Green plantations influence on wind transformation and car emissions dispersion in city streets

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Abstract. As the result of the car emissions dispersion physical modeling, the fields of exhaust gas concentrations along the streets’ cross-section were obtained. In the “carriage–shelterbelt–building” system, if the belt height is about half the height of the building, the most effective dilution of pollutants along the building façades and at the pedestrian ways is observed; as the belt height approximates to the height of the buildings, the air in the yards of the buildings is still cleaner because of a longer way the pollutants have to travel, but then they accumulate within the street space.

1. Introduction
The formation of greenery environment protective objects on transport areas that are particularly susceptible to anthropogenic impact is organically associated with the solution of the most common task of “reconstruction, construction and restoration of urban landscapes” [1-4]. The city’s main street networks green plantations protective role is especially great, where harmful car exhaust mass emission into the atmosphere occurs at a small height directly into the people-breathing zone and residential buildings. Numerous researches show that it is quite feasible to solve problems of regulation, optimization and bringing to the regulatory limits such discomfort factors as gas contamination and dust pollution of atmospheric air, transport noise, unsatisfactory aeration regime in residential development by greening means in the main streets, while simultaneously improving the aesthetics of the urban environment [5-12].

At the autotransport multifactorial negative influence on urban environmental systems, it is necessary to identify the dominant factor and to determine the available resources for reducing its influence on the residential environment. The full-scale observations in cities results analysis shows that the main environmental factor on the transport infrastructure objects is the gaseous nature of atmospheric air by car exhaust in combination with the microclimate leading factor - the wind regime, as there is a functional relationship between them [13-14].

In the city residential zone, the wind speed in the lower tier of the air basin, whose height is assumed equal to the tripled height of mid-rise buildings, is most influenced by the development in the form of arrays forming “macroroughness”. The streets and intradistrict territories aeration regime is most actively influenced by the building elements, as well as small irregularities in the underlying surface, roads, pedestrian ways, playgrounds, grassplots, etc. - “microroughness”. Moreover, the transformation of the airflow in terms of speed and direction takes place in the atmosphere surface layer, its height is equal to three heights of the obstacles [15]. Therefore, at a height of 1.5 m - the
level of human breathing, such elements of development as high embankments, slopes, retaining walls, trees and shrubs can affect the atmospheric pollution dispersion.

The goal of research is to develop an optimal constructive solution for tree and shrub plantations linear-belt structures on the cities’ main streets to ensure protection of residential buildings from the transport negative influence.

2. Methods used in the experiment

In accordance with the set up goal, a series of tests of models of green plantations belts and residential buildings was carried out at the large-scale simulation site, which is an open flat site measured 100x150 m and covered with asphalt.

In the experiment models of residential buildings with a flat roof, made of a thin wooden plate in a scale of 1:20 were used. The fragments of built-up sections of streets 300 meters long, oriented perpendicularly to the prevailing wind direction, were arranged along the center of the area from separate buildings sections of with a ratio of height, length and width of 1: 0.9: 0.8. With such a change in the linear dimensions of geometric bodies in the form of plates, the Reynolds number varies over a wide range ($10^3<R_e<10^7$) and self-similarity is observed when flowing around them.

In addition, models of tree and shrub plantations belts of non-blown and blown structures were used. According to F.L. Serebrovskiy’s characteristics [15], a leafy, dense top-to-bottom belt with a number of thorough gaps of no more than 5% has a non-blown construction. A belt of a blown construction is a dense or openness plantation with an open undertree space to a height of 1-2 m. The model of green plantations belt was a screen made in the form of a metal frame with a grid of lightweight construction on which synthetic fibers of a certain density were fixed. A specially designed pipeline simulating the transport flow was used as a linear source of car exhaust.

The carbon monoxide (CO) and nitrogen oxides (NO + NO₂) concentrations distribution in the vertical plane along the main streets cross-section was studied. In parallel with the research of the air pollution level at the observation points, an anemometric survey was carried out by using cup anemometers MC-13.

3. Results and discussion

Figure 1 shows the CO concentration fields in the street cross-section that are formed during the interaction of the green plantations of dense and blown structures with 5 and 9-storey frontal buildings. A similar pattern of the concentrations distribution is possible in conditions of one-sided city streets development, as well as on wide streets with the rupture of the general circulation zone between buildings in a street canyon. This occurs at a width of the street $B$ with the interval from 3 to $6H$ [16-20], when a windward building is formed by a low-pressure recirculation vortex, and a resilient closed high-pressure vortex flow is formed on the front wall of the lee building - the “air overpressure zone”.

In this case, the descending turbulent jets in the “air overpressure zone” are transformed in speed and direction, overcoming the convective countercurrent, arising at the building wall, and impenetrable barriers - balconies, retaining walls, slopes, driveways, and semipermeable obstacles in the form of trees and shrubs rows. At the same time, the linear-belt structures of green plantations as a kind of “microroughness” significantly change the nature of airflow over the buildings and the pollutants distribution in the street cross-section.

According to the nature of the isolines in Figure 1, it can be seen that at a dense construction of green plantings with a closed undertree space within the belt itself, the exhaust gas concentrations remain high due to then decrease in wind speed (Figure 1b).

In order to exclude zones of air stagnation in densely built-up sections of main streets, linear-belt structures of green plantations, it is necessary to form a blow-out structure that provides the necessary natural air exchange within pedestrian way zones and a more uniform dispersion of car exhaust at the buildings facades (Figure 1c).
It should be noted that, in combination with the building, environmental protection plantations dramatically change the nature of the influence on the airflow and the level of gas contamination when their relative height changes. If the belt height \( h \) and the buildings height \( H \) are equal, there is the increased concentrations of the car exhaust components along the building (Figures 1a, 1b 2a, 2b), then at \( h = 0.5H \) (Figures 1c, 1d, 2c, 2d) there is a significant pollutants dilution over facades and in the zone of pedestrian way, where intensive turbulent exchange is stimulated.

Figure 1. CO emissions dispersion from a linear source under simulated conditions in the "carriageway–shelterbelt–building" system by belts of a blown (a - at \( h = H \), c - at \( h = 0.5H \)) and dense construction (b - at \( h = H \), d - at \( h = 0.5H \)). Figures and isolines are concentrations of CO in % from the initial level \( q_0 \); \( h \) is the height of the belt; \( H \) is the building height.

In this regard, in the greening belts, the trees height within 0.4-0.6 \( H \) is most favorable, that ensures their maximum gas-protective efficiency.

The researches showed that the nature of the car emissions dispersion in the “carriageway–shelterbelt–building” system essentially depends on the construction, green plantings beltshight and the buildings storeys number, and the distance between them, i.e. pedestrian way width. Taking into account these factors, the gas protection effectiveness (according to CO) of gardening methods in relation to the pedestrian way zone can be calculated by the formula

\[
\omega = 57 \frac{11b^{0.22}(1 + 2.63K_{kk}^{1.7})h^{1.65}}{H^{1.87}e^{3.34\sqrt{b}/H} - 1}
\]

where \( b \) is the distance from the street curb to the building line, m.
Figure 2. Change in NO+NO₂ concentration and wind speed at 1.5 m in cross-section of streets with 5-storey (a, b) and 9-storey (c, d) buildings under the influence of green plantations belts of blown (a, c) and dense (b, d) constructions. a, b - at \( h = H \); c, d - at \( h = 0.5H \); \( q_0 \) and \( u_0 \) are, respectively, the NO+NO₂ content in air and the wind speed above the edge of the carriageway at an altitude of 1.5 m; \( q \) and \( u \) are the same at the points of observation in the pepper profile; \( L \) is the distance, m; \( K \) is the coefficient of openness - the ratio of the area occupied by the trees and shrubs stem, branches and foliage to the total area of the green protective belt frontal projection.

When the trees reach the level of the middle of the buildings facades it is necessary to limit their growth and prevent the development of crowns towards the carriageway by carrying out systematic constructive cutting outs, thinning, rejuvenation and topiaries.

As the trees height approaches the buildings height, an additional reduction in air pollution is observed in the yard facades and on the intra-district territory due to the pollutants routelengthening and the dispersion (Figures 1a, 1b).
In relation to the yard space, dense and tall plantings are the most effective (Figure 1b). However, dense planting of trees with thickened crown, showing together with building the best indicators of gas-protective efficiency in relation to the yard space, as height increases, accumulate pollutants on the street itself, which drift within the belt with insignificant speed (Figure 2b).

It should also be taken into account that in the formation of roadside belts along two sides in the form of vertical “walls” over the carriageway, a semi-enclosed space is formed, where, as in a street canyon, air flow reverse circulation occurs with cross wind. In this case, “there is a process of car emissions accumulation over the carriageway” because of the close location of the trees first rows, whose height reaches 15 m [21]. Therefore, in order to exclude the possibility of the car exhaust closed circulation occurrence the rows of plants nearest to the carriageway on both sides of the road must be represented by shrubs in the form of a two-tier hedge and trees with a low crown.

4. Summary and conclusions

The methods of the transport infrastructure greening should orient the green plantations to the maximum reflection of their environmental protection features. For this, it is necessary to determine their optimal position in relation to traffic flows, car parking lots and protection objects within residential areas, as well as rock composition, density and geometric characteristics.

The dominant environmental factor that reflects the transport negative influence on urban environmental systems in the conditions of the main streets overcompacted development is the level of air pollution connected with functional dependence on the aeration regime.

The streets aeration regime and intra-district territories are actively influenced by the buildings in the form of arrays and separate groups of buildings, as well as unevenness of the underlying surface and elements of the redevelopment.

In combination with the building, belts of blown and uniformly openness structures turn out to be more effective in relation to the pedestrian way areas and the buildings lower storeys when they reach the height half of the buildings height. In this case, there is a more moderate air pollution in front of the belt, intensive air exchange in the pedestrian way area is stimulated and a uniform distribution of the car exhaust components along the buildings facades is ensured. To exclude the air pollution foci connected with the peculiarities of the airflow over the buildings and green plantations, it is necessary to limit their height at the level of the middle of the buildings facades by carrying out structural cutting outs.

The shelterbelts for the densely built-up stretches of heavy-traffic streets should be of permeable structure to prevent pockets of stationary air; this ensures the necessary air interchange at the pedestrian ways and also more even pollutant dispersion at the building façades.

As the trees height approaches the buildings height, an additional reduction in air pollution is noted on the intra-district territory due to the increase in the motion trajectory and the pollutants dispersion in the atmosphere upper layer. However, in this case plantings dense is a secondary source of air pollution on the street by accumulated pollutants. Therefore, dense plantings from large trees with a dense crown should be used on sections of main roads in combination with front-linear non-residential buildings - in the form of a screen system, as the first echelon for effective protection against the negative influence of transport, far from red lines of residential areas.

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