Ecological technologies for environmental objects remediation

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Abstract. The greening of urban areas, including roofs of buildings, can be used as a means to reduce the concentration of pollutants in the air in large cities. In the context of high built-up density, when it is impossible to pick out free space, greening the roofs of existing buildings is a sole solution. In this paper, the movement of air flows and the diffusion of fine dust particles smaller than 2.5 microns (PM2.5) are modelled for a Moscow region with consideration of external non-stationary factors. The computation is made in ENVI-met program via the CFD analysis. In the future, it is planned to assess options for complex landscaping of the studied site, including greening the roofs of buildings along areas with a high content of fine particles, in order to reduce the concentration of PM2.5.

1. Introduction
In the context of intensive urban growth and technological development, the issue of air quality is becoming especially important for maintaining the health and well-being of the population. According to WHO, the most common air pollutants that pose a risk to human health are NO₂, O₃, SO₂, and solid suspended particles, especially fine dust particles smaller than 2.5 microns (PM2.5) [1, 2]. The problem of air contamination by PM2.5 dust particles remains poorly studied, which poses a great danger to the health of large cities population [3-5], especially near heavy transport routes [6]. The rapid pace of industrialization, the increase in population and, as a consequence, the number of vehicles and traffic density, as well as reduction of green areas in large cities lead to a significant increase in PM2.5 dust particles concentration in air. Motor vehicle exhaust gas is generally the main source of air pollution in urban areas [7, 8]. PM2.5 fine particles are one of the components of exhaust emissions. The fine particles formed as a result of fuel burning and the resuspension of road dust contribute to the deterioration of air quality and have an adverse effect on urban population health. Critical concentrations of PM2.5 occur in densely populated areas with poor ventilation and high traffic. Prediction and environmental monitoring of air dust pollution as well as development and analysis of effective methods for reducing PM2.5 dust particles concentration are currently priority tasks.

The OECD guidelines for 2020 [9] propose a set of measures to reduce pollutant emissions by replacing dirty fuels with cleaner ones, developing cleaner industry, reducing the consumption of products polluting environment, and introducing cleaner technologies. It is necessary to introduce environmentally friendly “green” technologies and “green” products, design and build houses with minimal impact on the environment, ensuring sustainable environmental development, and improve the quality of atmospheric air in cities.

Landscaping urban areas, including roofs of buildings, can be considered as a method to clean atmospheric air in large cities. It is possible due to the ability of plants to reduce the concentration of the main air pollutants: PM2.5, NO₂, O₃, and SO₂ [10]. Increasing the area of green spaces in large...
cities is one of the ways of phytoremediation of atmospheric air from these pollutants, and in the context of high built-up density, when it is impossible to pick out free space, greening the roofs of existing buildings is a sole solution [11, 12].

A review of existing studies has shown a significant effect of roof greening on NO₂ [13-17], O₃ [18, 19], SO₂ [20], and PM2.5 [21-24] concentration. For example, scientists from the United States and China [25] conducted a theoretical study where they estimated the volume of major air pollutants (NO₂, O₃, and SO₂) absorbed by existing green roofs in Chicago in 2006-2007. The study has shown that green roofs are the most capable of absorbing ozone (O₃) and the worst at coping with sulphur dioxide (SO₂). Scientists from Great Britain [26] quantified the ability of four plant species used in construction of extensive green roofs (Agrostis stolonifera, Festuca rubra, Plantago lanceolata, and Sedum album) to capture solid suspended particles of size less than 10 microns (PM10). The results were significant, with A. stolonifera and F. rubra performing best as passive filters, and S. album performing worst. The study has found that the largest amount of PM10 is captured by plants on green roofs near the main sources of pollution. The authors claimed that if all flat roofs in Central Manchester were planted with red fescue (Festuca rubra), this would help capture 1.61 tons of PM10 per year, which corresponds to 17.5 % of the total amount of PM10 entering this area.

In this paper, the movement of air flows and the diffusion of PM2.5 fine dust particles are modelled for a Moscow region with consideration of external non-stationary factors. The computation is made in ENVI-met program via the CFD analysis. In the future, it is planned to assess options for complex landscaping of the studied site, including greening the roofs of buildings along areas with a high content of fine particles, in order to reduce the concentration of PM2.5.

2. Methods

The research uses such scientific methods as analytical generalization and systematization of domestic and foreign research experience presented in scientific papers and special literature, the method of hydrodynamic analysis (CFD) for modelling dust pollution in a Moscow region.

The simulation was executed in the ENVI-met program using a three-dimensional model and computational fluid dynamics analysis. ENVI-met is suitable for modelling various processes in the atmospheric boundary layer, such as: wind flow, turbulence, microclimate modelling, and dispersion of pollutants in the air (dust, reactive and non-reactive gases). In this study, the ENVI-met V4.4.5 version was used to analyse dust pollution by PM2.5 fine particles on the territory of Moscow and the actual data from the weather station was used to compare with simulation results. ENVI-met solves numerically the air flow equations in discretized computational domain that takes into account the properties of the urban surface, the topology of buildings, the location and type of vegetation. Modelling allows estimating a pattern of three-dimensional fields of wind speed, turbulence, temperature, and humidity in a given area, as well as the diffusion of PM2.5 emitted from various types of sources. By the means of CFD analysis, it is expected to create a method to predict dust distribution in the city air, that will take into account green areas placed on buildings roofs.

The studied site is located in the southern administrative district of Moscow. It is adjacent to two routes with heavy traffic: Varshavskoe highway and Simferopol avenue (Fig. 1). This site was chosen due to high concentrations of PM2.5 fine particles recorded by the nearest weather station (Table 1).

| Table 1. Indicators obtained from the weather station at the address: Kashirsky driveway, 10. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Time, h.       | 0-2             | 2-4             | 4-6             | 6-8             | 8-10            | 10-12           | 12-14           | 14-16           | 16-18           | 18-20           | 20-22           | 22-24           |
| PM2.5 av, μg/m³ | 30              | 29              | 32              | 39              | 33              | 35              | 33              | 34              | 10              | 4               | 5               | 15              |
| PM2.5 max, μg/m³ | 54.80           | 29.50           | 40.60           | 38.50           | 43.70           | 34.90           | 46.80           | 34.00           | 12.60           | 13.20           | 136.90          | 15.20           |
| T, °C           | 21              | 19              | 18              | 18              | 18              | 20              | 20              | 20              | 17              | 17              | 17              | 16              |
| Humidity, %     | 84              | 100             | 100             | 100             | 100             | 93              | 96              | 99              | 100             | 95              | 91              | 100             |
Figure 1. Map of the studied site and the existing weather station position.

Figure 2. Three-dimensional model of the studied site.

Table 2. ENVI-met model parameters.

| Parameter                                | Value                          |
|------------------------------------------|-------------------------------|
| Simulation date                          | 26.08.2020                    |
| Simulation time                          | 20:00-22:00                   |
| The wind speed measured at a height of 10 m, m/s | 4.05                          |
| Wind direction                           | West, South-West              |
| The initial air temperature t, °C        | 21                            |
| Minimum temperature t_{min}, °C          | 16                            |
| Maximum temperature t_{max}, °C          | 21                            |
| Size of the model, m                     | 1300 x 1200 x 244             |
| Size of the model (number of grid cells in the xyz direction) | 151 x 140 x 40               |
| The size of the grid cell, dx, dy, dz    | 3 x 3 x 3                     |
| Geographical location (latitude, longitude) | 55.65, 37.60               |
| Nested grids                             | 8                             |
| The method of a vertical grid generation | Equidistant                   |
| Time zone                                | GMT +3                        |
On the site, residential and public buildings up to 15 floors high are located, the area occupied by low-rise and medium-rise buildings is 0.9097 km\(^2\) (74 % of the total built-up area), the area occupied by multi-storey buildings is 0.3202 km\(^2\) (Fig. 2). Air flows and distribution of PM2.5 fine particles simulated considering external non-stationary factors with the use of specialized computing software ENVI-met and based on the method of computational fluid dynamic. For this work, a 2-hour period was picked, and available weather data for temperature, humidity, wind speed and direction were used. The ENVI-met model parameters are shown in Table 2.

3. Results

A calculation of PM2.5 fine dust particles dispersion was made in ENVI-met (Fig. 3). Figure 3b shows the resulting PM2.5 concentrations. The results obtained in the course of modelling clearly demonstrate complex patterns of fine particles dispersion along roads and around buildings.

As shown by these results, the pollutant is heavily concentrated alongside the roads with relatively rapid dilution in the cross direction. Less than 10 metres from the roadway (the grid on the map is 3 x 3 m\(^2\)), the concentration of PM2.5 drops by 1.5 µg/m\(^3\) or more.

4. Conclusion

At the studied site, the main source of PM2.5 is motor vehicles exhaust emissions and road dust. Transport in this case is the only major source of PM2.5, contributing to high concentrations in this area.

In further studies, it is proposed to increase the area of greening (including vegetation installed on the roofs of existing buildings) along areas with the highest concentrations of PM2.5 fine dust particles to make air cleaner. Increasing the area of green spaces in large cities is one of the ways to phyto remediate atmospheric air from the main pollutants. In the context of high built-up density, when it is impossible to pick out free space for green areas, greening the roofs of existing buildings is the only solution.

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