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Application of an Architect-Friendly Digital Design Approach to the Wind Environment of Campus Dormitory Buildings

Qibo Liu [1,2], Yimeng Zhang [1], Wendong Ma [1] and Juan Ren [1,3,*]

[1] School of Architecture, Chang'an University, Xi'an 710061, China
[2] Engineering Research Center of Highway Infrastructure Digitalization, Ministry of Education, Xi'an 710061, China
[3] School of Architecture, Xi'an University of Architecture and Technology, Xi'an 710055, China
* Correspondence: juanren@chd.edu.cn

Abstract: Good natural ventilation can improve the comfort of campus dormitories and effectively avoid pollution caused by particle accumulation. Parametric design can effectively address the feedback and connection between building performance analysis and design. This study employs an architect-friendly digital design method based on the Rhino/Grasshopper parametric platform. It takes campus dormitories in the cold region as a case, using parameterized digital tools, such as the Butterfly plugin to simulate wind performance under three influencing factors: building layout, opening position, and building façade (shape and spoiler). Finally, the optimal design that can simultaneously meet the local winter and summer wind environment requirements is selected and validated. In addition, the reasonable design of external balconies and bathrooms in a dormitory can form buffer spaces to achieve effective wind shelter and insulation effects in cold regions. This article describes how to use digital tools to quickly and easily optimize the design of building forms based on wind simulations to promote campus sustainability.

Keywords: campus dormitory buildings; digital tool; wind environment simulation; natural ventilation; optimal design

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1. Introduction

1.1. Background

The dormitory building is an important place where college students live and study. An excellent indoor wind environment can improve students' quality of life and also help improve their learning efficiency. Many college students' dormitories in China have a high residential density, without a dedicated outdoor air system. In this physical environment, natural ventilation is the primary way to obtain fresh outdoor air [1]. Good natural ventilation can provide sufficient clean air for the room, reduce the concentration of pollutants, and shorten the residence time of pollutants in the site. It can also provide a comfortable thermal environment for the interior.

However, the unreasonable design of a dormitory building may result in slow wind speeds, low wind pressures, and poor ventilation in calm-wind areas. Pollutants cannot be discharged promptly through ventilation. On the other hand, the potential strong-wind areas brought by an unreasonable design may produce instantaneous strong winds. This can cause dust on the ground to fly and pose a risk to the comfort and safety of pedestrians [2,3]. One of the significant issues that architects need to resolve is combining design and technical strategies at the schematic stage to provide a good wind environment for the dormitory. In architect-led design expression, the parametric design offers a comparative selection of solutions or solves issues that architects could not have anticipated. The emergence of parametric technology provides a good solution for solving the feedback and linkage between performance simulation analysis and design and improving green

building design. A parametric design mode based on Rhino/Grasshopper has been widely used in architectural design in recent years [4,5]. In this study, Rhino digital modeling software (Rhino 7, Grasshopper Butterfly plugin 0.0.05) with the Grasshopper Butterfly plugin was used for computational fluid dynamics (CFD) simulations to predict the wind environment in the dormitory area under various conditions. Moreover, the regional climatic characteristics of the project location, the building layout, and other conditions were considered. Meanwhile, according to the Chinese Green Building Evaluation Standard for wind environments, a comprehensive comparison and an optimization design of the building's wind environments were also provided. The optimal design must simultaneously and sufficiently meet both the winter and summer requirements.

Xi'an was selected for this study because it is a typical city in a cold region of China and has numerous universities. According to a survey of multiple universities in Xi'an, the campus dormitories are mainly multistory, with mostly rectangular architectural layouts, and a north–south orientation [6]. Based on the above research, this study takes a representative multistory dormitory building in a university in Xi'an as a case and applies Rhino/Grasshopper parameterization methods to explore the path of wind environment optimization designs suitable for architects. This study analyzes the wind environment optimization design strategies suitable for dormitories in Xi'an, which helps to provide a practical reference for the design of dormitory wind environment in cold regions.

1.2. Literature Review

Building wind environments have been the subject of early research. It is mainly based on three methods: field measurements, wind tunnel tests, and computer numerical simulation and analysis. A relatively complete research system has been established during the long-term development practice to study the building wind environment. In the early days, research on the wind environment in buildings was mainly based on wind tunnel experiments and numerical simulations [7]. Numerical simulations have gradually been used as technology has advanced [8]. As a result, to investigate wind comfort and safety, computer simulation systems based on CFD technology have been developed [9]. Scholars have extensively compared the accuracy and efficiency of wind tunnel experiments and numerical simulations [10]. The results show that CFD simulation calculations have outstanding advantages in efficiency and cost compared with wind tunnel experiments. With algorithm optimization, CFD simulation accuracy has also significantly improved [11,12].

While widely recognizing the advantages of CFD simulations, the existing research proposes to improve the efficiency of CFD simulations further to achieve the rapid comparison of multiple schemes based on the uncertainty characteristics of design parameters and boundary conditions at the scheme stage [13,14].

Table 1 shows the sorting of relevant research on the representativeness of the campus building wind environment. More research is currently focused on the pedestrian-layer wind environment, outdoor pollutant diffusion, indoor air quality, and thermal comfort for the campus building wind environment. It is noteworthy that in recent years, the research on campus microclimates, including the wind environment, has attracted attention, and the research on the impact of human behavior on the indoor thermal environment has also gradually increased. However, research on campus dormitory buildings that considers indoor and outdoor wind environment performance simulations and proposed optimization design schemes is still scarce.

The early design stage is crucial for optimizing building performance. Through performance analysis, architects can obtain simulation results for design decisions in a timely manner. It can promote the sustainable potential of buildings and is also an important guarantee for improving building performance. Therefore, many scholars have researched architectural optimization design methods/decision supports for architects based on building performance (e.g., ventilation, building energy consumption, thermal comfort, and lighting performance). Hwang and Chen [53] suggested a novel method to connect the

façade design and building environment to support architect design strategies that balance energy conservation and thermal comfort through a better-glazed façade. Zhao and Du [54] proposed combining DesignBuilder and jEplus + EA to give designers different scheme choices based on preferences and provided the most recommended variable parameters of windows and shading systems in selective cities. Zhai et al. [55] proposed a multiobjective optimization method to help designers optimize the window design to minimize energy consumption while improving the thermal environment and visual performance. As proposed by Yuan and Cho [56], a building performance optimization process can be used by designers to assess the daylighting and energy efficiency of various envelope design options and produce an optimized design. Mahan et al. [57] developed an approach using building information modeling and machine learning that provides quick energy performance information. Zhang et al. [58] developed a parametric generative algorithm to automatically generate design schemes of typical Chinese urban residences based on a performance-oriented design flow. Han et al. [59] proposed a tool for integrating the machine-learning model into the early design environment and an annual daylight prediction model with greater generalizability. It is evident that dynamic simulations aid in making well-informed decisions. However, the separation of design and simulation software and the high cost of the calculation make it challenging to meet the architects' needs in the initial design stage.

Table 1. Selected research on campus building wind environments.

Factors	Sub-Factors	Selected Research Works
Campus natural ventilation	Indoor natural ventilation and air quality	[1,15,16]
	Outdoor wind and pollutant diffusion	[17–20]
	Pedestrian wind	[21–25]
	Ventilation and energy saving	[26]
	Wind energy utilization	[27,28]
Campus thermal comfort	Indoor ventilation and thermal comfort	[29–32]
	Outdoor wind and thermal comfort	[33–35]
Campus microclimate, mainly involving the wind environment	Based on regional climate characteristics and layout form	[36,37]
	Microclimate evaluation	[38]
Campus wind environment and health	Health-related performance	[39,40]
Influencing factors of natural ventilation on campus	Influence of natural ventilation on the façade of the building	[41]
	Influence of atrium on natural ventilation	[42]
	Influence of courtyard on natural ventilation	[43]
	Influence of campus building layout on ventilation	[44]
	Influence of human behavior mode on ventilation	[45–47]
Campus wind simulation method	CFD numerical simulations based on different software	[48–50]
	Simulation comparison of two turbulence models (RAN and LES)	[51]
	Wind tunnel experiment	[52]

Fluent, Phoenics, OpenFOAM, and other commonly used CFD simulation software are among those found in the literature on wind environment simulations of campus buildings. General CFD software such as OpenFOAM 9 requires a higher theoretical basis for users. More importantly, simple CFD software pays more attention to the solving process, and there still needs to be improvements in the design and optimization of modeling software. The Rhino/Grasshopper platform's parametric design method has gained popularity in architectural design due to its rigorous logic, simulation visibility, and quantitative correlation. As a result, it is now being applied to simulate physical building environments [60–62]. Grasshopper can accurately quantify the relationship between form and performance by controlling various parameters, such as the building's shape and the

surrounding environment. It can perform coupling calculations based on the same model for energy consumption, wind, light, and comfort. Butterfly is a plugin of Ladybug tools and a python library to create and run advanced CFD simulations using OpenFOAM (open-source field operation and manipulation). It is available in the Rhino modeling software to help architects with basic indoor and outdoor ventilation calculations. The Butterfly plugin calls OpenFOAM to create and run CFD simulations. OpenFOAM is the most widely used open-source CFD engine available, capable of running multiple advanced simulation and turbulence models with high accuracy and feasibility. Compared with the existing environmental simulation tools, the building information in the parametric platform has a correlation relationship, and the building model can be adjusted adaptively according to the numerical changes in the design parameters. It is suitable for multischeme comparisons during the creation phase and can significantly shorten the environmental simulation modeling time. Additionally, the high compatibility of the Grasshopper parametric platform makes it ideal for architects to use during the initial design phase for the collaborative calculation of CFD and other performance simulation tools for buildings.

2. Research Method

2.1. Simulation Methodology

OpenFOAM serves as the core algorithm engine for the CFD numerical simulation software. Moreover, it adheres to the fluid control equations' mass conservation, momentum, and energy conservation equations. Each of the three equations adheres to its corresponding conservation law. Direct numerical simulations (DNSs), Reynolds-averaged Navier–Stokes (RANS) equations, and large-eddy simulations (LESs) are the most frequently used turbulence calculation methods. In this study, only average values of the flow parameters in the flow field are of interest. Hence, the standard k-ε RANS model was adopted in this study.

One of the Ladybug tools, an open-source interface that connects the simulation engine OpenFOAM to the Butterfly parametric call platform, was utilized in this study. Butterfly was chosen as the parametric calling platform because it runs stably in the modeling software Rhino, allows data transfer between simulation engines, and enables geometric model creation, simulation, and visualization in one interface. Butterfly is, therefore, widely used to simulate urban wind patterns, outdoor wind simulations, thermal comfort, and indoor ventilation simulations. Figure 1 depicts the technical procedures used to carry out this research.

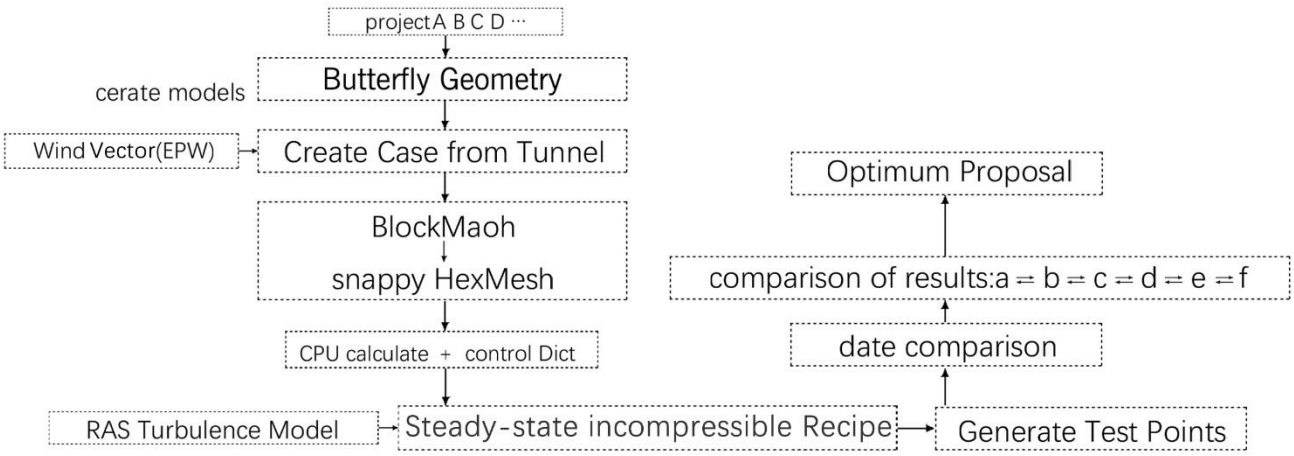


Figure 1. Related technical route.

There are several highlights of the model optimization of Butterfly:

- Based on the Rhino software platform, the target model supports the direct import of multiple formats simultaneously, without complex model format conversion, shortening the model processing time.

- The architect's requirements, optimized simulation time, and simulation solutions can all be taken into consideration when developing a selection of mesh-quality solutions. OpenFOAM also automatically calculates the best results the device can generate in the shortest time based on the basic configuration of the user's computer, finding the best balance between mesh quality and calculation time.
- Butterfly comes with an atmospheric boundary layer data template for most simulation conditions, saving time in setting up conditions. The model also considers near-surface roughness and a gradient wind setup module to bring the simulation results closer to reality.
- The Reynolds averaged simulation (RAS) turbulence model equation is one of three fundamental Butterfly-based turbulence models in terms of solvers. It is a control equation for the mean variable of the flow field, which is statistically averaged. Therefore, the need to calculate turbulent pulsations at each scale can be eliminated, which reduces spatial and temporal resolutions and speeds up computation times. It is suitable for most building wind simulations.
- The most significant advantages of Butterfly are its speed, low cost, and relatively high accuracy. Each step has been optimized to increase the calculation speed compared to conventional models. A wind simulation cell can be used for various situations. Butterfly uses gradient winds, surface roughness, atmospheric boundaries, and other specific methods to control the accuracy of the calculation, simulating the actual situation as closely as possible.

It is worth pointing out that, as Grasshopper is a nonprogramming simplified platform, the Butterfly plugin usually calculates simplified models, which is more suitable for architects carrying out comparisons of multiple schemes at the initial stage of design. However, its simulation accuracy for complex flow fields is slightly less than that of other mature professional CFD software.

2.2. Simulation Parameter Settings

This study takes as an example a university project under construction in Xi'an, Shaanxi Province, China, that covers a total planning area of 69.52 hectares. The campus forms an east–west axis with three buildings, namely, the library, the research building, and the office building. The rest of the teaching and living buildings are arranged in clusters along the north and south sides. The dormitory, depicted in yellow in Figure 2, comprises five clusters, with a planned total area of 22.93 hectares. These clusters are arranged along the east–west axis, with the sports playing field as the central location.

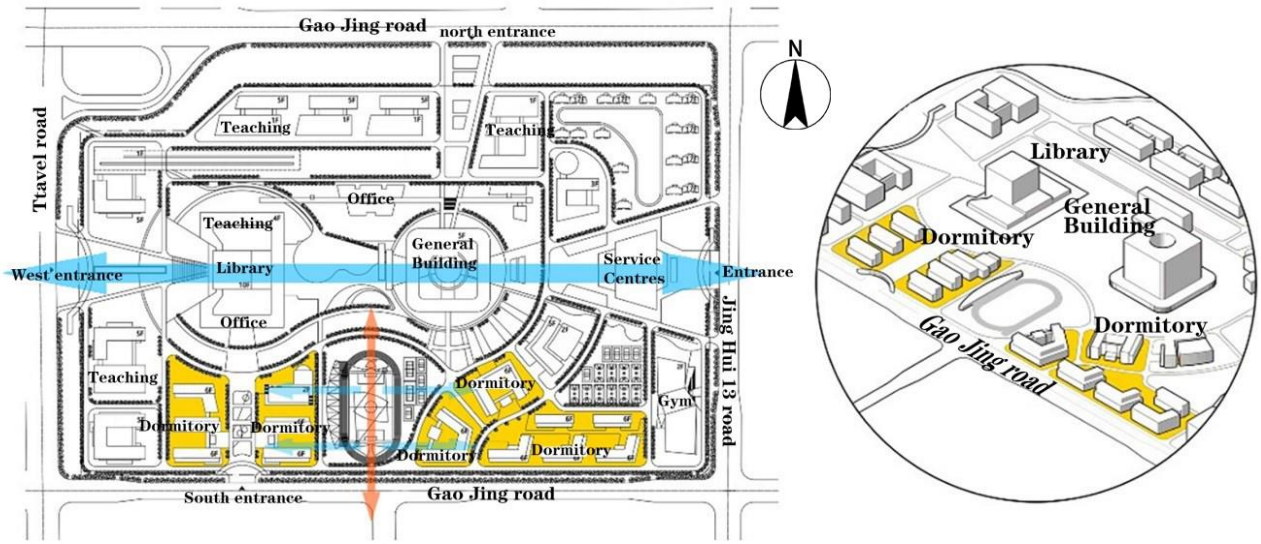


Figure 2. Campus dormitory area plane and simplified model map.

Xi'an, Shaanxi Province, is in a cold climatic zone in the monsoon region of China [63,64], between 33.42 and 34.45 degrees north and 107.40 and 109.49 degrees east. The annual average temperature in Xi'an is 13.3 °C. The average temperature of the hottest month is 26.68 °C, and that of the coldest month is −0.35 °C. The dominant wind direction in summer is northeast, and the dominant wind direction in winter is southwest [63]. The wind speed is within the range of 0~8 m/s, with 0~3 m/s accounting for 76% of the year. The average wind speed throughout the year is 1.8 m/s and the region is windless and light most of the time (Figure 3). The EPW meteorological file and wind environment parameter settings in Xi'n are shown in Figure 4.

The characteristic dimensions of the building are 71 m × 23 m × 23.7 m. The Reynolds number (Re) can be calculated via 23 m times 1.8 m/s divided by 1.5×10^{-5} m^2/s, according to its definition. Therefore, the Re is 2.76 × 106, which is large enough to keep the wake turbulent [65,66]. Unlike smooth walls, the wall surfaces of buildings are normally rough. Laminar flow can hardly exist in the wall surface of buildings. Due to the above analysis, a fully turbulent RANS model, the standard k-epsilon RANS model was employed in the simulations of this study.

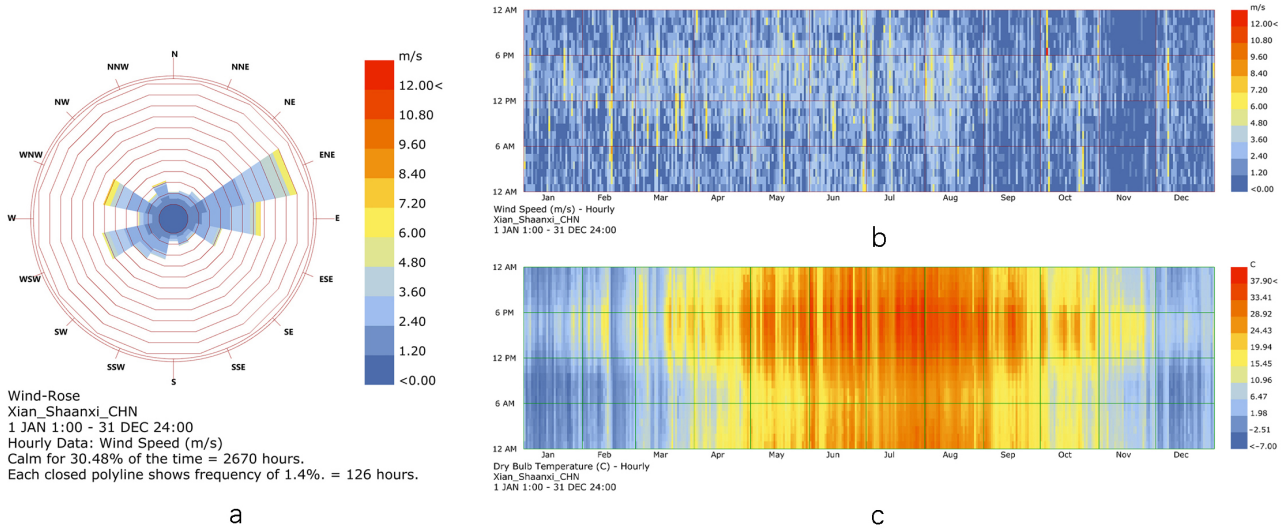


Figure 3. Visualization chart of the meteorological environment. (**a**) Wind rose chart. (**b**) Annual wind speed distribution. (**c**) Annual temperature distribution.

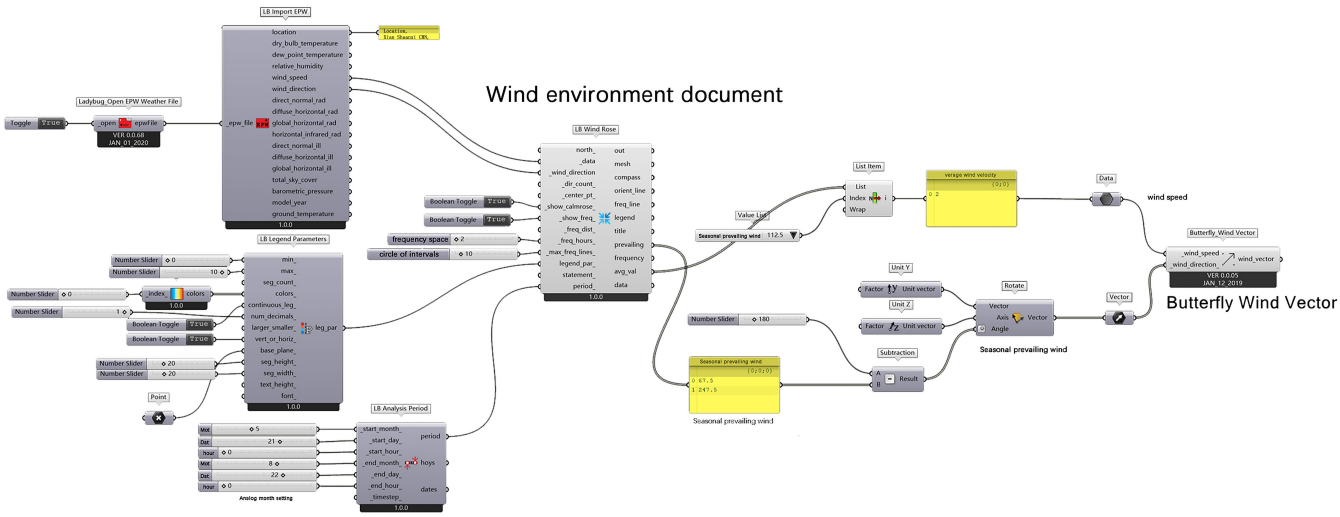


Figure 4. Depiction of the region's EnergyPlus Weather (EPW) file and the simulation's wind environment parameter settings.

2.3. Wind Tunnel Setup and Computational Gridding

The Butterfly-created case-form tunnel is essential to setting up the wind tunnel. Here, the wind vector parameters, such as wind speed and direction, are set based on the wind environment file for the project's location. In the wind tunnel setup, the calculated wind field is formed at three times the outer profile boundary of the target building (Figure 5).

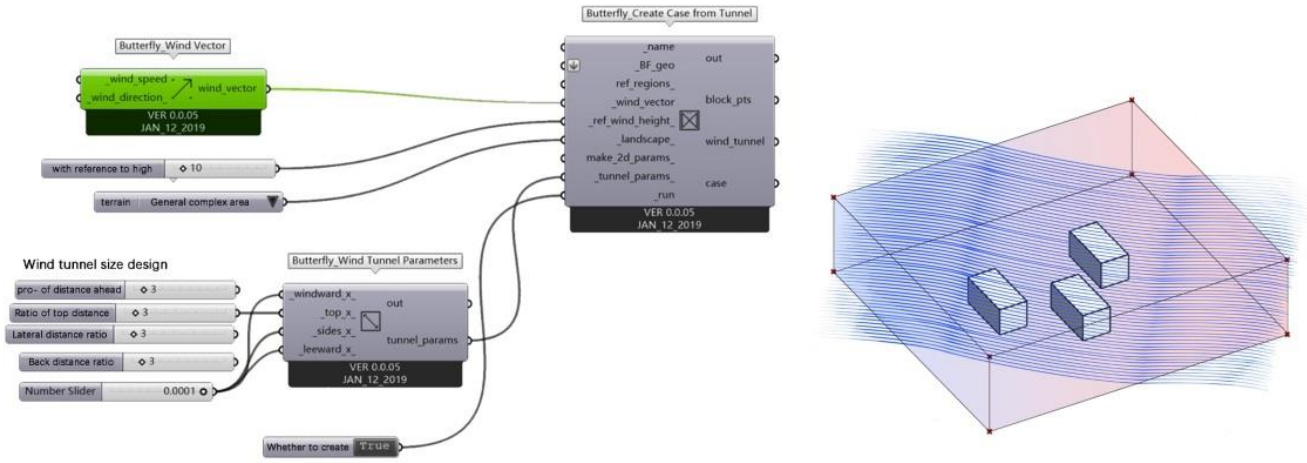


Figure 5. Wind tunnel creation.

A good set of calculation mesh can optimize the calculation process and results. In this study, the critical component of the mesh setup is blockMesh, and the mesh size was set to 80, 80, and 40 on the x, y, and z axes, respectively, with the values set reasonably in conjunction with the size of the overall building form. To precisely simulate the building's outdoor wind environment, the computational mesh was attached to the wall using the fine mesh snappyHexMesh (Figure 6). In contrast, the computational height was set according to the simulation conditions.

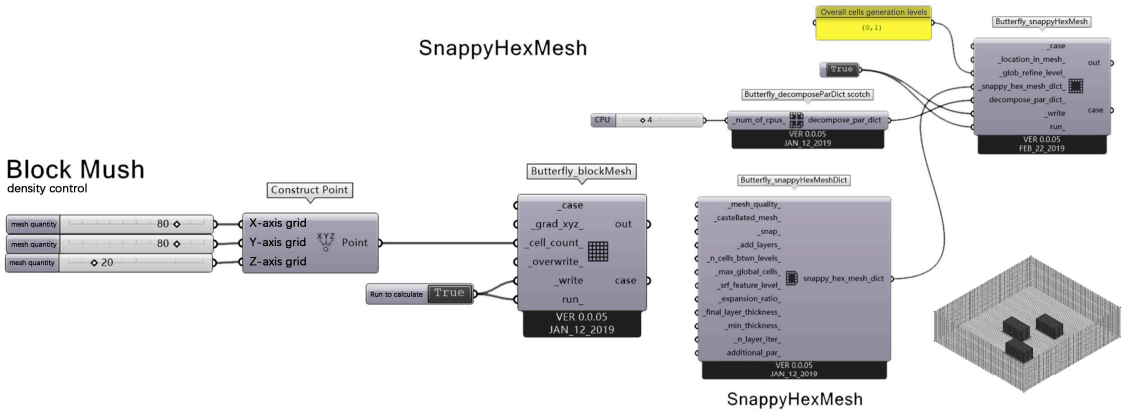


Figure 6. Computing grid.

2.4. Validation

This study used the Architectural Institute of Japan (AIJ)'s standard model of urban-building pedestrian wind environments during the validation phase of the simulation calculation [67] (Figure 7). This standard model has a central building size of 25 m × 25 m × 100 m and a prototype size of 40 m × 40 m × 10 m. The reliability of the wind environment simulation method used in this study was demonstrated by comparing the results of the wind tunnel experiments and Butterfly simulations by selecting 33 sets of test points.

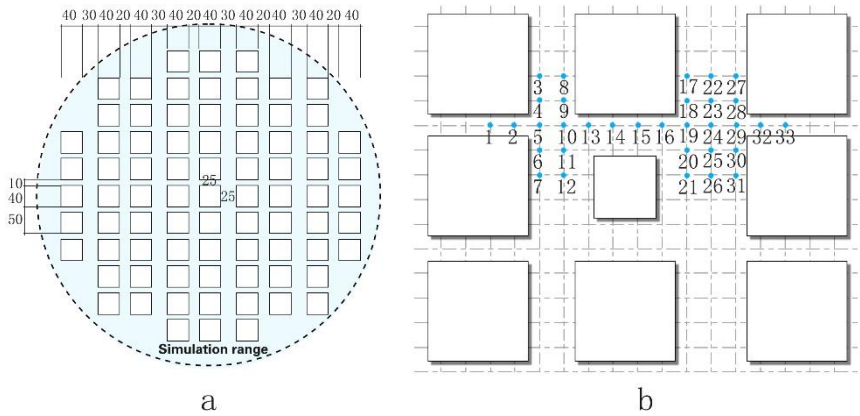


Figure 7. Urban-building pedestrian wind environment mode [67]. (**a**) Plane view of a building model for pedestrian-level wind environment wind tunnel test (unit: m). (**b**) Layout of measuring points for pedestrian-level wind environment.

Based on the relevant literature studies, the wind tunnel tests of the pedestrian wind environment were conducted in the atmospheric boundary layer wind tunnel of the South China University of Technology [68]. The wind velocity was measured at the reference height of 11.3 m/s. A laboratory-made modified Owen wind measured the wind velocity of the pedestrian-height wind environment. The probe was mounted at the height of 5 mm, corresponding to the prototype scale of 1.5 m.

The settings related to the wind environment simulation in Butterfly are shown in the previous section. The test point density was set to 7 on the data recording surface's (generator test point) process settings to correspond to the measurement point location in the wind tunnel simulation experiment. Figure 8 depicts the wind velocity vector clouds generated by the simulation and the extracted simulated wind velocity data from 33 measurement points in the output results.

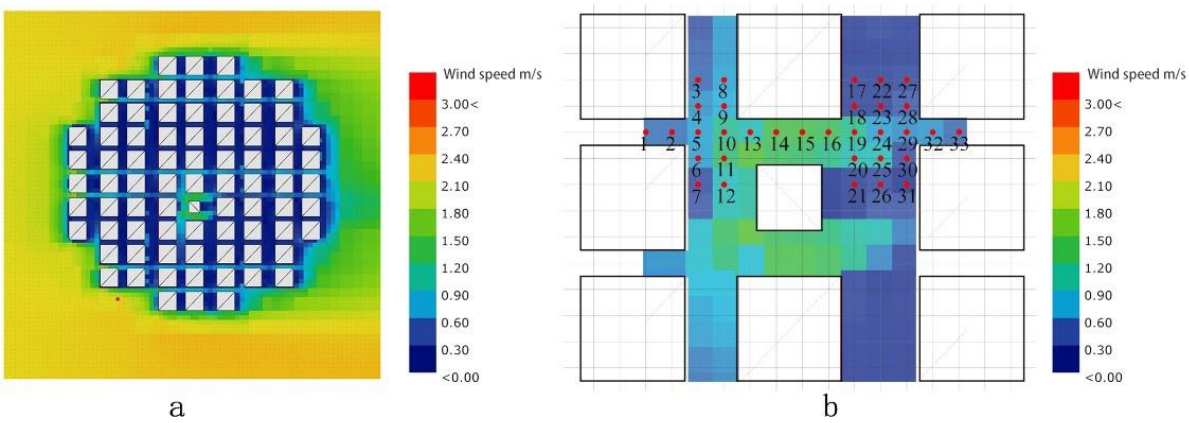


Figure 8. Wind environment simulation of the standard model. (**a**) Wind environment cloud map at 0° direction. (**b**) Wind speed cloud map at test point.

The magnitude of the wind velocity ratio R is defined as the ratio of the measured point wind velocity to the reference wind velocity. It is used to compare the effects that various central building heights and incoming wind angles have on the wind velocity field at pedestrian height near the building. This study shows the wind speed ratio R values of each measurement point obtained from the wind tunnel test and the Butterfly numerical simulation for the standard model at an incoming wind direction angle of 0°, as shown in the Figure 9, where wind1~wind33 represent measurement points 1~33, respectively.

It can be seen that the wind tunnel test and the Butterfly simulation were obtained from the wind speed ratio R-value of each measurement point, with the measurement

point of the overall consistency of the law (Figure 9). The average speed ratio error at each measurement point is approximately 12%, according to the examination of the three groups of indicators: root–mean–square error (RMSE), mean absolute percentage error (MAPE), and R-squared. Errors in CFD simulations, errors in the wind tunnel tests themselves, and errors in the complex turbulence in the near-surface region under realistic conditions were analyzed as the sources of errors between numerical simulations and wind tunnel tests. The following conclusions were obtained:

(1) The wind speed values obtained using computer numerical simulations are usually larger than the measured values. During the measurement process, changes in wind direction, traffic, pedestrian movements, and the surrounding vegetation can all cause the data to be small.
(2) The measured and simulated results are correlated. Under the same wind direction, the wind speed trend over time at each numerical simulation measurement point is consistent with the measured results. Therefore, it is of certain practical significance to use computer simulation software to simulate and analyze the outdoor wind environment in the dormitory area of colleges and universities in relevant areas. It has significant advantages in influencing outdoor wind environments in architectural design.

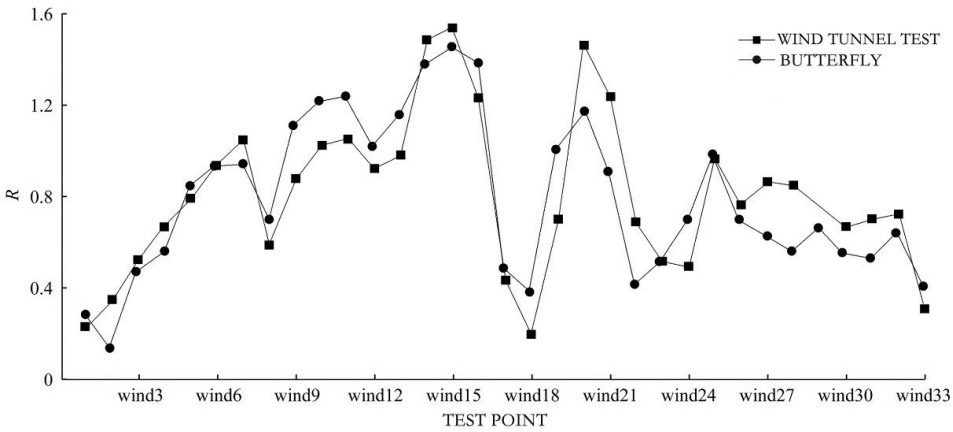


Figure 9. Comparison of Butterfly simulation results with wind tunnel test from Yang Y. et al., 2022 [68].

3. Results

3.1. Ideal Working Conditions and Target Classification

Natural ventilation is one of the crucial objectives in the comprehensive design of buildings as a requirement for evaluating design results; the standard specification also gives recommended values for parameters related to the wind environment. This study analyzes the ideal working conditions for natural ventilation during typical winter and summer seasons.

According to Chinese Green Building Evaluation Standard (GB/T50378-2019) [68], in winter, the wind speed at the height of 1.5 m from the ground in the pedestrian area around buildings is less than 5 m/s, which is an essential requirement that does not affect people's normal outdoor activities. In summer, there should be no vortices or windless areas in the outdoor activity area, as these areas will affect outdoor heat dissipation and pollutant dissipation. The wind pressure difference between indoor and outdoor surfaces greater than 0.5 Pa is conducive to the natural ventilation of the building.

Strong winds can easily raise dust from the ground and cause floating dust, which may contain many irritating substances, bacteria, and viruses. These particles can often cause respiratory diseases, eye diseases, and skin diseases [69]. In winter, excessive wind speeds can also cause a decrease in human comfort, leading to problems such as colds and difficulty breathing [70]. The wind pressure difference between the front and rear of the building is too large, which tends to introduce cold air into the interior of the building

and increase the energy consumption of the heating equipment, which is not conducive to building energy efficiency.

It is worth noting that natural ventilation is necessary and feasible for residential buildings in cold winter regions and is subject to maintaining indoor air hygiene to actively prevent pollution transmission. Furthermore, the results of research on natural ventilation for preventing pollution transmission in cold areas demonstrated this [66,67]. A survey of 600 college students in cold regions of China found that 91.14% of the participants would open windows and ventilate their dormitories during winter [71]. Relevant research results show that when the outdoor environment is slightly cold in winter (0 °C~−3 °C), opening ventilation windows reduces the indoor temperature. However, it is appropriate to open ventilation windows when the small air-supply volume is below 32 m^3/h and the indoor predicted mean vote (PMV) value is basically −0.5 [72]. The average outdoor temperature for the coldest month in Xi'an is −0.35 °C, which is relatively high in the cold regions of northern China. Therefore, when there is a demand for ventilation with open windows in winter, natural ventilation with a low wind pressure difference and a comfortable wind speed should be created quickly. This condition aims to treat indoor pollutant emissions in the winter to reduce heat loss as little as possible.

In architectural design, the four factors of elevated bottom, building layout, window form, and building façade have significant impacts on the wind environment [73–75]. At the beginning of the design process, six standard dormitory building layouts, six building façade forms, and six horizontal relative positions of doors and windows were identified based on previous research on dormitory buildings in northern China (Figure 10) [76–78]. Based on the analysis of wind environment simulation results, the optimal building form combination can be selected. According to relevant research [79,80], it is rare for dormitory buildings in Xi'an to adopt a low-rise overhead design, so this factor has not been considered in this article. The wind environment results were calculated for three influencing factors: building group layout, building opening position, and building façade form. In the ideal model design of this study, thermal pressure ventilation was not considered because the interior space of the dormitory unit is small and low and without multiple openings at different heights. Hence, the impact of thermal pressure ventilation on the interior is minimal.

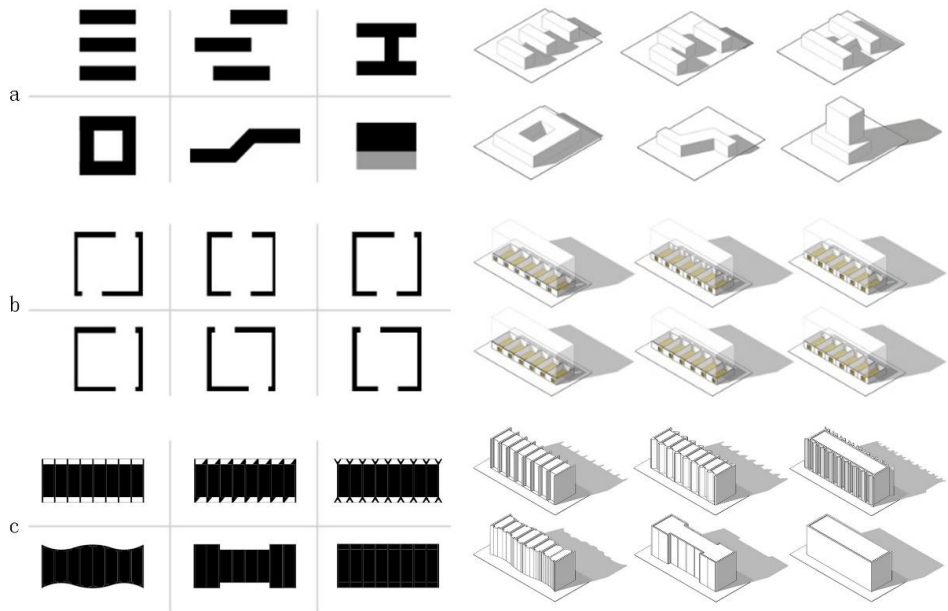


Figure 10. Wind environmental factors. (**a**) Six groups of plane forms and the shape of building layout. (**b**) Six groups of plane forms and the position of the room entrance. (**c**) Six groups of plane forms and shape of building façade form.

3.2. Simulation Calculation

Different from traditional simulations, the results require calculations from different independent models, and modifying and recalculating the models is quite complex. The calculation process in this study is based on the architect's design habit: if the design parameters need to be modified, the geometric modeling shall also change automatically, and the corresponding simulation calculation can be carried out [61].

This study investigated the outdoor wind environment of the dormitory buildings under different layouts and also studies the indoor wind environment of the dormitory rooms. This study selected a calculation area with a height of 1.5 m for simulation analysis. For the outdoor wind environment, based on the layout design of different building groups, this paper selected an area 3 m from the north and south exterior walls of the building and the central location of the layout. These three locations are common active places for pedestrians outside the dormitories. For the indoor wind environment, based on the design of different positions of openings, this paper chooses the door opening, the window opening, and the center of the room for analysis and discussion.

3.2.1. Group 1: Results of the Effect of Building Layout on the Outdoor Wind Environment

Analysis of the simulation shows that

(1) The building layout forms a, b, e, and f do not have windless or swirling areas in the summer climate. Additionally, the site's average wind speed in types a and b are 1.335 m/s and 1.3 m/s. The wind pressure difference within the group b layout site is 4.699 Pa, and the outdoor site can form a permeable, cool, and continuous wind environment. The maximum wind speed can reach 1.8 m/s, significantly improving the site's environmental comfort (Figure 11, Table 2).

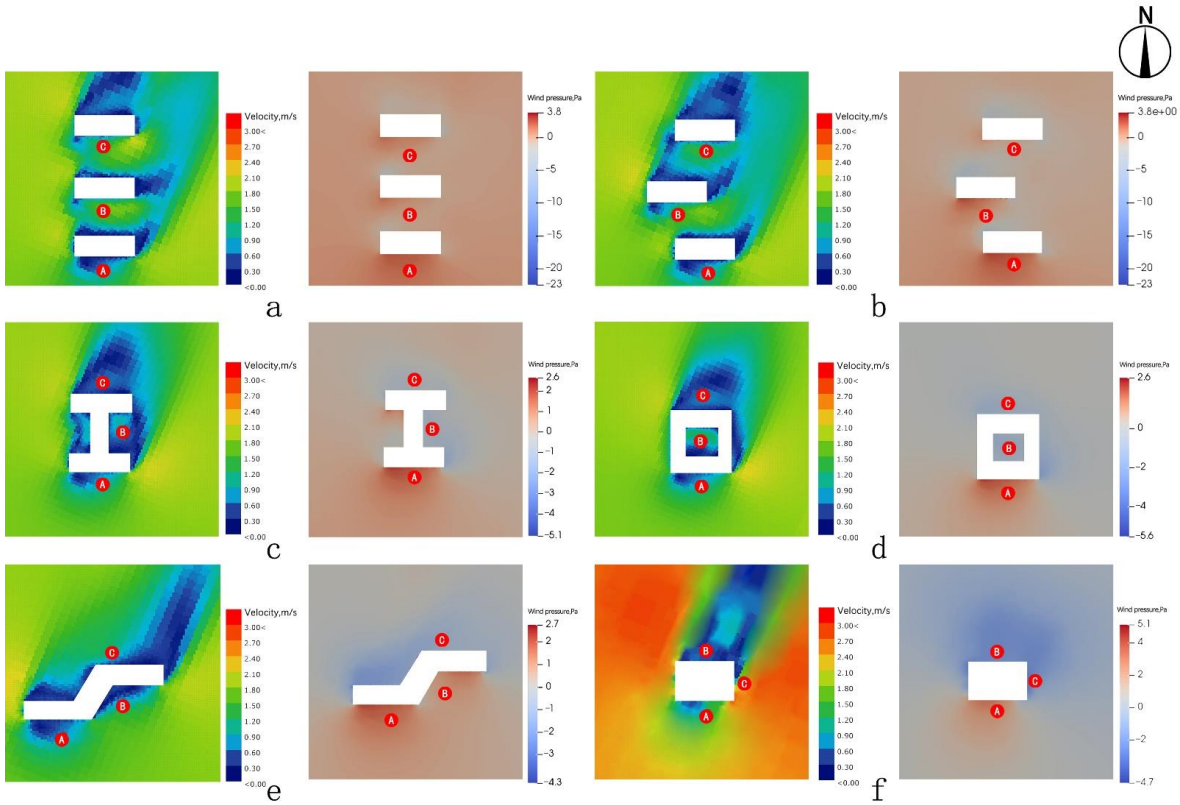


Figure 11. Impacts of different building layouts of Group 1 on wind environment during typical summer periods. (**a**) Arrangement layout. (**b**) Staggered layout. (**c**) I-shaped layout. (**d**) I-shaped layout. (**e**) Fold-line layout. (**f**) High-rise layout.

(2) In the winter environment, types a, b, and f of the building layout do not contain vortex or wind-free zones. Types c, d, and e of the layout form, where wind-free or vortex zones are found in particular areas, are not considered because they are likely to extend the time pollutants spend in the site. The site's average wind speeds in layout types a and b are 0.935 m/s and 1.099 m/s, which are basically in a breeze or no-wind state. The wind pressure difference in type b is higher than in type a, which can form ventilation quickly. The layout of this group can meet the reasonable working conditions and prevention and control requirements of ventilation in winter (Figure 12, Table 3).

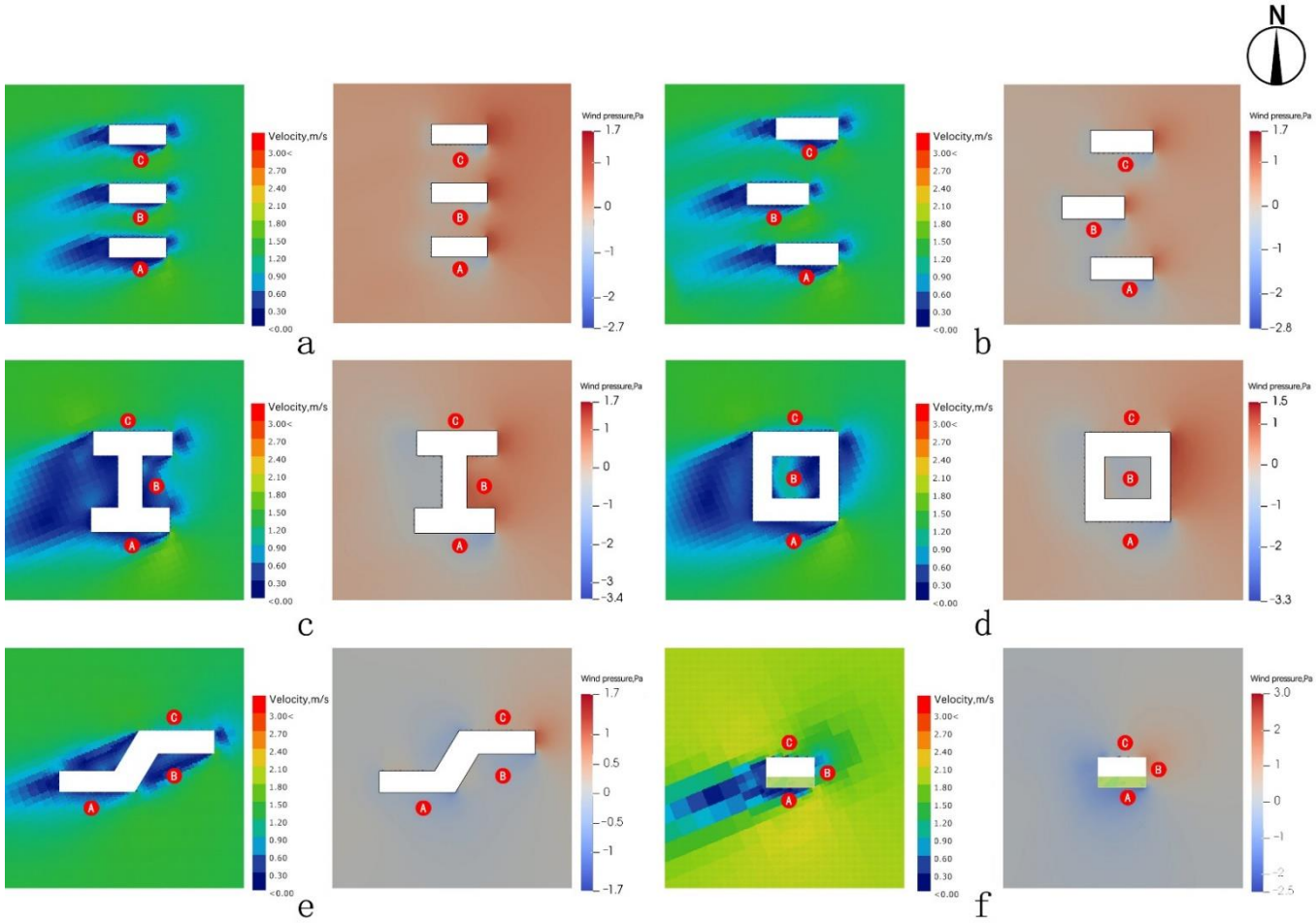


Figure 12. Impacts of different building layouts of Group1 on wind environment during typical winter periods. (**a**) Arrangement layout. (**b**) Staggered layout. (**c**) I-shaped layout. (**d**) I-shaped layout. (**e**) Fold-line layout. (**f**) High-rise layout.

Table 2. The output of the impact of building layout on the wind environment in typical summer periods.

Building Layout	a	b	c	d	e	f
wind at A (unit: m/s)	0.883	0.974	1.153	1.132	0.952	1.123
wind at B (unit: m/s)	1.812	1.362	0.795	1.161	1.141	0.781
wind at C (unit: m/s)	1.335	1.567	1.773	1.765	1.282	1.973
wind pressure at A (unit: Pa)	−1.275	2.994	1.753	1.765	1.284	1.678
wind pressure at B (unit: Pa)	0.865	0.857	−1.865	−1.526	0.865	−2.765
wind pressure at C (unit: Pa)	1.735	−1.695	−0.595	−1.438	−1.702	−1.792

a: Arrangement layout. b: Staggered layout. c: I-shaped layout. d: I-shaped layout. e: Fold-line layout. f: High-rise layout.

Table 3. The output of the impact of building layout on the wind environment in typical winter periods.

Building Layout	a	b	c	d	e	f
wind at A (unit: m/s)	0.373	0.964	0.953	0.932	0.971	0.921
wind at B (unit: m/s)	1.202	1.072	0.594	1.161	0.641	1.271
wind at C (unit: m/s)	1.231	1.264	1.553	1.876	1.282	1.973
wind pressure at A (unit: Pa)	−0.594	−0.675	−0.567	−0.385	−0.584	−1.356
wind pressure at B (unit: Pa)	−0.125	−0.365	1.265	0.426	−0.265	1.269
wind pressure at C (unit: Pa)	0.105	0.085	0.305	0.238	0.435	1.802

a: Arrangement layout. b: Staggered layout. c: I-shaped layout. d: I-shaped layout. e: Fold-line layout. f: High-rise layout.

3.2.2. Group 2: The Influence of the Opening Position of Building Windows and Doors on the Indoor Wind Environment

The simulation's analysis reveals that

(1) Due to the high temperature in summer in Xi'an, the maximum temperature and maximum air velocity that satisfy the comfort of the human body increase in dormitories without air conditioning [68,81–83]. The average indoor wind speed of the door and window openings of layouts in types a and b can reach above 1.2 m/s, which meets the recommended comfortable wind speed of under 1.5–2 m/s in the literature. In addition, the wind pressure difference between the interior and exterior of the opening is 0.83 Pa, which meets the requirement of realizing better natural ventilation with the wind pressure greater than 0.5 Pa [68]. Therefore, type a performs best in an indoor wind environment in summer. In the actual-use scenario, internal and external ventilation can be achieved by opening the windows. In the dormitory without an HVAC system in hot summers, this arrangement can significantly improve the intake air volume and comfort of the room (Figure 13, Table 4).

(2) As shown in Figure 14 and Table 5, although the indoor wind environment of type a of Group 2 (axisymmetric openings) performs well in summer, after opening doors and windows in winter, the interior wind speed distribution is not uniform, and the airflow velocity gradient is large. The average indoor wind speed in winter is 1.163 m/s (>1 m/s [81]), which will let the user have a strong sense of breeze. In winter, a wind pressure difference of 0.7 Pa (>0.5 Pa [68]) between indoor and outdoor wind environments causes strong cold air penetration, which has a significant influence on indoor comfort. Combined with the actual use, this study optimizes the design on this basis so that the dormitory can meet the wind environment requirements in winter and summer.

Table 4. The output of the influence of door and window openings on wind environment in a typical summer period.

Opening Location	a	b	c	d	e	f
wind at A (unit: m/s)	1.572	1.573	1.582	1.829	1.876	1.597
wind at B (unit: m/s)	1.241	1.181	0.965	0.976	0.487	0.806
wind at C (unit: m/s)	0.978	1.252	0.775	0.952	0.752	0.458
wind pressure at A (unit: Pa)	−0.674	−0.565	−0.356	−0.136	−0.256	−0.189
wind pressure at B (unit: Pa)	0.153	−0.758	−0.196	−0.335	0.168	−0.068
wind pressure at C (unit: Pa)	−0.126	−0.157	−0.165	−0.105	−0.067	0.076

a: Axisymmetric form. b: Left window and right door form. c: Left window and middle door form. d: Right symmetric form. e: Right window and middle door form. f: Right window and left door form.

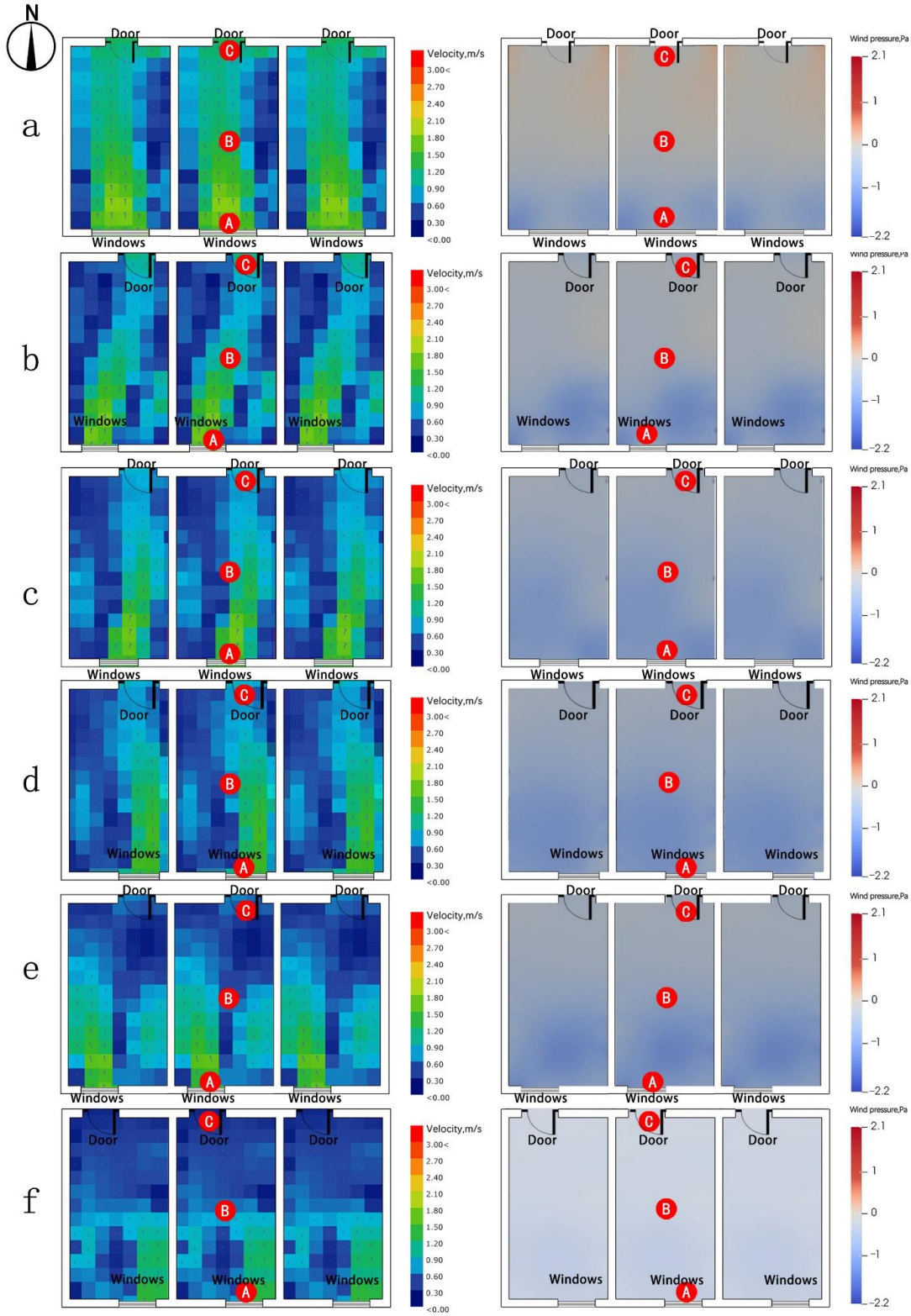


Figure 13. Impacts of different layouts of Group 2 (doors and windows) on wind environment during typical summer periods. (**a**) Axisymmetric form. (**b**) Left window and right door form. (**c**) Left window and middle door form. (**d**) Right symmetric form. (**e**) Right window and middle door form. (**f**) Right window and left door form.

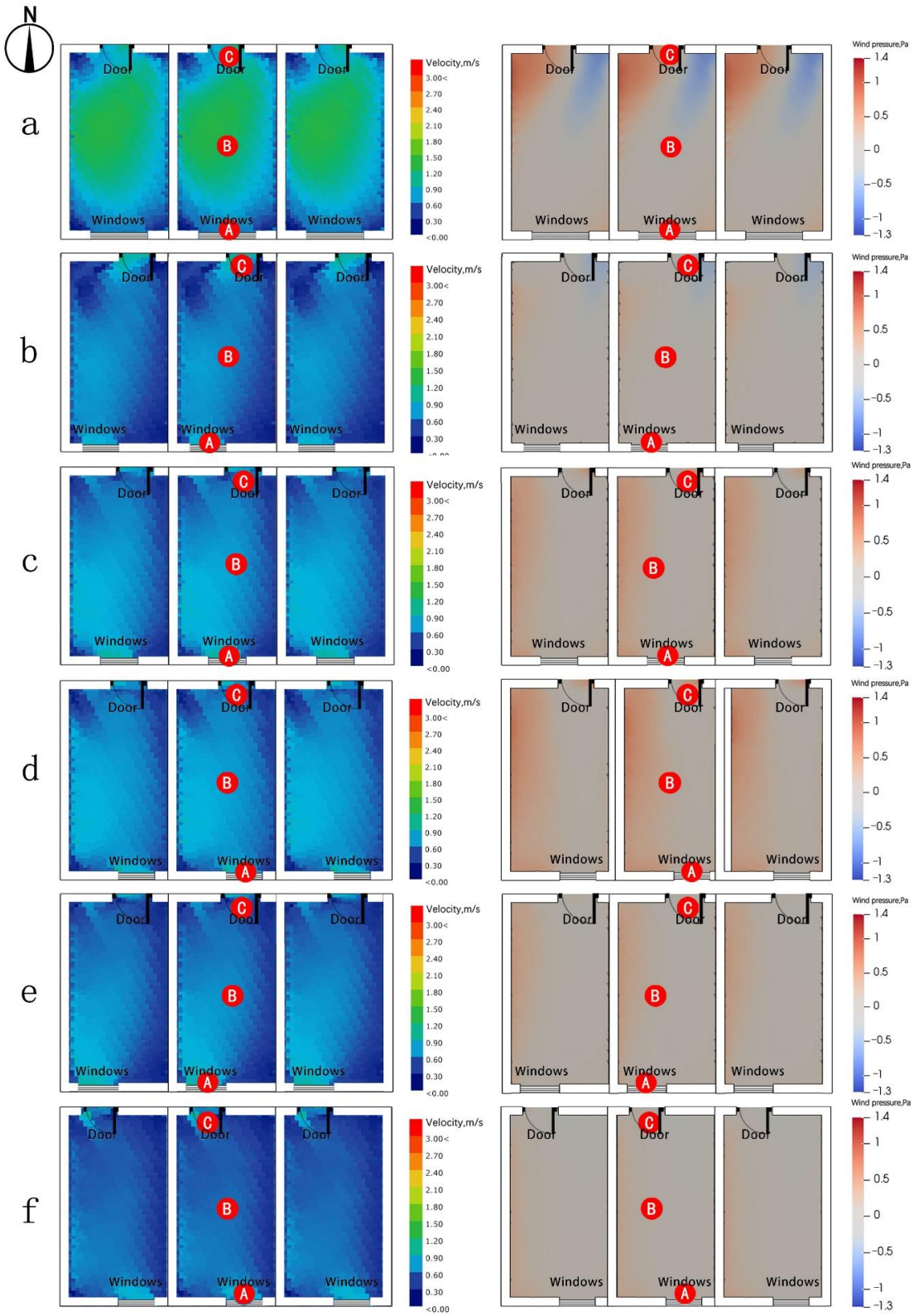


Figure 14. Impacts of different layouts of Group 2 (doors and windows) on wind environment during typical winter periods. (**a**) Axisymmetric form. (**b**) Left window and right door form. (**c**) Left window and middle door form. (**d**) Right symmetric form. (**e**) Right window and middle door form. (**f**) Right window and left door form.

Table 5. The output of the influence of door and window openings on wind environment in the typical winter period.

Opening Location	a	b	c	d	e	f
wind at A (unit: m/s)	0.972	0.973	0.965	0.976	0.927	0.797
wind at B (unit: m/s)	1.258	0.567	0.865	0.952	0.722	1.258
wind at C (unit: m/s)	1.261	1.265	1.282	1.292	1.156	1.306
wind pressure at A (unit: pa)	−0.256	0.025	0.165	−0.375	−0.256	−0.155
wind pressure at B (unit: pa)	−0.145	−0.124	0.202	0.254	0.425	0.560
wind pressure at C (unit: pa)	0.245	−0.014	0.135	−0.279	0.156	−0.060

a: Axisya: Axisymmetric form. b: Left window and right door form. c: Left window and middle door form. d: Right symmetric form. e: Right window and middle door form. f: Right window and left door form.

3.2.3. Group 3: Influence of Building Façade (Form and Spoiler) on the Outdoor Wind Environment

This study makes a comparative analysis of the wind environment under the influence of different building façade forms. There are three types of façades, composed of vertical rectangular components, triangular components, and diagonal folded components, as well as three types of façade forms with curved, concave, and flush shapes (Figure 10). The simulation results of the wind environment are as follows.

Analysis of the simulation shows that

(1) The building façade forms or spoilers affect the building wind environment. In the summer climatic environment, façade form types b and f have a guiding effect on the wind direction due to the addition of spoilers in the same direction as a southeast wind in summer. Average wind speeds of 1.325 m/s and 1.36 m/s can be achieved, which are optimal. At the same time, all types in the above design achieved a wind pressure difference above the standard 0.5 Pa requirement (Figure 15, Table 6).

(2) In the winter climate, when natural ventilation is required inside, the difference in air pressure between types a and b is less than 5 Pa and greater than 0.5 Pa, allowing for the quickest possible replacement of indoor and outdoor air. In comparison, the lower air pressure difference prevents the rapid entry of cold air and improves comfort in winter under natural ventilation conditions (Figure 16, Table 7).

Table 6. The output of the wind environment impact results of building façade in a typical summer period.

Building Façade Form	a	b	c	d	e	f
wind at A (unit: m/s)	1.753	1.256	1.274	1.343	1.032	1.532
wind at B (unit: m/s)	1.323	1.844	1.135	1.235	1.136	1.322
wind at C (unit: m/s)	0.457	0.875	0.845	0.996	0.972	1.246
wind pressure at A (unit: Pa)	0.495	0.265	0.465	0.275	1.365	0.487
wind pressure at B (unit: Pa)	0.156	−0.105	0.177	−0.146	0.244	−0.142
wind pressure at C (unit: Pa)	−0.488	−0.315	−0.563	−0.676	−0.456	−0.302

a: Rectangular strip. b: Triangular folded plates. c: Chamfered folded plates. d: Wave façade. e: Concave building form. f: Plane building form.

Table 7. The output of building vertical wind environmental impact results in the typical winter period.

Building Façade Form	a	b	c	d	e	f
wind at A (unit: m/s)	0.432	0.663	0.643	0.376	0.623	0.643
wind at B (unit: m/s)	1.323	1.253	1.165	1.025	1.246	1.345
wind at C (unit: m/s)	1.545	1.351	1.576	1.243	1.323	1.231
wind pressure at A (unit: Pa)	−0.246	−0.223	−0.245	−0.235	−0.223	−0.373
wind pressure at B (unit: Pa)	−0.156	−0.376	−0.156	−0.443	−0.123	−0.236
wind pressure at C (unit: Pa)	0.365	0.446	0.125	0.102	0.275	0.125

a: Rectangular strip. b: Triangular folded plates. c: Chamfered folded plates. d: Wave façade. e: Concave building form. f: Plane building form.

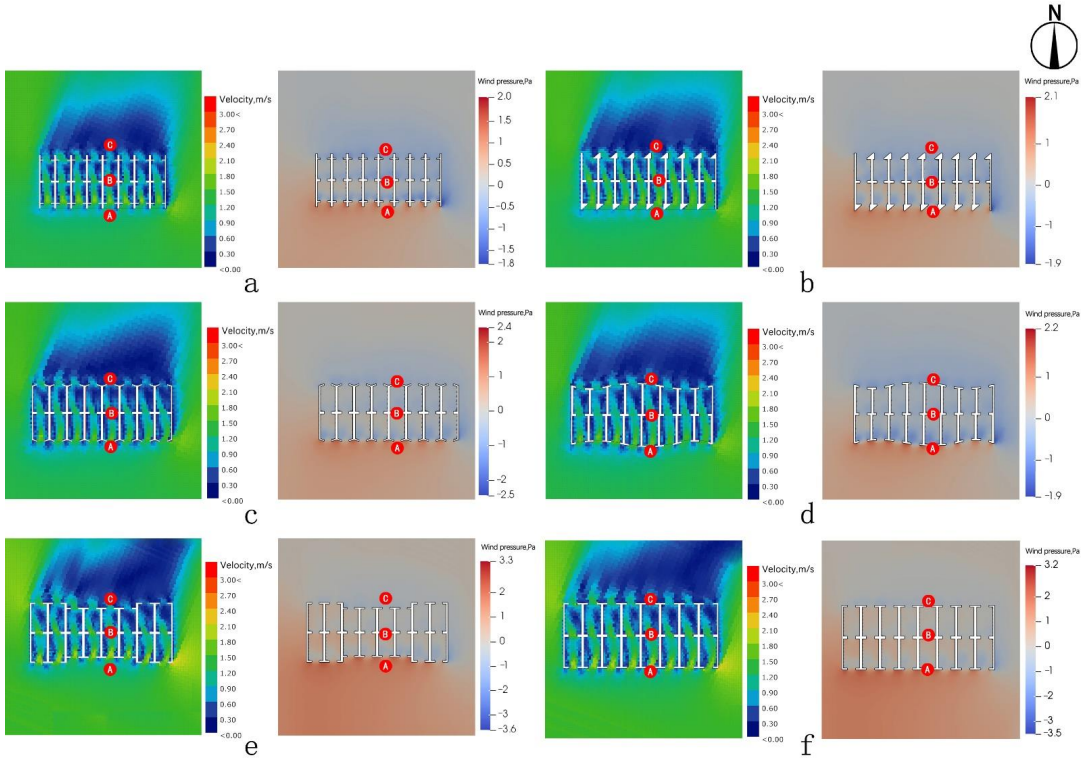


Figure 15. Impacts of wind on different building façades of Group 3 during typical summer periods. (**a**) Rectangular strips. (**b**) Triangular folded plates. (**c**) Chamfered folded plates. (**d**) Wave façade. (**e**) Concave building form. (**f**) Plane building form.

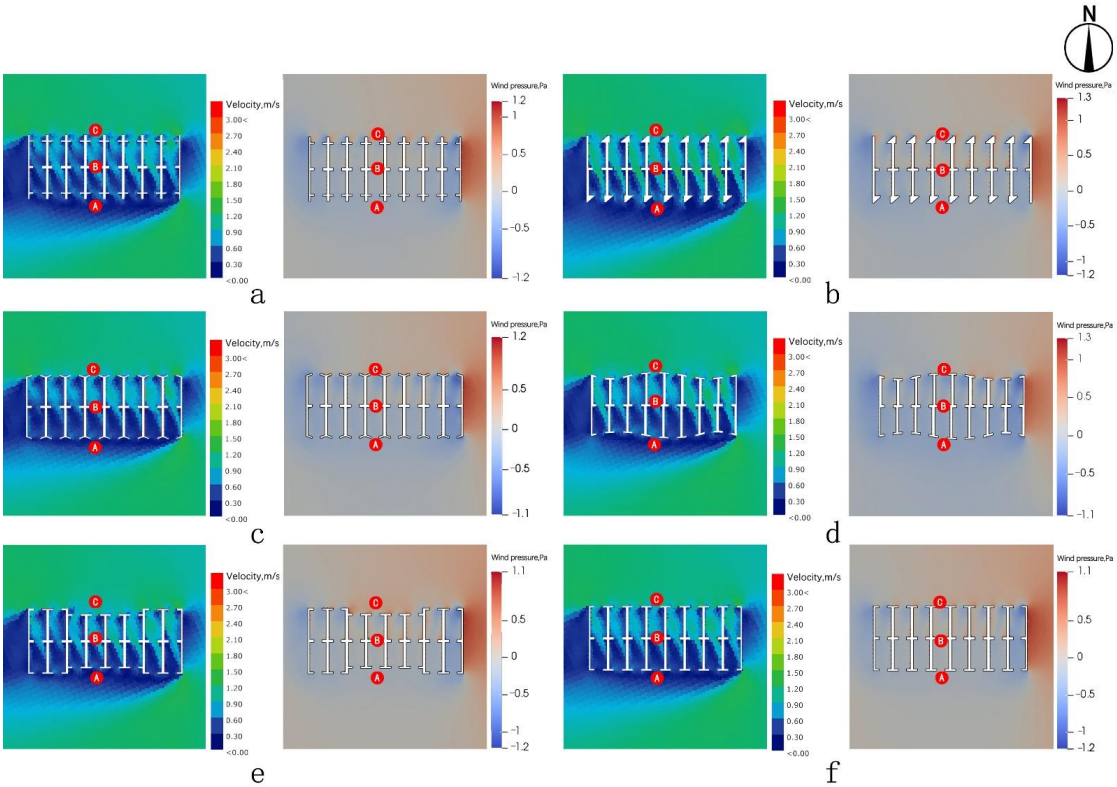


Figure 16. Impacts of wind on different building façades of Group 3 during typical winter periods. (**a**) Rectangular strips. (**b**) Triangular folded plates. (**c**) Chamfered folded plates. (**d**) Wave façade. (**e**) Concave building form. (**f**) Plane building form.

4. Discussion

4.1. The Effect of Building Layout on the Wind Environment

The ideal conditions of summer wind environments in cold areas should meet the relevant requirements of wind environments in the Green Building Evaluation Standard [68]. Under this standard, there must be no vortex or wind area in the pedestrian activity area of the site at the typical summer wind speed. Moreover, the wind pressure difference between the indoor and outdoor surfaces should be greater than 0.5 Pa. The wind speed at a height of 1.5 m within the pedestrian area around the building should be less than 5 m/s in winter. Furthermore, the wind speed in an outdoor rest area and children's entertainment area should be less than 2 m/s. Except for the first row of windward buildings, the wind pressure difference between the windward and leeward sides of the building should not be greater than 5 Pa. According to relevant studies, wind speeds ranging from 1 m/s to 5 m/s shall provide good occupant comfort. When the wind speed ranges from 1.5 to 3.3 m/s, it is suitable for people to conduct behavioral activities for a long time [84]. The comparisons between the simulation results of wind speed and wind pressure and relevant standards are shown in Figures 17 and 18.

The above wind environment simulation results were analyzed in conjunction with the actual use of the building. For the outdoor wind environment in summer, the traditional layout of low-rise buildings, such as types a or b of Group 1, with the uniform arrangement, helps to reduce the area of the static vortex zone. The average outdoor wind speed in summer is around 1.3~1.4 m/s, and the highest wind speed is 1.8 m/s, which conforms to the requirement proposed in related studies that comfortable outdoor wind speeds in cold regions in the summer are lower than 2.2 m/s [84]. The summer indoor wind performance of type a of Group 1 is optimal. According to the analysis of the indoor wind environment in summer, under the condition that doors and windows are fully opened for natural ventilation in summer, the indoor wind-field distribution of the layout of type a of Group 1 is reasonable. Its average wind speed is consistent with the relevant range of human thermal comfort in Xi'an under natural ventilation in summer [81]. The wind pressure difference between inside and outside the entrance is greater than 0.5 Pa, which satisfies the condition of good natural ventilation. The summer indoor wind performance of type a of Group 1 is optimal.

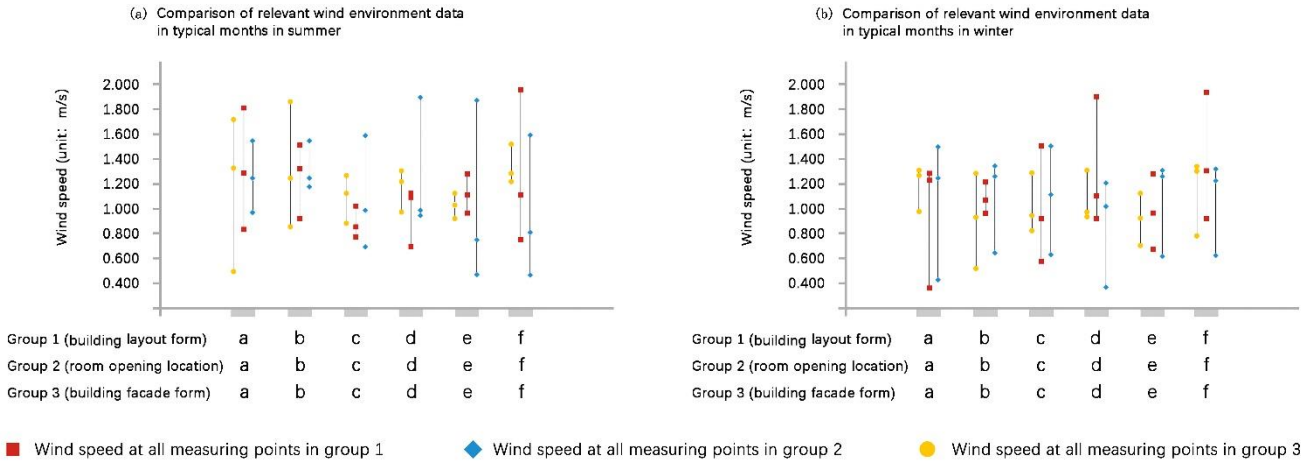


Figure 17. Comparison of wind speed simulation results and standard in typical summer periods. (**a**) Typical summer periods. (**b**) Typical winter period. For Group 1: a: Arrangement layout. b: Staggered layout. c: I-shaped layout. d: I-shaped layout. e: Fold-line layout. f: High-rise layout. For Group 2: a: Axisymmetric form. b: Left window and right door form. c: Left window and middle door form. d: Right symmetric form. e: Right window and middle door form. f: Right window and left door form. For Group 3: a: Rectangular strip. b: Triangular folded plates. c: Chamfered folded plates. d: Wave façade. e: Concave building form. f: Plane building form.

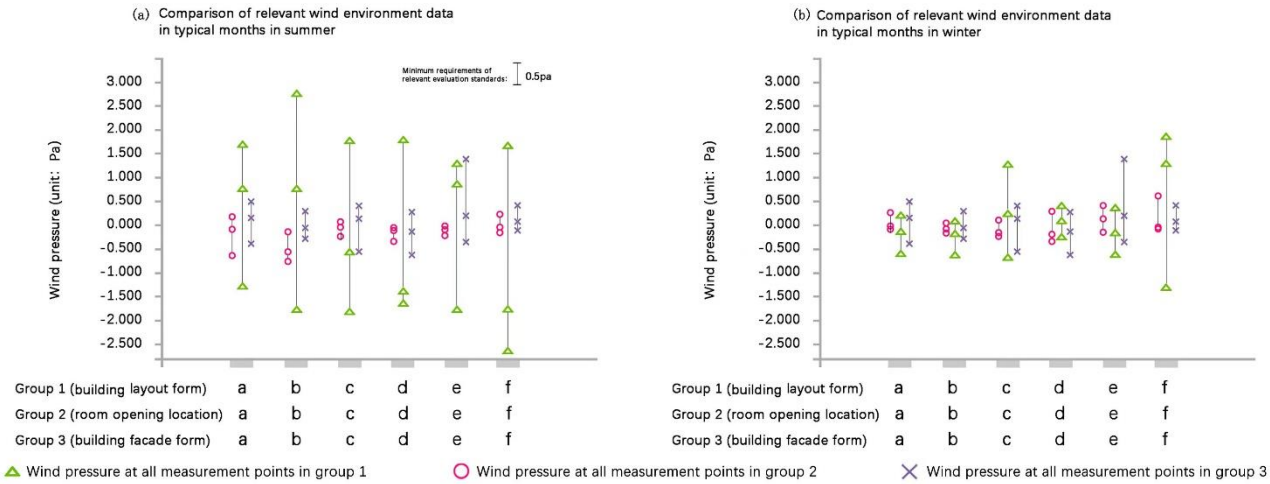


Figure 18. Comparison of simulation results of wind pressure in the typical summer period with standard. (**a**) Typical summer period. (**b**) Typical winter period. For Group 1: a: Arrangement layout. b: Staggered layout. c: I-shaped layout. d: I-shaped layout. e: Fold-line layout. f: High-rise layout. For Group 2: a: Axisymmetric form. b: Left window and right door form. c: Left window and middle door form. d: Right symmetric form. e: Right window and middle door form. f: Right window and left door form. For Group 3: a: Rectangular strip. b: Triangular folded plates. c: Chamfered folded plates. d: Wave façade. e: Concave building form. f: Plane building form.

The winter temperature outside is low in cold areas. When the dormitory needs natural ventilation, indoor and outdoor air exchange should be carried out quickly, reducing the cold-air penetration to discomfort. According to the analysis of the outdoor wind environment in winter, in type b of Group 1, the low-rise building blocks are staggered, and the outdoor wind speed at pedestrian height meets the requirements of winter (less than 5 m/s [68]). The wind pressure difference between the windward and leeward surfaces of the building also meets the requirement of less than 5 Pa [68]. In type b of Group 3, triangular folded spoilers combine the building façade with the dominant wind direction, which is conducive to bringing air into the room for rapid air displacement. According to the analysis of the indoor wind environment in winter, type a of Group 2 with axisymmetric openings has the best summer indoor wind performance. In winter, after the doors and windows are opened, the average indoor wind speed is too high and possesses a large gradient, which can easily cause cold air penetration and an uncomfortable draught sensation. Therefore, type a in Group 2 needs to be improved.

Combined with the above analysis, the type b layout of Group 1 (low-rise building, staggered) has the best outdoor wind environment performance. Type a of Group 2 (interior doors and windows with axisymmetric form) had the optimal indoor natural ventilation effect in summer but did not perform well in winter. Type b of Group 3 (triangular folded plate) is the best spoiler façade shape for wind environment performance. In Section 4.2, the optimization design shall combine the above three types of models with adding buffer space in the interior space to optimize and adjust the design of a good wind environment, both in winter and summer.

4.2. Optimized Design Solution

An optimized design solution under the influence of the wind environment is proposed following the comparison and consideration of the above conditions and analysis results. Figure 19 depicts this design's indoor and outdoor wind environment vector diagrams for typical winter and summer times. The simulated data of wind speed and pressure are shown in Tables 8 and 9.

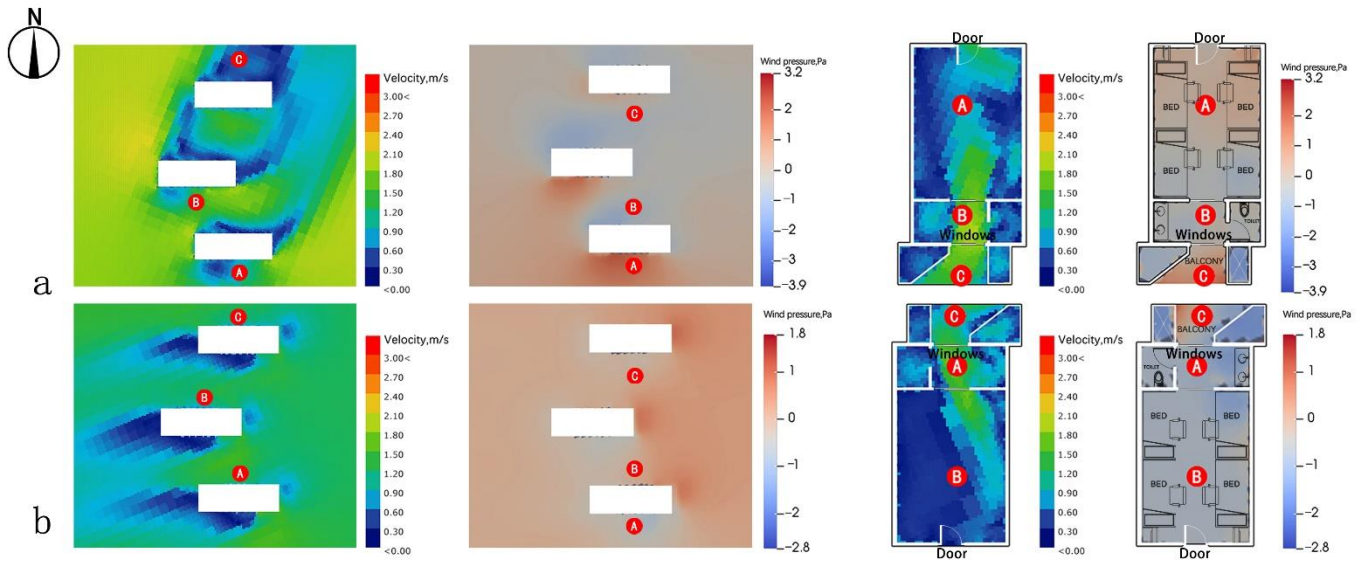


Figure 19. The output of simulation results of the optimization design. (**a**) Simulation results of indoor and outdoor wind environment in a typical summer period. (**b**) Simulation results of indoor and outdoor wind environment in a typical winter period.

Table 8. Wind speed simulation results.

Test Point	A	B	C	Average Value
summer field wind speed (unit: m/s)	1.277	1.545	1.328	1.383
winter field wind speed (unit: m/s)	1.275	1.505	1.465	1.415
room wind speed in summer (unit: m/s)	1.203	1.775	1.596	1.525
room wind speed in winter (unit: m/s)	1.526	0.408	0.338	0.757

Test Point "A", "B" and "C" as shown in Figure 19.

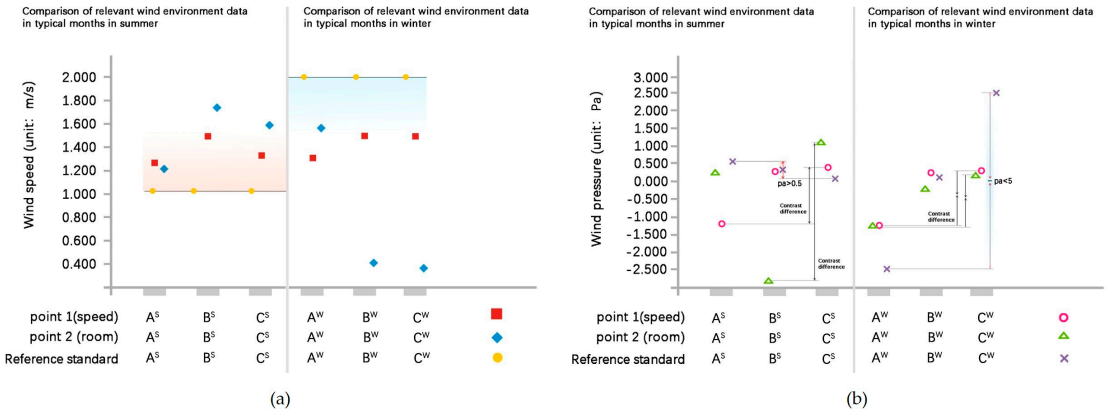
Table 9. Wind pressure simulation results.

Test Point	A	B	C	Average Value
summer site wind pressure (unit: Pa)	−1.254	0.243	0.412	1.666
winter site wind pressure (unit: Pa)	−1.235	0.156	0.276	1.511
room wind pressure in summer (unit: Pa)	0.234	−0.323	1.012	1.335
room wind pressure in winter (unit: Pa)	−1.206	−0.195	0.184	1.390

Test Point "A", "B" and "C" as shown in Figure 19.

The results of the optimized solution are shown in Figure 20. According to the study's results, no wind-free or swirling zones were observed in this type of building layout in the summer climate, and the average wind speed in the site was 1.383 m/s, which is a good wind speed effect. In summer, the room's average wind speed can reach 1.525 m/s, which is a high level of environmental comfort. The wind pressure difference within the site is 1.66 Pa, and the wind pressure difference at the interior window openings is 1.335 Pa. All values can reach above the standard requirements, so the indoor and outdoor spaces of the building can form a permeable, cool, and continuous wind environment characteristic in summer. The indoor and outdoor spaces in winter can still meet the wind environment standard requirements. According to the simulation results, the living room balcony or bathroom has the highest wind speed and wind pressure difference during the winter. The average wind speed and average wind pressure difference in the living space can be maintained at around 0.3 m/s and 0.4 Pa, respectively, which is basically in a windless state and plays a good role in heat preservation. With an average wind speed of 1.5 m/s and a wind pressure of 1.2 Pa, the living space's wind environment can remove pollutants and keep the area dry and clean. The optimized design solution provides a comfortable

and livable overall wind environment, with proper natural ventilation and wind avoidance bringing a comfortable space environment that is warm in winter and cool in summer. Based on the postepidemic period's impact on the environment, the building supposedly needs to be ventilated for a short time in the winter. In this case, it can also bring a gentle and comfortable natural breeze to avoid strong winds. As a result, the level of comfort rises while ensuring the space is safe and clean.



(a) (b)

Figure 20. Comparison of simulation results of optimization scheme with standard. (**a**) Wind speed. (**b**) Wind pressure. A^S: Test A in summer, B^S: Test B in summer, C^S: Test C in summer. A^W: Test A in winter, B^W: Test B in winter, C^W: Test C in winter.

4.3. Limitations

- The opening size of the building is a critical factor affecting the indoor environment. However, due to the relatively fixed and modular dimensions of the campus dormitory's doors and windows, this study does not consider the size of opening. Based on meeting the relevant national regulations (such as the requirements of energy saving and lighting), the selected opening dimension modulus is more common in the dormitory in the cold area of northern China. In future research, the influence of different opening sizes shall be investigated.
- The form and layout of university dormitory buildings studied in this paper are idealized models. For example, this paper sets the university dormitory buildings to a uniform height, and then predicts and analyzes the wind environment for typical cases. In practical projects, the form and layout will be more complex and need to be analyzed dynamically.
- This paper mainly studies the orientation and form of individual buildings and the layout and orientation of group buildings but does not consider other influencing factors of university dormitories, such as human behavior patterns (e.g., the habit of opening and closing doors/windows), plants outside the dormitory area, undulation of the terrain, and so on. To accurately assess and predict the wind environmental performance of university dorms, additional influencing factors must be considered in future research.
- This paper only studied the wind environment of university dormitory buildings in Xi'an in summer and winter and did not simulate the wind environment in other seasons. In addition, this study does not consider the natural ventilation situation when the HVAC system is turned on. Future research shall comprehensively consider the wind environment of these scenarios, so that university dormitories can be analyzed and optimized more reasonably and accurately.

5. Conclusions

In this study, a digital 3D model was first established according to the actual situation, and CFD quantitative simulations were carried out to analyze the outdoor and indoor

wind environments. The simulation results were used to optimize and verify the dormitory building's design. From this study, the following conclusions are drawn.

- For outdoor wind environments, the staggered layout of low-rise dormitory buildings (Type b of Group 1) performs best. For indoor wind environments, the layout of axisymmetric openings (Type a of Group 2) has optimal natural ventilation in summer but needs improvement in winter. The façade composed of triangular folded plate components (Type b of Group 3) has the most positive impact on the overall wind environment.
- In cold areas with lower outdoor temperatures in winter, campus dormitories can use balconies and bathrooms to form buffer spaces for wind protection and insulation. The design of the spoiler, combined with the dominant wind direction, can effectively promote the performance of the building's wind environment.
- In this article, architect-friendly simulation software was chosen for the wind environment simulation. The simulation process during the simulation phase was optimized to significantly reduce the multiobjective calculation time traditionally performed by software, thereby helping architects reduce the design time.

Under the influence of many factors, the design of buildings is diverse. The influence of environmental wind factors is a measure of human comfort and is an essential index of a building's environmental safety. Design methods and supporting tools that are comprehensive, up-to-date, and simple to use are essential for architects. Parameterized design platforms and techniques for architects should be combined with their knowledge base and design habits in future research. We should not only pay attention to the influence of the building's ventilation on single-factor objectives but should also consider the optimization of multiobjectives and ensure that the building has the ability to adapt to the environment and adjust its performance quickly.

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References

1. Li, H.; Li, X.; Qi, M. Field testing of natural ventilation in college student dormitories (Beijing, China). *Build. Environ.* **2014**, *78*, 36–43. [CrossRef]
2. Ratcliff, M.A.; Peterka, J.A. Comparison of pedestrian wind acceptability criteria. *J. Wind Eng. Ind. Aerodyn.* **1990**, *36*, 791–800. [CrossRef]
3. Davenport, A.G. An approach to human comfort criteria for environmental wind conditions. In Proceedings of the Colloquium on Building Climatology, Stockholm, Sweden, 4–6 September 1972.
4. Eltaweel, A.; Su, Y. Controlling venetian blinds based on parametric design; via implementing Grasshopper's plugins: A case study of an office building in Cairo. *Energy Build.* **2017**, *139*, 31–43. [CrossRef]
5. Sung, W.; Jeong, Y. Site planning automation of apartment complex through grid-based calculation in grasshopper. *Autom. Constr.* **2022**, *138*, 104216. [CrossRef]

6. Ma, Y. Study on the Outdoor Wind Environment Comfort of University Dormitory Area in Xi'an Area under the Goal of Environmental Livability. Master's Thesis, Chang'an University, Xi'an, China, 2022. [CrossRef]
7. Yang, L.; Liu, X.; Sun, B. Building wind environment research progress. *Build. Sci.* **2018**, *34*, 147–156.
8. Li, Y.; Deng, Y.; Li, A.; Xu, T. During tower of wind pressure distribution of wind tunnel experiment and CFD simulation. *J. Build. Struct.* **2022**, *43*, 81–91. [CrossRef]
9. Chen, Q. Ventilation performance prediction for buildings: A method overview and recent applications. *Build. Environ.* **2009**, *44*, 848–858. [CrossRef]
10. Ju, P.; Li, M.; Wang, J. Review of Research Advances in CFD Techniques for the Simulation of Urban Wind Environments. *FDMP Fluid Dyn. Mater. Process.* **2022**, *18*, 449–462. [CrossRef]
11. 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]
12. Toparlar, Y.; Blocken, B.; Maiheu, B.; van Heijst, G. A review on the CFD analysis of urban microclimate. *Renew. Sustain. Energy Rev.* **2017**, *80*, 1613–1640. [CrossRef]
13. Guo, H.; Zhou, Y.; Li, Y.; Zhang, Z.; Li, H. An Experiment-Based Simplified Method for the Model of Building Groups in CFD Simulation. *Adv. Civ. Eng.* **2021**, *2021*, 8811684. [CrossRef]
14. Marzullo, T.; Keane, M.M.; Geron, M.; Monaghan, R.F. A computational toolchain for the automatic generation of multiple Reduced-Order Models from CFD simulations. *Energy* **2019**, *180*, 511–519. [CrossRef]
15. Cuce, E.; Sher, F.; Sadiq, H.; Cuce, P.M.; Guclu, T.; Besir, A.B. Sustainable ventilation strategies in buildings: CFD Rwesearch. *Sustain. Energy Technol. Assess.* **2019**, *36*, 100540.1–100540.10. [CrossRef]
16. Gadyszewska-Fiedoruk, K.; Zhelykh, V.; Pushchinskyi, A. Simulation and Analysis of Various Ventilation Systems Given in an Example in the Same School of Indoor Air Quality. *Energies* **2019**, *12*, 2845, Retracted *Energies* **2021**, *14*, 4932. [CrossRef]
17. Ozerdem, B.; Turkeli, M. An investigation of wind characteristics on the campus of Izmir Institute of Technology, Turkey. *Renew. Energy* **2003**, *28*, 1013–1027. [CrossRef]
18. Cichowicz, R.; Dobrzański, M. 3D spatial dispersion of particulate matter and gaseous pollutants on a university campus in the center of an urban agglomeration. *Energy* **2022**, *259*, 125009. [CrossRef]
19. Dai, T.; Liu, S.; Liu, J.; Jiang, N.; Liu, W.; Chen, Q. Evaluation of fast fluid dynamics with different turbulence models for predicting outdoor airflow and pollutant dispersion. *Sustain. Cities Soc.* **2022**, *77*, 103583. [CrossRef]
20. Gao, W.; Li, L. Wind environment simulation and assessment of a university campus based on CFD. In Proceedings of the 2nd International Conference on Big Data & Artificial Intelligence & Software Engineering (ICBASE), Zhuhai, China, 24–26 September 2021; pp. 751–755. [CrossRef]
21. Palmer, D.G.; Vazquez, D.B.; Knapp, G.; Wright, N.; Happold, B. The practical application of CFD to wind engineering problems. In Proceedings of the Eighth International IBPSA Conference, Eindhoven, The Netherlands, 11–14 August 2003.
22. Du, Y.; Mak, C.M.; Tang, B.S. Effects of building height and porosity on pedestrian level wind comfort in a high-density urban built environment. *Build. Simul.* **2018**, *11*, 1215–1228. [CrossRef]
23. Du, Y.; Mak, C.M.; Liu, J.; Xia, Q.; Niu, J.; Kwok, K. Effects of lift-up design on pedestrian level wind comfort in different building configurations under three wind directions. *Build. Environ.* **2017**, *117*, 84–99. [CrossRef]
24. Janssen, W.D.; Blocken, B.; Hooff, T.V. Pedestrian wind comfort around buildings: Comparison of wind comfort criteria based on whole-flow field data for a complex case study. *Build. Environ.* **2013**, *59*, 547–562. [CrossRef]
25. Yasa, E. Computational evaluation of building physics—The effect of building form and settled area, microclimate on pedestrian level comfort around buildings. *Build. Simul.* **2016**, *9*, 489–499. [CrossRef]
26. Becker, R.; Goldberger, I.; Paciuk, M. Improving energy performance of school buildings while ensuring indoor air quality ventilation. *Build. Environ.* **2007**, *42*, 3261–32761. [CrossRef]
27. Wang, B.; Sun, S.; Li, Y.; Xie, Y.; Hou, Y.; Jin, Q.; Ren, Y. Campus wind environment evaluation in north China–A case study of NCUT. *Energy Rep.* **2020**, *6*, 787–793. [CrossRef]
28. Strasszer, D.; Xydis, G. CFD-Based Wind Assessment for Suburban Buildings. The Case Study of Aarhus University, Herning Campus. *Front. Energy Res.* **2020**, *8*, 539095. [CrossRef]
29. Jindal, A. Thermal comfort study in naturally ventilated school classrooms in a composite climate of India. *Build. Environ.* **2018**, *142*, 34–46. [CrossRef]
30. Wang, D.; Jiang, J.; Liu, Y. Student responses to classroom thermal environments in rural primary and secondary schools in winter. *Build. Environ.* **2017**, *115*, 104–117. [CrossRef]
31. Wu, Z.; Li, N.; Wargocki, P.; Peng, J.; Li, J.; Cui, H. Adaptive thermal comfort in naturally ventilated dormitory buildings in Changsha, China. *Energy Build.* **2019**, *186*, 56–70. [CrossRef]
32. Khidmat, R.P.; Koerniawan, D.; Suhendri, M. Wind Movement Comparison Between Student Dormitory 2 and 3 ITERA and The Correlation Toward its Indoor Thermal Comfort. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2018; Volume 152.
33. Li, X.; Wang, J.; Eftekhari, M.; Qi, Q.; Jiang, D.; Song, Y.; Tian, P. Improvement Strategies Study for Outdoor Wind Environment in a University in Beijing Based on CFD Simulation. *Adv. Civ. Eng.* **2020**, *2020*, 8850254. [CrossRef]
34. Niu, J.; Liu, J.; Lee, T.-C.; Lin, Z.; Mak, C.; Tse, K.-T.; Tang, B.-S.; Kwok, K.C. A new method to assess spatial variations of outdoor thermal comfort: Onsite monitoring results and implications for precinct planning. *Build. Environ.* **2015**, *91*, 263–270. [CrossRef]

35. Zhao, L.; Zhou, X.; Li, L.; He, S.; Chen, R. Study on outdoor thermal comfort on a campus in a subtropical urban area in summer. *Sustain. Cities Soc.* **2016**, *22*, 164–170. [CrossRef]
36. Ghaffarianhoseini, A.; Berardi, U.; Ghaffarianhoseini, A.; Al-Obaidi, K. Analyzing the thermal comfort conditions of outdoor spaces in a university campus in Kuala Lumpur, Malaysia. *Sci. Total Environ.* **2019**, *666*, 1327–1345. [CrossRef] [PubMed]
37. Chen, S.; Cui, P.; Mei, H. A Sustainable Design Strategy Based on Building Morphology to Improve the Microclimate of University Campuses in Cold Regions of China Using an Optimization Algorithm. *Math. Probl. Eng.* **2021**, *2021*, 2304796. [CrossRef]
38. Sun, B.; Zhang, H.; Zhao, L.; Qu, K.; Liu, W.; Zhuang, Z.; Ye, H. Microclimate Optimization of School Campus Landscape Based on Comfort Assessment. *Buildings* **2022**, *12*, 1375. [CrossRef]
39. Dorizas, P.V.; Assimakopoulos, M.-N.; Helmis, C.; Santamouris, M. An integrated evaluation study of the ventilation rate, the exposure and the indoor air quality in naturally ventilated classrooms in the Mediterranean region during spring. *Sci. Total Environ.* **2015**, *502*, 557–570. [CrossRef]
40. Wu, Y.; Wu, S.; Qiu, X.; Wang, S.; Yao, S.; Li, W.; You, H.; Zhang, J.; Xia, S.; Guo, Y. Integrated Evaluation Method of the Health-Related Physical Environment in Urbanizing Areas: A Case Study from a University Campus in China. *Front. Public Health* **2022**, *10*, 801023. [CrossRef] [PubMed]
41. Shao, J.; Liu, J.; Zhao, J.; Zhang, W.; Fu, Z.; Zhu, Q. Field Measurement of the Convective Heat Transfer Coefficient on Vertical External Building Surfaces Using Naphthalene Sublimation Method. *J. Build. Phys.* **2010**, *33*, 307–326. [CrossRef]
42. Liu, P.C.; Lin, H.T.; Chou, J.H. Evaluation of buoyancy-driven ventilation in atrium buildings using computational fluid dynamics and reduced-scale air model. *Build. Environ.* **2009**, *44*, 1970–1979. [CrossRef]
43. Yang, L.; Liu, X.; Qian, F.; Niu, S. Research on the wind environment and air quality of parallel courtyards in a university campus. *Sustain. Cities Soc.* **2020**, *56*, 102019. [CrossRef]
44. Yang, D.; Jiang, L. Simulation study on the Natural Ventilation of College Student' Dormitory. *Procedia Eng.* **2017**, *205*, 1279–1285. [CrossRef]
45. Faheem, M.; Bhandari, N.; Tadepalli, S.; Abinaya, J. Investigation on window opening behavior in naturally ventilated hostels of warm and humid climate. *Energy Build.* **2022**, *268*, 112184. [CrossRef]
46. Kumar, S.; Singh, M.K.; Al-Tamimi, N.; Alotaibi, B.S.; Abuhussain, M.A. Investigation on Subjects' Seasonal Perception and Adaptive Actions in Naturally Ventilated Hostel Dormitories in the Composite Climate Zone of India. *Sustainability* **2022**, *14*, 4997. [CrossRef]
47. Ota, N.; Olanipekun, E.A.; Olugboyega, O.; Ojelabi, R.A. Thermal Comfort and Occupant Behaviour in Naturally Ventilated Students' Hostel Buildings: A Case of Covenant University. *Civ. Environ. Res. J.* **2017**, *9*, 44–60.
48. Kastner, P.; Dogan, T. Eddy3D: A toolkit for decoupled outdoor thermal comfort simulations in urban areas. *Build. Environ.* **2022**, *212*, 108639. [CrossRef]
49. Dadioti, R.; Rees, S. Performance of Detached Eddy Simulation applied to Analysis of a University Campus Wind Environment. *Energy Procedia* **2017**, *134*, 366–375. [CrossRef]
50. Zhang, L.; Zhang, L.; Jin, M.; Liu, J. Numerical study of outdoor thermal environment in a university campus in summer. *Procedia Eng.* **2017**, *205*, 4052–4959. [CrossRef]
51. Vita, G.; Shu, Z.; Jesson, M.; Quinn, A.; Hemida, H.; Sterling, M.; Baker, C. On the assessment of pedestrian distress in urban winds. *J. Wind Eng. Ind. Aerodyn.* **2020**, *203*, 104200. [CrossRef]
52. Du, Y.; Mak, C.M.; Ai, Z. Modelling of pedestrian level wind environment on a high-quality mesh: A case study for the HKPolyU campus. *Environ. Model. Softw.* **2018**, *103*, 105–119. [CrossRef]
53. Du, G.; Liu, M.; Fan, X.; Shi, C.; Ge, T. Study on the influence of ventilation window air supply on indoor thermal environment in winter. *Build. Therm. Vent. Air Cond.* **2017**, *36*, 30–34.
54. Hwang, R.L.; Chen, W.A. Creating glazed facades performance map based on energy and thermal comfort perspective for office building design strategies in Asian hot-humid climate zone. *Appl. Energy* **2022**, *311*, 118689. [CrossRef]
55. Zhao, J.; Du, Y. Multi-objective optimization design for windows and shading configuration considering energy consumption and thermal comfort: A case study for office building in different climatic regions of China. *Sol. Energy* **2020**, *206*, 997–1017. [CrossRef]
56. Zhai, Y.; Wang, Y.; Huang, Y.; Meng, X. A multi-objective optimization methodology for window design considering energy consumption, thermal environment and visual performance. *Renew. Energy* **2019**, *134*, 1190–1199. [CrossRef]
57. Yuan, F.; Cho, S. Design optimization of building geometry and fenestration for daylighting and energy performance. *Sol. Energy* **2019**, *191*, 7–18. [CrossRef]
58. Mahan, S.M.; Chirag, D.; Philipp, G. Early-stage design support combining machine learning and building information modelling. *Autom. Constr.* **2022**, *136*, 104147. [CrossRef]
59. Zhang, J.Y.; Liu, N.X.; Wang, S.S. Generative design and performance optimization of residential buildings based on parametric algorithm. *Energy Build.* **2021**, *244*, 111033. [CrossRef]
60. Han, Y.; Shen, L.; Sun, C. Developing a parametric morphable annual daylight prediction model with improved generalization capability for the early stages of office building design. *Build. Environ.* **2021**, *200*, 107932. [CrossRef]
61. Liu, Q.; Han, X.; Yan, Y.; Ren, J. A Parametric Design Method for the Lighting Environment of a Library Building Based on Building Performance Evaluation. *Energies* **2023**, *16*, 832. [CrossRef]
62. Freitas, J.D.S.; Cronemberger, J.; Soares, R.M.; Amorim, C.N.D. Modeling and assessing BIPV envelopes using parametric Rhinoceros plugins Grasshopper and Ladybug. *Renew. Energy* **2020**, *160*, 1468–1479. [CrossRef]

63. Maskarenj, M.; Deroisy, B.; Altomonte, S. A new tool and workflow for the simulation of the non-image forming effects of light. *Energy Build.* **2022**, *262*, 112012. [CrossRef]
64. Liu, J.P. *Urban Environment Physics*; China Architecture & Building: Beijing, China, 2011; pp. 131–132.
65. Achenbach, E. Experiments on the flow past spheres at very high Reynolds numbers. *J. Fluid Mech.* **1972**, *54*, 565–575. [CrossRef]
66. Coutanceau, M.; Defaye, J.R. Circular Cylinder Wake Configurations: A Flow Visualization Survey. *Appl. Mech. Rev.* **1991**, *44*, 255. [CrossRef]
67. Tominaga, Y.; Mochida, A.; Yoshie, R.; Kataoka, H.; Nozu, T.; Yoshikawa, M.; Shirasawa, T. AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. *J. Wind Eng. Ind. Aerodyn.* **2008**, *96*, 1749–1761. [CrossRef]
68. Yang, Y.; Zhang, Z.Y.; Yu, X.F. A Comparative Study of Pedestrian-Level Wind Environment Based on a Standard Urban Building Model. *J. Tongji Univ.* **2022**, *50*, 784–792.
69. *GB/T50378-2019*; Ministry of Housing and Urban-Rural Development of the People's Republic of China. Green Building Evaluation Standard. China Construction Industry Press: Beijing, China, 2019.
70. Gao, S.J. The Harm of Strong Winds and Defense Measures. *Heilongjiang Sci. Technol. Inf.* **2012**, *12*, 59.
71. Ji, D. A Study on the Common Cold Based on Ancient Literature. Master's Thesis, Nanjing University of Chinese Medicine, Nanjing, China, 2019.
72. Zhuang, L. The Effect of Opening Window on the Indoor Environment in the Naturally Ventilated Dormitory in a University of Northern China in Winter. Master's Thesis, Shandong Jianzhu University, Jinan, China, 2020.
73. Alfano, F.; Ianniello, E.; Palella, B.I. PMV-PPD and acceptability in naturally ventilated schools. *Build. Environ.* **2013**, *67*, 129–137. [CrossRef]
74. Wang, J.; Wang, S.; Zhang, T.; Battaglia, F. Assessment of single-sided natural ventilation driven by buoyancy forces through variable window configurations. *Energy Build.* **2017**, *139*, 762–779. [CrossRef]
75. Razak, A.A.; Hagishima, A.; Ikegaya, N.; Tanimoto, J. Analysis of airflow overbuilding arrays for assessment of urban wind environment. *Build. Environ.* **2013**, *59*, 56–65. [CrossRef]
76. Liu, Q.; Ren, J. Research on the Building Energy Efficiency Design Strategy of Chinese Universities Based on Green Performance Analysis. *Energy Build.* **2020**, *224*, 110242. [CrossRef]
77. Wu, S. Energy-Saving Design of University Dormitory Building Based on BIM Technology—A Case Study of Xi'an. Master's Thesis, Chang'an University, Xi'an, China, 2019.
78. Wu, F. Research on Dormitory Space Design of Colleges and Universities in Northern China. Master's Thesis, Tianjin University of Science and Technology, Tianjin, China, 2017.
79. Ye, W.H.; Wang, Y. Researching the Design of OpenGround-floor Space. *New Archit.* **2001**, 55–58.
80. Cai, Y.Q. Research on the Design Strategy of Architectural Layout Based on Wind Environment. Master's Thesis, Beijing Jiaotong University, Beijing, China, 2020.
81. Yang, L. Research on Building Climate Analysis Strategy. Ph.D. Thesis, Xi'an University of Architecture and Technology, Xi'an, China, 2003.
82. Edward, A.; Richard, G.; Larry, B.; McNall, P.E.; Lutfi, Z. A new bioclimatic chart for environment design. Building Energy Management. In Proceedings of the Conventional and Solar Aprroaches, Proceedings of the International Congress, Póvoa de Varzim, Portugal, 12–16 May 1980.
83. Hoyt, T.; Arens, E.; Zhang, H. Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings. *Build. Environ.* **2015**, *88*, 89–96. [CrossRef]
84. Soligo, M.J.; Irwin, P.A.; Williams, C.J.; Schuyler, G.D. A Comprehensive Assessment of Pedestrian Comfort Including Thermal Effects. *Wind Eng. Ind. Aerodyn.* **1998**, *77*, 753–766. [CrossRef]