Formation of linear-strip greening objects in urban environmental systems

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Abstract. The observations were made in the streets of major cities and on physical models of buildings and green belts of three degrees of density, from dense to permeable. The dependence of air-pollutant shielding efficiency of green belts on their density and height has been determined. Vertical concentration fields on the street cross-section have been obtained by physical modeling, and consistent patterns of car emissions dispersion by the shelterbelts of a various structure have been found. The lowest car emissions concentration behind green belts is observed at a distance, equaling \( h \) (belt height) to 1.5\( h \), where the pedestrians move; the highest, at a distance of 2\( h \) to 3\( h \). To effectively protect the pedestrian ways and the areas along the road from car emissions, dense and evenly semi-open shelterbelts, 15 to 30m wide, should be used.

1. Introduction
The urban areas occupied by the transport infrastructure objects differ in highly transformed, “a special kind of anthropogenic landscape” [1]. Its characteristic features are “violation of a unified structure” and “dismemberment of transport communications” [2]. As the result of the urban space use intensification, “plant complexes (biogeocenosis) that are required to have environment-forming, nature-friendly and aesthetic functions have disappeared here” [3].

Here, greening is used as the main means of the volumetric-spatial composition and the territory structure formation, the tension and conflict in the urban environment reduction.

Green plantations belts, formed on the objects of transport infrastructure within the urban ecological system “urban transport – the natural environment – residential area”, are a green filter that provides urban residents everyday needs in the fresh air, recreation and communication with nature.

With intensive use of the territory to pass traffic flows and store cars in the cities’ planning zones and historical centers in conditions of street space shortage, there is an acute problem of the natural and green areas proportion preserving and increasing. It is especially necessary to choose the most effective landscape compositions and structures of green plantations, taking into account their environment-protective features.

In the cities transport territories where the “linear forms of pollution” are mostly observed [4], linear-strip structures of green plantations have appeared in the form of alternating solid planes in the type of rectilinear, curvilinear, and also located along a zigzag line “walls” separating the residential area from the carriageway. However, the “techniques and traditions in urban greening, as well as the
landscape-aesthetic principles of their design” [11] have not yet fully provided ecological well-being and comfort in residential area [5,6].

Trees and shrubs, unlike impenetrable elements of landscaping and buildings, are partially permeable obstacles, behind which there is a mixing of two turbulent jets - passing through the barrier and enveloping it [7]. Due to this aerodynamic property, the reduction in the level of air pollution by the green plantations roadside belt occurs in part by the absorption of individual components of the car exhaust [8], and also — mainly — due to their dispersion in the surrounding space flowing from above air stream [9]. In such a case, belts’ wind-protecting effect directly depends not on their width, but on the trees and shrubs density. In the field-protective forestation, this feature of the forest belts makes it possible to reduce to a certain minimum their width and area on the slopes without a noticeable weakening of wind protection effectiveness [10].

In this connection, a similar task arises to study the green plantations linear-stripe structures geometric characteristics and design features influence on the wind transformation and the car emissions dispersion in urban streets, the width of which along building lines, regulated by building codes, allows the formation of greening belts with a limited number of woody plants rows.

2. Methods used in the experiment
The research on the green plantations gas-protective functions was carried out on the streets of large cities and the range of large-scale modeling [11-13] using the models of belts of tree and shrub plantations of dense, openness and blown structures, which characteristics are given in the papers by Ya.A. Smalko [9] and F.L. Serebrovsky [7]. The models were metal wire frames made at a scale of 1:20 and filled to a given density with a synthetic fiber.

Previously, for each belt, the coefficient of openness \( K \) was determined as the ratio of the area of obstacles in the path of the car exhaust distribution — the elements of the framework and the synthetic material — to the total area of its frontal projection. For this, the models were photographed against a light background, and then the resulting negatives were placed in a photoelectric colorimeter ФЭК–56 camera. The coefficients of the belt openness were determined by comparing the optical densities of the models negatives and the impermeable screen. The same method was used to establish the openness coefficients of the greening belts in full-scale conditions.

In the modeling, a specially designed pipeline was used as a source of atmospheric pollution, which was connected to the car engine exhaust pipe. From the holes of the lateral branches imitating transport flow, a mixture of gases continuously and strictly horizontally exhausted along the tube. This excluded the gas jets escape speed influence on the airflow velocity vector at the points of the car exhaust investigated components concentrations determination.

Air samples were taken at the point grid nodes on a cross-section to the source section, with a step at height of 1.5 m at horizontal distances, multiples of the plantations height. As the result of the samples chemical analysis, carbon monoxide (CO) concentration fields in the vertical plane were obtained in the open area and according to the scheme “carriageway – green strip”.

3. Results and discussion
From the experimental results, it follows that in the open space conditions, the most intense car exhaust dispersion occurs exponentially in the limits of a roadside belt of width up to 30 m. Further decrease in the ingredients content in the air follows a linear law. In accordance with this, CO concentration (in mg/m³) in the direction perpendicular to the road can be calculated by the formulas:

\[ q_x = q_0 e^{-0.0413x} \quad (1) \]
\[ q_x = 0.29q_0 - 0.14(x - 30) \quad (2) \]

where \( x \) is the distance from the edge of the carriageway to the calculated point, m; \( q_0 \) is the initial concentration of CO at the edge of the carriageway at the height of 1.5 m, mg/m³.
Figure 1 shows the isolines of CO concentration behind the greening belts of the blown and dense structures as mechanical barriers in the path of the gas-air flow. In both cases, the lowest level of atmospheric air pollution is observed directly behind the belt - in the areas of pedestrian traffic. The maximum gas contamination is noted in the zone where the plume touches the earth's surface at a distance of 2-3 belt heights. The nature of the isolines confirms the above provision that green plantations are semipermeable screens that divert some of the contamination into the upper atmosphere and disperse it. In this case, its another part can be absorbed by a greening belt when the gas-air mixture passes through the branches and leaves [8].

![Figure 1](image_url)  
**Figure 1.** CO dispersion, %, in the open area (a) and in green plantations belts: b-blown construction (one-two-row tree planting); c-dense construction (two-three-row planting of trees with shrubs). 1-carriageway; h is the height of the belt; figures are the concentration of CO, %. 100% is the concentration of CO along the edge of the carriageway at the height of 1.5 m.

Thus, if in real conditions the amount of the absorbed ingredient is more determined by the trees and shrubs dendrological composition and the degree of the belt permeability, then its dispersion effectiveness, as follows from the experiment results, depends significantly on its height and density. According to this effect, equations 1 and 2 are transformed as follows:

\[
\begin{align*}
\text{at } x \leq 30m & \quad q_x = q_0 \left(1 - \frac{x}{100}\right) e^{-0.0413x} \\
\text{at } x > 30m & \quad q_x = 0.29q_0 \left(1 - \frac{x}{100}\right) - 0.14(x - 30)
\end{align*}
\]

where $\omega$ is the gas-protective efficiency of the green plantation belt, %, determined by the formula obtained empirically:
\[ \omega = 48 \cdot (1 + 0.016h) \cdot K^{\frac{3}{2}} \]  

where \( h \) is the height of green plantations, m \((h \geq 5)\); \( K \) is the openness coefficient.

From a comparison of CO dispersion schemes in Figure 1 it follows that the most advantageous in the system “carriageway – the green strip” are linear-strip structures of green plantings of a dense non-blown structure. Their gas-resistant efficiency is 30% greater than that of blown structures due to a more evident insulating capacity.

The graphical dependence of the gas-protective efficiency of the green plantation belts on the density characterized by the coefficient of openness \((K)\) is obtained according to the results of researches on models and is shown in Figure 2. In the course of the curves, it can be seen that with an increase in the belts density, their gas-protective effect first sharply increases, and then a less intense decrease in the CO concentration is observed.

This should be taken into account when, in the presence of engineering dividing belts for laying utility networks, where the conditions of their operation do not prescribe tree planting, the width of the street is insufficient to set the most dense woody and shrub plantations. In such conditions it is necessary, within the limits of the street transverse profile, to form belts of green plantations of optimum density with \( K = 0.5—0.6 \) corresponding to the sections of the steepest position of the curves in the Figure 2.

![Figure 2. Dependence of the green plantations belts gas-protective effectiveness on density and height. 1 - \( h = 1.6 \) m (shrub); 2 - 9 m; 3 - 14 m. \( h \) is the height of the belt.](image)

However, within the limits of the plantations themselves, the car exhaust concentrations appear to be higher than in the open area due to a sharp decrease in wind speed. The belt of a dense construction in this case, like a forest area, fulfill the “role of the pollutant accumulator” [14]. In addition, in the formation of roadside belts along the two sides in the form of vertical “walls” above the traffic area, as in the street canyon, reverse circulation of air flow appears [15–18], “the process of accumulation of car emissions over the road because of the close arrangement of the first rows of trees” [19] occurs as the result.

Therefore, from a practical point of view, strict factor differentiation of the environmental protection belts constructive solution is impractical. Here it is necessary to take into account the complex nature of the greening protective effect, when the same structurally-constructive type of a belt simultaneously turns out to be more or less effective in relation to all the leading factors of environmental discomfort, namely gas-, noise- and dust-wind impacts.

4. Summary and conclusions

The operation of transport infrastructure facilities is accompanied by a negative transport influence on the main environmental systems and living conditions of the population in cities.
On the sections of the highway route and other transport infrastructure objects, a special kind of natural-anthropogenic landscape is formed, it is characterized by dissection, violation of a single structure, transformation and increase in rigidity due to displacement of the vegetation cover.

Green plantations are an important component of the ecosystem, able to resist the transport negative influence on the residential environment on especially sensitive ecologistical territories. On the main roads and streets with the help of green plantations harmonization of rigid landscapes is achieved with the restoration of their softness and aesthetic appeal.

Trees and shrubs as partially permeable obstacles reduce the level of air pollution by absorbing the components of car emissions when the air-gas mixture passes through branches and leaves and mainly by dispersion them when the wind blows through the landscaping belts from above. The crowns height, shape and density, the stem character, the step of planting the trees in the row, the size of the rows and the dendrological composition of the plantings play a leading role in the transformation of airflows through the forest belts.

The lowest level of atmospheric air pollution is observed directly behind the landscaping belts — in the areas of pedestrian traffic. Maximum gas contamination is noted when plume touches the earth's surface at the distance of 2—3 belt heights.

With the increase in belts density of different heights green plantings, their gas-protective action first rises sharply, and then a less intense decrease in the car exhaust concentration is observed. This should be taken into account when choosing greening methods in those cases where the streets width in the presence of engineering belts for utility networks, where, according to the conditions of their operation, there is no provision for planting a row of trees, it does not allow to set tree-shrub plantations of maximum density with $K=1$. In such conditions, it is necessary, within the limits of the streets transverse profiles, to form green plantations belts of optimal density with $K=0.5—0.6$.

Plantings for the greening of urban roads and streets should be fast-growing, sufficiently gas-resistant and capable to absorb harmful substances [16]. In this case, it is necessary to take into account the competitive relations of individual species among themselves in the process of growth, to distinguish main, additional and decorative (finishing) ones.

The volumetric-spatial solution of the universal protective belt is a symmetrical composition formed by the multi-row parallel arrangement of tree-shrubby species, providing a close dense structure of plantings [5]. The degree of implementation of such a strip protective properties in relation to the considered factors of discomfort can be adjusted by applying different schemes for planting basic and accompanying species — ordinary, chess, free, as well as the step of planting trees and the size of interrows.

In the environment protection plantings of a dense symmetrical structure, the nearest rows of vegetation from the carriageway should be represented by shrubs (low-growing and tall-growing ones) in the form of a two-tier hedge, and then one or two rows of accompanying trees with a low stem. Then, the “core” of the medium-protective belt is formed by a multi-row construction of the main tree species.

The step-shaped cross-sectional shape of the environmental protection belt ensures plantations phytomass maximum production due to favorable insolation. In this case, boundary marginal rows have the maximum luminous density.

When choosing a plant assortment in environmental protection belts, it should also be taken into account that their aerodynamic characteristics, gas and noise protection effectiveness significantly depend on the structural features of the various breeds trees and shrubs crowns, as well as on their age and seasonal variability.

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