Investigation of the airflow conditions at the city residential areas

V D Meshkova¹, A A Dekterev¹,², and S A Filimonov¹,²

¹ Kutateladze Institute of Thermophysics, Siberian Branch, Russian Academy of Sciences, pr. Acad. Lavrentyev 1, Novosibirsk, 630090 Russia
² Siberian Federal University, Svobodny av. 79, Krasnoyarsk, 660041, Russia

Redel-VD@yandex.ru

Abstract. There are the computerised simulation results of the airflow around Krasnoyarsk residential areas (“Tikhiye Zori” and “Beliye Rosi”) and the impact assessment of these estates on particular areas of the city.

1. Introduction
In these days there is understanding that the risk assessment of aerodynamic influence of airflow conditions at the city is important in terms of structural solidity and other aspects that are related to the environment and the comfort of living environment for humans.

It is necessary to consider the airflow influence within the residential construction area to regulate the temperature-humidity conditions because the airflow (or the wind) promotes air-mass transportation, equalizes temperature differences among the particular areas of the city, and has a significant effect on air pollution. According to the analysis of town planning there are cases of low-using opportunities of airflow conditions regulation during architectural-planning decisions and in some cases there is a mismatch of planning and building to environmental conditions that enhance areal conditions of the area [1-2].

The airflow conditions are considered only for development of particular projects, mainly experimental. There is no differentiated approach in town planning, especially when the cities have different airflow conditions. It is explained by the fact that there are no instructions in law regulations that consider and regulate the airflow conditions. In fact there are instructions that consider airflow conditions for choosing residential and industrial areas regarding to the prevailing airflows [3].

Changing the airflow conditions that is caused by urban development is a complex event because it is influenced by hydrodynamics and heat-exchanging laws. In general, urban development influences the airflow velocity by increasing number of windless days in the city and reducing the maximum wind speed to 10-30% on average as compared with undeveloped suburban areas. The decreasing of wind speed for more than 70% [4] reduces the level of diffusion and relocation of pollution within the areas of high-developed areas and enclosed and semi-enclosed spaces (or precincts) forming a stagnant air zone also known as "dead air zone". At the same time, the airflow that flows up and around the building accelerates, compensating its cross-section area that causes human malaise.

The traditional evaluation method of airflow conditions near the constructions of different forms is a wind-tunnel experiment. An alternative method is a computerized simulation of airflows. Compared with the wind-tunnel experiment, the computerized simulation has more advantages: it is cheaper and
faster; it gives us more detailed information about air-pressure distribution over and velocity field around the buildings; it gives us different form varieties of designing buildings for comparative analysis of airflow conditions.

There are the computerized simulation results of the airflow around Krasnoyarsk residential areas ("Tikhiye Zori" and "Beliye Rosi") and the impact assessment of these estates on particular areas of the city.

2. Computerized simulation of aerodynamic influence

The computerized simulation of incompressible liquid (or ideal liquid) under the turbulent flow condition describes the airflows circulation around buildings and constructions. This simulation is represented by the Reynolds-averaged Navier-Stokes equations (or RANS equations):

\[ \nabla \cdot (\rho \mathbf{v}) = 0, \]

\[ \rho (\mathbf{v} \cdot \nabla) \mathbf{v} = -\nabla p + \nabla (\hat{\tau}^m + \hat{\tau}^T) + \mathbf{F}, \]

\( p \) is pressure, \( \mathbf{v} \) is velocity vector, \( \mathbf{F} \) is body force vector, \( \hat{\tau}^m \) is viscous stress tensor and \( \hat{\tau}^T \) is Reynolds turbulent stress tensor:

\[ \tau_{ij}^m = \mu \left( \frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i} \right), \]

\[ \tau_{ij}^T = \mu_t \left( \frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i} \right) - \frac{2}{3} \delta_{ij} \rho k, \]

\( v_i \) is velocity vector components, \( \mu, \mu_t \) are liquid viscosity and turbulent liquid viscosity, \( k \) is specific kinetic energy of turbulent fluctuations. The \( k-\omega \) SST model [5] is used for the closing the equations under the turbulent flow conditions. The discretization of the conservation equation on the computational domain is performed by the final volume approach [6]. The above mathematical model was verified using a natural experiment [7].

2.1. Solution of the equations and software package

The final volume approach is used for solution of equations that describe-air behavior. This method is implemented for the solution based on arbitrary unstructured computational grids. The Simple-C splitting procedure is used to align the velocity field and the pressure. The second-order accuracy schemes are used for the approximation of unsteady and spatial derivatives.

The SigmaFlow software package is noncommercial universal CFD software package that has been developing for more than 15 years in cooperation with the Kutateladze Institute of Thermophysics and the Siberian Federal University, Thermophysics Department and is used for the computerized simulation [8]. The SigmaFlow can simulate a wide variety of tasks and includes the computational grid formation module, self-computing module, and representation of simulation results module. Thus, the software package can make parallel computing by modern multicore processors and cluster systems.

3. Task

This is the simulation of unsteady aerodynamic flow of two residential areas "Tikhiye Zori" and "Beliye Rosi" of Krasnoyarsk city (figure 1). It provides standard conditions of the environment properties (20 °C): density of 1.205 kg/m³, dynamical viscosity of 1.5•10⁻⁵ Pa•s, time step of 1 s. The airflow is regarded under the aspect of isothermal approximation, the air is unicomponent.
3.1. Geometrical arrangement and computational grid

The computational area is represented by the parallelepiped whose X-axis is directed along the airflow direction or Y-axis, and in the vertical direction or Z-axis (figure 2).

The computational area is divided into a grid by the Octree method [9]. This method can describe a complex geometry by the hexagonal cells. Further, we can use the approximation of equations and maintain the high order accuracy. The typical size of the cells varies from 1 m near the buildings to 30 m at a distance. The size of the computational grids varies from 3.5 to 4.5 million grids, depending on the task model.

Figure 1. The computational areas.

Figure 2. The computational grid near the buildings.
4. Results

According to the wind rose of Krasnoyarsk the dominant airflow direction is south-west; the average annual wind speed is 2.5 m/s. The velocity profile of the incoming airflow at the border of the computational area is given by the power law according to urban development (figure 3) [10-11].

![Figure 3. The buildings arrangement and the initial airflow velocity profile.](image)

There are specific airflow lines represented in figure 4. According to the result analysis of the "Tikhiye Zori" residential area we can see that in general the starting markers flow around along the border of the computational area at the height of 2 m; the stagnant air zones are formed behind the first line of buildings which forms almost a single flow-permeable barrier. The large-scale spatial vortex structures are formed in these areas. The construction of the "Beliye Rosi" residential area with the described direction represents itself as a freely permeable medium.

![Figure 4. The airflow lines (South-West direction, 2.5 m/s).](image)

Considering the velocity modulus at Y-axis at the heights of 2 m and 30 m we can see that behind the buildings of the "Tikhiye Zori" residential area the stagnant air zones begin to form with the velocities less than 2 m/s; the airflow velocity rises up to 5 m/s between the buildings. The same situation of rising of the airflow velocity up to 5 m/s is observed in the centre of the "Beliye Rosi" residential area construction; the low-speed airflows stagnant air zones are formed along every building of the residential area.
5. Conclusion

Based on the computerized simulation we can make a conclusion that negative changings caused by the building elements depend on the airflow direction and the airflow velocity. The fact is that within the residential areas with the airflow velocity of 2.5 m/s at the height of 2 m (maximum human height) there is no impact on human malaise, which is 5 - 7 m/s.

Using the airflow conditions simulation of residential areas at the designing stage, practically we can foresee negative conditions and propose measures to neutralize or reduce negative effects. According to the results of the simulation there are different ways to design public gardens, playgrounds, outdoor concessions stands, parking spaces, etc. We can reduce the "dead zones" at the ground level using green planting areas.

Air-mass transport alone is not enough to model the impact of urban development on the environment. We have plans to develop the computerized simulation in the future, adding non-isothermal problem accounting (including natural convection) and pollutions and dispersed matters transportation.

The research is a part of the cycle about the local airflow system formation specifics in the city [7].

Acknowledgments

The reported study was funded by RFBR and the government of Krasnoyarsk region according to the research project No.18-41-242006. This work was carried out under the state contract with IT SB RAS.

References

[1] Menter F R A Scale-Adaptive Simulation Model using Two-Equation Models / AIAA Paper, AIAA/ - 2005/ - p 1093-1095

Figure 5. The velocity (m/s) field at Y-axis on the height of 2 m and 30 m.
[2] Franke J Hellsten F Schlunzen H Best practice guideline for the CFD simulation of flows in the urban environment, quality assurance and improvement of microscale meteorological models. – 2007
[3] Code of Regulations SP 20.13330.2016 2016 Updated version of SNiP 2.01.07-85 Loads and effects (Moscow: OJSC TsPP) p 85
[4] Information material Guidelines for assessing and regulating wind housing development/ TsNIIP urban planning Gosgrazhdanstroya. - M.: Stroiizdat, 1986
[5] Menter F R Zonal two equation k-ω turbulence models for aerodynamic flows // AIAA Paper. 1993. No. №93-2906. P. 21
[6] Patankar C Numerical methods for solving problems of heat transfer and fluid dynamics. - M.: Energoatomizdat, 1984
[7] V.D. Meshkova, S.A. Filimonov, A.V. Shebelev Computational modeling of architectural and construction aerodynamics problems // IOP Conf. Series: Materials Science and Engineering. 2018, V. 456. (doi:10.1088/1757-899X/456/1/012079)
[8] Khrebtov M Yu Khrebtov, A A Gavrilov, A A Dekterev, E S Tepfer Development of the Mathematical Model of the Dynamics of the Atmosphere and the Distribution of Harmful Emissions Over the city of Krasnoyarsk. Journal of Siberian Federal University. Engineering & Technologies/, 2017, 10 (8), 1000-1006
[9] Lezhenin A A, Raputa V F, Yaroslavtseva T V Numerical analysis of atmospheric circulation and processes of distribution of contaminants in the vicinity of the Norilsk industrial region // Optics of the atmosphere and the ocean. 2016. T.29. №6. Pp. 467-471
[10] Karl J. Nilsson Estimation of wind energy production in relation to orographic complexity // Master of Science Thesis. – 2010. – 83 p.
[11] A. G. Davenport The application of statistical concepts to the wind loading of structures // Proceedings, Institution of Civil Engineers, London, England, 1961. –Vol. 19. – Pp. 449-472