Areas of Probable Air Pollution in Mountains and Valleys

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Abstract. Many cities of the world are located in river valleys or are associated with mountains. The article presents the characteristic landscape positions of many cities in the world. Among them is very important to study the wind regime, which is located in the conditions of the basin. In these cities, general pollution and deterioration of the microclimatic regime of the atmosphere are observed during periods of windless weather, and especially during inversions. It occurs either due to the gradual accumulation of harmful impurities of road transport under adverse meteorological conditions. The contribution of vehicles to the total air pollution is up to 80%. Currently, their composition of vehicle exhaust gases contains more than 200 different substances. With 95 ... 99% of emissions represent an aerosol of complex composition, depending on the engine operating condition and the composition of the mixture. The composition of the atmosphere of cities should meet the established standards for the content of the main components of air and harmful impurities (dust, gases), taking into account existing state standards. Biomedical requirements for the composition of air in cities are determined by the maximum permissible concentrations (MAC). However, the content of toxic substances in the air at the level of the MPC cannot be considered as the optimal composition of the air environment. In cities located in the depressions, deterioration of air exchange conditions is observed, which is associated both with a drop in wind flow activity and a decrease in the intensity of solar insolation per unit area of exposed surfaces of the slopes. In the work to improve the wind mode, the base for establishing the main stages for regulation is set to be direct; recycling; and combined i- recirculation direct-flow, as well as direct-flow-recirculation schemes of natural ventilation. The formulas for determining the criterion for evaluating the effectiveness of ventilation are given. We used computer modeling technologies that significantly simplify the analysis of the wind regime and reduce the time spent on research, the purpose of which was to compare the results of experiments in a wind tunnel with the data of virtual studies of the wind flow around natural wind patterns in a wind tunnel with the use of SolidWorks 2015, with the addition of Flow Simulation.

1. Introduction
Pollution of the air basin (dustiness) of cities is formed on the basis of the presence of industrial enterprises, vehicles. Sources of pollutants are very diverse. These are industry, energy, transport, agriculture, etc. At the same time, the industry, in turn, is divided into metallurgical, chemical, petrochemical, machine-
building, radio-electronic, food, light, etc. In this regard, thermal power plants, construction, coal, metallurgical, and cement enterprises pose the greatest danger for urban air pollution. Pollution in some cities also depends primarily on their geographical location and terrain.

The impact of anthropogenic pollution on the state of the air basin has not been fully studied. They differ in structure and properties, which makes it impossible to accurately assess the scale of their harmful effects. Their content in the Earth's atmosphere is growing every year.

Pollution (dust) indirectly affects the climate: it blocks the passage of sunlight and participates in the formation of clouds, acting as condensate cores. Therefore, when designing cities, you should take into account such natural factors as: solar radiation, (direct and scattered), temperature and relative humidity, wind speed and direction. For the formation of wind conditions on the territory of an important role is played by the terrain and its formation.

Taking into account and being able to use these factors correctly creates a great economic effect when planning and building cities and their residential development.

Historically, many cities in the world are located in river valleys or associated with mountains. These include the following cities and highlight their characteristic landscape positions:

- Valley - Paris, Baghdad, Cairo, Kyiv, Moscow, Nizh. Novgorod, Yaroslavl, Mesopotamia, etc.;
- Piedmont - Istanbul, Shanghai, Tokyo, Mumbai, Rio de Janeiro, Havana, San Francisco, Vladivostok, Sochi, Sevastopol, and others;
- Foothills - Samarkand, Tashkent, Ashgabat, Almaty, Vladikavkaz, Grozny, Milan, Munich, and others;
- mountain-hollow - Yerevan, Kabul, Tehran, Damascus, Geneva, Sana'a, Bishkek, Dushanbe, etc.

Here, we touch upon the problems of airing cities located in the conditions of a mountain hollow.

2. Relevance of the research topic

Providing good microclimate conditions in the cities located in the mountain hollows of the relief is an important objective of urban planning science. This goal is achieved by solving such problems as the development of methods and means of eliminating harmful substances at the places of their formation or isolation and using natural forces and factors to intensify natural ventilation.

General pollution and deterioration of the microclimatic regime of the atmosphere are observed, as a rule, during periods of windless weather and especially during inversions. It occurs either due to the gradual accumulation of harmful impurities of road transport under adverse meteorological conditions.

In case of weak winds, it is possible to form difficultly aired “stagnant” zones with elevated concentrations of harmful impurities, i.e. local pollution. Local air pollution is usually observed in areas of the highest concentration of exhaust gases of road transport.

The main technogenic source of air pollution in the world is vehicles, with more than 80% of the main emissions in major cities coming from road transport. The contribution of vehicles to the total air pollution is up to 80%. Automobile internal combustion engines pollute the atmosphere with harmful substances emitted with exhaust gases, crankcase gases, and fuel fumes. Currently, their composition is determined by more than 200 different substances. At the same time, 95... 99% of harmful emissions are from exhaust gases, which are an aerosol of complex composition, depending on the mode of operation of the engine and the composition of the mixture.

Of the aerosol components of the most dangerous soot, emitted in the form of particles with a predominant size of 0.05-0.5 μm (up to 98%). Soot release is characteristic of diesel engines. Soot is harmful because it can adsorb carcinogens in the exhaust gases. In addition, the smoke and the smell of exhaust gases with a large amount of soot have an unpleasant effect on a person. Soot particles, possessing a significant specific surface area (up to 50 -60 m/g), adsorb carcinogenic and other toxic substances, which, entering the human body, can lead to serious consequences.
3. Problem statement
The composition of the atmosphere of mountain-hollow cities is rather complicated and its assessment should be approached on the basis of medical and biological requirements, taking into account the concentration of harmful impurities, the direction of their action, the degree of toxicity. Biomedical requirements for the composition of air in cities are determined by the maximum permissible concentrations (MAC). However, the content of toxic substances in the air at the level of the MPC cannot be considered as the optimal composition of the air environment. Considering the simultaneous presence of a large number of aerosol and gaseous impurities in cities, it is necessary to strive to achieve concentrations that are much lower than the maximum permissible concentrations.

4. Research methodology
The effect of dust on the skin is reduced mainly to mechanical irritation. As a result of this irritation, slight itchiness, an unpleasant sensation occurs, and with scratching, redness and some swelling of the skin may appear, which indicates an inflammatory process.

The dust particles can penetrate the pores of the sweat and sebaceous glands, clogging them and thus hampering their functions. This leads to dry skin, sometimes cracks, rashes. Microbes trapped with dust in clogged sebaceous glands can develop, causing pustular skin diseases, pyoderma. The blockage of sweat glands with dust at high temperatures helps to reduce perspiration and thus makes thermoregulation difficult.

Some toxic dust in contact with the skin cause chemical irritation, which is expressed in the appearance of itching, redness, swelling, and sometimes ulcers.

When dust enters the mucous membranes of the eyes and upper respiratory tract, its irritating action, both mechanical and chemical, is most pronounced. The mucous membranes compared with the skin more thin and tender, they are irritated by all kinds of dust, not only chemicals or sharp edges, but also amorphous, fibrous, etc.

The composition of the atmosphere of cities should meet the established standards for the content of the main components of air and harmful impurities (dust, gases), taking into account existing state standards. Nontoxic dust, lingering in the lungs for a long time, gradually cause the connective tissue around each speck of dust, which cannot absorb oxygen from the inhaled air, saturate it with blood and release carbon dioxide during expiration, as normal lung tissue does. The process of proliferation of connective tissue proceeds slowly, as a rule, over the years. However, in conditions of high dustiness, the overgrown connective tissue gradually replaces the pulmonary tissue, thus reducing the main function of the lungs - the absorption of oxygen and carbon dioxide return. Prolonged lack of oxygen leads to shortness of breath during fast walking or work, weakening the body, lowering the working capacity, reducing the body's resistance to infectious and other diseases, changes in the functional state of other organs and systems.

Due to the impact of non-toxic dust on the respiratory organs, specific diseases called pneumoconiosis to develop.

5. Theoretical section
Meteorological observations have established that an own microclimate is being formed in the urban space, the features of which appear more clearly as the depth of the basin increases. In the lower horizons of deep cities, there are significant differences in air temperature, humidity, atmospheric transparency, and amount of precipitation. The increase in depth is accompanied by deterioration of the air exchange conditions in the urban space, which is associated with both a drop in the activity of the wind flow and a decrease in the intensity of solar insolation per unit area of the exposed surfaces of the slopes.

The consequence of this is the emergence of difficult-to-ventilated "stagnant" zones, the volume of which increases with depth and depends on the wind speed on the surface. The main factors determining the activity of natural air exchange in cities are wind energy, solar radiation and thermal stratification of the
atmosphere of the city and the overlying layers. Under certain conditions, oxidative processes and the deep heat of the Earth can affect the natural air exchange (especially at high geothermal gradients).

In real conditions, air exchange in cities is determined by the joint action of a number of factors, of which wind energy is decisive. Local streams caused by solar radiation, in the presence of wind, perform a secondary role. Thermal stratification of the atmosphere in the city and overlying layers either contributes to the development of vertical movements of air or prevents it.

Thus, the basis for establishing the main stages for regulating the microclimatic regime of a city are straight-through; recycling; and combined-recirculation direct-flow and direct-flow-recirculation schemes of natural ventilation.

Their qualification is based on the aerodynamic characteristics of air movement in cities, which occurs when the wind is applied, taking into account the main parameters, which include: L - the size of the basin at the surface in the direction perpendicular to the movement of wind; B is the length of the depression in the direction of the wind; \( \frac{B}{H} \) - the relative length of the depression in the direction of the wind; H is the depth of the basin; \( \beta_\text{L} \) and \( \beta_\text{H} \) - respectively, the corners of the slopes of the leeward and windward slopes of the basin.

The parameters of the basin that determine the wind pattern of its ventilation are presented in Table. one.

With air flow structure with the direct flow; recycling; recirculation direct-flow and direct-flow-recirculation schemes of natural ventilation (Figure 1.).

**Table 1.** Natural construction schemes arising from different geometric parameters of the city’s hollow space.

| Airing pattern                  | Defining parameters                                                                 |
|---------------------------------|-------------------------------------------------------------------------------------|
| Recycling                       | For \( \frac{H}{H} < 5 \div 6L \) and \( \beta_\text{H} \geq 15^0 \)               |
| Direct flow                     | For any B and H and \( \beta_\text{H} < 15^0 \) at leeward slope                   |
| Recirculation direct-flow       | For \( \frac{H}{H} > 7L \) and \( \beta_\text{H} \geq 15^0 \)                      |
| Direct-flow recirculation       | For any B and H and \( \beta_\text{H} \geq 15^0 \) the slopes                     |

![Diagram](image-url)
Recirculation scheme ventilation pit: AOW - free jet; BOC - recirculation zone; OB - air flow dividing line

**Figure 1.** The structure of the air flow in a-flow; b- recirculation; c- recirculation-direct-flow and d-direct-flow-recirculation schemes of natural ventilation.

The criterion for evaluating the effectiveness of ventilation is a dimensionless quantity:

$$H_{cp} = \frac{H_{gr}}{H_{rp}}$$

Where $H_{rp}$ -the depth of the location of the meeting point of the outer boundary of the turbulent jet with the leeward slope of the basin, in m;
$H$-depth of the basin, in m.

From the formula, it follows that with different combinations $H_{rp}$ и $H$ magnitude $H_{cp}$ may have different values in the range of $0 \leq H_{cp} \leq 1$.

Based on the effectiveness of natural ventilation, taking into account the influence of dust or harmful substances on the level of pollution of the atmosphere of the city, the corresponding depths determined by $H_{cp}$. Consider 3 cases: 1-case - $H_{cp} > 0$; second $0,5 > H_{cp} > 0$; third $H_{cp} <0$.

Thus, the maximum depth of the basin in the first case $H_{1} = 0.5 H_{cp}$, on the second $H_{2} = H_{cp}$ and in the third case $H_{3} > H_{cp}$.

In the first and second cases (Fig. 1 a and b), the wind blowing from the suburb is not subject to change, i.e. the air of the city is ventilated along with a direct flow (For $\beta_{n} \geq 15^0$) or recirculation direct-flow scheme (For $\beta_{n} > 15^0$). However, most of it is in the area of direct air flow, and the recirculation covers a relatively small part adjacent to the leeward slope of the city. As a result, pollution and calm air conditions are not observed or their level is insignificant. In this case, the speed of the air flow on the slope and bottom of the hollow part of the city with an average annual wind speed $U_{a}$ more than $0.5 U_{a}$ that completely provides effective airing.

In the third case (Fig.1c), the air of the city is ventilated according to recirculation direct-flow or recirculation schemes. At the same time, the main part of the city is located in the air flow recirculation zone. As a consequence, pollution or calm city air conditions can reach significant levels. When $H = H_{rp}$ air velocity at the surface of the slopes and bottom of the basin does not exceed $0.5 U_{a}$, with an average annual
wind speed of 1.5 m/s and more, it can provide quite satisfactory ventilation of individual residential areas of the city.

In the fourth case (Fig. 1 d), the air of the city is ventilated according to the recirculation or recirculation direct-flow scheme. This results in pollution or calm city air conditions at the bottom of the basin, and air velocity at the surface of the slopes and at the bottom of the basin. With average annual wind speeds of 1.5 m/s and more are 0.1-0.2 \( \frac{m}{sec} \), which is not enough for effective ventilation of the atmospheric air of the city. Particularly adverse atmospheric conditions (severe pollution or stable calm conditions) may occur at certain deep parts of the relief.

Wind flow is detached from the slope, forming a free jet, within which the air moves from the lee to the windward slope. The latter one of the air masses turns in the opposite direction, forming a recirculation zone, the second along the windward side comes to the surface. Wind speed in the quarry decreases with height at first, reaching zero on the air flow dividing line, and then increases. The presence of air recycling contributes to the accumulation of hazards in the career; their removal is carried out only through the top. part of the free jet. The pattern is typical for deep quarries. With a variable angle of inclination of the slope of the relief, a direct-flow-recirculation wind scheme is possible. Thermal schemes of the depression are realized at a wind speed on the surface of less than 1-1.5 m/s. The convective scheme occurs when the slopes of the relief are heated (Fig. 2).

The speed of ascending convective flows along with the slopes increases with height and at the upper edge of the slope may be 1-1.5 m/s. Removal of hazards is carried out along the slopes. The inversion pattern of the ventilation of the city occurs when the slopes of the relief are cooled. The colder air masses, which are adjacent to the slopes, descend, filling the bottom part of the city and pushing warm air upwards (Fig. 3).

![Figure 2. Convective ventilation of the basin.](image1)

![Figure 3. Inversion pit ventilation pattern: a-a-inversion level; h-thickness of the inversion layer.](image2)

The air velocity at the slopes does not exceed 1 m/s; below the level of inversion, there is practically no air movement, which leads to the accumulation of harmful substances and may cause air stagnation (calm conditions) and the accumulation of polluted harmful gases of automobiles.

6. Results of experimental studies

Computer modeling techniques were also used in the work, which significantly simplifies the analysis of the wind regime and reduces the time spent on research.

One purpose of these studies was to compare the results of experiments in a wind tunnel with the data of virtual studies process flow of natural wind flow relief forms in a wind tunnel using SolidWorks program 2015 with additions it Flow Simulation.

Tests of models of natural relief in this program allowed us to establish a qualitative and quantitative picture of the flow of models by airflow depending on:

- model forms;
- parameters of the cross-section of the model, including the angle of slope and the relative height (depth) of the shape of the relief.
For the first series of experimental studies, two models of mountain-hollow relief were taken with different widths of the notch itself (s = 6h, s = 10h) and with the same angle of inclination of the sides equal to 17˚; as well as 3 models of the hollow with a fixed width of s = 6h, but with different bead angles of 17˚, 30˚, 41˚, which corresponds to the relationship of the depth of the notch to the laying of the beads, respectively, equal to 1/3.3; 1/1.7; 1/1.1.

For the second series of studies, three models of a trapezoidal blade with a slope angle of 17˚, 30˚, 41˚, and apex width equal to s = 3h were taken.

In the third series of experiments, we studied the pattern of current lines in the flow around a basin and a heap with the same bottom length S = 6h, the angle of inclination was taken as 30˚.

General settings specified before conducting research in the program SolidWorks: Task type - external; Fluid medium - Air (gases); The type of flow is only turbulent Turbulence intensity - 2%; The scale of turbulence is 0.0001; Humidity is absent;

Airflow velocity measurements were made at a height H = 10 m from the ground (or 10 mm on the model), which corresponds to the height of the weather vane location. All measurements were carried out on a scale of 1: 1000.

At the start of the study, diagrams were obtained for the distribution of the air flow with regard to the specified conditions. Flow rates at different sites are indicated by a characteristic color. Further, using plots, the transformation ratio values were calculated for each point using the formula \( \tau = \frac{U_i}{U} \), where U is the unperturbed flow velocity specified in the input data, \( U_i \) is the velocity on the model at the selected point.

The results were decorated in a graphical way. On the basis of the data obtained, diagrams and graphs were constructed, combining the results of the initial and conducted studies.

The transformation ratios of incoming airflow at each of the points were processed with the help of lines of the same speed, which were carried out every 0.2 values of the coefficient, that is, the points were connected with indicators of 0.6; 0.8; 1.0, etc. (Fig. 3).

7. Conclusion and suggestions

When designing high-rise buildings in urban development, you should assess the impact of significant wind loads that occur when the building is more than 25 stories high. With the increase in the number of storeys of the building, the wind speed increases significantly, in addition, there are swirls and turbulent flows around the building, which act not only on the building itself, but on the surrounding territories, as the wind flow breaking up against the building goes in different directions vertically and horizontally.

Thus, the results of the study allow us to draw the following conclusions:

1. The influence of pollution (dustiness) of the air basin of cities located in the mountain-basin area in the construction science is little studied;
2. The proposed research method is the first approximation that takes into account the design process of residential development of mountain-basin cities.
3. The data obtained can also be used to calculate the dust conditions or environmental components of various cities with very rough terrain.

8. References

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