Wind potential at the sustainable design of residential development

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Abstract. Consideration of the climatic factors of the city in the buildings design and urban planning is one of the key points of sustainable design. Use of natural ventilation to ensure indoor air quality significantly improves the energy efficiency of buildings. Analysis of climatic data for the cities of Kazan and Vladivostok with different wind potential revealed the orientation of the buildings for maximum capture of the wind pressure. The results of calculating the available pressure for different orientations of the buildings to the prevailing wind directions showed that the maximum capture of the wind pressure can sometimes lead to a deterioration of natural ventilation of buildings and tipping over traction even in the cold season. One-sided apartments are particularly sensitive to wind environment. Correcting the orientation of the buildings in relation to the prevailing wind directions significantly increases the performance of natural ventilation. Even at the stage of making design decisions, it is necessary to analyze the climate data in order to assess the effectiveness of natural air exchange, so that passive means can increase the efficiency of natural ventilation.

Keywords: sustainable design, wind velocity, residential development, natural ventilation, planning, wind environment.

1 Introduction

The design of both stand-alone buildings and urban development as a whole, taking into account the requirements of sustainable development, is one of the most important tasks today. Sustainable architectural and construction design primarily means creating a comfortable environment using modern, rational, friendly solutions.

Hence the full-fledged correct accounting of the natural and climatic conditions of the construction site, such as relief, sun, wind, planting and water resources is of great importance [1–4]. The design of buildings using the maximum environmental potential allows creating not only a comfortable external urban environment [5–7] but also increases the energy efficiency of buildings [8–10].

At the design stage it is very important to think over the solutions that ensure ecologically friendly internal environment in the building since a person spends more than 70% of his time inside [11]. To maintain a clean air environment the building is provided with ventilation. It has been proven that the use of natural ventilation significantly reduces energy consumption in both low-rise and high-rise buildings [12–15]. Natural air exchange is triggered by the outside temperature (Figure 1a) and wind (Figure 1b) [16,17], that is the reason why these climatic factors have attracted the attention of designers for a long time [18].

Figure 1. Stimulus of natural air exchange: temperature difference (a) and wind (b).
However, in designing buildings, the wind is most often viewed from two perspectives. Either from the cooling the internal space of buildings or from the classical sense in the form of a wind load [9,18]. When designing urban areas, great attention is paid to the wind in terms of aeration of the outer space, as well as protection against dust transfer in the streets or wind [19–20]. That means the question of ensuring comfortable wind speeds at the level of pedestrians, especially around high-rise buildings becomes acute [21–24]. Thus, in designing residential buildings, wind potential as a stimulus of the natural air exchange inside the buildings has not been properly taken into account at the stage of residential building design. Moreover, the quality of air exchange in the rooms depends not only on the constructive device of natural ventilation but also largely based on architectural decisions [11,24], including the orientation of the building relative to the prevailing wind flows [15].

The purpose of this study is to determine the potential of the wind as the stimulus of natural air exchange of the placements so that even in the early stages of the design of residential buildings it was easy to make some architectural decisions that could increase the performance of natural ventilation. Ensuring a decent quality of the indoor environment without additional energy costs with the natural renewable climatic resources as much as possible, is one of the key tasks of sustainable design.

2 Materials and methods

The paper discusses the influence of the wind environment of the construction site on the natural ventilation of the premises using the example of a development of strip-type multi-floor residential buildings which is most typical for multi-unit housing in new areas. Two settlements were selected for the analysis with fundamental differences in the wind regime - the cities of Kazan and Vladivostok. Kazan is located in the central part of the Russian Federation and has a temperate continental climate. Severe frosts and sultry heat are not typical for this region. The coldest month of the year is January with an average monthly temperature of -11.6 °C. The warmest month of the year is July with an average monthly temperature of 19.7 °C. The prevailing wind direction in winter is southern with an average speed of 3.9 meters per second (m/s). In summer north and west winds are prevailing. Vladivostok is a coastal city located in the eastern part of the Russian Federation. The climate is temperate monsoon. The temperature regime is close to Kazan where the coldest month of the year is January with an average monthly temperature of -12.6 °C and the warmest month of the year is August with an average monthly temperature of 19.8 °C (in July 17.7 °C). The prevailing wind direction in winter is northern. Its average speed is 6.2 m/s. In summer southern winds are mostly prevailing.

To assess the climate data in terms of natural ventilation, the pressure created by them \( \Delta P \) was determined. The heat pressure \( \Delta P_t \) as a stimulator of natural air exchange does not depend on the orientation of the buildings to the cardinal points but depends on the difference in the densities of the external \( \rho_{ex} \) and internal \( \rho_{in} \) air and the distance from the center of the air outlet to the mouth of the exhaust shaft \( h \) and can be calculated by the Eq. (1):

\[
\Delta P_t = hg(\rho_{ex} - \rho_{in})
\]

where \( \Delta P_t \) is heat pressure \([Pa]\),
\( \rho_{ex} \) – external air density \([kg/m^3]\),
\( \rho_{in} \) – internal air density \([kg/m^3]\),
\( g \) – acceleration of gravity \([m/s^2]\),
\( h \) – distance from the center of the air outlet to the mouth of the exhaust shaft \([m]\).

Wind pressure \( \Delta P_w \) largely depends on the space-planning decisions of buildings. The orientation of the building relative to the direction of the wind, its geometric dimensions and the environment are important here. The magnitude of the wind pressure can be calculated by the Eq. (2):

\[
\Delta P_w = k \frac{\rho_{ex}v^2}{2}
\]

where \( \Delta P_w \) – wind pressure \([Pa]\),
\( \rho_{ex} \) – external air density \([kg/m^3]\),
\( v \) – wind velocity \([m/s]\),
$k$ – coefficient taking into account the aerodynamic characteristics of the building and development [16].

The wind pressure is a vector value, therefore, depending on the orientation of the building it can be either positive – from the windward side or negative – from the leeward side (Figure 1). As you know, the wind velocity increases with height [6,16], so the maximum effect of wind on natural ventilation will be felt on the upper floors. In this regard, the work considered the combined effect of heat and wind pressure on the example of the top floor of a 10-storey residential building.

The average monthly outdoor temperatures and monthly average wind velocities were taken as the calculated parameters. The wind direction of the greatest probability was taken as the estimated wind direction.

3 Results and Discussion

The work was carried out in two stages. One-sided apartments, due to the lack of cross ventilation are most sensitive to wind direction and insolation requirements. Therefore, at the first stage the values of the wind pressure were determined for buildings where one-sided apartments maximally captured the wind pressure regarding insolation requirements. After analyzing the data obtained the orientation of the buildings in the development was adjusted.

Calculations of the heat pressure $\Delta P_t$ for the top floor of a 10-storey residential building for the cities of Kazan and Vladivostok are presented in Table 1.

| Months | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|--------|---|----|-----|----|---|----|-----|------|----|---|----|-----|
| Kazan  | $t_{ex}$ [°C] | -11.6 | -10.9 | -4.3 | 5.3 | 13.2 | 17.6 | 19.7 | 17.4 | 11.5 | 4.2 | -3.2 | -8.9 |
|        | $\Delta P_t$ [Pa] | 6.28 | 6.12 | 4.69 | 2.74 | 1.23 | 0.42 | 0.04 | 0.46 | 1.54 | 2.95 | 4.46 | 5.68 |
| Vladivostok | $t_{ex}$ [°C] | -12.6 | -9.1 | -2.1 | 4.8 | 9.7 | 13.4 | 17.7 | 19.8 | 15.8 | 8.8 | -0.9 | -9.5 |
|        | $\Delta P_t$ [Pa] | 6.50 | 6.12 | 4.23 | 2.84 | 1.88 | 1.19 | 0.40 | 0.03 | 0.75 | 2.06 | 3.98 | 5.81 |

Table 2 shows the monthly average wind velocities and the prevailing monthly directions for both cities.

| Months | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|--------|---|----|-----|----|---|----|-----|------|----|---|----|-----|
| Kazan  | $v$ [m/s] | 4.4 | 4.2 | 4.2 | 3.9 | 4.0 | 3.4 | 3.1 | 3.2 | 3.6 | 4.3 | 4.4 | 4.4 |
|        | Direction | S  | S  | S  | S  | S  | NNW | NNW | WNW | SSW | S  | S  | S  |
| Vladivostok | $v$ [m/s] | 6.9 | 6.8 | 6.1 | 6.5 | 6.4 | 5.9 | 5.5 | 5.5 | 5.6 | 6.5 | 6.5 | 6.3 |
|        | Direction | N  | N  | N  | S  | S  | S  | S  | S  | S  | N  | N  | N  |
Figure 2 shows the initial types of buildings for the cities of Kazan and Vladivostok, formed on the basis of the analysis of the wind environment so that the apartments with one-sided orientation maximally capture the wind pressure.

![Diagram of buildings](image)

**Figure 2.** Initial development for Kazan (a) and Vladivostok (b), and plan of the residential building (c).

Table 3 shows the obtained values of the wind pressure for months, taking into account the adjustment of the average monthly wind velocity depending on the direction of the wind flow to the facade, the geometric parameters of the building and the height of the supply opening from the ground level.

| Months | I  | II | III | IV | V  | VI | VII | VIII | IX | X  | XI | XII |
|--------|----|----|-----|----|----|----|-----|------|----|----|----|-----|
| Kazan  | \( \nu \) \[ m/s \] | 2.86 | 2.73 | 2.73 | 2.54 | 2.6 | 2.21 | 2.02 | 2.08 | 2.34 | 2.8 | 2.86 | 2.86 |
|       | \( \rho_{ex} \) \[ kg/m^3 \] | 1.350 | 1.347 | 1.314 | 1.268 | 1.233 | 1.215 | 1.206 | 1.216 | 1.241 | 1.273 | 1.308 | 1.337 |
|       | \( \Delta P_{V} \) \[ Pa \] | 4.42 | 4.02 | 3.92 | 3.27 | 3.33 | -1.78 | -1.48 | -0.9 | 2.72 | 4.17 | 4.28 | 4.37 |
| Vladivostok | \( \nu \) \[ m/s \] | 4.49 | 4.42 | 3.97 | 4.23 | 4.16 | 3.84 | 3.58 | 3.58 | 3.64 | 4.23 | 4.23 | 4.1 |
|        | \( \rho_{ex} \) \[ kg/m^3 \] | 1.356 | 1.338 | 1.303 | 1.271 | 1.249 | 1.233 | 1.214 | 1.206 | 1.222 | 1.253 | 1.297 | 1.34 |
|        | \( \Delta P_{V} \) \[ Pa \] | -8.20 | -7.84 | -6.16 | 9.1 | 8.65 | 7.27 | 6.22 | 6.18 | -4.86 | -6.73 | -6.96 | -6.76 |

The calculation results show that with this orientation of the buildings in the city of Vladivostok, the wind pressure takes negative values for most of the year (Figure 3).

![Graphs of pressure changes](image)

**Figure 3.** Dynamics of changes in heat \( \Delta P_h \), wind \( \Delta P_{V} \) and available \( \Delta P \) pressure by months for the cities of Kazan (a) and Vladivostok (b) with the orientation of buildings at an angle of 90° to the prevailing wind flow.
Table 4 shows the values of the available pressure for the apartments under study in both cities. It can be seen that for the city of Kazan this orientation of buildings increases the final available pressure in the winter due to the capture of the wind pressure. And only in the three summer months, the main winds blow from the opposite facade thereby creating a zone of negative pressures from the side of the tested apartment. Whereas for Vladivostok such orientation of buildings leads to the fact that 7 months of the year the wind pressure becomes negative and thereby leads to the tipping of the draft even in the winter months when the heat pressure reaches its maximum values.

Table 4. The final values of the available pressure by months for the investigated apartment for the cities of Kazan and Vladivostok.

| Months | I  | II | III | IV | V  | VI | VII | VIII | IX | X  | XI | XII |
|--------|----|----|-----|----|----|----|-----|------|----|----|----|-----|
| Kazan  |    |    |     |    |    |    |     |      |    |    |    |     |
| $\Delta p_t$ [Pa] | 6.28 | 6.12 | 4.69 | 2.74 | 1.23 | 0.42 | 0.04 | 0.46 | 1.54 | 2.95 | 4.46 | 5.68 |
| $\Delta p_v$ [Pa] | 4.42 | 4.02 | 3.92 | 3.27 | 3.33 | -1.78 | -1.48 | -0.9 | 2.72 | 4.17 | 4.28 | 4.37 |
| $p$ [Pa] | 10.7 | 10.14 | 8.61 | 6.01 | 4.56 | -1.36 | -1.44 | -0.44 | 4.26 | 7.12 | 8.74 | 10.05 |

Vladivostok

| Months | I  | II | III | IV | V  | VI | VII | VIII | IX | X  | XI | XII |
|--------|----|----|-----|----|----|----|-----|------|----|----|----|-----|
| $\Delta p_t$ [Pa] | 6.50 | 6.12 | 4.23 | 2.84 | 1.88 | 1.19 | 0.40 | 0.03 | 0.75 | 2.06 | 3.98 | 5.81 |
| $\Delta p_v$ [Pa] | -8.20 | -7.84 | -6.16 | 9.1 | 8.65 | 7.27 | 6.22 | 6.18 | -4.86 | -6.73 | -6.96 | -6.76 |
| $p$ [Pa] | -1.7 | -1.72 | -1.93 | 11.94 | 10.53 | 8.46 | 6.62 | 6.21 | -4.11 | -4.67 | -2.98 | -0.95 |

Obviously, this orientation of the buildings is not acceptable, since it will ultimately lead to the fact that even in the cold season natural ventilation will not work effectively. In this case, it is necessary to adjust either planning decisions or change the layout of the building. You can orient buildings in such way to reduce the wind pressure from the leeward side, for example, by turning the buildings not at right angles to the wind flow, thereby smoothing the effect of the wind. Or exclude one-sided apartments from the layout of the building.

Figure 4 shows the possible orientation of buildings in the adjusted development for the city of Vladivostok, to mitigate the effect of wind flows while observing the insolation requirements for one-sided apartments.

Figure 4. Orientation of buildings in adjusted residential development for the city of Vladivostok (a), where the one-sided apartment is located at an angle of 10° (b) and 45° (c) to the prevailing wind flow.
The calculation results for different locations of buildings (Table 5) show that a change in orientation significantly affects the annual course of the available pressure, thereby improving the natural air exchange of rooms with passive means. When a one-sided apartment is oriented at the angle of 10° to the prevailing winds, the available pressure in the winter months is higher than it was at the angle of 90°. But the values of available pressure in the summer months decrease. When buildings are oriented at the angle of 45° to the prevailing winds, the values of the available pressure in the winter months are already lower than at the angle of 10°, but still, there is no tipping of the thrust. Whereas in the warm season the available pressure increases significantly.

The annual course of the available pressure (ΔP) for a different orientation of the building for the city of Vladivostok is shown in Figure 5.

**Table 5.** Values of the wind (ΔPv) and available pressure (ΔP) by months for different orientation of buildings for the city of Vladivostok.

| Months | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|--------|---|----|-----|----|---|----|-----|------|----|---|----|-----|
| ΔPv 10° [Pa] | -1.39 | -1.33 | -1.05 | 1.55 | 1.47 | 1.24 | 1.06 | 1.05 | -0.83 | -1.14 | -1.18 | -1.15 |
| ΔPv 45° [Pa] | -5.82 | -5.57 | -4.37 | 6.73 | 6.40 | 5.38 | 4.61 | 4.58 | -3.45 | -4.78 | -4.94 | -4.8 |
| ΔP 10° [Pa] | 5.11 | 4.79 | 3.18 | 4.39 | 4.39 | 2.43 | 1.46 | 1.08 | -0.08 | 0.92 | 2.8 | 4.66 |
| ΔP 45° [Pa] | 0.68 | 0.55 | -0.14 | 9.57 | 8.28 | 6.57 | 5.01 | 4.61 | -2.7 | -2.72 | -0.96 | 1.01 |

**Figure 5.** Dynamics of changes in available pressure (ΔP) by months for the city of Vladivostok with the orientation of buildings at different angles to the wind flow.

**4 Conclusions**

The results of the study show a significant effect of wind environment on natural indoor air exchange. Analysis of the wind potential of the construction site at the design stage can increase the efficiency of natural ventilation with passive means, hence improve the indoor air quality without additional energy costs. The maximum capture of wind pressure on the facade of the building is not always the best solution, especially for one-sided apartments. The placement of buildings in the development, using the wind potential can significantly increase the value of the available pressure for natural ventilation.

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