Street canyons of the city have different spatial and geometric characteristics: width, length, spatial orientation of the canyon, continuity and composition of buildings (weighted average height of buildings, density of buildings, average angle of rotation of buildings to the axis of the street). There are also symmetrical and asymmetrical street canyons. The following zones are distinguished in the street canyon: the windward side, which is characterized by a minimum level of pollution due to the inflow of clean air; the inner part and the leeward side, for which the maximum level of pollution is observed [10; 11].

When modeling the level of pollution, a distinction is made between wind speed and direction at the level of the roof of buildings, which is determined by the global transfer of air masses and wind speed at the street level. There is also a recirculation zone, which is characterized by the inflow of pollutants from another part of the street canyon and is determined by the length of the turbulent vortex, the geometric parameters of the canyon [11] Figure 1.

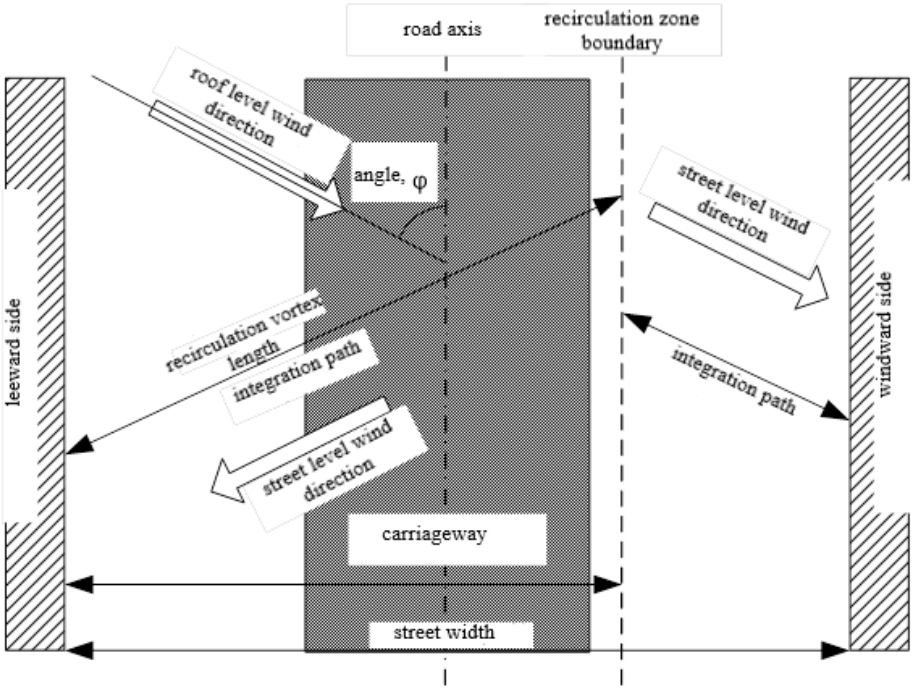

Fig. 1. The main parameters of the street canyon

The concentration of pollutants is determined within the street canyon and is equal to the sum of the concentration of direct scattering of pollutants (C_d), the concentration caused by air recirculation in the street canyon (C_r) and the urban background concentration (C_o) [6; 7].

$$C = C_d + C_r + C_o. \quad (1)$$

The concentration of direct scattering of pollutants from the traffic flow is equal to:

$$C_d = \sqrt{\frac{2}{\pi}} \int \frac{Qdx}{U_s W \sigma_z(x)}, \quad (2)$$

where Q – intensity of pollutant emissions from "efficient" transport flow, mg / m * s;

U_s – wind speed at street level, м/с;

W – width of the street canyon, m;

$\sigma_z(x)$ – the parameter of the vertical variance at a distance x from the emission source;

The wind speed at street level is determined as follows:

$$U_s = U_r \frac{\ln(h_0 / z_0)}{\ln(H / z_0)}(1 - 0.2p\sin\varphi), \quad (3)$$

where U_r – wind speed at the roof level, m/s;

z_0 – effective size of inequality, m, z_0=0.6;

h_0 – effective height of a loop after movement of the car, m, h_0=2;

H – average height of street canyon buildings (on the windward and leeward side of the canyon), m;

p – the ratio of the height of buildings on the leeward side to the average height of buildings on the street canyon;

φ – the angle of the wind direction at roof level relative to the axis of the street, rad;

The parameter of the vertical dispersion of pollutants at a distance x from the emission source is determined by the following formula:

$$\sigma_z(x) = \sigma_w \frac{x}{U_s} + h_0, \quad (4)$$

where σ_w – vertical turbulence dispersion, m/s;

x – is the distance from the source to the calculation point, m

$$\sigma_w = \sqrt{(0.1U_s)^2 + {\sigma_{W0}}^2}, \quad (5)$$

where σ_{W0} – turbulence variance caused by vehicle traffic, m/s;

$$\sigma_{W0} = 0.3\sqrt{\frac{NVS}{W}}, \quad (6)$$

where N – traffic intensity, bus/s;

V – average speed of traffic flow, m/s;

S – the average area occupied by the vehicle, m^2;

Thus, the concentration of pollutants from direct scattering perpendicular to the wind direction to the axis of the street is determined:

$$C_d = \sqrt{\frac{2}{\pi}} \frac{Q}{W\sigma_W} \ln\left(1 + \frac{W\sigma_W}{h_0 U_s}\right). \quad (7)$$

The calculation of the concentration of pollutants in the recirculation zone of the street canyon is carried out depending on the length of the turbulent vortex:

$$l_v = 2rH_{l.} \quad (8)$$

where r – an indicator that depends on the wind speed (for wind speeds <2м/с $r = U_r / 2$ in other cases $r = 1$).

The concentration from the recirculation of pollutants within the street canyon is determined as follows:

$$C_r = \frac{Q \cdot l_r}{W \cdot \left(\omega_t \cdot l_t + \omega_s \cdot l_s\right)}, \quad (9)$$

where l_r, l_t, l_s – geometric characteristics of the recirculation zone;

ω_t, ω_s – the rate of dispersion of pollutants through the upper and side of the street canyon, respectively, m/s.

$$\omega_t = \sqrt{\left(0{,}1U_r\right)^2 + \left(0{,}4\sigma_{w0}\right)^2}, \quad (10)$$

$$\omega_s = \sqrt{U_s{}^2 + \sigma_{w0}{}^2}. \quad (11)$$

Based on this model, an estimate of the concentration of pollutants in the street canyons of the city can be performed, taking into account the daily dynamics of traffic intensity. Emission intensities are estimated on the basis of the concept of "efficient transport flow", ie a model flow, the technogenic effect of which on the environment is equivalent to the action of a real transport flow containing a similar number of vehicles. "Efficient" traffic flow is a statistical set of "efficient" vehicles of the respective categories [12].

Therefore, the obtained results can be used in modeling the level of pollution in the street canyons of cities and streets of the metropolis, which will allow to perform operational forecasts of air pollution and timely environmental measures to normalize the environment.

Figure 2 shows the daily course of the concentration of the main pollutants, namely carbon monoxide and nitrogen oxides in one of the most typical street canyons (I. Mazepa Street). The wind speed at the roof level is 5 m/s.

Thus, at the established intensities of traffic flow and wind speed of 5 m / s, the dynamics of the concentration of pollutants in the street canyon in the period from 8:00 to 20:00 was determined [13]. Thus, in the morning periods, when the greatest traffic intensities are observed, the concentrations reach the maximum allowable values.

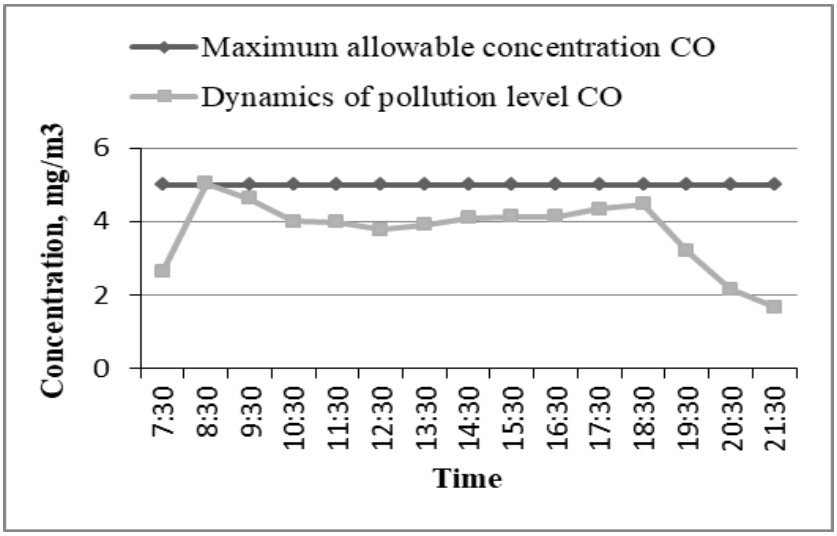

Fig. 2. Dynamics of the level of carbon monoxide concentration during the day (I. Mazepa Street)

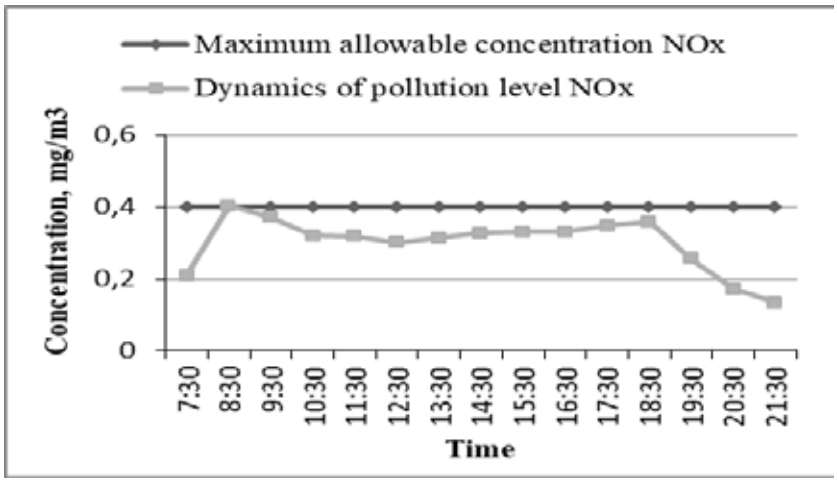

Fig. 3. Dynamics of the level of nitrogen oxides concentration during the day (I. Mazepa Street)

Conclusions. The main models of pollutant scattering in the atmosphere are analyzed. A model of urban street canyons (OSPM) is proposed to determine the daily dynamics of the concentration of major pollutants in the street canyons of the metropolis. The proposed model will allow modeling critical pollution levels both for individual sites and for the network as a whole. Therefore, the obtained results can be used in modeling the level of pollution in the street canyons of cities, which will make operational forecasts of air pollution and timely environmental measures to reduce the concentration of pollutants.

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