

Fine dust atmospheric pollution from the objects of infill construction

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Abstract. Air pollution emissions are released from both natural and anthropogenic sources. During the environment pollution researching and monitoring the special attention should be paid to the construction operations, since during the construction processes many pollutants are released, especially fine dust particles, which are harmful to the health of construction workers and the population living near the construction site. The construction of any object in urban terrain has bad influence not only on the nearby buildings and city infrastructure, but on the existing environment of urban areas. The identification of the important pollution sources that contribute to ambient concentrations of pollutants is essential for developing an effective air quality management plan during building construction. Particular attention should be paid to emissions of fine particles during technological processes of construction with a special degree of dust emission. Control and regulation of the dynamic state of dispersed systems released during technological construction processes using a number of protective measures will reduce emissions of pollutants into the air. The objects of this research were the construction site and residential buildings of a large residential complex «Ekaterininskiy» located in Rostov-on-Don. The obtained measurement data as a result of this type of environmental monitoring showed the level of atmospheric air pollution from the construction industry using the example of the construction of the residential complex “Ekaterininskiy” in Rostov-on-Don. After analyzing the situation with dust pollution the protective measures were suggested.

1 Introduction

The production of a wide range of construction works, from excavation to installation works and finishing is accompanied by the release of fine dust not only into the air of working areas of construction sites, but also into the atmosphere of urban areas. During some construction works, the level of dust pollution is many times higher than the maximum permissible concentration (MPC). Thus, the study of the dust pollution of the urban areas during construction work is one of the important research tasks for reducing the dust emission into the environment [1, 2].

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The construction of any object in urban terrain has bad influence not only on the nearby buildings and city infrastructure, but on the existing environment of urban areas.

Dust pollution of urban areas – is one of the most important ecological problem at the moment. The air with a great number of dust particles is a threat to the health of not only workers, but also people living near construction sites. This problem is closely connected with the problem of labor and environmental protection [3-5].

The dust varies with a particle size. There are three types of construction dust according to figure 1. The first type is visible dust. It falls out the air quickly, the particle size is more then 10µm. The second type is microscopic dust with the size of 0,25-10µm (it falls out the air slowly). The third type is ultra-microscopic dust with the particle size less then 0,25µm. This type of dust propagates in the air according to the laws of Brownian motion. Construction dust is usually polydisperse, i.e. dust particles of different size are taken place simultaneously in air.

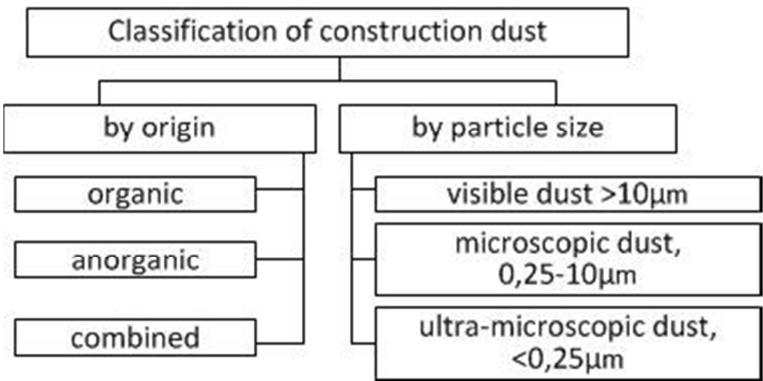


Fig. 1. Classification of construction dust

Taking into account the recommendations of the World Health Organization (WHO) some countries try to rotate and control the dust with the size maximum 2,5 µm and 10µm in the air [6].

Construction dust can cause not only respiratory diseases, but also eye diseases (conjunctivitis), and can also damage the skin of a person, causing peeling and various eczema and dermatitis [7].

It should be noted that the particle size distribution characterizes dust particles from different sides. In addition to the physicochemical properties, the particle size distribution also reflects the nature and conditions of dust distribution in the air. Coarse particle dust settles on the surface not far from the sources of pollution, fine dust can be carried by air currents over considerable distances, spreading far from emission sources. In addition, fine dust precipitates much more slowly, and ultra-microscopic fine dust practically does not precipitate at all [8].

Since June 21, 2010, sanitary-hygienic standard have been introduced in Russia [9]. It set the maximum permissible concentration (MPC) of pollutants in atmospheric air in mg/m3 for particulate matters (PM) of size less than 10 µm (PM₁₀) and less than 2.5µm (PM_{2.5}), shown in table 1.

Table 1. Maximum permissible concentration of pollutants.

№	Material name	MCP value (mg/m ³)	
		maximum permissible	daily average
1	Suspended particulate matters PM ₁₀	0,3	0,06
2	Suspended particulate matters PM _{2,5}	0,16	0,035

It can be concluded that an important task in environment protection at the moment is the development of new methods of dust protection and the introduction into operation of modern equipment designed to localize and reduce dust emissions generated during the construction of buildings or structures in many cities.

2 Materials and Methods

2.1 Dust pollution in the air of Rostov-on-Don

There is a poor environment situation in the city of Rostov-on-Don at the moment. In the space of two years the ecological indexes of the city have gone down twice. The least polluted areas of the city are located on the outskirts, away from industrial enterprises and highways. There the mass of precipitation of insoluble inorganic dust does not exceed 20 kg/km² per day, insoluble organic substances - 13-15 kg/km² per day. In the bedroom suburbs, on the outskirts of the city, dust air pollution is noticeably lower, but anyways it is in 30-50 times above the background here, due to the constant building up.

It should be noted that particles of fine dust predominate in the air there. The highest concentration of this type of dust is observed at the level of 11-15 floors. The building up of the residential high-rise complexes, with a large number of objects (usually each residential complex consists of 10 residential buildings), requires environmental monitoring of dust pollution near residential houses and buildings under construction [10].

2.2 The ecological monitoring of dust pollution on the construction site and the nearby territory

During environmental monitoring, atmospheric air pollution with fine dust was considered. It should be noted that this is the most harmful type of air pollution, since its distribution horizontally and height along is much greater [11].

A portable particle counter Handheld 3016 was used for sampling. The measurements were carried out on the territory of the residential complex "Ekaterininskiy" in the city of Rostov-on-Don in the Magnitogorskaya str., 1. The subjects of research were a construction site of a 20-storied residential building, a 25-storied residential building with full occupancy taken into use 2 years earlier, 20-storied residential building taken into use 2 weeks before the study, where repair and construction work began.

Sample taking was carried out in the houses floor-by-floor, on the 1st, 6th, 11th, 16th, 20th, 25th floors, as well as along the perimeter of the construction site during the planning of the territory in the summer time and the backfilling process of the underground part of the building in winter time. The layout of the objects of study and sampling points are shown in Figure 2.

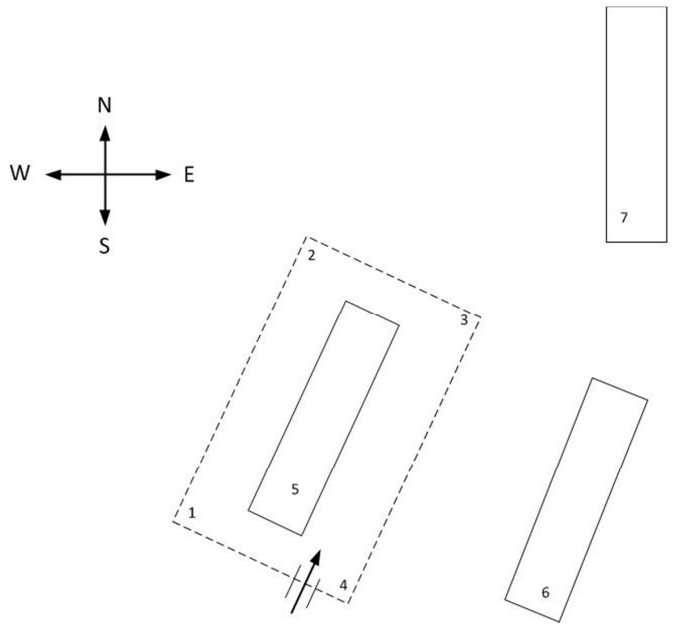


Fig. 2. The layout of the dust sampling points at a construction site in summer and winter.
The summer conditions: 1. Wind direction - east, 2. Air temperature + 25C.
The winter conditions: 1. Wind direction - north-west, 2. Air temperature - 4C.
Legend: 1-4 - sampling points in construction site, 5 - Building under construction, 6 - 25-storied residential building, 7 - 20-storied residential building, - - - The site boundaries.

The obtained measurement data as a result of this type of environmental monitoring showed the level of atmospheric air pollution from the construction industry using the example of the construction of the residential complex “Ekaterininskiy” in Rostov-on-Don.

2.3 The natural environment damage analysis

During environmental monitoring, it is necessary to apply a mathematical model to assess the damage caused to the territory under the influence of construction production [12].

In territory *G*, at point *A* (*x*, *y*), a construction industry is located. It produces the fine dust pollution of various fractions at a height of *z*=*h*. Let it be *a*1, *a*2 ... This fine dust pollution propagates in the atmosphere over this territory, partially precipitating on the surface and polluting the environment. In the process of transfer and diffusion, some particles pass into other forms under the influence of chemical reactions in the atmosphere. So, the transformation chain can be as follows: *a*1 → *a*11 → *a*12 → ... and, accordingly, *a*2 → *a*21 → *a*22 → ... The problem is to find the optimal placement of the construction site in territory *G* taking into account the minimum pollution of all environmentally significant objects and the given maximum permissible norms.

It is necessary to introduce formalized operator notation. To this end, we consider the problem of the transfer and diffusion of a certain concentration of dust emissions $\varphi_j(j = \overline{1, n})$:

$$\frac{\partial \varphi_j}{\partial t} + u \frac{\partial \varphi_j}{\partial x} + v \frac{\partial \varphi_j}{\partial y} + \omega \frac{\partial \varphi_j}{\partial z} + \sigma_j \varphi_j - \frac{\partial}{\partial z} v \frac{\partial \varphi_j}{\partial z} - \mu \Delta \varphi_j = f_j; \quad (1)$$
$$\varphi_j = 0 \text{ on } \Sigma,$$

$$\frac{\partial \varphi_j}{\partial z} = \alpha_j \varphi_j \text{ on } \Sigma_0, \quad (2)$$

$$\begin{aligned} \frac{\partial \varphi_j}{\partial z} &= 0 \text{ on } \Sigma_H; \\ \varphi_j(r, T) &= \varphi_j(r, 0) \end{aligned} \quad (3)$$

Here u , v , w are the components of the vector $\mathbf{u}^*$, interconnected by the continuity relation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0, \quad (4)$$

f_i is dust emission source in j construction sites.

Let us assume that

$$f_j = Q_j \delta(r - r_{0j}), r_{0j} = r_{0j}(x_{0j}, y_{0j}, h_j). \quad (5)$$

Let us introduce the linear operator

$$A = \frac{\partial}{\partial t} + \operatorname{div}(u *) - \frac{\partial}{\partial z} v \frac{\partial}{\partial z} - \mu \Delta$$

and the space of functions φ , whose elements satisfy certain smoothness conditions, as well as boundary conditions (2) and initial data (3). Then problem (1) - (3) can be formally represented as

$$A\varphi_{j0} + \sigma_{j0}\varphi_{j0} = f_j. \quad (6)$$

But, as noted above, the dust emission φ_j is not passive. On the contrary, when it gets into the atmosphere, it is converted from one form to another along the chain $\varphi_j = \varphi_{j0} \rightarrow \varphi_{j1} \rightarrow \varphi_{j2} \rightarrow \dots$. It means that m new indexes must be added to equation (6):

[illegible]

Hereinafter, the index j for m is omitted for simplicity. The last equation does not contain a term of the form $\sigma\varphi$, since the chain of transformations of the substance φ is assumed to be finite, and therefore φ_{im} is an indecomposable admixture.

If we want to solve equations (6), (7), it is necessary to satisfy the smoothness conditions and relations similar to (2), (3):

$$\begin{aligned} \varphi_{jl} &= 0 \text{ on } \Sigma, \\ \frac{\partial \varphi_{jl}}{\partial z} &= \alpha_{jl} \varphi_{jl} \text{ on } \Sigma_0, \\ \frac{\partial \varphi_{jl}}{\partial z} &= 0 \text{ on } \Sigma_H, \\ \varphi_{il}(r, T) &= \varphi_{il}(r, 0), l = \overline{0, m}. \end{aligned} \quad (8)$$

Let us introduce the space of vectors

$$\varphi_j = \begin{bmatrix} \varphi_{j0} \\ \varphi_{j1} \\ \vdots \\ \varphi_{jm} \end{bmatrix}, \quad f_j = \begin{bmatrix} f_j \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

and matrix

$$L_j = \begin{bmatrix} A + \sigma_{j0} & \ddots & 0 \\ -\sigma_{j0} & \ddots & A + \sigma_{j,m-1} \\ 0 & -\sigma_{j,m-1} & A \end{bmatrix}$$

Then problems (6), (7) for propagation and conversion φ_j concentration of dust pollution into new components can be represented in the vector-matrix form:

$$L_j \varphi_j = f_j. \quad (9)$$

Now we introduce the Hilbert space of vector functions with the scalar product:

$$(g, h) = \sum_{l=0}^m \int_0^T dt \int_G g_l h_l dG$$

and consider the conjugate problem

$$L_j \varphi_j = p_j, \quad (10)$$

$$\varphi_j = \begin{bmatrix} \varphi_{j0} \\ \varphi_{j1} \\ \vdots \\ \varphi_{jm} \end{bmatrix}, \quad p_j = \begin{bmatrix} p_{j0} \\ p_{j1} \\ \vdots \\ p_{jm} \end{bmatrix}, \quad (11)$$

where p_j is an undefined vector-function. We find the functional L_j using the Lagrange identity

$$(\varphi_j, L_j \varphi_j) = (\varphi_j, L_j \varphi_j). \quad (12)$$

We arrive at the function L_j using the definition of a scalar product and integrating the left relation in parts:

$$L_j = \begin{bmatrix} A + \sigma_{j0} - \sigma_{j0} & & \ddots & 0 \\ & A^* + \sigma_{j,1} & \ddots & \\ & & A^* + \sigma_{j,m-1} - \sigma_{j,m-1} & \\ 0 & & & A^* \end{bmatrix}$$

where the functional A^* has a form

$$A^* = -\frac{\partial}{\partial t} - \operatorname{div}(u *) - \frac{\partial}{\partial z} v \frac{\partial}{\partial z} - \mu \Delta.$$

Moreover, the space of conjugate functions φ^* contains the elements of the necessary smoothness that satisfy the following conditions for their components:

$$\begin{aligned} \varphi_{jl} &= 0 \text{ on } \Sigma, \\ \frac{\partial \varphi_{jl}}{\partial z} &= \alpha_{jl} \varphi_{jl} \text{ on } \Sigma_0, \\ \frac{\partial \varphi_{jl}}{\partial z} &= 0 \text{ on } \Sigma_H, \\ \varphi_{jl}(r, T) &= \varphi_{jl}(r, 0), l = \overline{0, m}. \end{aligned} \quad (13)$$

Further, we write equation (10) in an exploded form:

$$\begin{aligned}
 A^* \varphi_{j0} + \sigma_{j0} \varphi_{j0} - \sigma_{j0} \varphi_{j1} &= p_{j0}, \\
 A^* \varphi_{j1} + \sigma_{j1} \varphi_{j1} - \sigma_{j1} \varphi_{j2} &= p_{j1}, \\
 &\dots\dots\dots \\
 A^* \varphi_{j,m} &= p_{jm}.
 \end{aligned}
 \tag{14}$$

Let us make the definition of the vector function p_j . To this end, we first assume that the source of dust pollution with the j -th dust component f_j is a delta function of coordinates, i.e.

$$f_j = Q_j \delta(r - r_0), \tag{15}$$

where Q_j is the air emission strength. We scalarly multiply (9) by φ_{*j} , and (10) by φ_j and subtract the resulting relations from one another. Then

$$(\varphi_j, L_j \varphi_j) - (\varphi_j, L_j \varphi_j) = (\varphi_j, f_j) - (p_j, \varphi_j). \tag{16}$$

According to the Lagrange identity, the left side vanishes, and we have

$$(\varphi_j, f_j) - (p_j, \varphi_j). \tag{17}$$

Let us define p_j as follows. Suppose that the fine dust pollution φ_{jl} , propagated in the territory G_k during the year is

$$\xi_{jl} \int_0^T dt \int_{G_k} \varphi_{jl} dG,$$

where ξ_{jl} is the coefficient characterizing the damage from this component. Then the total damage of all components with number j is

$$Y_j = \sum_{l=0}^m \xi_{jl} \int_0^T dt \int_{G_k} \varphi_{jl} dG. \tag{18}$$

Let us take this functional as the initial one and require that (p_j, φ_j) coincide with Y_j . That's why we should put

$$p_{jl} = \begin{cases} \xi_{jl}, & \text{if } r \in G_k \\ 0 & \text{out of } G_k. \end{cases}$$

with this choice p_{jl} of the right-hand side in (17) will be equal to Y_j , while the left-hand side will be

$$Y_j = (\varphi_j, f_j) = \int_0^T dt \int_G Q_j \varphi_{j0} \delta(r - r_0) dG,$$

or, more simply,

$$Y_j = Q_j \int_0^T \varphi_{j0}(r_0, t) dt. \tag{19}$$

Thus, the determination of the pollution dose of the territory G_k by all components belonging to the chain $\varphi_{j0} \rightarrow \varphi_{j1} \rightarrow \varphi_{j2} \rightarrow \dots$ demands to solve the conjugate problem (14) in the reverse order:

$$\begin{aligned}
 A^* \varphi_{j,m} &= p_{jm}, \\
 A^* \varphi_{j,m-1} + \sigma_{j,m-1} \varphi_{j,m-1} - \sigma_j \varphi_{jm} &= p_{j,m-1}, \\
 &\dots\dots\dots \\
 A^* \varphi_{j0} + \sigma_{j0} \varphi_{j0} - \sigma_{j0} \varphi_{j1} &= p_{j0},
 \end{aligned}
 \tag{20}$$

using the boundary conditions and the initial data in the form (13) during the calculating in the reverse course of time. Let we estimate the pollution from all components of fine dust $j = \overrightarrow{1,m}$. In this case, functional (18) and (19) will go over to the following:

$$Y^k = \sum_j \sum_l \xi_{jl} \int_0^T dt \int_{G_k} \varphi_{jl} dG, \tag{21}$$

$$Y^k = Q \sum_j \eta_j \int_0^T \varphi_{j0}(r_0,t) dt. \tag{22}$$

Here Q is the emission strength of all dust at the construction site; η_j is the fraction of each component in terms of particle size ($j = \overrightarrow{1,n}$).

This calculation bases on experimental data. The calculation showed that the sanitary protection zone of the construction area must be increased by 20%.

3 Results

The results of dust pollution monitoring in the atmospheric air of the residential complex “Ekaterininskiy” showed the following results and the dependences shown in Figures 3-5.

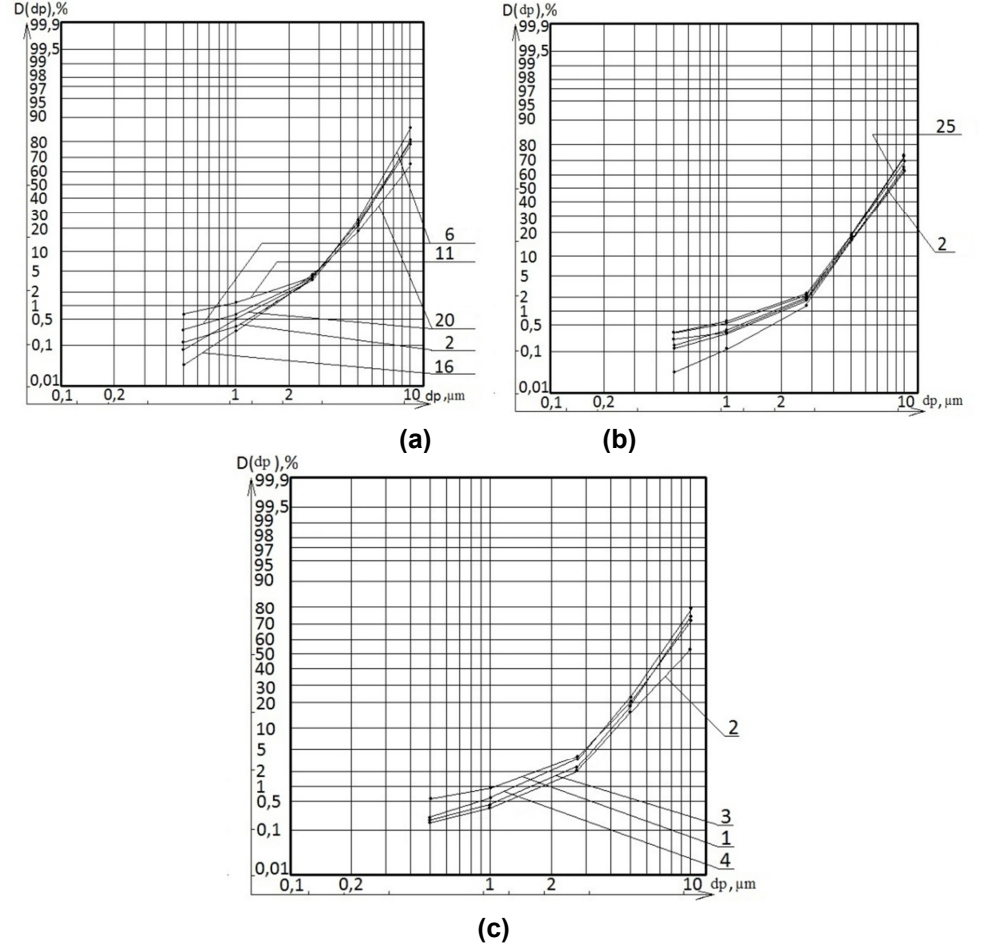


Fig. 3. The results of the ecological monitoring in the summer time: a) 20-storied residential building b) 25-storied residential building c) construction site site.

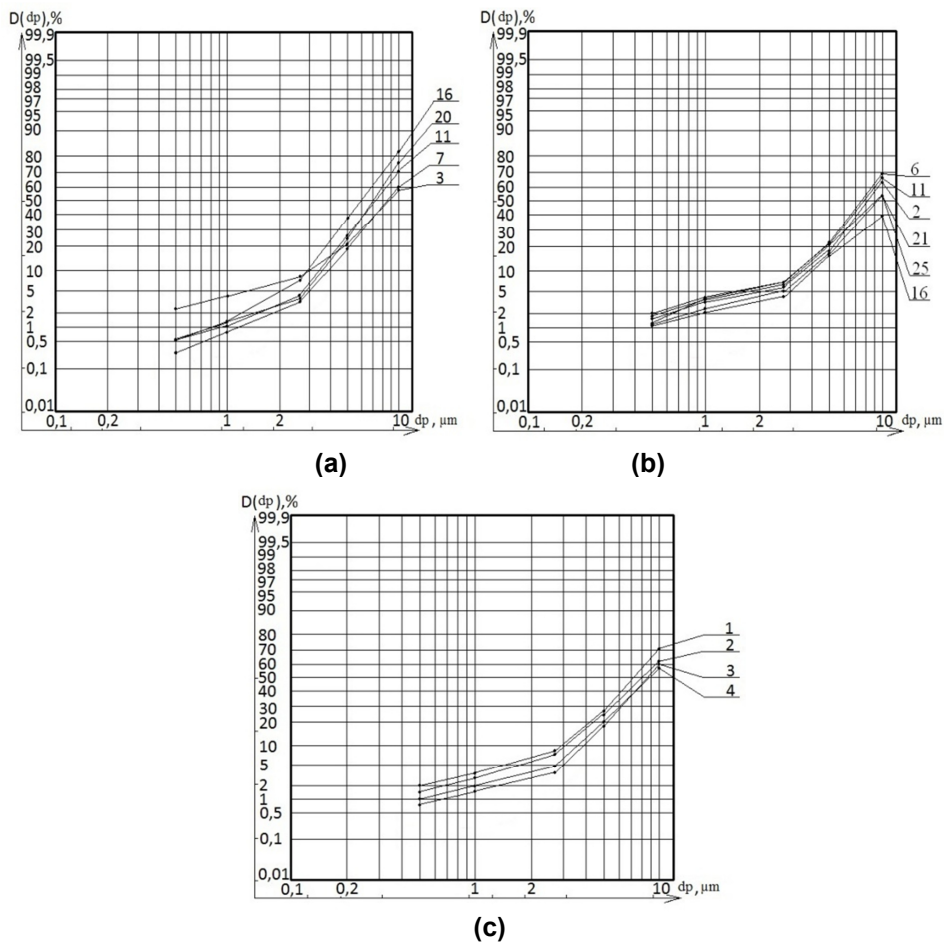


Fig. 4. The results of the ecological monitoring in the winter time: a) 20-storied residential building b) 25-storied residential building c) construction site.



Fig. 5. The results of measurements of dust pollution of the habitable inner spaces in the building located near the construction industry in the summer and winter periods (all sizes are in mm)

4 Discussions

4.1 The ecological monitoring of dust pollution in a residential building near the object of construction

The results of ecological monitoring of dust pollution in a residential building near the object of construction works showed the following values.

The dispersion of PM_{10} dust fractions on the floors of the building next to the construction site in the summer is from 61 to 72 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_{10} fraction is from 39 to 69 percent of the total mass.

The dispersion of PM_5 dust fractions on the floors of the building next to the construction site in the summer is from 15 to 19 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_5 fraction is from 15 to 22 percent of the total mass.

The dispersion of $PM_{2.5}$ dust fractions on the floors of the building next to the construction site in the summer is from 1.2 to 2.5 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the $PM_{2.5}$ fraction is from 4 to 7 percent of the total mass.

The dispersion of PM_1 dust fractions on the floors of the building next to the construction site in the summer is from 0.13 to 0.6 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_1 fraction is from 2 to 4 percent of the total mass.

The dispersion of $PM_{0.5}$ dust fractions on the floors of the building next to the construction site in the summer is from 0.03 to 0.4 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the $PM_{0.5}$ fraction is from 1 to 2 percent of the total mass.

In winter, the concentration of fine dust ($PM_{0.5}$; PM_1 ; $PM_{2.5}$) in the air of a residential building near the construction site is much higher than in summer. This may be due to the activation of a new type of works at the construction site.

The range of variation in the size of dust inside the habitable inner spaces is from $1.3\mu m$ to $13\mu m$, the median diameter $d_{50} = 7.9\mu m$. The most common dust size is from $9\mu m$ to $13\mu m$. These values were identical for all measurements.

4.2 The ecological monitoring of dust pollution in a residential building with the implementation of repair works

The results of ecological monitoring of dust pollution in a residential building with the implementation of repair works showed the following values.

The dispersion of PM_{10} dust fractions on the floors of the building with repair works in the summer is from 63 to 84 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_{10} fraction is from 58 to 81 percent of the total mass.

The dispersion of PM_5 dust fractions on the floors of the building with repair works in the summer is from 18 to 24 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_5 fraction is from 19 to 38 percent of the total mass.

The dispersion of $PM_{2.5}$ dust fractions on the floors of the building with repair works in the summer is from 3 to 4.5 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the $PM_{2.5}$ fraction is from 3 to 7 percent of the total mass.

The dispersion of PM_{10} dust fractions on the floors of the building with repair works in the summer is from 0.2 to 1.1 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_{10} fraction is from 0.7 to 4 percent of the total mass.

The dispersion of $PM_{0.5}$ dust fractions on the floors of the building with repair works in the summer is from 0.03 to 0.6 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the $PM_{0.5}$ fraction is from 0.02 to 2.1 percent of the total mass.

4.3 The ecological monitoring of dust pollution at the construction site

The results of ecological monitoring of dust pollution at the construction site showed the following values.

The dispersion of PM_{10} dust fractions at a construction site in the summer is from 51 to 80 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_{10} fraction is from 57 to 70.05 percent of the total mass.

The dispersion of PM_5 dust fractions at a construction site in the summer is from 15 to 22 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_5 fraction is from 18 to 27 percent of the total mass.

The dispersion of $PM_{2.5}$ dust fractions at a construction site in the summer is from 2 to 3 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the $PM_{2.5}$ fraction is from 3 to 8 percent of the total mass.

The dispersion of PM_1 dust fractions at a construction site in the summer is from 0.4 to 0.9 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the PM_1 fraction is from 1.4 to 4 percent of the total mass.

The dispersion of $PM_{0.5}$ dust fractions at a construction site in the summer is from 0.2 to 0.55 percent of the total mass. In winter, the measuring span in the concentration of dust particles of the $PM_{0.5}$ fraction is from 0.7 to 2 percent of the total mass.

According to the results of the monitoring, it can be determined that the ratio of the concentration of fine dust at the construction site in the winter time is much higher than in the summer time.

Conclusions

According to the results of ecological monitoring of the territory near the construction industry we can draw the following conclusions.

1. The results of these calculations can give a current assessment of the impact of dust emissions on the ecology of the residential complex «Ekaterininskiy» and thus determine the optimal location of the construction site in territory *G*, taking into account the minimum pollution of all environmentally significant objects and specified maximum permissible standards.

2. The analysis and the comparison of practical data on atmospheric air pollution with $PM_{0.5}$ - PM_{10} fine dust indicates an unfavorable situation with local air pollution from construction works. In winter, the dust concentration increases significantly by 15-25%, since in winter in Rostov-on-Don the wind load increases, which contributes to greater dust pollution. The highest concentration of fine dust particles is determined at the levels of 11-15 floors, according to the graphic and mathematical processing of the monitoring results.

3. The data obtained as a result of the research made it possible to propose measures that reduce local dust pollution in the process of construction works [13-15]. Such measures include the installing safety screens, dust screens on windows during repairs in the building, the equipping the construction industry with exhaust fans for dust collection. These

protective measures can reduce the cost of environmental safety of the territory near the construction industry, first of all, by introducing them into working plans of construction.

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