Experimental studies of the formation of zones resulted from air flow around a system of model buildings

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Abstract. This paper presents the results of working out the methodology for conducting experimental studies of the flow around the objects modeling the urban environmental conditions. The experiments were conducted in the wind tunnel of the Siberian Federal University. Two objects of different heights imitating buildings were considered the models. Special attention was paid to the study of the flow pattern at the tandem arrangement of model buildings. Visualizing the flow, the low-velocity and high-velocity zones, as well as recirculation areas were identified. At that, these zones had their peculiarities in terms of the direction of flow twisting behind each object. The study allowed revealing that the vortices separating from the edges of the studied objects play a special role in the flow formation.

1. Introduction
The main task of urban planning is not only to provide the population with living space but also to ensure that it meets the requirements of general and environmental safety and is comfortable from the perspective of citizens staying in it.

As it has been repeatedly noted, the contemporary location of buildings in the urban neighborhood units leads to a significant decrease in the aeration regime of the territory \cite{1,2}. Dense development, i.e. the close location of buildings to each other contributes to the formation of many local zones with low wind velocities, which results in decreasing the dispersion of pollutants in the atmosphere, leading to the opposite effect, that is, their accumulation \cite{3}.

Contemporary approaches in architecture and urban planning allow the construction of buildings of various geometric complexity and height. The peculiarity of this choice leads to the fact that high-rise buildings form flow acceleration zones around themselves, which lead not only to the undesirable transfer of pollutants to high altitudes but also are very uncomfortable for people \cite{4}.

There are many studies of the wind flow effects on individual model structures, but most of these studies are of private concernment. Currently, no specialized experimental base is available for conducting physical modeling of the flow around urban planning elements and evaluating them from the standpoint of environmental safety and comfort.

The main problem is that a group of buildings in real conditions interacts with a set of vortex structures that arise as a result of the interaction of the air flow with the underlying surface and buildings, located upstream. Also, the problem of temperature influence on the flow remains unsolved, since when considering high-rise buildings, not only changes in wind velocity and direction are observed, but also
the temperature of the flow itself changes both from outside (the environment) and inside (the building). If studying not only the modes of isothermal flow around buildings but also evaluate the effect of real heat sources, the analysis becomes even more complicated due to the significant mutual influence of aerodynamics and heat transfer.

To understand the current conditions, it is necessary to identify the main patterns of interaction of the flow with the elements of the urban environment. As a rule, a numerical study allows demonstrating clearly the spatial structure of the flow for various configurations of districts and building structures, as well as quickly analyzing their changes. However, the main question concerns the degree of adequacy of the results obtained in numerical simulation, since for their validation it is necessary to have data from field and laboratory experimental measurements, which are extremely poorly presented in research articles.

To solve this problem, this publication presents an initial stage of work that will allow further approaching a comprehensive solution to the problems under consideration.

The purpose of the scientific research was to develop methods and approaches in carrying out experimental work by determining the characteristic zones formed as a result of air flow around two closely located models of buildings that simulate real structures.

2. Problem statement

A physical experiment was conducted to work up experimental techniques and verify the numerical model. The concept of selecting research objects was based on the study [5].

Two geometric models of different heights, externally imitating buildings with a flat roof, were considered as the research objects (Fig. 1):

- cube of 50x50x50 mm (low-rise building);
- parallelepiped of 50x50x100 mm (multi-rise building).

The option of their tandem arrangement was considered. The models were made of optically transparent Plexiglas. The facets located on the observation side of the camera were covered with an opaque film to reduce the glare sources (fig. 2).

![Figure 1. The characteristic dimensions of the objects under study.](image-url)
3. Approaches and methods
The experimental study was carried out in the wind tunnel of the Siberian Federal University, which can be attributed to the class of low-velocity open-type wind tunnels with a closed working part. Structurally, the wind tunnel consists of the following elements: a fan, a diffuser, a working section, and a nozzle. Visualization during the flow around the studied objects was implemented using a continuous diode laser.

A micro-scale model of atmospheric air based on the Reynolds-averaged Navier-Stokes equations for incompressible flows with variable density was used for numerical simulations. The system of basic equations includes the equations of continuity, motion, and energy conservation. To close the equations in the turbulent regime, the $k-\omega$ SST model was used [6]. The simulation was carried out employing a SigmaFlow non-commercial universal software package developed by specialists of the Institute of Thermophysics SB RAS and the Department of Thermophysics of SFU [7]. The proposed numerical model was verified earlier using the data of experimental works of foreign scientists, and showed good consistency of the numerical simulation with the experimental results [8,9].

4. Analysis of the results obtained
The experimental results are presented in the form of flow visualization using talc. The choice of this substance is due to its physical properties, namely, the small size of 20-50 microns and low density of 2.58-2.83 g/cm$^3$ [10]. Talc particles do not cause additional disturbances into the flow and allow demonstrating the flow structure (Fig. 3a,b).
Visual observations of the flow around buildings have shown that complex non-stationary three-dimensional vortex flows and large-sized zones of separated flow with the formation of wave effects are formed around buildings, and especially from the windward side (zones 1,2). A stable recirculation area (zone 3) is formed between a low-rise and a high-rise building, where particles are practically not carried outside. An aerodynamic shadow is formed behind a high-rise building (zone 4), which also leads to the cycling movement (Fig. 3b).

The numerical study allows demonstrating that the qualitative, simulated, and experimental flow patterns have a similar character and reflect the appearance of all peculiar zones as a result of the interaction of the flow with the objects under study (Fig. 4).

**Figure 3.** Visualization of the flow structure when flowing around objects, using talc.
5. Discussion

The results of the work conducted allow demonstrating the formation mechanism of the characteristic zones when objects are streamlined by the wind flow, as well as assessing the degree of influence of both buildings on the change in the flow structure, and the influence of objects on each other. In the context of a dense location of the observed objects, a special role is played by the interaction of vortices separated from the edge of buildings, and the presence of separation and recirculation zones near buildings. At that, changes in the characteristic sizes of the objects under study and the distances between them lead to an increase or a decrease in the formation of a particular zone.

The present work is the first in the cycle of research, conducted in the field of computational modeling of the ecological situation in the urban environment and assessment of pedestrian comfort of citizens in the territories under consideration.

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