Article

Features of Assessment and Formation of the Aeration Regime of Residential Development on the Sloping Lands of the Russian Arctic

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Abstract: The urban development of areas in the Arctic zone of the Russian Federation is a relevant and important task to be tackled by contemporary urban planners. This focus is largely explained by the development of the Northern Sea Route (NSR) and its port cities. Last but not least, to develop these cities means to ensure a comfortable living environment for local residents and visiting specialists. However, given the harsh climate in the Arctic zone of the Russian Federation, this task requires a more elaborate approach. Current building techniques, designed for flatlands with relatively comfortable climates, cannot be applied to this territory without degrading the quality of the living environment. Environmental comfort is influenced by many factors, and one of them is the aeration regime. This study is aimed at researching the aeration regime of built-up areas on the sloping lands of the Arctic zone of the Russian Federation and identifying the features of its formation. The object of this study is a residential development on the sloping lands of the Arctic zone of the Russian Federation. The subject of the study is the external aeration regime at the level of 1.2 m from the ground level of the residential development on the sloping lands of the Arctic zone of the Russian Federation. These parameters were explored, and the aeration regime was assessed using such advanced software packages as QG for the GIS analysis of the area and ANSYS Fluent for the mathematical modeling of the aeration regime. The results of the research are presented in the form of graphs, dependency tables, and petal diagrams visually demonstrating the distribution of discomfortable zones for different morphotypes of development on various slopes most widely spread in the Arctic zone of the Russian Federation. The theoretical research was pilot-tested in the existing residential development area in Murmansk. The results of the study are usable in practice if respective land use documents are drafted for residential areas of settlements in the Arctic zone of the Russian Federation.

Keywords: Russia; arctic region; wind comfortability; aeration; slope terrain; CFD modeling

1. Introduction

Many Russian and foreign researchers studied the development of Arctic areas [1]. The development of cities in the North is rather comprehensively covered in the works of Putintsev [2]. The author believes it is necessary to take into account harsh climatic conditions, such as low temperatures and strong winds, when site design projects are drafted and morphotypes are selected for residential areas in the Arctic zone of the Russian Federation (AZRF). The geomorphological parameters to be taken into account in the course of developing residential areas were analyzed by Krogius and Abbott [3]. The influence of the terrain and its forms on the aeration regime were investigated by such researchers as V.D. Olenkov, G. Schlichting, and others [4–6]. To assess the extent of influence of the slope parameters on the aeration regime, it is important to understand the class of aerodynamic roughness of the terrain. The topography of the entire land surface consists of sub-horizontal surfaces and slopes. Sloping surfaces are the surfaces where gravity plays a major role in moving matter downward. Slopes, hills, and construction facilities have

different dimensions, and this difference influences the local aeration regime [7]. According to the classification, proposed by P.P. Kovalenko and L.N. Orlova, these items can be considered as different types of aerodynamic roughness depending on their height [8].

The relevance of development of Arctic areas is comprehensively covered in the works of D.A. Gainanov, S.A. Kirillova, Yu. A. Kuznetsova, V.G. Alexeev, and others [9,10]. Housing construction problems in the AZRF were considered in the works of K.N. Agafonov, Belyaev, Velli, Dokuchaev, and others [11,12]. Additionally, the relevance of the Arctic zone and its development are highlighted in the regulatory documents of the Russian Federation. Presently, a fairly well-developed regulatory and technical framework ensures the development of AZRF. The main legal act, regulating the development of areas in the Arctic zone of the Russian Federation, is Presidential Decree No. 645 of 26 October 2020 "On the Development Strategy of the Arctic zone of the Russian Federation and national security for the period up to 2035" [13]. One of the main objectives of the Strategy is "formation of the modern urban environment in settlements also by improving public and courtyard spaces, taking into account features of the natural environment and climate of the Arctic and introduction of advanced digital and engineering solutions".

The main problems of housing construction in the Arctic zone are its harsh climatic conditions, geomorphological parameters of its territory, low temperatures, strong winds, etc. The microclimate of Arctic territories and its impact on people are covered in the works of Konstantinov and Varentsov [14]. Ratner also studies the influence of wind and temperature regimes on human comfort in the Arctic settlements [15]. The importance of taking into account harsh natural and climatic conditions of the Arctic is also emphasized in the "Strategy for the development of the Arctic zone of the Russian Federation and national security for the period up to 2020". The main task of the program is "improving the quality of life and protection of the population in the Arctic zone of the Russian Federation". "Extreme natural and climatic conditions, such as low air temperatures, strong winds, and the presence of an ice cover on the waters of Arctic seas" are listed as the key factors affecting the socio-economic development of the Arctic zone of the Russian Federation. The importance of taking climatic parameters into account in the course of construction was mentioned by researcher Konstantinov and others [14,16,17].

The issue of estimating the aeration regime was repeatedly raised in the works of Serebrovsky, Retter, Olenkov, Balakin, et al. [18–23]. However, a more sophisticated approach is needed to assess the aeration parameters of the Arctic zone so that each climatic and urban development factor is taken into account.

Perception of the thermal environment, taking into account the aeration regime based on the wind chill index, was studied by such researchers as Quayle and Steadman, Carder, and others [24,25]. A detailed description of the influence of temperature and wind speed parameters on the psychological and physical condition of a person can be found in the works of Osczevski [26]. It is also worth mentioning that Russian scientist E.M. Ratner developed a graph showing the integrated impact of temperature and wind on buildings and people [15,27,28]. This graph is used to assess the integrated impact of temperature and wind, which is perceived by a person as discomfortable.

CFD modeling is successfully used to study the aeration regime. The accuracy and reliability of this modeling tool is confirmed in the numerous works of such researchers as Blocken, Ricci, Repetto, etc. [29–31]. The process of CFD modeling toward aeration regime evaluation, as well as visualization of its results, are described quite fully in the works of Valger, Fedorov, and Fedorova [32].

At present, there is a need to develop a technique for estimating the aeration regime of residential development on sloping lands [33]. Such studies are necessary because the development of the Arctic zone of the Russian Federation requires a careful and systematic approach. In terms of urban planning, assessment approaches applicable to flatlands and territories with more comfortable climates are not suitable. Thus, any preparation for the urban development of territories in the Arctic zone of the Russian Federation requires additional research and development [34].

2. Study Area

The object of this study is residential development on the sloping lands in the Arctic zone of the Russian Federation (AZRF).

AZRF occupies 18% of the RF territory. Its population is 2391.6 thousand people, or 1.7% of the population of the Russian Federation. It boasts the principal and most important navigable Russian waterway, or the Northern Sea Route (NSR). NSR stretches from the Barents Sea to the Chukchi Sea, and key ports of the Northern Sea Route are situated in their water areas. The main seaports of the Northern Sea Route, located in the AZRF, include Murmansk, Arkhangelsk, Naryan-Mar, Varandey, Sabetta, Dudinka, Igarka, Khatanga, Tiksi, Pevek, Provideniya, and Anadyr.

Cities with a population over 10,000 people, such as Murmansk, Arkhangelsk, Naryan-Mar, Dudinka, Igarka, and Anadyr, were chosen for the study. The analysis of the AZRF settlement system allowed to identify the cities that are suitable for further studies. The next step is to analyze each factor of the theoretical model to identify the main parameters that will be used as input parameters for mathematical modeling. The full research methodology includes three stages presented in Figure 1.

Figure 1. Research stages.

2.1. Analysis of Geomorphological Parameters of Residential Development on the Sloping Lands of the Arctic Zone of the Russian Federation

All of the abovementioned cities in the Arctic zone of the Russian Federation were considered for the purpose of assessing geomorphological parameters, in particular:

2.1.1. Determining the Share of Sloping Lands within City Limits

Earlier studies have proven that sloping lands are slopes with a gradient of more than 52‰ [35]. To determine the share of sloping lands, occupied by the settlements of the Arctic zone of the Russian Federation, geomorphological parameters of the territory were analyzed using Quantum GIS technology and photogrammetric ASTER GDEM data on the terrain of the towns in question, as well as the visualization made in the form of color gradation of the terrain by the degree of slope steepness (Figure 2).

The studies have shown that each city has some sloping lands. However, Anadyr, Dudinka, Naryan-Mar, and Murmansk have a large percentage of sloping lands, and it is these cities that are chosen for the next stage of the study.

2.1.2. Determining the Percentage of Residential Areas on the Sloping Lands of AZRF Cities and Towns

To determine the share of the residential area in Anadyr, Dudinka, Naryan-Mar, and Murmansk, GIS technologies and data on functional zones, defined in the land use and development rules (land use plan) as well as in the general plans (master plans) of the above cities, were used. Quantum GIS software was employed to overlay maps of land use plans of the abovementioned cities on the topographic map of the territory, made using its photogrammetric images. Further, boundaries of residential areas in the selected cities were determined and compared with the boundaries of sloping lands with a gradient of more than 52‰.
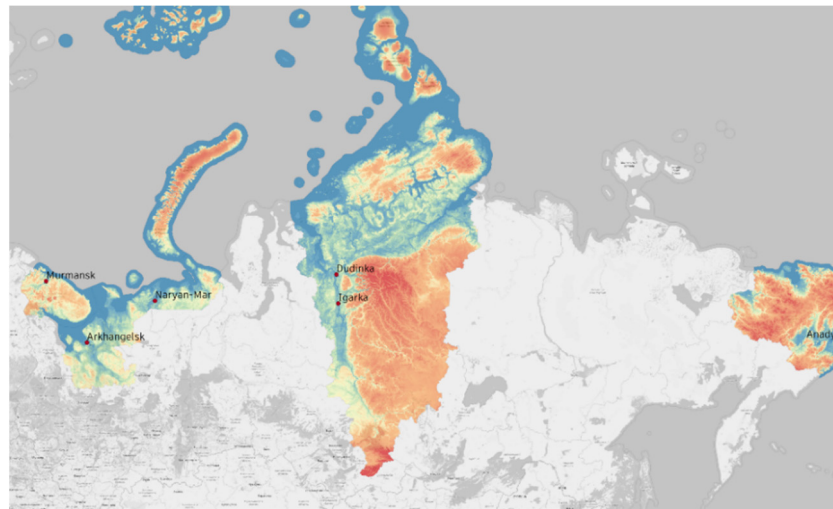
Figure 2. Topographic map of the Arctic zone of the Russian Federation.

For the purpose of further research, it is important to know the percentage of residential areas located on slopes. Toward this end, residential areas, located on slopes with a gradient of more than 52‰, were selected using GIS analysis tools (Figure 3).
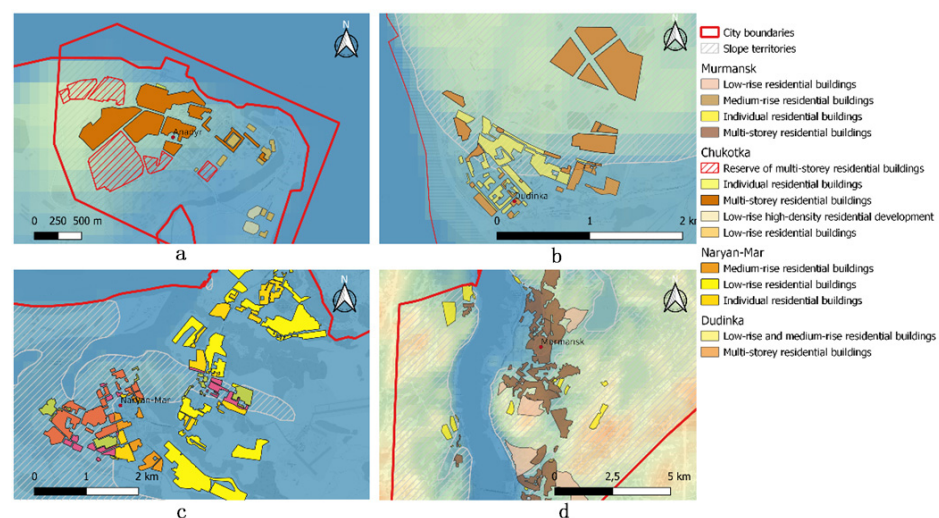

Figure 3. Topographic maps showing boundaries of residential areas in: (**a**) Anadyr, (**b**) Dudinka, (**c**) Naryan-Mar, and (**d**) Murmansk.

These data were used to make diagrams showing the ratio of the area of residential areas on the slopes to the area of inhabited flatlands in NSR port cities (Figure 4).

Thus, GIS analysis has revealed that more than half of the residential areas are located on sloping lands with a gradient of more than 52‰ in the cities of Anadyr, Dudinka, and Murmansk. However, most of the considered morphotypes of buildings are designed for flatlands, and their adaptation to sloping lands was made by changing structural elements to adapt buildings to slopes. At the same time, neither the aeration regime nor any issues of wind comfort were considered. Obviously, it is necessary to develop a methodology for assessing the aeration regime that will help to determine the most suitable morphotype of residential development in the sloping lands of the Arctic zone of the Russian Federation taking into account a comfortable aeration regime and the safety of residents.
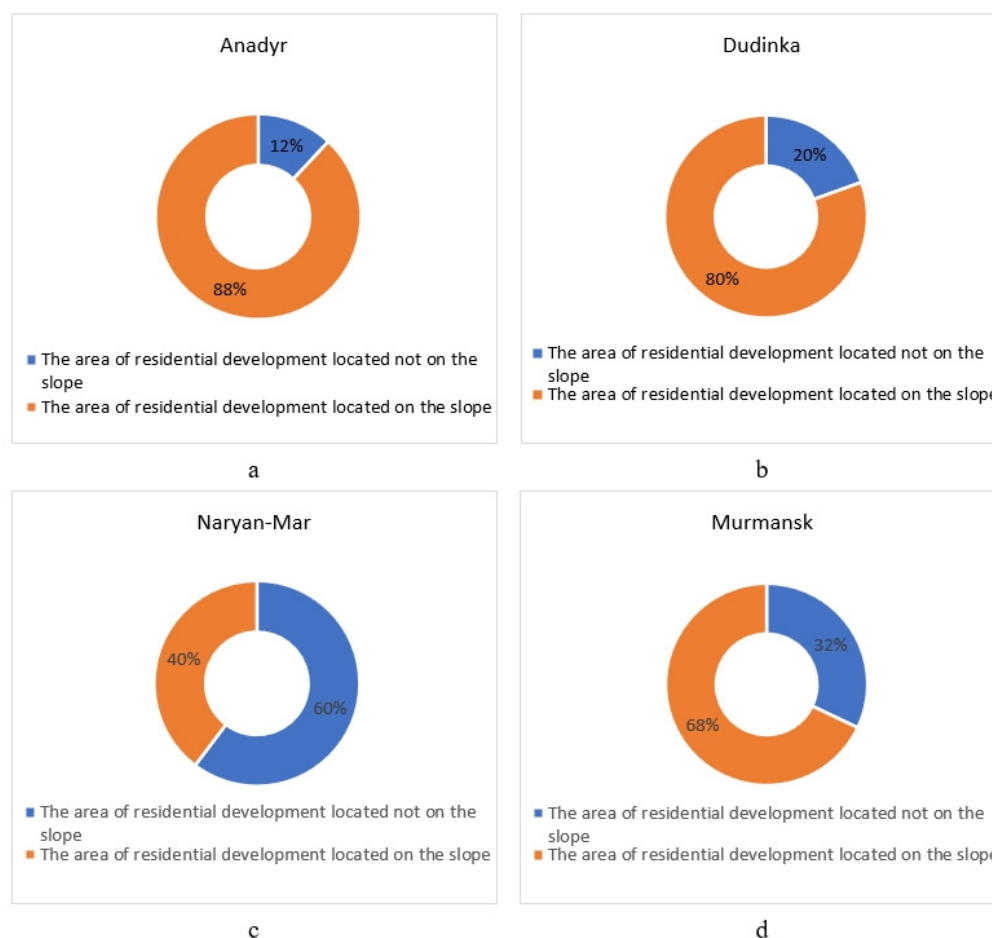
Figure 4. The ratio of residential areas, located on slopes, to residential areas located on flatlands: (**a**) Anadyr, (**b**) Dudinka, (**c**) Naryan-Mar, and (**d**) Murmansk.

Slopes with a gradient of 52–190‰, which are typical for settlements in the Arctic zone of the Russian Federation, were used in the theoretical research as geomorphological parameters.

2.1.3. Determination of Slope Exposure in All Directions (North, South, West, East)

At the third stage of assessment of geomorphological parameters, the exposure of the slope in all directions (North, South, West, East) is to be determined.

GIS analysis was made in Quantum GIS to determine the most widely spread slope exposures in the settlements of the Arctic zone of the Russian Federation. Given the results of the GIS analysis of exposure of slopes in the settlements in the Arctic zone of the Russian Federation, it is impossible to distinguish the priority exposure (Figure 5).

Four slope exposures (North, South, West, East) were used as initial data. The data were obtained on residential areas, located on the slopes, and their characteristics contributed to our further theoretical research.

2.2. Analysis of Aeration Parameters of Sloping Lands of the Residential Development of the Arctic Zone of the Russian Federation

To analyze the aeration parameters of settlements on the sloping lands of the Arctic zone of the Russian Federation and to identify the boundary conditions needed for mathematical modeling, Murmansk was chosen as the territory with the largest share of sloping lands within settlement boundaries (80%) and a large percentage of residential areas located on the slopes (68%). The following parameters were determined for the analysis of aeration factors:

- The average air temperature during the season of discomfort, °C;
- The average wind velocity, m/s, during the period with average daily air temperature $\leq 8\,°C$;
- The prevailing wind direction during the season of maximum discomfort;
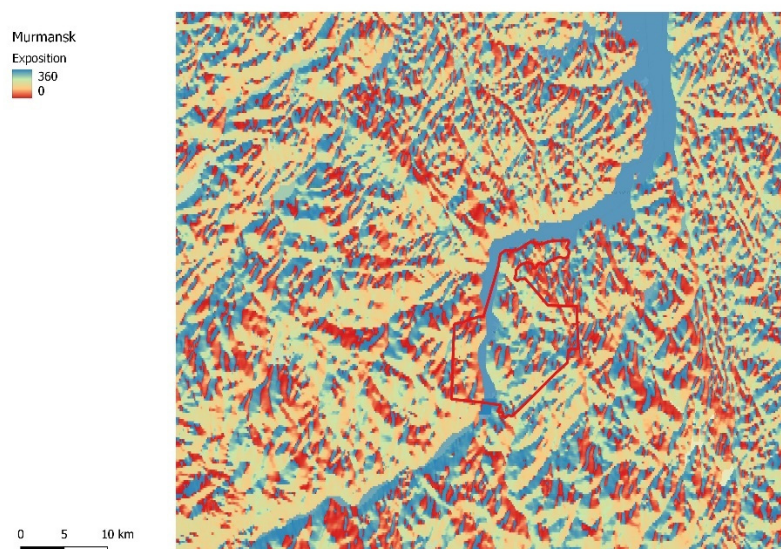- The threshold value of the wind velocity compatible with a comfortable aeration regime in the residential area.

Figure 5. The case of GIS analysis of the slope exposure of settlements in the Arctic zone of the Russian Federation; part of the territory of the Murmansk region.

Data from SNiP (Construction Norms and Regulations) 23-01-99 "Construction Climatology" were used to determine the above parameters. All aeration regime parameters for Murmansk are provided in Table 1 [36].

Table 1. Average statistical aeration parameters of AZRF settlements in the winter period.

Average Air Temperature in the Season of Discomfort	Average Wind Speed, M/S, in the Period with an Average Daily Air Temperature $\leq 8\,°C$	Prevailing Wind Direction in December–February
−18	4.9	SW

A recurrence-based wind rose was made to determine the most common wind direction.

The southwest direction of wind flows dominates in the AZRF settlements (Figure 6). To find the wind velocity that will serve as the boundary value to determine discomfortable conditions, we use the table of integrated effects of temperature and wind on buildings and people, developed by E.M. Ratner [15].

Having analyzed the average air temperature during the season of discomfort and the average wind velocity (m/s), we determine the wind velocity, at which the integrated effect of temperature and wind on a person will be perceived as discomfortable. To determine the boundary discomfortable wind speed, we use E.M. Ratner's graph of integrated influence of temperature and wind on buildings and people (Figure 7).

Having compared the average wind velocity and average temperature of the cold period with the table of E.M. Ratner, we assume that the threshold value of wind velocity V, compatible with a comfortable aeration regime in the residential area, equals 4 m/s.
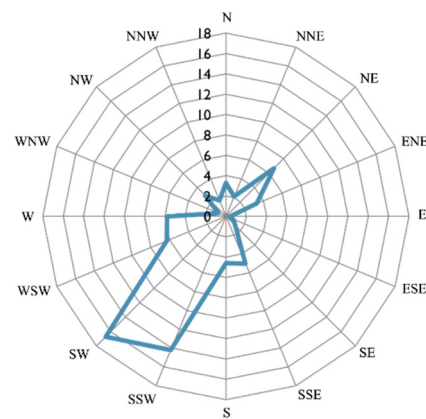
Figure 6. Wind rose characteristic of AZRF settlements in winter (according to RosHydroMet, the Russian meteorological service).
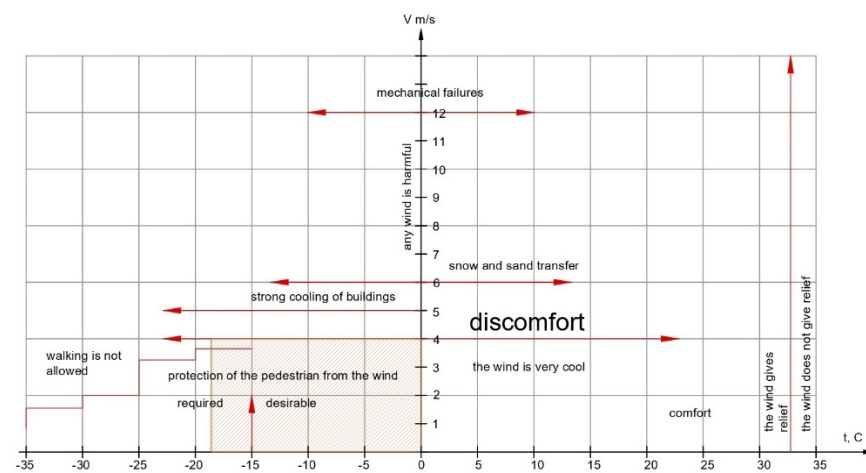

Figure 7. Determination of the boundary velocity for a theoretical study on the aeration regime in the residential development on sloping lands of the AZRF.

2.3. Analysis of Urban Planning Parameters of Residential Development on the Sloping Lands of the Arctic Zone of the Russian Federation

The residential development on the sloping lands of the Arctic zone of the Russian Federation was analyzed to assess the urban planning parameters of the theoretical model, including:

- building density;
- number of stories in buildings;
- building morphotype.

To analyze the buildings on the slopes, we used a GIS data map and such attributes as the number of stories and the size of the built-up area. The analysis allowed us to identify the building density, the average number of stories, and the most frequent morphotypes of residential buildings on the slopes of settlements in the Arctic zone of the Russian Federation.

Residential areas (neighborhoods) of the AZRF settlements, located on the slopes with a gradient of over 52‰, were analyzed to determine the most characteristic morphotypes, density, and number of stories (Table 2). As a result, seven standard neighborhoods, featuring different morphotypes were chosen.

Table 2. Principal urban planning parameters of residential areas on the slopes of AZRF settlements.

No	Name	Building Density	Average Number of Stories	Built-Up Area, Ha	Morphotype	Max. Gradient of the Built-Up Area, %
1	Neighborhood 1	0.93	9	39.8	Ribbon, perimeter, sporadic	290
2	Neighborhood 2	1.1	8.8	24.5	Ribbon, perimeter	210
3	Neighborhood 3	1.05	9	15.7	Perimeter	90
4	Neighborhood 4	0.71	9	27	Sporadic	240
5	Neighborhood 5	0.62	7.1	21.7	Perimeter	200
6	Neighborhood 6	1.2	9	19.5	Perimeter	180
7	Neighborhood 7	0.89	5.2	21.8	Perimeter	110

For the purpose of further studies, we choose a nine-story building, as it is the most widely spread type of residential buildings on sloping areas, according to the findings of analysis. The building density was analyzed for the same type of the built-up area; the average building density was 0.95.

The above morphotypes were applied for simulation purposes. Perimeter, ribbon, and sporadic morphotypes with a density factor of 0.95 and the average number of floors, equaling nine, were selected. Each model was placed on six types of slopes and had four exposures (northern, eastern, southern, and western).

3. Study Methodology

According to the results of the integrated analysis of geomorphological, aeration, and urban planning factors influencing settlements in the Arctic zone of the Russian Federation, as well as the main factors and parameters influencing the aeration regime of residential buildings on sloping lands, the theoretical model of the aeration regime was developed for residential buildings on the sloping lands of the Arctic zone of the Russian Federation (Figure 8). This theoretical model allows us to assess the aeration regime of the residential development on the sloping lands of the Arctic zone of the Russian Federation by obtaining data on the share of discomfortable built-up areas by means of mathematical modeling.

A comfortable living environment, enabling residents to take advantage of the courtyard amenities, is a binding condition needed to ensure a comfortable aeration regime of the residential development. Hence, the finite element to be simulated is courtyard area S. The courtyard area is the territory adjacent to a residential building and limited by residential buildings, structures, facilities, or fences, including pedestrian paths and driveways to the residential building, parking lots, green spaces, playgrounds, areas for recreation and sports, and service yards.

The theoretical model of the study has 3 levels:

- Level 1: residential area.
- Level 2: built-up area.
- Level 3: courtyard area.

Table 2 has a detailed description of all groups of factors that determine the features of the aeration regime of the residential development on sloping lands, as well as the procedure for their calculation.

Each level has certain parameters:

- Level 1—residential area—x_1, x_2, x_3, u_1, u_2.
- Level 2—built-up area—z_1, z_2, z_3.
- Level 3—courtyard area—optimization parameter k, obtained in the process of simulating Level 1 and Level 2 parameters and parameter Y (area S of discomfortable zones).
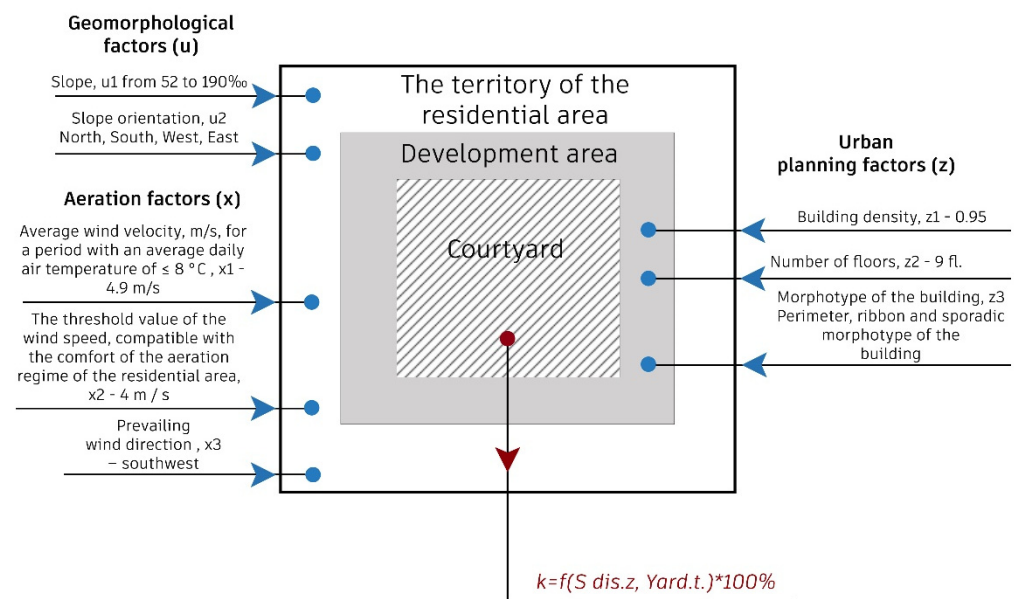
Figure 8. Theoretical model of the aeration regime of the residential development on the sloping lands of the Arctic zone of the Russian Federation with boundary conditions for modeling purposes.

The output parameter of the theoretical model will be Y, the area of discomfortable zones. Parameter Y is a function in which arguments include all factors x, u, and z listed above.

$$Y = F(xk, uk, zk) \tag{1}$$

The main optimization parameter and indicator of a comfortable aeration regime of a built-up area is the share of discomfortable zones k, expressed as a percentage and derived from Y and *S* of the courtyard area. Parameter *k* is used to assess the design of the residential area. It will be identified as a result of an experimental study.

$$k = \frac{S\text{dis.} \times 100\%}{S\text{yard area}} \tag{2}$$

The theoretical model allowed us to assess the aeration regime in the residential development on the sloping lands of the Arctic zone of the Russian Federation by obtaining data on the share of discomfortable zones in the residential development using mathematical modeling.

The main urban planning task was to reduce the share of discomfortable zones in courtyards.

The process of modeling requires the following actions to be taken:

1. Making a solid model of the built-up area (the residential development);
2. Mathematical modeling;
3. Using grapho-analytical methods or an analytical script to identify the share of discomfortable zones, in which wind velocity exceeds the acceptable value.

The authors used the above factors and the model of the study to draft a succession of actions needed to study the comfort of the aeration regime of a space-planning solutions designated for residential buildings on sloping lands (Figure 9).

A systematic approach to this research project was developed to conduct further studies. To determine the share of discomfortable zones, 4 morphotypes, 4 types of exposure, and grading of slopes, defined in Section 2.1, were identified. A total of 84 cases were simulated (Figure 10).
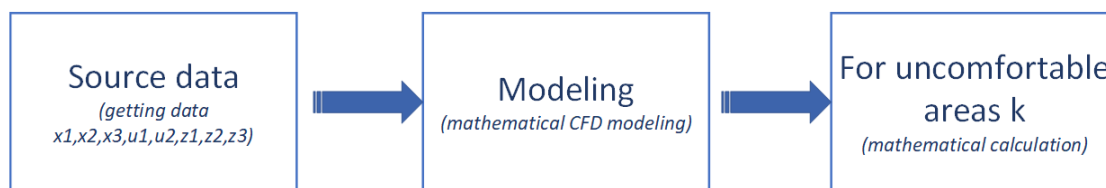
Figure 9. Method of modeling the aeration regime of residential buildings on sloping lands of the Arctic zone of the Russian Federation.
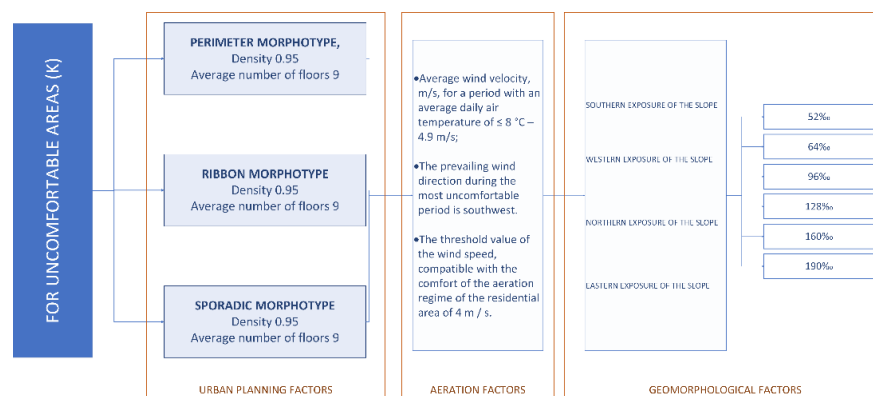

Figure 10. A systematic approach to the study of the aeration regime of residential construction on the sloping lands of the Arctic zone of the Russian Federation.

In our theoretical study, we used the input data defined above. The first stage of the theoretical study was mathematical modeling in ANSYS Fluent. CFD models were made on the basis of the solution to the system of equations describing the three-dimensional motion of a viscous medium (Navier-Stokes) with a continuity equation. ANSYS Fluent software package is one of the most efficient and accurate methods of mathematical modeling used to assess the aeration regime at a given moment. Modeling in ANSYS Fluent has a number of advantages over other methods of determining wind conditions (for example, wind tunnel research, field observations, etc.). Modeling in ANSYS Fluent allowed us to correctly assess the aeration regime of residential buildings on slopes since it has a function of registering velocity isofields in layers as cross-sections in any point.

Mathematical modeling in ANSYS Fluent was used to identify the main dependencies between the slope gradient and the exposure of the slope, the morphotype, and the aeration regime of the area.

4. Theoretical Study Using CFD Analysis

Mathematical modeling was performed upon derivation of basic parameters. The aeration regime was simulated for the morphotypes that had been defined earlier (Table 3). Perimeter, ribbon, and sporadic morphotypes with a density factor of 0.95 and an average number of floors equaling nine were selected. Each model was placed on six types of slopes at four slope exposures (northern, eastern, southern, and western).

The table shows the visual processing of the experimental data obtained using ANSYS Fluent software, or velocity fields, for different combinations of gradients and slope exposures for the most discomfortable prevailing southwest wind direction. The velocity scale shows velocities resulting from changes in wind direction, pressure, and speed. In the velocity fields, velocity gradation is shown as the color gradation indicated at the end of the table.

Modeling results were processed using mathematical and grapho-analytical methods. Based on the results of mathematical modeling in ANSYS Fluent, the share of discomfortable zones for each of four slope exposures is calculated according to 24 types of slopes defined in the area of studies. The results were visualized using the ANSYS Workbench

calculation platform. The ANSYS Workbench platform allows us to visualize wind velocity fields obtained using ANSYS Fluent modeling in any plane at a height of 2 m from the ground level. Since the aeration regime of residential developments on the slopes with a gradient greater than 52‰ is divided into several macro-levels of air masses in AN-SYS Workbench, it is necessary to visualize velocity fields of wind flows at each of the micro-levels.

Table 3. Models used in the theoretical study of the aeration regime of residential development on the sloping lands of the AZRF.
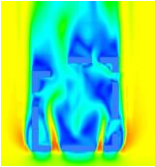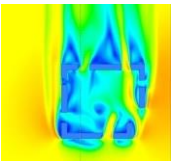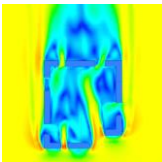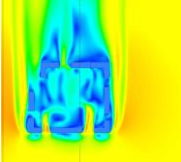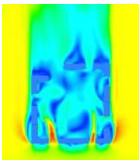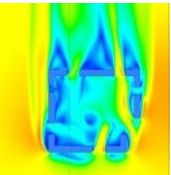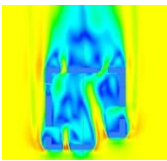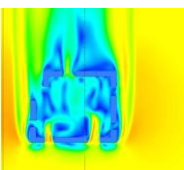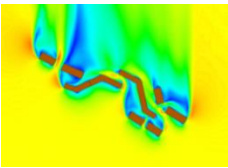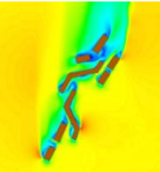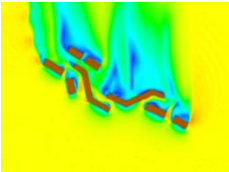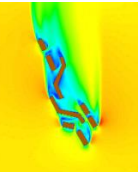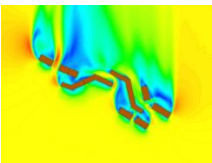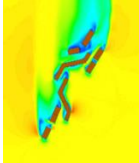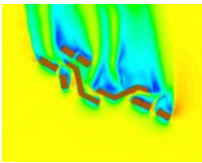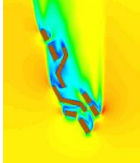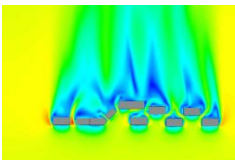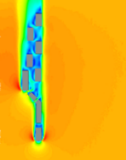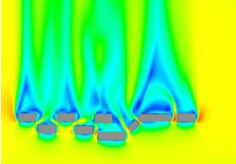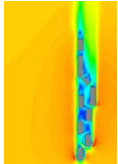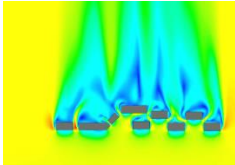
Morphotype 2 Perimeter Semi-Enclosed Development with a Shared Courtyard	Morphotype 3 Ribbon Development Composed of Highly Maneuverable Individual Buildings on the Slope	Morphotype 4 Sporadic Curvilinear Ribbon Development
Building density coefficient: 0.95	Building density coefficient: 0.95	Building density coefficient: 0.95
Average number of floors: 9	Average number of floors: 9	Average number of floors: 9

All obtained velocity isofields are consolidated in tables for each morphotype (Table 4). Colored areas from yellow to red in the legend indicate the presence, distribution, and shape of discomfortable zones in the residential area, where the average wind velocity exceeds 4 m/s. The obtained data allow us to make graphs showing the relationship between the slope gradient, exposure, and the share of discomfortable zones in the total space along the perimeter of the residential development.

4.1. Perimeter Morphotype of Development: Mathematical Modeling of the Aeration Regime in the Sloping Area

If the gradient varies from 52–190‰, mathematical modeling of wind flows in ANSYS Fluent shows that the most discomfortable areas are driveways to courtyards. Wind flows accelerate dramatically between the end sides of houses irrespective of the types of slopes and exposures. Driveways are particularly discomfortable if located on one axis relative to the prevailing wind direction and opposite each other (southern exposure at 64‰ and 160‰); such an arrangement of driveways triggers the effect of cross ventilation. The arrangement of driveways with a slight axial displacement relative to each other also triggers the effect of cross ventilation in the courtyard area (for the western exposure of slopes and all types of gradients). A large area of discomfortable zones is observed if the driveway to the courtyard is located opposite the central part of the courtyard area. The most valuable area that can accommodate socially significant landscaping components be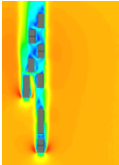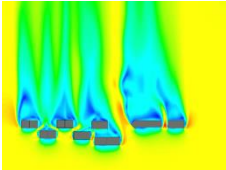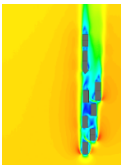comes discomfortable and unsuitable for playgrounds. Obviously, the location of driveways between the houses plays a sgnificant role and should be further investigated as part of the assessment of the aeration regime of design solutions of the residential development on the slopes of the Arctic zone of the Russian Federation. Discomfortable zones, having highest wind flow velocities, are typical for north-facing slopes, but the total area of discomfortable zones is smaller than in the cases of south-, east-, and west-facing slopes. It is necessary to use different methods of protection from winds to reduce the share of discomfortable zones in the perimeter development.

Table 4. Fragment of tables showing isopoles of wind flow velocities for perimeter, sporadic, and ribbon morphotypes.

‰	North	West	South	East
Perimeter morphotype				
96				
Max V	Max. wind velocity: 8.3 m/s	Max. wind velocity: 5.3 m/s	Max. wind velocity: 7 m/s	Max. wind velocity: 8.3 m/s
128				
Max V	Max. wind velocity: 9.3 m/s	Max. wind velocity: 8 m/s	Max. wind velocity: 7.4 m/s	Max. wind velocity: 6.3 m/s
Sporadic morphotype				
96				
Max V	Max. wind velocity: 8.3 m/s	Max. wind velocity: 5.3 m/s	Max. wind velocity: 7 m/s	Max. wind velocity: 8.3 m/s
128				
Max V	Max. wind velocity: 9.3 m/s	Max. wind velocity: 8 m/s	Max. wind velocity: 7.4 m/s	Max. wind velocity: 6.3 m/s
Ribbon morphotype				
96				
Max V	Max. wind velocity: 7.3 m/s	Max. wind velocity: 9.3 m/s	Max. wind velocity: 6.2 m/s	Max. wind velocity: 8.3 m/s
128				
Max V	Max. wind velocity: 8.3 m/s	Max. wind velocity: 9.2 m/s	Max. wind velocity: 7.4 m/s	Max. wind velocity: 9.1 m/s
	Vmin 0 m/s			Vmax 10 m/s
	Wind velocity scale			

4.2. Sporadic Morphotype of Development: Mathematical Modeling of the Aeration Regime in the Sloping Area

If the gradient varies from 52–190‰, modeling of wind flows in the sporadic development identifies a substantially larger number of discomfortable zones, in contrast to the perimeter development. This is due to the fact that the perimeter development shelters the courtyard from negative factors (including discomfortable wind), while the sporadic development is more open. The advantage of sporadic development is that it can be easily placed even on a slope with a large gradient. The flexibility of sporadic development allows buildings to be placed on natural terraces of the terrain, but this flexibility creates a large number of open windswept spaces. In this model, the largest number of discomfortable zones are observed for the western exposure because a semi-enclosed courtyard of such a sporadic development faces the windward side and the most discomfortable wind. In addition to large open spaces, there is a wind tunnel effect between parallel terraced buildings, including those located on terraces of different levels on the slope (for example, south-facing slopes at 190‰). This morphotype does not encourage the application of standard compositional and spatial solutions in the neighborhood. It is necessary to assess the aeration regime in the locality for all planning options, if the sporadic morphotype is used on the slopes of the Arctic zone of the Russian Federation.

4.3. Ribbon Morphotype of Development: Results of Mathematical Modeling of the Aeration Regime in the Sloping Area

Simulated wind flows on the slopes with a gradient varying from 52 to 190‰ show a quite large share of discomfortable zones in the ribbon morphotype. Same as the sporadic morphotype, the ribbon morphotype is also effective when the residential area is located on the slopes with a steep gradient since buildings that are not long-stretching can be easily placed on natural terraces. In contrast to the sporadic morphotype, the ribbon development has small courtyards, and most of them have discomfortable zones.

The next step is to interpret the resulting velocity fields. For the purpose of making further calculations, the obtained parameters were presented in the .csv database format, which contains the coordinates of a point (x, y, z) and identifies the wind velocity there (Figure 11).

To determine the optimization parameter or the share of discomfortable zones, we use the threshold value of the wind velocity, compatible with a comfortable aeration regime of a residential area V = 4 m/s. To analyze and identify the share of discomfortable zones (k), we use the formula that was derived earlier, and the script was created in Excel. The script allows calculating discomfortable zones for each specific type of development, using only attributes of coordinates and wind velocities obtained in ANSYS Fluent in the .csv format and parameters of the development. The operation of the script can be described as follows:

- The database in the .csv format, which has coordinates of each point of the development in the XY plane limited by the courtyard area, is downloaded from ANSYS Fluent and uploaded to the .xls file. The value of the wind velocity, determined by means of numerical simulation, is assigned to each point.
- The script interface has two cells. The threshold wind velocity, beyond which the wind will be discomfortable, is to be entered into the first one. The second one has the area of the yard. The formula in Section 2.2 is used to calculate the share of discomfortable zones.
- Then, the software calculates the share of discomfortable zones according to the formula and displays the result in the second cell.

All data on the share of discomfortable zones were collected in graphs to determine the dependence of the share of discomfortable zones on the geomorphological and urban planning parameters of the development.

	1	2	3	4	5	13	14	15	16	17
1	Column1	Column2	Column3	Column4						
2										
3	[Name]						57%	The area of dis-comfortable zones, % S (k)		
4	[Data]							Courtyard area (m2)		
5	X [m]	Y [m]	Z [m]	Velocity [m s			-	The area of dis-comfortable		
93	2.65357361e+00	3.06545143e+00	-1.18730949e+00	0.00000000e+000						
94	2.65357361e+00	3.07386436e+00	-1.20845490e+00	0.00000000e+000						
95	2.63318207e+00	3.06394176e+00	-1.20849434e+00	1.82735789e+000						
96	2.63318207e+00	3.07235470e+00	-1.22963974e+00	0.00000000e+000						
97	2.61279053e+00	3.06243191e+00	-1.22967926e+00	1.85099912e+000						
98	2.61279053e+00	3.07084484e+00	-1.25082458e+00	1.64620638e+000						
99	2.59239929e+00	3.06092224e+00	-1.25086411e+00	1.64456701e+000						
100	2.59239929e+00	3.06933517e+00	-1.27200951e+00	1.51361048e+000						
101	2.57200775e+00	3.05941238e+00	-1.27204895e+00	2.22411275e+000						
102	2.57200775e+00	3.06782352e+00	-1.29319443e+00	1.80669451e+000						
103	2.55161621e+00	3.05790272e+00	-1.29323380e+00	1.86462152e+000						
104	2.55161621e+00	3.06631565e+00	-1.31437927e+00	2.19039774e+000						
105	2.53122467e+00	3.05639286e+00	-1.31441864e+00	2.22314191e+000						
106	2.53122467e+00	3.06480579e+00	-1.33556412e+00	1.86618984e+000						
107	2.51083328e+00	3.05488319e+00	-1.33560364e+00	2.08926868e+000						
108	2.51083328e+00	3.06329613e+00	-1.35674896e+00	2.05544615e+000						
109	2.49044174e+00	3.05337353e+00	-1.35678848e+00	2.02550793e+000						
110	2.49044174e+00	3.06178627e+00	-1.37793381e+00	2.06302524e+000						
111	2.47005020e+00	3.05186386e+00	-1.37797333e+00	1.88088179e+000						
112	2.47005020e+00	3.06027660e+00	-1.39911865e+00	1.81646812e+000						
113	2.44965881e+00	3.05035400e+00	-1.39915817e+00	1.77594388e+000						
114	2.44965881e+00	3.05876694e+00	-1.42030350e+00	1.79002666e+000						
115	2.42926727e+00	3.04884434e+00	-1.42034302e+00	1.67550421e+000						
116	2.42926727e+00	3.05725727e+00	-1.44148849e+00	1.92271984e+000						
117	2.40887589e+00	3.04733448e+00	-1.44152786e+00	1.61198127e+000						
118	2.40887589e+00	3.05574741e+00	-1.46267334e+00	1.73991597e+000						
119	2.38848434e+00	3.04582481e+00	-1.46271271e+00	1.51821399e+000						
120	2.38848434e+00	3.05423756e+00	-1.48385818e+00	1.75554490e+000						
121	2.36809296e+00	3.04183216e+00	-1.47765701e+00	1.17015970e+000						
122	2.37205917e+00	3.04624500e+00	-1.48388992e+00	1.42430830e+000						
123	2.73513947e+00	3.06025677e+00	-1.07433456e+00	null						
124	2.71474792e+00	3.04474220e+00	-1.06031876e+00	null						
125	2.69435669e+00	3.04323235e+00	-1.08150360e+00	null						
126	2.69435669e+00	3.03481941e+00	-1.06035828e+00	null						
127	2.67396515e+00	3.03330975e+00	-1.08154312e+00	0.00000000e+000						
128	2.67396515e+00	3.02489700e+00	-1.06039772e+00	0.00000000e+000						

Лист1 **Форма Расчёта**

Figure 11. An example of the wind velocity database in the .csv format that demonstrates the share of discomfortable zones.

Residential Development: Modeling the Aeration Regime on the Sloping Land of the Arctic Zone of the Russian Federation

Modeling results are presented as diagrams for each type of development, four directions, and six slopes. The results are presented as matrix and petal diagrams. As a result of theoretical modeling, the minimum share of discomfortable zones in the perimeter development was 15% of the total area of a courtyard. The maximum share of discomfortable zones was 41%. The result of the theoretical modeling of the sporadic morphotype of development was the minimum share of discomfortable zones that equaled 11%, and the maximum share reached 56%. The result of the theoretical modeling of the ribbon morphotype was the minimum share of discomfortable zones that equaled 18%, while the maximum share reached 62%. To find dependence between coefficient k, the slope gradient, the slope exposure, and the morphotype, it is necessary to present the results in the form of graphs and charts. Graphs showing dependence of coefficient k on the slope gradient were made for four types of exposures (Figures 12–14). Excel software package was used to make these graphs.

The results of numerical modeling of wind flows in the perimeter development show that the north-facing slope is the most comfortable one (Figure 12). It is characterized by lowest k values. The gradient, varying from 65–135‰, is least comfortable for north-facing slopes, as there is a significant increase in k there. However, if the gradient exceeds 135‰, the share of discomfortable zones goes down. Hence, we can assume that this effect is connected to the boundary layer theory of G. Schlichting [6]. During the modeling experiment of wind flows running up the slope, it turned out clearly that, if the gradient reached 80–100‰, turbulation and substantial acceleration of the flow occurred, but if the gradient reached 140–160‰, the wind flow that divided the slope into two levels tore off; the upper flow became laminar, and the flow velocity went down drastically. South-, east-, and west-facing slopes had significantly higher values of k, but there was also an increase in the share of discomfortable zones at a gradient of 65–135‰.
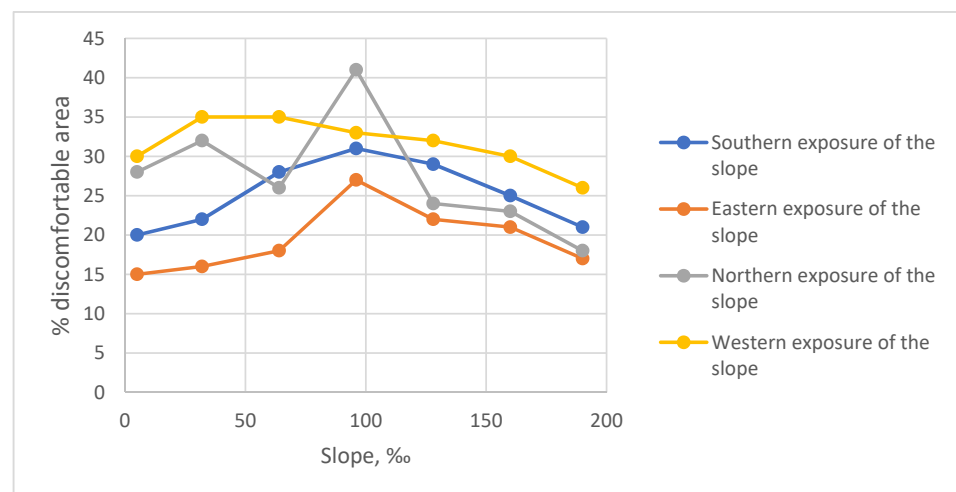
Figure 12. The dependence of k on the slope gradient for the perimeter type of development.
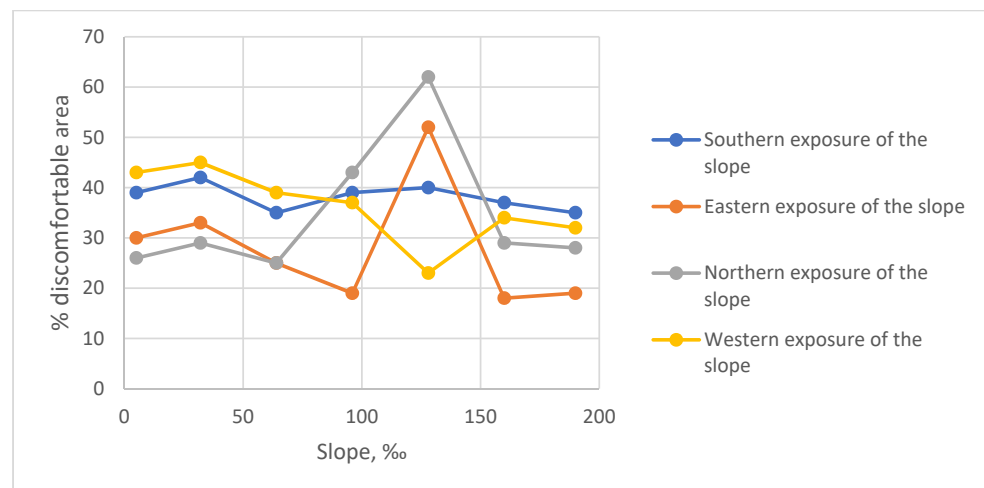

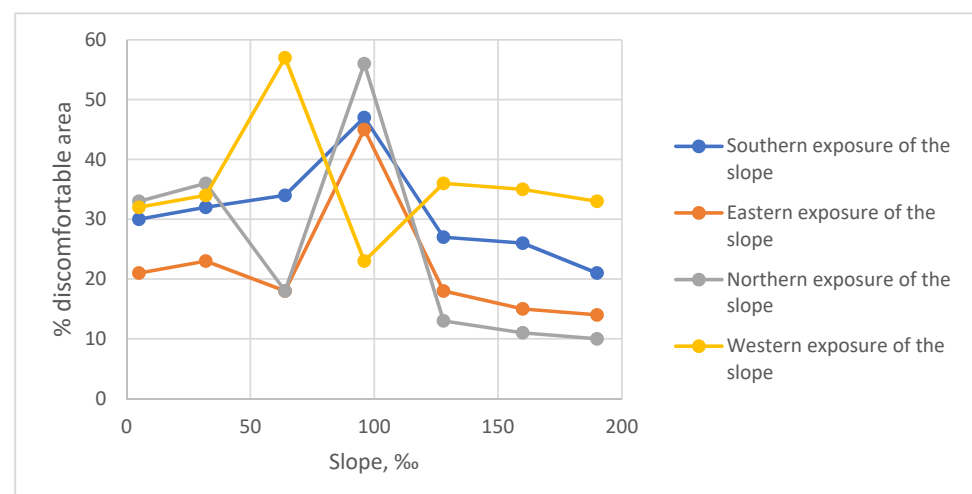**Figure 13.** Dependence of k on the slope gradient for the ribbon development.

Figure 14. Dependence of k on the slope gradient for the sporadic type of development.

Mathematical modeling, made for the sporadic morphotype, shows results similar to the perimeter morphotype (Figure 13). North-facing slopes can be considered the most

comfortable, and north-facing development demonstrates the smallest share of discomfortable zones. In cases of ribbon and sporadic morphotypes, there is a sharp increase in the share of discomfortable zones k for the north-facing slopes by more than 40% when the slope gradient is 60–160‰. However, the opposite decrease in k by 15% is observed for west-facing slopes where the gradient varies from 90–160‰. For south-facing slopes, an increase in k at a gradient of 60–160‰ is not as significant as for east- and north-facing slopes, as it does not exceed 5%.

When wind flows in the sporadic morphotype of development are simulated, a larger share of discomfortable zones becomes more pronounced if the gradient is intermediate (Figure 14). It varies from 60–160‰ for this morphotype. There is more than a twofold increase in k there, if slopes face south, north, and east. However, on west-facing slopes an increase in k is observed at a gradient of 45–90‰, while if the gradient is 60 to 160‰ a decrease is observed. This effect is associated with the planning features of the development model.

Simulations and calculations were made for all 112 models and consolidated in a table of dependencies, showing the share of discomfortable zones for each type of development, 7 different gradients and 4 exposures of slopes (northern, southern, western and eastern). The obtained data were used to grade the lack of comfort represented by coefficient k (Figure 15).
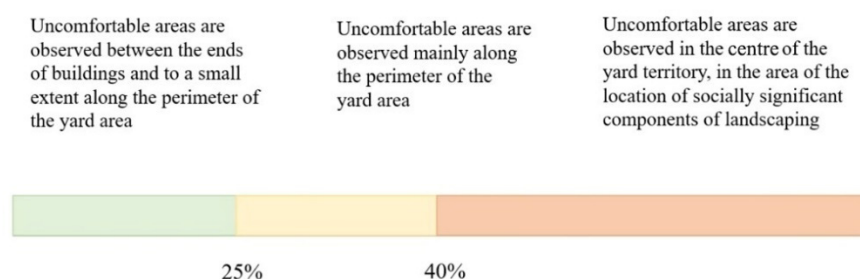

Figure 15. Graded aeration comfort of the residential development on the sloping lands of the AZRF.

Isofields of velocities and the pattern of flow distribution in the courtyard area were visually examined to make a gradation for each morphotype. It was found that if coefficient k was less than 25% discomfortable areas were observed between the side walls of buildings and, to an insignificant extent, along the perimeter of the courtyard area. At k of 25–40%, discomfortable areas were observed mainly along the perimeter of the courtyard area. At k over 40%, discomfortable areas were observed in the center of the courtyard area, or in the area where socially significant components of landscaping are located.

The table, showing dependence of the share of discomfortable areas on the gradient and morphotype of development (Table 5), was compiled on the basis of simulation results and analysis of the data obtained in the course of the study. The table of dependencies shows that the smallest share of discomfortable zones is characteristic of the perimeter type of development on north-facing slopes. Sporadic and ribbon morphotypes are least comfortable on the sloping lands of the Arctic zone of the Russian Federation. A substantial increase in the share of discomfortable zones is observed for gradients from 64 to 128‰ and all morphotypes.

Based on the available data, petal diagrams, or navigators, were made to choose the exposure and the morphotype of development for the sloping lands of the AZRF (Figures 16–18). The diagram is a navigator that shows directions denoting four slope exposures (northern, southern, western, and eastern) and percent shares of discomfortable zones (k). The navigator helps to determine the exposure with the smallest share of discomfortable zones for slopes with a gradient varying from 52 to 190‰.

Table 5. Table of dependencies of the share of discomfortable zones on the gradient and morphotype of development.

Values of the Share of Discomfortable Zones K at Different Gradients (u1)											

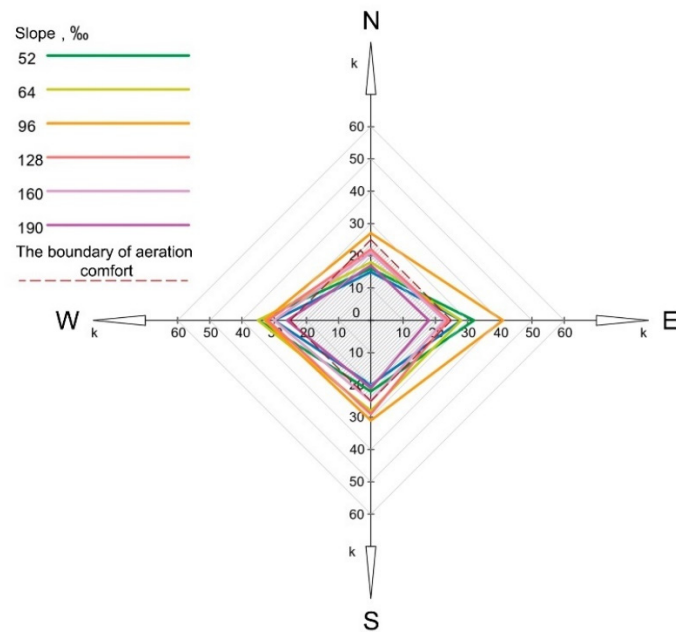| ‰	N	W	S	E	N	W	S	E	N	W	S	E
52	16	35	22	32	23	34	32	36	33	45	42	29
64	18	35	28	26	18	57	34	18	25	39	35	25
96	27	33	31	41	45	23	47	56	19	37	39	43
128	22	32	29	24	18	36	27	13	52	23	40	62
160	21	30	25	23	15	35	29	11	18	34	37	29
190	17	26	21	18	14	33	25	10	19	32	35	28

Figure 16. The petal diagram showing the breakdown of the share of discomfortable zones k for the perimeter type of development, gradients from 52–190‰, and four exposures of the slope.

The petal diagram for the perimeter morphotype of development shows that the most discomfortable slope has eastern exposure and a gradient of 96‰ (Figure 16). For the western exposure, all values of the share of discomfortable zones vary between 26% and 35%. The northern exposure of the slope is most comfortable for the perimeter morphotype of development.

The petal diagram, made for the ribbon morphotype of development, shows that the most discomfortable gradient is 128‰; northern and eastern exposures are most discomfortable (Figure 17). On the whole, the range of shares of discomfortable zones is much wider for the ribbon morphotype in terms of all four exposures.

On the petal diagram made for the sporadic morphotype of development, the most discomfortable is the slope gradient of 96‰ for all exposures and 64‰ for the western exposure (Figure 18). For gradients greater than 128‰, there is a significant decrease in the share of discomfortable zones.
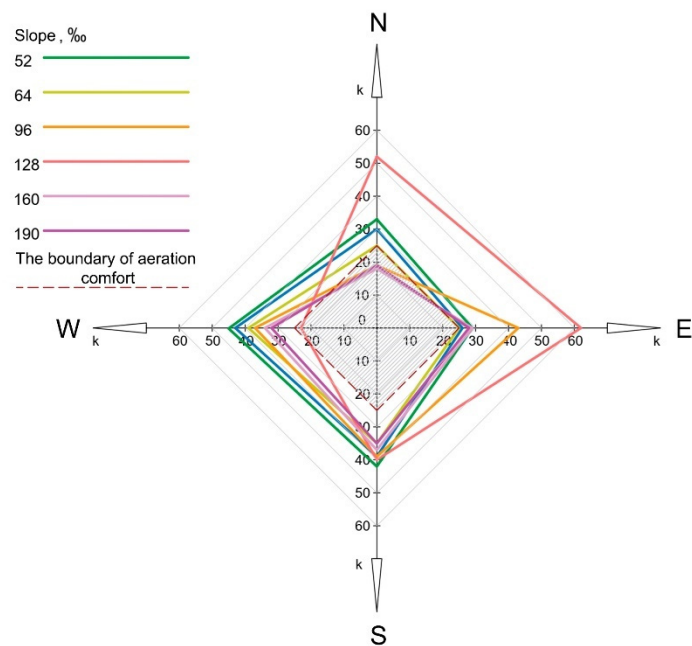
Figure 17. The petal diagram showing the breakdown of discomfortable zones k for the ribbon type of development, at gradients from 52–190‰, and four exposures of the slope.
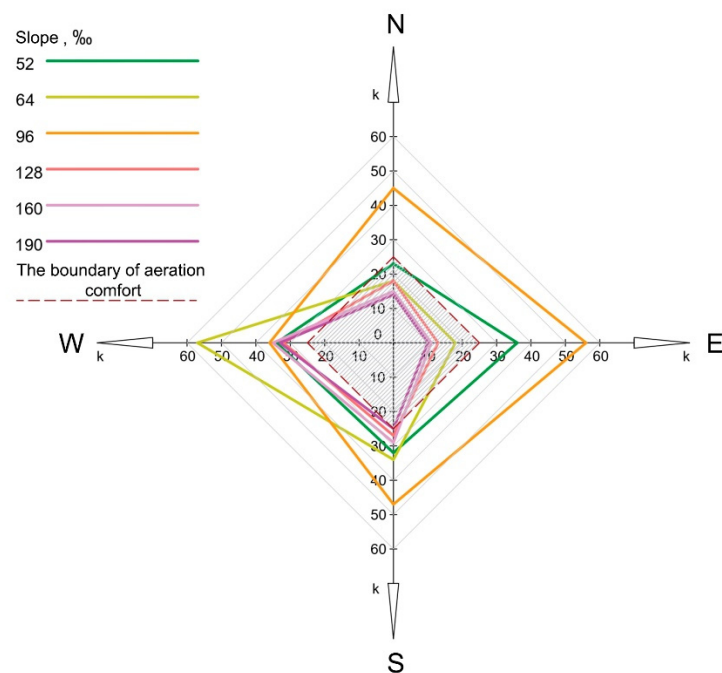

Figure 18. The petal diagram showing the breakdown of discomfortable zones k for the sporadic type of development, at gradients from 52–190‰, and four exposures of the slope.

The table of dependencies and navigators allow to determine the most optimal morphotype for a particular slope gradient of the sloping area. A control experiment is needed to validate the results of the theoretical study.

5. Control Experiment

Neighborhood 403 in Murmansk, known as Skalny (Figure 19), was chosen for the control experiment. This neighborhood is located in the sloping area with a gradient of 5–220‰. It has a mixed type of development, composed of perimeter and ribbon

morphotypes. The ribbon development in the southwestern part of the neighborhood is stretched along the vector of the prevailing discomfortable winter southwestern wind. The development density is 16.9%, and the average number of floors is nine.

Figure 19. Design project of neighborhood 403, Murmansk, including the topographic contour and the prevailing wind direction.

5.1. Urban Planning Parameters

Basic urban planning factors, such as density, the average number of floors, and morphotypes of development, were calculated for the selected area. The density of the neighborhood (z_1) is 16.9%; the average number of floors (z_2) is nine. The morphotype (z_3) is mixed with the predominance of ribbon and perimeter types (Figure 20). The ribbon development is located mainly in the areas with the highest gradient. The perimeter morphotype is concentrated in slightly sloping areas.

5.2. Aeration Regime Parameters

Basic parameters of aeration and temperature regimes in Murmansk are needed to determine the boundary comfortable velocity during the most discomfortable period (Table 6).

Winter is the most discomfortable season in Murmansk; southwestern wind direction prevails in winter there. Part of the neighborhood is located on the windward side relative to the prevailing wind direction in winter. The residential development of the ribbon type is located along the wind flow of the prevailing southwestern wind. The courtyards of some residential buildings are open to the main vector of wind flows. A decision was made to choose five different groups of residential buildings for further calculations and testing. Even though they belong to the same morphotype, they are located on the slopes, having different gradients.
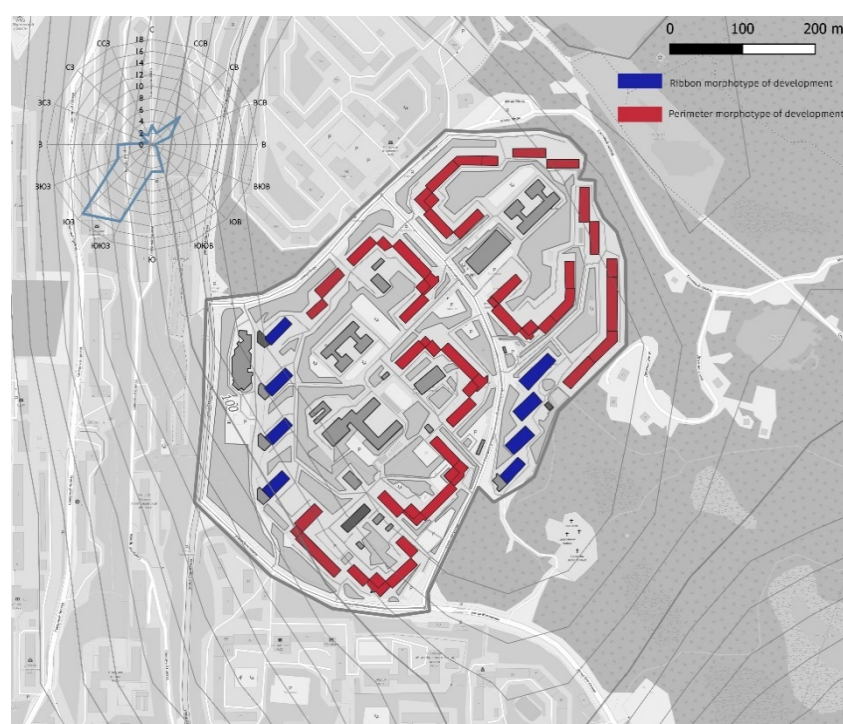
Figure 20. Site design developed for Neighborhood 403, Murmansk, that indicates the morphotypes of development and the prevailing wind direction.

Table 6. Natural climatic characteristics of the winter period in Murmansk.

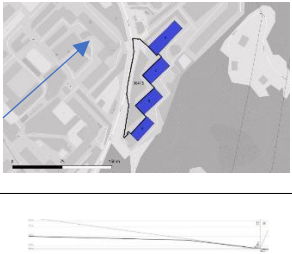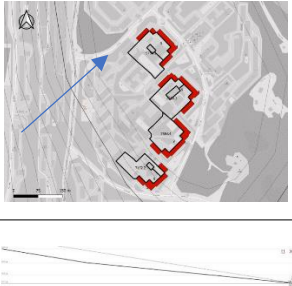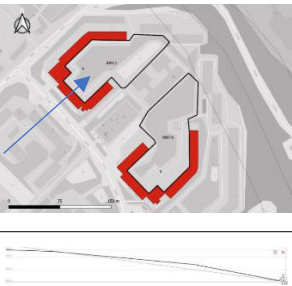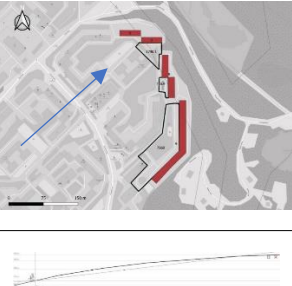| Average Air Temperature of the Discomfortable Period	Average Wind Velocity, M/S, during the Period with Average Daily Air Temperature $\leq 8\,^{\circ}$C	Prevailing Wind Direction in December–February
−18	4.9	SW

5.3. Geomorphological Parameters
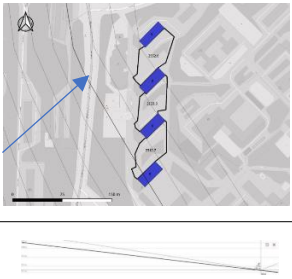
The site has a southwestern exposure of the slope; it is located on the windward side relative to discomfortable southwestern wind. The gradient of the site in question varies from 5 to 220‰. Areas with the highest gradient accommodate the ribbon development (S1, S2); areas with the lowest gradient accommodate the perimeter development (P1, P2, P3).

The ribbon development of the first type (S1) is located on the site with the maximum gradient (u1) of 40–200‰. The exposure of the slope (u2) is southwestern; the slope is located on the windward side relative to discomfortable south-easterly wind, typical for the winter season. The residential development has four nine-story buildings placed diagonally along the main vector of the southwestern wind flow.

The ribbon development of the second type (S2) is located on a site with a relatively flat topography and a characteristic gradient (u1) of 20–50 ‰ (Table 7). The exposure of the slope (u2) is southwestern. Four nine-story residential buildings are located diagonally to the main direction of the southwestern wind.

The perimeter development (P1) is a group of four nine-story buildings with semi-enclosed courtyards, two of which are located on the windward side having a southwestern exposure, and the other two have a northwestern exposure, but they are protected from prevailing discomfortable wind (Table 7). Potentially discomfortable are the areas between the end sides of buildings located on the same axis as the direction of the wind flow. The site has a relatively smooth terrain; its gradient (u1) varies from 5–30‰, and its exposure (u2) is southwestern.

Table 7. Principal parameters of groups of residential buildings in question.

		u1	u2	Parameters
S1		from 40‰ to 200‰	SW	The ribbon development of the first type (S1) is located in the highest gradient area (u1) equaling 40–200‰. The exposure of the slope (u2) is southwestern; residential buildings are located on the windward side relative to discomfortable south-easterly wind characteristic of the winter period. The group of residential buildings has four nine-story buildings placed diagonally along the main vector of the southwestern wind flow.
S2		from 20‰ to 50‰	SW	The ribbon development of the second type (S2) is located on relatively flat terrain with a characteristic gradient (u1) of 20 to 50‰. The exposure of the slope (u2) is southwestern. Four nine-story residential buildings are placed diagonally along the main direction of the southwestern wind flow.
P1		from 5‰ to 30‰	SW, NW	The perimeter development (P1) is a group of four nine-story buildings with semi-enclosed courtyards, two of which are located on the windward side, and they have a southwestern exposure; the other two have a northwestern exposure, although they are protected from prevailing discomfortable wind. Potentially discomfortable are the areas between the end walls of the buildings located on one axis with the direction of the wind flow. The site has a relatively flat topography; its gradient (u1) varies from 5 to 30‰, and its exposure (u2) is southwestern.
P2		from 30‰ to 120‰	NE	The perimeter development of the second type (P2) is located on a relatively slight slope oriented toward northeast (u2). The gradient (u1) varies from 30 to 120‰. The development is a group of two buildings; their courtyards have a northeastern exposure; hence, they are protected from discomfortable southwestern wind. Given the theoretical research, one can assume that the area between the two buildings may be discomfortable due to significant wind acceleration caused by the wind tunnel effect. The wind flow, coming from the rear façade of the buildings, also accelerates.
P3		from 30‰ to 220‰	SW	The perimeter development (P) is located in the area that has a large gradient difference (u1) of 30 to 220‰; the exposure (u2) of the slope is southwestern. The group has five nine-story buildings; its courtyard spaces are located on the windward side and oriented toward southwest.

The perimeter development of the second type (P2) is located on a relatively mild slope oriented toward northeast (u2) (Table 7). The gradient (u1) varies from 30–120‰. This is a group of two buildings; their courtyards have a northeastern exposure and are protected from discomfortable southwestern winds. Relying on the theoretical research,

one can assume that the area between the two buildings may be discomfortable due to significant wind acceleration because of the wind tunnel effect. The wind flow, coming from the rear façades of the buildings, can also intensify.

The perimeter development (P) is located on a site with a large gradient difference (u1) from 30–220‰; the exposure (u2) of the slope is southwestern (Table 7). The group has five nine-story buildings; courtyard spaces are located on the windward side and oriented toward southwest.

To determine the share of zones of discomfort and, hence, to verify the results of the theoretical study discussed in Chapter II, mathematical CFD modeling was performed using the ANSYS Fluent software package; visualization and processing of the results were performed using the ANSYS Workbench calculation platform. For the purposes of further modeling and research, we made a solid model of the development and a computational grid imitating the geometry of the neighborhood development and the mesorelief of the area (Figure 21). The number of floors in all buildings of Skalny neighborhood was preserved.
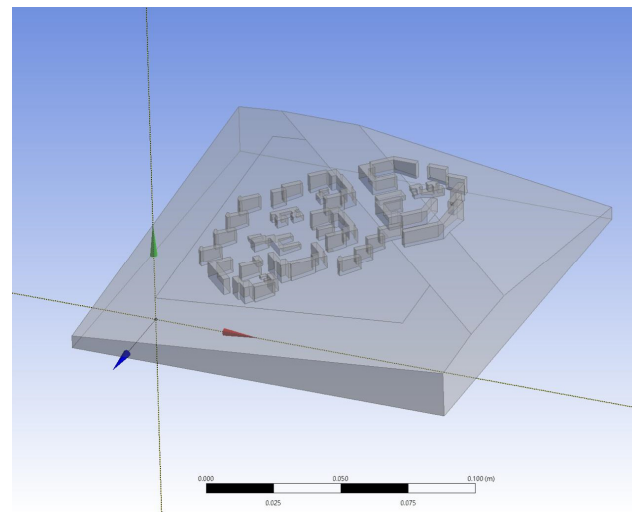

Figure 21. Computational model for mathematical simulation of aeration regime in ANSYS Fluent.

Further, boundary and initial calculation conditions were set. Boundary conditions were the same as in the theoretical study. In addition to boundary conditions, we needed to set the initial parameters in each cell within the computational domain. For the purpose of this calculation, initial conditions are the input velocity, which is assumed to be the average velocity of the most discomfortable winter period in Murmansk, when the wind velocity is 4.9 m/s, as determined in Section 2.2, and the dominant direction of the flow vector, which is southwestern.

The second stage of the experiment is an assessment of the exposure and morphotype of development. To obtain data on the speed and direction of wind flows in the area, simulation in ANSYS Fluent was made. After that, the data were exported to ANSYS Workbench software module as a database, and the results were visualized in the form of wind zoning maps (velocity isofields).

Calculation results (velocity isofields), visualized in ANSYS Workbench (Figures 22 and 23), clearly show that the zones of significant wind velocity amplification are observed in the areas of ribbon and group development. Courtyard areas of the perimeter development P1, P2, and P3 are well protected from the wind, but the least comfortable areas emerge in between the buildings due to the wind tunnel effect (P1, P2). Since there are important elements of landscaping in these areas, such as a playground between the P2 buildings, they need additional protection from wind. Additionally, areas of discomfort emerge between the main long sides of the buildings of the ribbon morphotype S2. However, the acceleration of wind flows is obviously lower around the buildings of the ribbon

morphotype S1. Significant wind acceleration in the S2 development is explained by the fact that it is located at the foot of the slope, while S1 is in the middle of the slope and closer to its top. A decrease in the wind velocity for S1 is explained by the fact that there are other buildings in front of the residential group, which serve as wind proofing in this case.
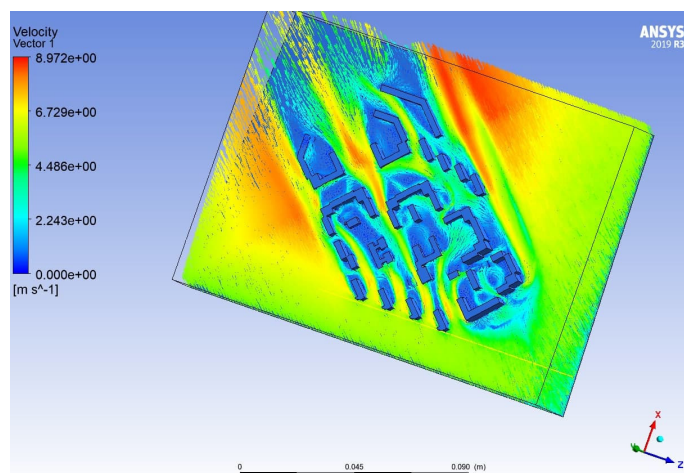

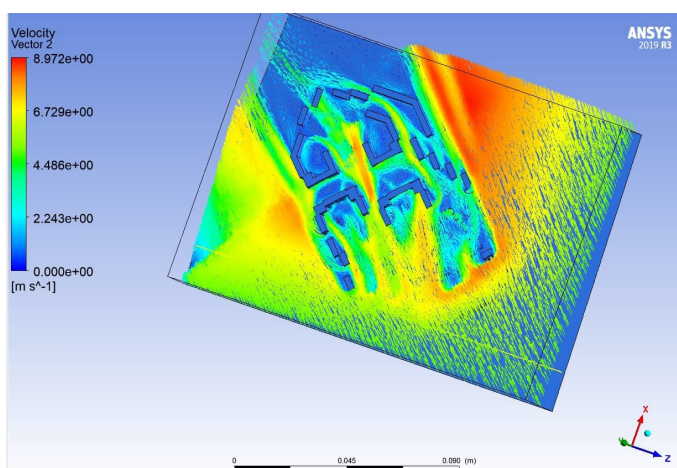**Figure 22.** Velocity isofields obtained as a result of simulation, Level 1.

Figure 23. Velocity isofields obtained as a result of simulation, Level 2.

Same as in the theoretical study, by comparing the average speed and average temperature of cold periods typical for Murmansk with E.M. Ratner's table, we assume that the threshold value of the wind speed compatible with the aeration regime that ensures comfortable living is V = 4 m/s. Then, we apply the exported wind speed databases and a script created in Excel to each point in the courtyard to calculate the share of discomfortable zones for each courtyard area.

To calculate the share of discomfortable zones, we selected courtyard areas of five groups of residential buildings belonging to different morphotypes (two types of the ribbon development, three types of the perimeter development). Figure 24 shows the boundaries of courtyards and their dimensions.

Having determined the dimensions of courtyards for each type of development using the formula derived above, we calculated the percentage of discomfortable zones.

Based on the results of the theoretical study and the most discomfortable zones identified in the course of the research, navigators were developed to select the slope exposure with the lowest share of discomfortable zones for different types of gradient (Table 8). These navigators were used (Figure 25) to verify the data obtained in the course

of the control experiment. Having compared the data obtained in the course of the control experiment with the simulation data described in Section 2, we can argue that coefficients k for each morphotype, exposure, and gradient correspond to the matrix of dependencies and "navigators" obtained by means of the theoretical study.
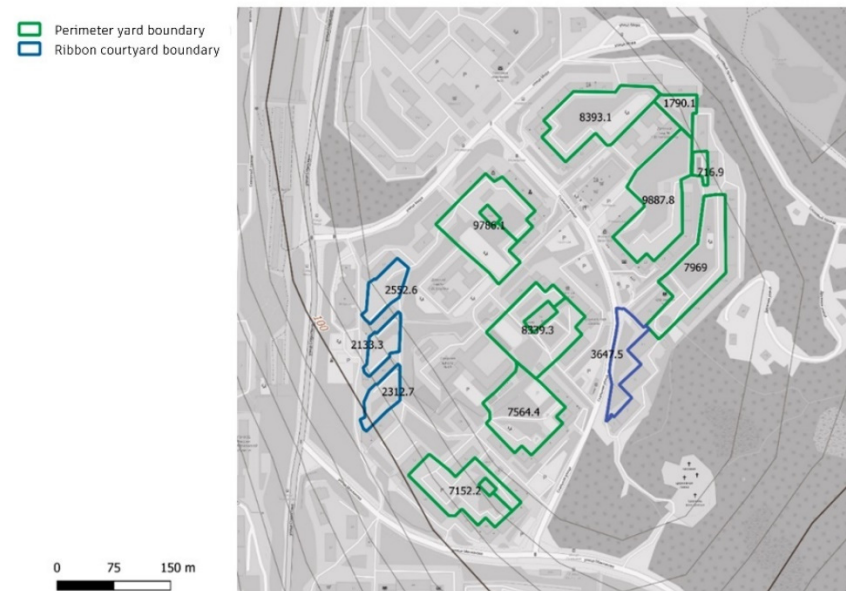

Figure 24. Dimensions of courtyard areas in Neighborhood 403, Murmansk.

Table 8. Results of simulation of Neighborhood 403, Murmansk, needed to determine the share of discomfortable zones in the residential development on the sloping lands of the Arctic zone of the Russian Federation.
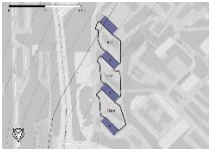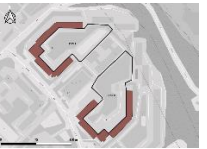
	S1	S2	P1	P2	P3
Morphotype					
Gradient, ‰ (u1)	40–200‰	20–50‰	5–30‰	30–120‰	30–220‰
S dis. zones, m² (Y)	5019.1	1026.9	9730.9	6054.4	3875.2
Share of dis. zones (k)	72%	28%	30%	33%	37%

Figure 26 shows that the courtyard areas of all groups of houses are outside the boundaries of comfort, and group S1 has a very large share of discomfortable zones according to the results of the theoretical study. To correct, or to reduce, the share of discomfortable zones, it is necessary to apply methods of improving aeration comfort by taking actions aimed at protecting these areas from wind.

Given the results of the control experiment, the findings concerning the influence of the morphotype, gradient, and exposure on the aeration regime and the available wind proofing methods, a project proposal was developed for Skalny neighborhood in Murmansk to protect it from wind (Figure 26). We propose three types of actions to correct the aeration regime in the current development; they include wind proofing landscape structures, wind proofing walls, and single- and multi-row tree planting.
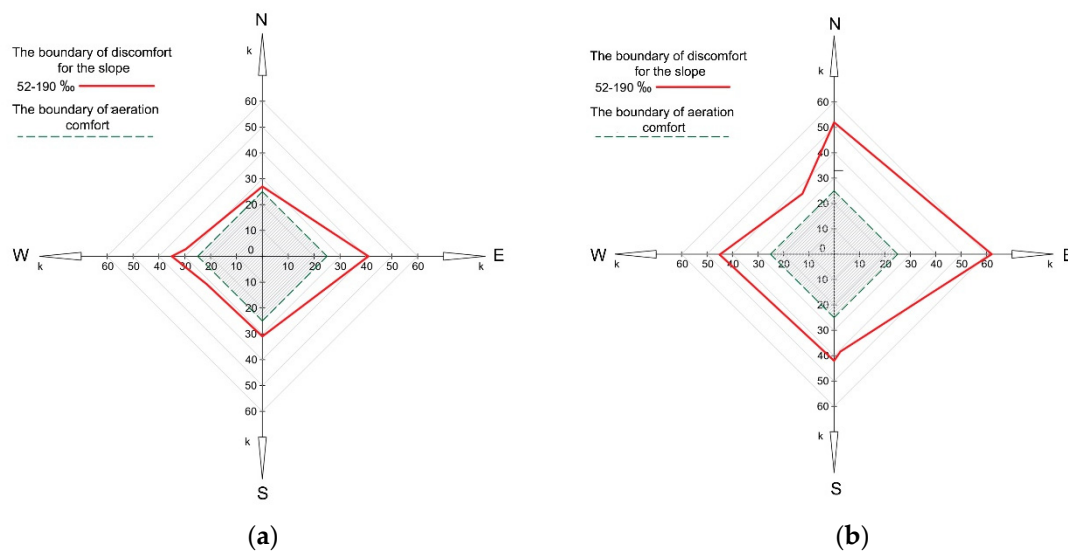
Figure 25. Petal diagrams showing the boundary of discomfort at gradients 52–190‰ and data on the share of discomfortable zones k: (**a**) perimeter morphotype, (**b**) ribbon morphotype.

Figure 26. General plan of Skalny neighborhood and windbreaks.

Wind-shielded playgrounds are proposed for P1 and P2 groups of buildings because a discomfortable drafty zone is formed near the school building, and in this case, landscape structures can be multifunctional: they can reduce the speed of wind flows and act as playgrounds for children. Wind proofing by planting trees and shrubs was proposed for S1 and S2 groups of buildings. The areas of discomfort between groups P1 and P2 were eliminated by building windproof walls along the main driveway.

As a result of wind-proofing actions, k coefficients decreased to the boundary value of aeration comfort. The values of coefficient k were marked on the petal diagrams to indicate the boundary of discomfort at the gradients of 52–190‰ (Figure 25). Relying on the existing studies, we can argue that the proposed actions can reduce Y coefficient by 30–70%. The proposed wind proofing actions were selected to improve the areas of discomfort in respect of all factors, including those dealing with geomorphology, aeration, and urban development. After the implementation of wind proofing actions, the values of all k factors reduced to the threshold of comfort, which demonstrates the effectiveness of the proposed method of assessment of the share of discomfortable zones in residential development areas on the sloping lands of the Arctic zone of the Russian Federation.

6. Discussion

Many scientists, including E.I. Retter, E.M. Ratner, F.L., V.D. Olenkov, and O.I. Poddaeva, addressed the aeration regime of residential development in the domestic research literature. F.L. Serebrovsky, N.N. Zaitseva, and I.V. Dunichkin determined the aerodynamic coefficients for the vertical surface of a building and the mutual influence of buildings in a group subjected to air flows, but the influence of the slope on the aeration of buildings was not taken into account [37–39]. Problems of interaction between the slope and the aeration regime were studied by V.D. Olenkov. F.L. Serebrovsky also studied the influence of slope parameters on the aeration regime and determined the coefficients of wind speed change in different terrain conditions compared to open flatlands [40]. However, the influence of these parameters and urban development features of residential development on sloping land under low temperature conditions were not considered. During the experiment, it was determined that the slope with the eastern exposure and a gradient of 96‰ is most discomfortable for the perimeter morphotype of development; it is obvious that the most discomfortable conditions for the ribbon morphotype of development include the slope that has a gradient of 128‰, northern and eastern exposures, the slope gradient of 96‰ for all exposures, and 64‰ for the western exposure are most uncomfortable for the sporadic morphotype of development. As a result of simulation, a table of dependences between the share of discomfortable zones, the gradient and the morphotype of development was made and petal diagrams were plotted; they can be used to draft an area planning project.

Recent studies on the development of the Arctic zone of the Russian Federation (Velli, Dokuchaev, Belyaev, etc.) offer recommendations with a focus on frozen soils and low temperatures [41]. However, the aeration regime, directly affecting the comfort of the environment, is not taken into account. Current standards request that emerging innovative technologies must be taken into account. Current guidelines for the assessment and regulation of wind in residential areas require the introduction of advanced methods and tools needed to assess the aeration regime [42]. Construction norms, developed for the Arctic, mainly solve the problem of construction in conditions of permafrost soils, while current general norms and standards of construction cannot be applied to the development of residential areas in the AZRF because they do not take into account the climatic characteristics of the region.

This research and pilot test, conducted in the Skalny neighborhood, have demonstrated the applicability of the ANSYS Fluent software package to the assessment of the aeration regime in the residential development built in the sloping areas of the AZRF [35,43]. The effectiveness of CFD modeling is confirmed by many studies completed by such authors as Hu, Cheng, and Qian. Studies of domestic scientists Valger and Fedorov confirm that mathematical modeling in ANSYS Fluent allows us to obtain the results necessary to determine the most optimal compositional and spatial solutions for residential development with regard to aeration comfort [32,44].

The study demonstrated the effectiveness of current actions taken to reduce the share of discomfortable zones in residential developments on the slopes of the AZRF, which confirms the validity of research made by such authors as Dolzhenkova, Kalashnikova, and others [45,46]. Wind proofing structures can be multifunctional in the Arctic zone; for example, they can function as landscaping elements or playgrounds.

7. Conclusions

The urban development of areas in the Arctic zone of the Russian Federation has numerous unique features, and comfortable living in this area depends on the ability to take them into account. The results of this study demonstrate the applicability of the method to the assessment of the aeration regime of residential buildings on the sloping lands of the Arctic zone of the Russian Federation. Development of research projects, focused on the study and assessment of the aeration regime in built-up residential areas on the sloping lands of the Arctic zone of the Russian Federation is feasible, if other morphotypes of residential buildings on sloping lands are also considered with account taken of the research

projects focused on the formation and assessment of the aeration regime in areas having different natural and climatic conditions. This topic can be developed in a study of wind proofing actions and their ability to effectively reduce the share of discomfortable zones. The economic and environmental substantiation of assessments of the aeration regime of residential buildings on sloping lands of AZRF is feasible. Any identified regularities, features of assessment, and formation of the aeration regime of residential areas on the sloping lands of the AZRF can be applied to introduce and substantiate urban planning regulations within the framework of regulatory documents governing the sustainable development of settlements in the Arctic zone of the Russian Federation.

References

1. Bredikhin, A.V.; Eremenko, E.A.; Kharchenko, S.V.; Belyaev, Y.R.; Romanenko, F.A.; Bolysov, S.I.; Fuzeina, Y.N. *Zoning of the Russian Arctic by Types of Anthropogenic Development and Associated Relief Transformation Based on Cluster Analysis*; Bulletin of the Moscow University: Moscow, Russia, 2020; Volume 1, pp. 42–56.
2. Putintsev, E.P. Integrated concept of Northern Urban Development: Northern Urban Development in the I Climatic Region. Ph.D. Thesis, MARHI, Moscow, Russia, 2005.
3. Krogius, V.R.; Ehbbot, D.; Pollit, K. *Urban Planning on the Slopes*; Stroiizdat: Moscow, Russia, 1988; 205p.
4. Olenkov, V.D.; Kolbin, D.S. Aeration regime of the city and its accounting in urban planning design. *Constr. Educ.* **2011**, *14*, 71–74.
5. Kolbin, D.S.; Olenkov, V.D.A. *Study of the Wind Regime with the Aim of Aeration and Windbreaks Urban Areas*; The Bulletin of Perm national Research Polytechnic University Construction and Architecture: Perm, Russia, 2011; pp. 36–39.
6. Schlichting, G. *The Theory of the Boundary Layer: 1-528*; Foreign Publishing House. Lit: Moscow, Russia, 1962; pp. 1–203.
7. Korobeynikova, A.E. *Designing on a Complex Terrain Taking into Account the Morphology and Aeration Regime of Sloping Lands*; Bulletin of the Moscow Information Technology University–Moscow Architectural and Construction Institute: Moscow, Russia, 2018.
8. Kovalenko, P.P.; Orlova, L.N. *Urban Climatology*; Stroiizdat: Moscow, Russia, 1993; 144p.
9. Gainanov, D.A.; Kirillova, S.A.; Kuznetsova, Y.U.A. The Russian Arctic in the context of sustainable development. *Econ. Soc. Chang. Facts Trends Forecast.* **2013**, *30*, 68–77.
10. Alekseev, G.V.; Antipov, S.K.; Afonichkin, A.I.; Afonichkina, E.A.; Baburov, S.V.; Balashova, E.S.; YUshkov, O.A.; Panov, D.V.; Komkov, N.I.; Frolov, I.E.; et al. *The Arctic Space of Russia in the XXI Century: Development Factors, Management Organization*; Publishing House "Nauka": Saint Petersburg, Russia, 2016; 1016p.
11. Agafonov, K.N. *Some Issues of Housing Construction in the Far North*; Moscow, Russia, 1962; Available online: https://www.dissercat.com/content/modelirovanie-vetrovogo-potoka-i-perenosa-zagryaznyayushchikh-primesei-s-tselyu-prognozirova (accessed on 13 August 2022).
12. Velli, Y.Y.; Dokuchaev, V.V.; Fedorov, N.F. *Buildings and Structures in the Far North: A Reference Guide*; Gosizdat: Moscow, Russia, 1963.
13. Decree of the President of the Russian Federation No. 645 Dated 10/26/2020 "On the Strategy for the Development of the Arctic Zone of the Russian Federation and Ensuring National Security for the Period up to 2035". Available online: https://www.ru-society.com/jour/article/view/23/15 (accessed on 13 August 2022).
14. Konstantinov, P.I.; Varentsov, M.I. What do we know about the microclimate of the largest cities of the Arctic zone of the Russian Federation. *Arct. Res. Extensive Dev. Integr. Dev.* **2018**, 25–27. Available online: https://www.elibrary.ru/item.asp?id=35571112 (accessed on 13 August 2022).
15. Ratner, E.M. Method of physiological assessment of the local climate by its impact on the thermal state of a person. *Issues Cult. Stud.* **1967**, *5*, 446–451.

16. Konstantinov, P.I.; Varentsov, M.I.; Repina, I.A.; Artamonov, A.Y.; Shuvalov, S.V.; Samsonov, T.E.; Grishchenko, M.Y.; Semenova, A.A.; Vorotilova, P.G.; Ezau, I.N.; et al. Study of microclimate and thermal comfort conditions of cities in the Arctic zone of the Russian Federation (using the example of the UHIARC network) A study of the microclimate and thermal comfort indicators in the Russian arctic towns. *Environ. Probl. North. Reg. Ways Solve* **2019**, 185. Available online: https://istina.msu.ru/publications/article/229006973/ (accessed on 13 August 2022).

17. Konstantinov, P.I.; Varentsov, M.I.; Grishchenko, M.Y.; Samsonov, T.E.; Shartova, N.V. Assessment of thermal stress in the Arctic city in the summer period. *Arct. Ecol. Econ.* **2021**, *11*, 219.

18. Serebrovsky, F.L. Interaction of wind and residential development. In *Abstract of the Dis. for the Degree of Candidate of Architecture*; Moscow State University, Architectural Institute: Moscow, Russia, 1964.

19. Retter, E.I.; Serebrovsky, F.L. Aerodynamic characteristics of residential buildings. *AVOK Vent. Heat. Air Cond. Heat Supply Constr. Thermophys.* **2008**, *5*, 80–87.

20. Olenkov, V.D.; Tazeev, N.T. *Calculation of Wind Loads Taking into Account Local Changes in Wind Speed in Buildings*; Series: Construction and Architecture; Bulletin of the South Ural State University: Chelyabinsk, Russia, 2019; Volume 19.

21. Balakin, V.V. Wind flow around residential buildings on city streets. *Resour.-Energy-Effic. Technol. Constr. Complex Reg.* **2017**, *8*, 265–269.

22. Balakin, V.V.; Sidorenko, V.F. Transformation of air flow when flowing around residential buildings on city streets. In *Vestnik Volgogradskogo Gosudarstvennogo Arhitekturno-Stroitelnogo Universiteta*; Stroitelstvo i Arhitektura: Volgograd, Russia, 2016; Volume 44.

23. Balakin, V.V.; Sidorenko, V.F. Wind Transformation around Residential Buildings in Street Canyons. *Procedia Eng.* **2016**, *150*, 2049–2054. [CrossRef]

24. Carder, M.; McNamee, R.; Beverland, I.; Elton, R.; Cohen, G.R.; Boyd, J.; Agius, R.M. The lagged effect of cold temperature and wind chill on cardiorespiratory mortality in Scotland. *Occup. Environ. Med.* **2005**, *62*, 702–710. [CrossRef]

25. Quayle, R.G.; Steadman, R.G. The Steadman wind chill: An improvement over present scales. *Weather Forecast.* **1998**, *13*, 1187–1193. [CrossRef]

26. Osczevski, R.J. The basis of wind chill. *Arctic* **1995**, 372–382. Available online: https://www.jstor.org/stable/40511941 (accessed on 13 August 2022). [CrossRef]

27. Ratner, E.M. The Experience of Physiological and Hygienic Characteristics of the Climate of the Territories of Settlement Based on the Assessment of the Thermal State of a Person. Ph.D. Thesis, AMN of the USSR, Moscow, Russia, 1967.

28. Demina, D.M.; Kandor, I.S.; Ratner, E.M. The thermal state of a person as the basis of sanitary and climatic zoning of the territory of the USSR. *Medicine* **1974**. Available online: https://earthpapers.net/harakteristika-klimata-mezhgornyh-kotlovin-yuga-vostochnoy-sibiri-dlya-otsenki-zhiznedeyatelnosti-cheloveka (accessed on 13 August 2022).

29. Blocken, B.; Janssen, W.; van Hoff, T. CFD simulation for pedestrian wind comfort and wind safety in urban areas: General decision framework and case study for the Eindhoven University campus. *Environ. Model. Softw.* **2012**, *30*, 15–34. [CrossRef]

30. Blocken, B. *Urban Physics*; 2020; Available online: https://www.taylorfrancis.com/chapters/edit/10.1201/9781003060826-142/urban-building-physics-cfd-study-venturi-effect-non-parallel-passages-buildings-blocken-stathopoulos-carmeliet (accessed on 13 August 2022).

31. Blocken, B.; Stathopoulos, T.; Van Beeck, J.P.A.J. Pedestrian-level wind conditions around buildings: Review of wind-tunnel and CFD techniques and their accuracy for wind comfort assessment. *Build. Environ.* **2016**, *100*, 50–81. [CrossRef]

32. Valger, S.A.; Fedorov, A.V.; Fedorova, N.N. Modelling of incompressible turbulent flows in the vicinity of poorly streamlined bodies using PC ANSYS Fluent. *Comput. Technol.* **2013**, *18*, 5.

33. Korobeynikova, A.E. Criteria for assessing the aeration regime and the quality of design solutions for residential development in the sloping lands of settlements in the Arctic zone of the Russian Federation. *Sustain. Dev. Territ.* **2019**, 33–39. Available online: https://cyberleninka.ru/article/n/trend-razvitiya-i-formirovaniya-zhiloy-sredy-poseleniy-na-sklonovom-reliefe-v-usloviyah-arkticheskoy-zony-rf (accessed on 13 August 2022).

34. Korobeynikova, A.; Danilina, N.; Makisha, N. Sustainable development of the slope lands of the Russian arctic: Investigation of the relationship between slope aspects, wind regime and residential wind comfort. *Land* **2021**, *10*, 354. [CrossRef]

35. Korobeynikova, A.E. Features of the formation of the aeration regime of slope territories intended for urban development in the conditions of the Russian Arctic. *Innov. Investig.* **2019**, *8*, 125–128.

36. *131.13330.2012 P*; Construction Climatology. Updated Edition of SNiP 23-01-99. Ministry of Regional Development of Russia: Moscow, Russia, 2012; p. 108.

37. Serebrovsky, F.L. *Construction Aerodynamics and Aeration of Populated Areas*; Chelyabinsk, Russia, 1977; Available online: https://www.dissercat.com/content/osobennosti-aeratsionnogo-rezhima-zhiloi-zastroiki-pri-razvitii-i-rekonstruktsii-na-primere- (accessed on 13 August 2022).

38. Poddaeva, O.I.; Churin, P.S.; Dunichkin, I.V. *Assessment of Bioclimatic Comfort of Urban Development*; Publishing House of the National Research University MGSU: Moscow, Russia, 2016.

39. Olenkov, V.D.; Kolmogorova, A.O.; Sapogova, A.E. *Computer Simulation of Aeration Regime of Residential Buildings for the Purpose of Ventilation and Wind Protection*; Series: Construction and Architecture; Bulletin of the South Ural State University: Chelyabinsk, Russia, 2021; Volume 21, pp. 5–11.

40. Serebrovsky, F.L. *Aeration of Populated Areas*; Stroiizdat: Moscow, Russia, 1985; 172p.

41. Belyaev, I.S. Problems of Arctic Construction: Trends and Prospects. *Bull. Civ. Eng.* **2021**, *2*, 248–255. [CrossRef]

42. *Guidelines for the Assessment and Regulation of the Wind Regime of Residential Development*; TSNIIP gradostroitel'stva: Moscow, Russia, 1986; Available online: https://files.stroyinf.ru/Index2/1/4293801/4293801575.htm (accessed on 13 August 2022).
43. Korobeynikova, A.E. Assessment and features of the formation of the aeration regime of residential development on sloping lands on the example of the Skalny neighbourhood of the city of Murmansk. *Ecol. Urban. Territ.* **2021**, *4*. [CrossRef]
44. Valger, S.A.; Fedorova, N.N. Numerical study of the flow of buildings by turbulent air flow in the ANSYS Fluent PC. *Proc. NGASU* **2013**, *1*, 55.
45. Dolzhenkova, E.I.; Kalashnikov, D.V. Modelling of windproof structures. *Bull. Landsc. Archit.* **2015**, *5*, 32–36.
46. Balakin, V.V.; Sidorenko, V.F.; Slesarev, M.Y.; Antyufeev, A.V. Formation of environmental protection objects of landscaping in urban ecological systems. *Vestn. MGSU* **2019**, *14*, 1004–1102. [CrossRef]