Consideration of Wind Speed Changes in the Design of Ventilation Systems for High-rise Buildings

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Abstract. The average percentage of high-rise residential buildings in Russia is approximately 5% from the general volume of house construction. However, the demand for this type of buildings begins to increase. This factor relates to establishment of coherent multifunctional living environment with complex infrastructure. All of this facts cause the problem of high-rise building construction, including the design of engineering systems. Building air mode is influenced by external pressures applied to the centers of air-permeable openings, including wind pressure. Wind speed increases in the height of the building, but this change is often neglected in multi-storey houses, of course it is necessary to take this phenomenon into account designing high-rise buildings. The article presents various methods of accounting wind speed change in height, which were calculated for different cities in Russia. According to the of wind speed results obtained, the specific rate of infiltration air has been calculated, which significantly exceed the values in the case of a constant speed.

1. Introduction

One of the current trends of modern building development in Russia is renovation of housing stock and improvement of environment quality. The most common concept is construction of multistory and high-rise buildings to ensure new lifestyle and establish coherent multifunctional living environment with complex infrastructure. Such direction of residential buildings construction is taking place in many developed countries [1, 2].

HVAC systems energy consumption in high-rise buildings is representing about 33% of the entire premises [3]. One of the main strategy of enhance the sustainability of high-rise buildings is the implementation of natural ventilation systems, which can be used to reduce heat gains in a hot period of a year, for example, night cooling [4, 5]. The term “re-introduction” of natural ventilation systems frequently can be found in modern scientific literature. This notion is used deliberately to emphasize antiquity of such techniques on the one way, and the new concepts of using natural ventilation systems on another way.

Designing of natural ventilation systems in high-rise buildings in cold period of a year is a complex target: engineer has to find the best solution that can provide required air exchange and comfortable microclimate in occupant zone with minimal energy consumption. Multidisciplinary approach remains the key to the success of effective building services.
Building air mode is influenced by the boundary conditions: pressures applied to the centers of air-permeable openings and the top of ventilation shaft [6, 7]. External pressures include gravity and wind components. The change of wind speed along the height of the building is often neglected, which may be due to insignificant influence of wind pressure on the building air mode compared to the gravitational pressure [8]. Moreover, this change is imperceptible in low-rise construction.

The choice of outdoor climatic parameters in designing of high-rise buildings has its own characteristics, which is associated with a linear change of air temperature and atmospheric pressure in height. Special attention is paid to the reasonable choice of estimated wind speed, which depends on the climatic features and topography of built-up area. There are various methods of calculating the wind speed along the height of the building: power, logarithmic dependencies and engineering calculation, which is based on the use of speed change coefficients. In order to select the most appropriate one, it was decided to perform the calculation of infiltrating air volume for a high-rise residential building along the one vertical glazing.

2. Calculation methods

According to the results of numerical studies of wind speed vertical profiles, interpolation formulas of the following form were obtained:

1. Method 1. In several research studies [9, 10] are shown that wind profiles in atmospheric layer are accurately described by formula:

\[
\frac{v_z}{v_h} = \left( \frac{z}{h} \right)^m
\]  

(1)

2. Method 2. In logarithm formula parameter \( z_0 \) (roughness parameter) has a clear physical meaning of magnitude altitude at which the average speed is influenced by the roughness surface becomes zero. Therefore, the use of parameter \( z_0 \) may be preferable because it allows you to bind the change in average wind speed in height with the structure of underlying surface [11]:

\[
\frac{v_z}{v_h} = \frac{\ln z - \ln z_0}{\ln h - \ln z_0}
\]  

(2)

\( \frac{v_z}{v_h} \) – average wind speed at the altitude considered \( z \), m/s;

\( v_h \) – average wind speed. Measurement of the average wind speed is made at a height of 10 meters from the ground level for open areas, which include: seas coasts, lakes and reservoirs, rural areas, including buildings with a height less than 10 m and etc. Average wind speed is always used as initial data, which means an expression of the multi-year regime for the considered period of the year and region of construction. The maximum of the average wind speeds by points for January is used for calculation of infiltration air volume;

\( m \) – power index, which is a complex function of climatic characteristics and terrain.

In the study [12] the dependence between power index \( m \) and roughness parameter \( z_0 \) was obtained:

\[
z_0 = 29,1\cdot m^2 - 6,8\cdot m + 0,4
\]  

(3)

The average annual coefficients, presented in Table 1, were taken like initial data for calculation.

| Table 1. \( z_0 \) and \( m \) height function values |
|------------------|----------|--------|
| City             | \( m \)  | \( z_0 \) |
| Astrakhan        | 0.19     | 0.16   |
| Orenburg         | 0.25     | 0.52   |
3. Method 3. According to SP 253.1325800.2016 “Engineering systems for high-rise buildings”, the estimated wind speed should be determined taking into account the speed change coefficient, $\xi$, according to the height of the building (Table 2).

### Table 2. Speed change coefficient, $\xi$.

| Building height | 2   | 2.5 | 3   | 4   | 5   | 6   | 7   | 8   | 10  |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 10              | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 50              | 2.3 | 1.8 | 1.8 | 1.5 | 1.4 | 1.4 | 1.3 | 1.2 | 1.2 |
| 100             | 2.8 | 2.4 | 2.2 | 1.9 | 1.8 | 1.7 | 1.5 | 1.4 | 1.2 |
| 150             | 3.2 | 2.8 | 2.5 | 2.1 | 2.0 | 1.8 | 1.7 | 1.6 | 1.4 |
| 200             | 3.5 | 3.0 | 2.7 | 2.4 | 2.1 | 2.0 | 1.8 | 1.7 | 1.4 |
| 250             | 3.8 | 3.2 | 2.8 | 2.5 | 2.3 | 2.1 | 1.9 | 1.8 | 1.5 |
| 300             | 3.8 | 3.4 | 3.0 | 2.6 | 2.4 | 2.2 | 2.0 | 1.9 | 1.6 |
| 350             | 4.0 | 3.4 | 3.0 | 2.6 | 2.4 | 2.3 | 2.1 | 2.0 | 1.7 |
| 400             | 4.0 | 3.4 | 3.2 | 2.8 | 2.5 | 2.3 | 2.1 | 2.1 | 1.8 |
| 450             | 4.0 | 3.6 | 3.2 | 2.9 | 2.6 | 2.4 | 2.2 | 2.2 | 1.8 |
| 500 and higher  | 4.0 | 3.6 | 3.2 | 2.9 | 2.6 | 2.5 | 2.3 | 2.2 | 1.9 |

In this case, the formula for determining average speed at the considered height will take the following form:

$$\bar{v}_i = \bar{v}_h \cdot \xi$$

(4)

3. Results and discussions

According to the calculation results, graphs of wind speed changes constructed for different cities of Russia (Figure 1).

Calculation results show that power and logarithmic formulas reveal a high level of convergence for all cities, regardless of terrain conditions and average wind speed. In cases, where roughness parameter $z_o < 0.5$ (Astrakhan, Penza and Saratov – flat terrain) calculation method 3 gives excessive wind speeds, most notably with increasing altitude, which further leads to heat over expenditure during the cold period of the year.
When $0.5 \leq z_0 < 1$ (Orenburg and Ufa – forest steppe), the difference in averaged velocities in height is not more than 10%.

For cases where $z_0$ is greater than 1 (Tambov – undulating terrain with ravines), method 3 gives underestimated wind speeds along the height of the building, which may further affect the overcooling of upper floors during the cold season.

To assess the degree of initial data influence (changes in wind speed over the height), the specific rate of infiltrating air was calculated (Figure 2).

![Figure 1. Wind speed change along the height of a building for various cities of Russia](image1)

![Figure 2. Specific rate of infiltration air change along the height of a building for various cities of Russia](image2)

For undulating terrain with ravines, value of infiltration losses calculated by using wind speed from method 3 is underestimated by almost 40%. For regions with flat terrain, of infiltration losses calculated by using wind speed from method 3 provide a margin up to 25%.
4. Conclusions

Analysing the obtained results, we can conclude that the specific rate of infiltration air is significantly greater in the case of taking into account changes of wind speed in height.

The main disadvantage of method 3 is the lack of consideration for influence of terrain on wind speed. Turbulent mode of air flow is changing under the action of uneven terrain. In complex forms of relief, local air circulation occurs, ascending and descending flows are formed, and wind direction changes in a special way. Calculation methods 2 and 3 show a high convergence of the results.

Considering the entire building as a complex aerodynamic network, where the movement of air occurs under the action of a pressure difference, wind speed change is much more important not on the rate of infiltration air, but on air exchange throughout the building. That required performing calculation of air mode of the building [6, 8, 13, 14], which is planned to be implemented in the next research work.

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