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Studies and evaluation of bioclimatic comfort of residential areas for improving the quality of environment

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Abstract

The topical issues of computational and experimental studies of wind effects of residential complexes in Moscow are reviewed on the examples of project building objects for verification of design solutions. The continued development of scientific school of architecture and construction aerodynamics is presented as well as its research on the aeration, urban air quality and pedestrian comfort. The results of these researches are various comfort criteria actually used in most affluent countries as a guide in the design of apartment houses. As a research method, physical modeling in a wind tunnel and numerical modeling in specialized software complexes are considered. Studies were conducted on the basis of Educational-Scientific-Production Laboratory for Aerodynamic and Aeroacoustic Test Building Constructions (ESPLab AATBC) using the Large Research Gradient Aerodynamic Tunnel. The results of a comprehensive computational and experimental study of the effect of wind on urban areas are used to develop design solutions (landscaping and urban greening and others) for integrated land improvement to compensate for bioclimatic discomfort.

Keywords

bioclimatic comfort,
wind tunnel,
numerical modelling,
physical modelling,
residential areas,
landscaping,
urban greening

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1 Introduction

Efforts to improve the efficiency of the use of urban areas entail the development of multi-store complexes, increasing the number of floors and housing density. The main purpose of this research was to determine the parameters and the assessment of the bioclimatic comfort considering the season of the residential area. The designing of gardening and the placing of small architectural forms was also the purpose for a compensation of the discomfort and the improvement of the quality of the environment. When investigation design solutions employed for build projects for housing and site designs of micro-districts and blocks, in supplement to aspects related to insolation and noise protection, it is needful to take into consideration the direction, distribution and velocity of airflows in the area of development, which therefore is immediate related to the bioclimatic comfort for pedestrians. The atmospheric conditions and the wind are the main factors for the overall quality of the environment. The wind perception largely depended on the extreme values of wind speed and wind variability. The research of the urban aeration allows us to take into consideration the aforementioned influences when scope out the locality of urban greening and hard landscaping (Oliveira and Andrade 2007).

Using of techniques with due regard to wind effects involves determination of wind velocity experimentally in specialized wind tunnels, for example, in the study of a residential complex with infrastructure facilities at: 141, Varshavskoye Highway, Uzhnoe Chertanovo, Moscow, in a wind tunnel and with the help of numerical modeling of wind flows. The research based on the testing method of the model in the Large gradient wind tunnel (Fig. 1) as well as on verified numerical modeling of wind fields at a height of 2 meters from the surface of the territory.

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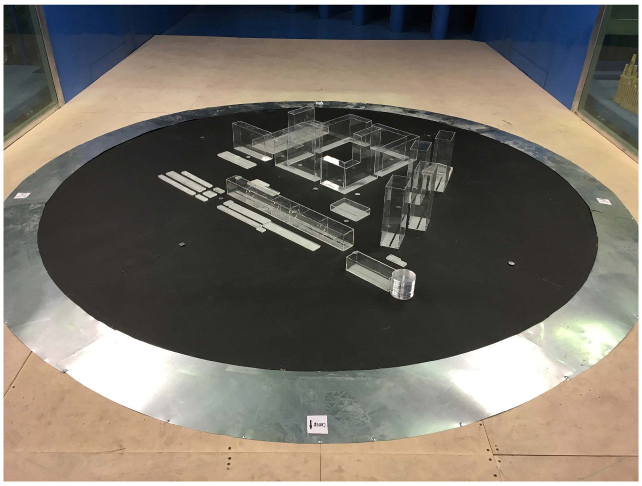

Fig. 1 Model of the high-rise residential complex (141, Varshavskoye Highway, Uzhnoe Chertanovo, Moscow) on an automated rotary table in the working area of the wind tunnel of the Educational, Scientific and Industrial Laboratory for Aerodynamic and Aeroacoustic Tests of Building Structures

Methods of microclimatic conditions forecasting for urban environment and evaluation of aeration of the territory and aerodynamics of the development had been verified. To analyze the nature of the flow-around of the object, an experiment was performed with a gradient flow, characteristic of the surface layer of the climate in the conditions of Moscow (Dunichkin et al. 2013).

The world practice of conducting such studies shows that despite short duration and comparatively lower cost of numerical simulation in specialized and certified software packages (ANSYS CFX and ANSYS FLUENT), it is necessary to perform experimental simulation in a wind tunnel to verify the software package, which is associated with a great variety of variants of the numerical solution of the set task (various models of turbulence, variants of constructing an analysis grid, etc.). For the decades, the atmospheric boundary layer wind tunnel has been the standard tool to determine the design-related contribution in PLW studies. In the past 15 years, CFD has entered the scene. In the past decade, several researchers have adequately highlighted possibilities and limitations of CFD in general (Blocken et al. 2016). The optimal and most reliable method of research is numerical-experimental simulation. Verification is also needful because there are no codes of wind regime and bioclimatic comforts. The current Russian and international building codes did not contain recommendations of the appointment of the aerodynamic coefficients required to determine design wind loads on structures for the tall buildings with complex shape (Poddaeva et al. 2014).

Climatic analysis based on the statistics of weather stations on the frequency and direction of winds calms, taking into account warm and cold seasons, provides the initial data of numerical-experimental studies, the results of which are aggregate wind velocity fields for cold and warm seasons.

The determining a suitable bioclimatic comfort area deals first with as evaluating bioclimatic comfort conditions such as temperature, relative humidity, and wind conditions. In addition to these basic factors, radiation, the number of hot days, the rainfall situation, emerging pests and diseases due to air pollution events, and the amount of oxygen in the atmosphere also affect human comfort (Cetin et al. 2018). All of these effects should be determined considering several bioclimatic comfort conditions. Therefore, in this study, the evaluation of bioclimatic comfort by seasons is based on the method of solving of a heat-balance equation and the method of maximum permissible level of wind pressure on human vision system and the method of maximum permissible concentrations of repugnant substances and biologically dangerous microorganisms during the calm.

Conducting of the research at the design stage helps to significantly improve the comfort of a person's stay on the territory of the object that is especially important for densely developed areas, as well as for areas with high-rise buildings. Areas that are poorly ventilated appear to be associated with lower building-height variation (Antoniou et al. 2017). Therefore, an increase in the variability of building height in a given neighborhood or urban area can improve the breathability in complex urban areas.

2 Criterion for estimation bioclimatic comfort

In the scales of a district or city, changes in microclimatic conditions are expressed primarily in the formation of the "urban heat island, UHI" and the decrease in wind velocity to a certain height, depending on the height of buildings and structures (Weng 2003). High-density residential districts will lead to the deterioration of residential wind environment, thereby resulting in wind currents, wind shadow areas, poor ventilation, and other adverse weather phenomena, which considerably affect the thermal comfort of people and even cause pedestrian safety problems (Hu et al. 2018). The descriptions of the most significant micro-climatic consequences are the following:

- formation of zones of steady decrease in wind velocity (zones of air blanketing);
- formation of wind velocity amplification zones for certain directions along the housing boundary;
- changes in the conditions of insolation of the territory;
- the formation of zones of thermal discomfort (excessive heat in summer and excessive cold in winter (Myagkov et al. 2007).

Conditions for the dispersion of repugnant substances are getting worse in the areas of air blanketing, that can lead to the increment in their concentrations by several times in comparison with the open areas. Summing up of background gas contamination in a city with incremented concentrations of dust content in zones of air blanketing leads to a negative impact on human health and urban landscape. The scenario of repugnant substances transport in the zones of air blanketing is connected with deposition of dust particles of repugnant substances into the soil, which easily rise to the air-ground interface in dry weather (up to 10 m from the active surface) at wind velocity more than 0.7 m/s. At the same time, the energy of the gust of the airflow is not enough to considerably shift the formed cloud of dust suspension by more than 10 meters, which leads to a repeated settling of dust particles in the zones of air blanketing. These processes can be verified by the chemical pollution of urban soil, which coincide with the zones of air blanketing in ranges. Thus, it is advisable to consider and analyze the symptoms of people's urban diseases with influence on the chemical composition of landscape elements (urban greening and soils), while comparing the location of zones of air blanketing. The content of suspended particulate components of pollution remained more stable, due to the features of atmospheric circulation, rugged terrain and residential development (Veremchuk et al. 2016). According to the research of urban environment, the probability of occurrence of asthmatic diseases increments when a person is in the zones of air blanketing, with the velocity of air mass movement below 0.5 m/s. In the zones of increasing wind velocity, pulsations of air currents occur and the wind velocity can reach 10 m/s and more, even at average climate velocities of the background wind. This wind velocity is dangerous for pedestrians and causes deflation from the surface of the ground cover, causing an increment in dustiness of the air in the surface layer. It is especially dangerous when zones of air blanketing and zones of wind velocity increment are formed at a close distance from each other.

A correct estimation of the bioclimatic comfort of a pedestrian is possible only in accordance with the season microclimate. The greatest influence on the comfort of people, as well as the density and velocity of human flows has always been a change in the velocity of the movement of air masses, so the wind regime is always regarded as the main factor in changing the bioclimatic comfort of pedestrians. Temperature accounting allows defining criteria for a more detailed evaluation of people's comfort in the street. The used indices for assessment of comfort were the following: (a) "Comfa", which was based on estimating the energy budget of a person in an outdoor environment and (b) "thermal sensation", based on the satisfaction or dissatisfaction sensation under the prevailing climatic conditions of the outdoor spaces (Gaitani et al. 2007). Thus, on the basis of these and other studies on the heat balance of human body, for the climatic conditions of the middle lane of Russia, the range of winter breezes is 0.5 m/s to 3.0 m/s, and during the summer period is from 1.0 m/s to 5.0 m/s.

Based on the experimental results obtained in the wind tunnel and verified numerical simulation, it is possible to draw conclusions for a background wind velocity of 2.2 m/s on the presence of zones with low wind velocities (Zones of air blanketing) in which repugnant substances and chemically active dust can accumulate (Fig. 2(a)). The bioclimatic comfort mapping methods were useful to urban managers and planners (Cetin 2015). The compilation of seasonal schemes of Bioclimatic comfort mapping methods with the imposition on the master plan has made it possible to move from research to design practice and justify the design solutions for the territory of the projected construction (Fig. 2(b)).

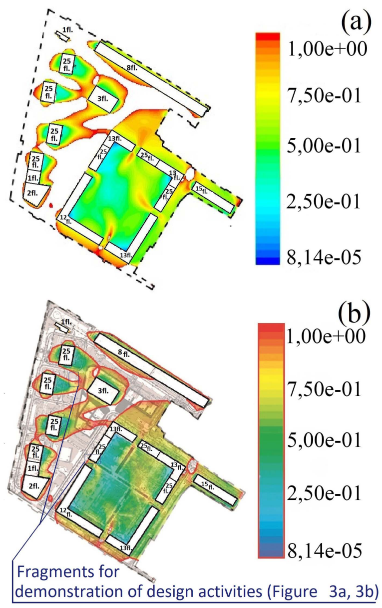

Fig. 2 Zones of air blanketing. (a) Aggregate cartogram for summer (the zone marked with color has a velocity of less than 1 m / s with the most repeated wind directions); (b) scheme for the location of blanketing air zones (highlighted in color) with respect to facilities for the development of design measures for ventilation and protection against overheating

3 Analysis of the evaluation

Basing on the evaluation findings of aerodynamic comfort of housing areas, there can be drawn conclusions about the quality of the proposed master plan design decision. Namely, it was found that on the territory of the domain 141 on the Varshavskoye Highway in Moscow the maximum zone of air blanketing arises when the wind blows from East and West. The territory of the courtyard within the entire perimeter will be poorly ventilated in summer and requires appropriate measures for urban greening and placing hard landscaping. Under calm background conditions, thermal convection will be induced around the planned buildings. The wind velocity in the adjacent area will be about 0.45 m/s. This velocity is insufficient to ensure the bioclimatic comfort of the territory at the values of the main meteorological elements appropriate to the initial climate data. The parameters of the bioclimatic comfort will correspond almost everywhere to the environment excess temperature. Only in the proximate vicinity of buildings walls, where the supply of solar radiation is limited, comfortable parameters will be provided. Especially strong overheating will be observed in the open areas of the courtyard. With the increase in the height of the estimated space from 2 meters to 6 meters above the ground surface, the wind velocity rises approximately twice, which satisfies the conditions for airing and dispersing repugnant substances in the atmosphere relatively the windows of a residential building.

In January at the average north wind velocity 3.2 m/s and the average air temperature of the heating period (−15 °C) in the courtyard, there is practically no chance for frostbite on open skin area. Time restriction of static stay of an adult person in the adjoining area for up to 30 minutes at the average monthly wind velocity occurs only if the air temperature drops to 18 °C below zero or lower. In winter due to the seasonal insolation decrease for astronomical reasons and denser clouds, the temperature contrast between the different areas of housing, which is needful for thermal convection, is getting lower. In addition, in winter, the quantity of calm situations with unstable stratification of the atmosphere decreases. The winds of medium strength are observed more often, and in the case of lack thereof, as a rule, we can see an inversion state of the atmosphere, suppressing vertical convection. The described winter processes make it possible to reduce significantly the local concentration of repugnant substances in the air and at this require wind protection for the entrance groups and resting places.

4 Development of design solutions

Special attention is paid to the structure of the system of urban greening of built-up areas while forecasting changes in the aerodynamic and micro-climatic conditions. On the one hand, existing greenery without special measures for their adaptation to new microclimate conditions can die, as a result, of physiological stress or changed aerodynamic influences. On the other hand, it is possible to form a steadily functioning system of urban greening, which will create comfortable and safe conditions for the population to stay in the urban territory, only taking into account the forecast of microclimatic conditions. In the recommendations below, the results of the study of windproof properties of urban greening on the basis of field studies and experiments on models were used. In the case of module size of 10 m, and intermodular spaces of 5 m, the wind velocity index was 71.8% of the background value (Nazarova 2016). Dimensions of modular green linear groups are suitable for urban areas, and the resulting patterns have been partially confirmed by experiments on building models with greening and hard landscaping. Selection of the range of trees and shrubs was performed on the basis of crown openness data from the agricultural afforestation standard.

For the draft master plan it is recommended to provide measures for wind protection and urban greening of the planned residential complex in the following way:

A) The area of the grounds near the entrance groups and people's short-stay areas is recommended to protect from the wind along the perimeter with single-row plantings of coniferous trees or ordinary plantings of deciduous trees (with frequency 8–12 m), linked with single-row plantings of coniferous shrubs with thick dense crown (with frequency 1–3 meters) or dense single-row plantings of deciduous shrubs (with frequency 0.5–2 m)—when taking these recommendations into consideration the wind velocity decrease near the entrance of the building will be within 10%–17% (Fig. 3(a)).

B) The territory of the land improvement areas and people's long-term stay (more than 10 minutes) are recommended to be landscaped in two ways, based on the results of zoning of zones of air blanketing and discomfort zones. (Fig. 3(b)).

B.I) For benches in resting places and at children's playgrounds in areas of discomfort, it is needful to plant around the perimeter, at least, one row of shrubberies (shrubby bushes—with spacing 0.5–2 m), while the second row is planting trees (horse chestnut, rowanberry, bird cherry—with spacing 5–8 m) (Fig. 3(b)). The wind speed is reduced by 14%–21%.

B.II) For benches in resting places and at children's playgrounds in zones of air blanketing, it is needful to make dense groups of trees at a distance of 3 meters (horse chestnut, rowanberry, bird cherry—clear stem with frequency 3–5 m) to organize a shadow and ensure micro ventilation at the expense of the effect of temperature convection (Fig. 3(b)). The speed of air circulation during the calm is incremented by 10%–20% (minimum 0.65 m/s).

Also for the draft master plan, it is recommended to provide for the installation of landscaping areas for more than 70 square meters of hard landscaping, made of windproof structures with a spatial grating serving as a diffuser for damping gusts of wind. The recommended design parameters have the arrangement of columns and rails in the form of a spatial grating serving as a diffuser for damping gusts

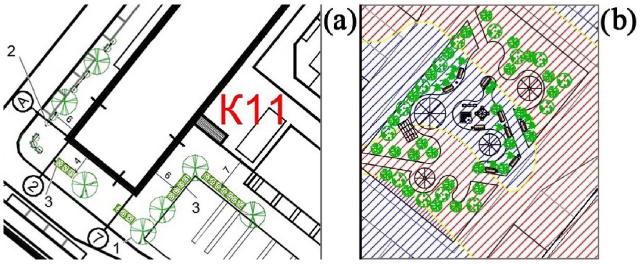

Fig. 3 Recommendations for land improvements and urban greening of a fragment of the territory. (a) Entrance group to the building; (b) resting places, playgrounds outside a closed calm courtyard (Zones of air blanketing are shown in red hatching, Discomfort zones are shown in blue hatching)

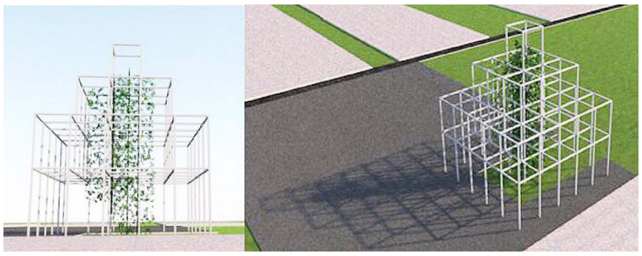

Fig. 4 Examples of windproof structures with a spatial grating—a diffuser for damping gusts of wind. It is possible to apply vertical urban greening of the structure

of wind. The distance from the edge of the area of land improvements is at least 2–3 meters. The overall dimensions of the diffuser are not less than—2 m × 2 m, $h \geq 3$ m. The cell size of the spatial grating is 0.2–0.4 m (Fig. 4).

The proposed sample of hard landscaping (Fig. 4) can be used as an object of the parametric architecture and 3d-Espaliers for climbing plants. In this case, the construction not only protects against gusts of wind, but also reduces its speed in the vicinity of 6 meters by 7%–10%. The windproof structures can have addition of moving kinetic architecture designs. The focus was on components that constantly varied their configurations to adjust to weather variations and fluctuations of spatial programs (Naboni 2007). The parameterization process defined the dynamic movements of the components. This proves the relationship between parametric design and kinetic architecture. Layout 3d-Espalier helped obtain more accurate geometric characteristics and to clarify the percentage reduction in the average wind speed and wind gust speed for the repeated numerical simulation taking into account the recommendations of the design actions (Fig. 5).

5 Conclusion

The solution of the current problem of discomfort due to high wind velocity as well as environmental problems of excess temperatures and zones of air blanketing with increasing concentrations of repugnant substances is presented on a real example of Moscow in the research of the bioclimatic comfort of residential housing. Analysis of the results of the evaluation of bioclimatic comfort, considering to the temperature regime of the season allowed developing design solutions for the placement of hard landscaping and urban greening. The presented methodology and project approach give opportunity to ensure the creation of the living environment that is functionally organized and well-maintained in accordance with the requests of various socio-demographic groups and favorable for sanitary and hygienic conditions for real natural and climatic conditions with severe winters and cases of urbancalm in summer. The placement of windproof structures, modular green linear groups and individual trees in accordance with the town planning codes of the Russian Federation in places recommended by the evaluation of bioclimatic comfort compensates wind discomfort by, at least, on the average 15% at the wind velocity and the effect of summer excess temperatures and local accumulation of repugnant substances in the atmosphere at the ground surface in the courtyard space.

The above approach to the evaluation of bioclimatic comfort successively takes into account the influence of factors, wind, temperature, harmful substances and biological pollution and can be applied in other regions and types of urban area for the design of a special landscaping for the winter. The object of study is planned to be kept under observation for statistics in natural conditions, analysis of the influence of air humidity and perfection of the methodology. This result will be used in the subsequent creation of a dynamic computer model of bioclimatic comfort of urban area taking into account the seasons and the growth of trees and bushes for a few years.

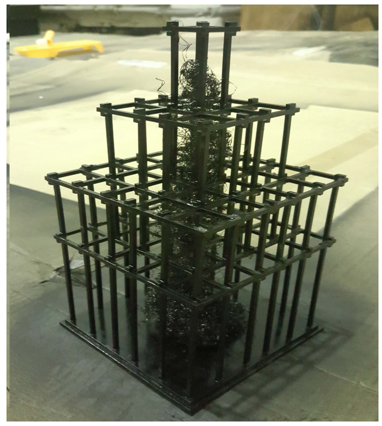

Fig. 5 Layout 3d-Espalier

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