Representativeness of monitoring station readings in the context of urban environment

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Abstract. In this paper, a comprehensive analysis of the interaction of the urban environment elements with the natural environment components is carried out. The assessment of the complex impact of meteorological parameters on the human body is analyzed based on data obtained from monitoring stations. The readings of monitoring stations concerning both wind speed and directions are found to significantly deviate in different parts of the city due to urban development. A numerical study of the neighborhood with the monitoring station also shows a very complex mechanism for determining the pollution intensity of the area and the relevance of the data obtained, especially concerning pollutants.

1. Introduction

The urban environment is a set of anthropogenic objects with components of the natural environment. As a rule, the main part of the urban territory consists of artificially created elements, such as residential neighborhoods, public and industrial buildings, streets, highways, parks, and other structures necessary for a comfortable and safe living of the population. In this regard, each city consists of a large number of free-standing buildings, whose shapes and locations are very complicated and unique in their way. But an artificially created system cannot exist beyond the natural environment, so, each unit of the urban environment to some extent leads to a change in the initial state of the natural environment components. Ultimately, the appearance of new anthropogenic elements leads to a significant change in the physical parameters. Accordingly, as a result of this impact, each city is characterized by its specific microclimate [1].

The main factor determining meteorological processes are air flows. The nature of their motion in the urban environment and above is of fundamental importance in assessing the pollution intensity, temperature balance, humidity, etc., which, in turn, determine the external and internal climate of the city [2].

The complicated geometry of the built-up areas leads to different airflow patterns, which are accompanied by a sharp change in parameters both in space and time. For example, the configuration of modern neighborhoods leads to such a strong weakening of the wind power inside the neighborhood that the frequency of calmness increases three times. This results in forming zones with wind speeds of less than 1 m/s and creating stagnant areas, where pollutants accumulate. Besides, zones with high wind speeds (Venturi effect appearing usually between high-rise buildings), which due to undesirable vertical rise of dust make the stay of people uncomfortable, may appear [3–5]. Such microclimate in the urban environment can negatively affect both people’s health and the environmental condition in general.
Due to this fact, various monitoring networks are created in cities that allow monitoring the atmospheric air condition, as well as evaluating and predicting the main trends in its quality to timely identify the adverse impact of both natural and anthropogenic factors.

As a rule, in large cities, monitoring stations are located evenly throughout the city, which allows considering the current situation in general. The main thing that should be taken into consideration is the location of these stations since this strongly influences the informativeness of the recorded parameters.

Based on the above, an interest arises to the problem of wind flow behavior under the influence of the urban environment elements, as well as to the conditions formed as a result. Assessing the representativeness of existing monitoring stations is also of particular importance. Such analysis can be implemented using contemporary methods of computational fluid dynamics (CFD). The uniqueness of CFD models lies in the fact that they allow linking and simulating all possible aspects (thermophysical and spatial) of the microclimate, providing the possibility to obtain spatial information on the dynamics of velocity fields, which is extremely necessary to solve the problem under consideration [6].

2. Changes in the main parameters of wind flows under the impact of the urban environment evidence from the city of Krasnoyarsk

Of particular interest is the question of how meteorological indicators behave in the same period under different conditions of the urban environment. To answer this question, data from various monitoring stations in Krasnoyarsk are analyzed to assess the severity of exposure and changes in the considered influence on the fundamental parameters describing the atmospheric air condition. To analyze the microclimate of Krasnoyarsk, a bioclimatic assessment of the environment condition is carried out based on the biometric index, namely, effective equivalent temperature (EET) [7].

The main advantage of assessing the bioclimatic impact of meteorological factors is that the effects of not just one factor are taken into account, but a combination of several factors at the same time. This approach allows assessing the integrated impact of climatic conditions in the city on the human body.

The algorithm of bioclimatic diagnostics of Krasnoyarsk is based on the database of climatic parameters, which is formed based on the results of measurements at nine automated observation posts (AOP) located in each administrative district of Krasnoyarsk (Fig. 1), as well as several observation posts situated in the suburban territory, where conditionally there are no urban environment effects. The data for each day of the year, in an hourly time interval, are considered, and then the average values are obtained first for the day, then for the month [8].

Figure 1. Sketch map of the administrative division of the Krasnoyarsk and the location of automated observation posts [8].
The results of the EET calculation for the annual interval for all automated observation posts are shown in Fig. 2. The results of the analysis have shown that the EET index fluctuated within the normal range throughout the year, and the environmental conditions were comfortable. While considering the EET, corresponding to selected particular days, when the average air temperatures in the cold period were below $-30 \ldots -35^\circ C$, at high humidity, and an average wind speed of about $2.5 \text{ m/s}$, the environmental conditions were extremely uncomfortable, since there was a possibility of frostbite, while on hot summer days, when the ambient air temperature reached to $+30 \ldots +32^\circ C$, there was a threat of strong thermal load.

![Figure 2. Change in the effective equivalent temperature during the year, by B.A. Aizenshat, $^\circ C$ [9].](image)

It is worth noting that the concerned indicator varies greatly depending on the AOP location, as it depends on the wind speed. Within the same time interval, the wind speed at the AOP varies from 0 to 6 m/s. The jump in values is caused by the location of the AOPs. Some AOPs are located in almost enclosed courtyards, where there is no natural wind blowing, while other stations in the city show higher wind speed values. Possibly, this is because these AOPs are situated in the zones of wind flow acceleration. It should be noted that the location of the AOP is determined by the main directions of the winds. Analyzing the windrose diagrams of different AOPs, one can note that they have a weak correlation with each other. One may assume that this can be caused by the effect of the urban environment elements (Fig. 3).
3. Assessment of the impact of the urban environment elements on the readings of monitoring stations

Based on the performed bioclimatic analysis, the possible effects of the location of the monitoring stations on meteorological data was considered evidence from the AOP Vetluzhanka, which is situated in the Oktyabrsky residential district of Krasnoyarsk (Fig. 1).

3.1. Mathematical model and software package

A micro-scale mathematical model of the urban atmosphere is implemented based on the Reynolds-averaged Navier-Stokes equations for incompressible flows with variable density. The system of equations for averaged meteorological quantities includes the equations of continuity, motion, and energy conservation, which are written in terms of potential temperature. To correctly calculate the surface temperature, a model of conjugate heat transfer is implemented, which includes a one-dimensional equation of thermal conductivity for the ground and the walls of buildings. The k-ω SST model is used to close the equations describing the turbulent flow regime. The discretization of the conservation equation is performed using the control volume method [10]. Due to the small particle size and low concentrations, as well as the lack of interaction between them and the weak influence on the gas flow, a diffusion-inertial model of the motion of low-inertia particles is implemented [11]. The radiation transfer model is considered as consisting of short-wave solar radiation and long-wave atmosphere and terrestrial radiation, treated independently in the calculation [3]. The non-commercial universal SigmaFlow CFD software package is employed for simulations [6, 12].

3.2. Problem statement

The geometry of the simulated neighborhood is shown in Fig. 4. The winter season was considered. The incoming airflow velocity at an altitude of 10 m was 2 m/s, and the potential temperature near the ground surface was 253 K. These values remained unchanged for two days. The monitoring point was situated at the location of the AOP at a height of 3 m, the incoming flow velocity (directed along the x-axis) at this height was about \( V_x = 1 \) m/s.
3.3. Analysis of the obtained numerical simulation results

During the analysis, it was revealed that the buildings had the greatest influence on the magnitude and direction of the airflow velocity. In the daytime, the airflow velocity in the monitoring points had a lateral direction and was equal to $V_y = -0.8$ m/s, in contrast to the incoming airflow velocity, which within the same time interval, was equal to $V_x = 0.1$ m/s. In the late afternoon, the flow pattern was changing, and the $V_y$ component was decreasing. Next, the airflow changes were observed before sunrise and were reaching a value $V_y = 0.2$ m/s. The $V_x$ component also changed its direction and was equal to $V_x = -0.2$ m/s. Based on this, one can conclude that during the period of monitoring, neither local velocity direction nor its magnitude coincided with the incoming flow velocity (Fig. 5). On the other hand, in the present case, the effect on temperature was minimal (less than 1.5 K) which was likely due to the lack of correlation between the internal heat transfer and constant temperature of the incoming flow (Fig. 6).

Figure 4. The geometry of the area under consideration with the main structural elements.

Figure 5. Daily velocity variations at the monitoring point.
Assuming that in the territory under consideration there is a source of pollutant emissions in the form of road transport (Fig. 1), certain difficulties arise when identifying its impact on the overall AOP readings since it is necessary to know the initial level of pollution, that is, to set a certain level of pollution in the incoming flow, as well as determine the local source power. The concentration readings at the monitoring point of the local source of pollution should also reflect the known trend of daily structural changes in air flows (Fig. 7).

**Conclusions**

Based on the performed study, it has been revealed that certain elements of the urban environment affect its physical parameters, changing them significantly. The complexity of the urban structure determines the formation of local microclimates in certain areas, and each neighborhood of the city has its specific microclimate. Thus, meteorological stations located within the city blocks show the current situation directly at the location of the station. Its particular location, as well as nearby local sources of pollutant emissions strongly influences the values of measured environmental parameters. However, it is extremely difficult to judge how much this data are characteristic even for nearby areas. At that, the appearance of additional sources of anthropogenic pollution may significantly change the measured indicators. This especially concerns pollutants, since additional environmental factors and the characteristics of the emission source make significant changes in overall environmental condition.

**Acknowledgments**

The reported study was funded by RFBR, project number 19-31-90096.
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