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Article

Enhancing the winter wind conditions in the dormitory vicinity of Hohhot University through a biomechanical perspective

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Abstract: The rapid expansion of higher education in China has necessitated extensive new construction and renovation of university dormitories, prompting increased attention to the wind environment within these facilities. Hohhot, situated in a region characterized by severe cold, presents a unique opportunity to examine the winter wind environment in university dormitories from a biomechanical perspective, which can significantly enhance the quality of the human environment. This study employs Computational Fluid Dynamics (CFD) simulation software, PHOENICS, to model and analyze the winter wind conditions in the dormitory areas of universities in Hohhot. Furthermore, it investigates the relationship between the architectural configurations of typical group buildings—specifically I-type, L-type, and U-type layouts—and the resulting wind environment in the dormitory vicinity. The findings indicate that the wind environment for L-type and U-type building configurations is enhanced when arranged in a row and column layout. Conversely, the U-type building configuration exhibits superior wind conditions during the winter months when implemented in a diagonal column layout. All three building forms are applicable in an enclosed layout; however, it is crucial to consider the emission of pollutant gases. The incorporation of green plants is recommended to enhance the internal wind environment. This study aims to optimize the wind environment within the dormitory areas of universities in Hohhot through biomechanical optimization, thereby improving student living comfort. Additionally, it seeks to provide optimization strategies and models from a biomechanical perspective for the construction projects of university dormitory areas located in regions characterized by severe cold climates.

Keywords: fluid dynamics; student accommodation; wind environment; numerical simulation; optimization strategy

1. Introduction

China is presently undergoing significant economic growth, which is accompanied by a continuous rise in energy consumption. The substantial energy demands associated with building infrastructure have emerged as a considerable strain on the national economy. Consequently, the integration of sustainable development principles within the context of green buildings has garnered considerable attention within academic discourse [1]. Designers are increasingly focusing on the application of contemporary ecological and architectural design methodologies to create a green and health-promoting outdoor wind environment for educators and students, tailored to local conditions [2–4]. The establishment of a favorable wind environment is a critical factor influencing residential comfort. An optimal wind environment contributes to the creation of a pleasant microclimate and aids in the reduction of energy consumption in buildings. It is essential to employ architectural strategies to effectively direct wind speed and direction, thereby enhancing the outdoor wind conditions surrounding the structure.

The theoretical framework and practical applications of wind environment research in international contexts have reached a significant level of maturity, encompassing eight primary research directions [5]. In 1970, wind tunnel tests were conducted on two high-rise buildings located in the Vauxhall area of the United Kingdom [6]. Subsequently, in 1992, Uematsu et al. examined high-rise apartment buildings in suburban Japan, testing four distinct corner shape configurations [7]. In 1995, To and Lam et al. assessed experimental outcomes by analyzing building layout forms through metrics such as average wind speed [8]. Furthermore, in 2006, Lamberts Roberto performed ventilation simulations for a campus building utilizing computational fluid dynamics (CFD) software, illustrating that effective passive ventilation can facilitate adequate human comfort in warm and humid climates [9]. In 2007, Testu et al. conducted wind tunnel experiments on 22 residential neighborhoods in a Japanese city, which elucidated the correlation between building density in residential zones and the average wind speed at pedestrian levels [10]. Subsequently, in 2010, Omar S. Asfoury performed a parametric three-dimensional modeling study utilizing computational fluid dynamics (CFD) software in the arid region of Gaza [11]. In 2012, B-Blocken et al. employed the campus of Eindhoven University of Technology as a site for wind environment simulations, comparing the simulation outcomes with both long-term and short-term on-site wind speed measurements to evaluate aspects of wind comfort and safety [12].

Research on the wind environment within higher education institutions in China remains limited. In 2012, Wang Ling advanced a series of design protocols for the technical retrofitting of ventilation systems in college and university teaching facilities, alongside methodologies for such retrofitting. Furthermore, Wang Ling introduced an innovative approach to ventilation retrofitting [13]. In 2017, Song Shuai and colleagues enhanced the simulation of the indoor wind environment in the teaching buildings at Shandong University of Architecture, while also investigating retrofitting options [14]. In 2021, Diao et al. employed the simulation and visualization capabilities of Building Information Modeling (BIM) technology to examine optimization strategies for the physical environments of historic university buildings [15]. In 2022, Cui Yanqiu and colleagues conducted an investigation into the indoor wind environment of university dormitories utilizing computational fluid dynamics (CFD) techniques [16]. Similarly, Jiang Jiayang and associates examined the wind environments surrounding nine university buildings in Northeast China and established evaluation criteria [17]. Given China's extensive geographical expanse and the diverse climatic conditions across its various regions, the applicability of these guidelines is limited. Furthermore, the existing literature does not adequately address the outdoor environments of campus dormitories situated in severely cold regions, particularly concerning the outdoor wind conditions of clustered buildings. This represents a significant gap in the research and highlights a lack of generalizability.

Currently, research on the effects of wind direction and wind environment changes on human physiological functions has made some progress. In 2007, Zhu et al. [18] proposed that when the air temperature is lower than the skin temperature, wind can enhance heat conduction and convection, accelerating heat dissipation from the body. When the skin temperature is lower than the air temperature, wind intensifies convection, which not only heats the body but also increases evaporation, thereby improving heat dissipation efficiency. In 2015, Wang et al. [19] pointed out that under the same wind speed, as the operative temperature increases, the amount and proportion of sensible sweat evaporation for heat dissipation increase significantly, while the amount and proportion of radiative and convective heat dissipation decrease markedly, and the other heat dissipation amounts and proportions also decrease accordingly.

An examination of the current landscape of Computational Fluid Dynamics (CFD) applications, both domestically and internationally, reveals that the utilization of CFD simulation software for analyzing the outdoor wind environment of buildings has reached a considerable level of maturity. PHOENICS, a versatile CFD software, is employed for simulating various processes, including heat transfer and fluid flow. Its user-friendly interface and the clarity of its data presentation enhance its accessibility. In comparison to traditional methods such as on-site measurements and wind tunnel experiments, numerical simulations offer a substantial reduction in experimental duration while conserving both human and material resources. Furthermore, the wind environment in higher education institutions located in China's severely cold regions can be effectively analyzed and studied using the PHOENICS CFD simulation software. Based on the meteorological parameters specific to the Hohhot region, a physical model has been developed. The computational domain has been segmented, with a grid established and boundaries defined. Utilizing hydrodynamic simulation software, an analysis of the wind environment surrounding university student dormitories in Hohhot has been conducted. This study examines the impact of architectural morphology and the arrangement of building clusters on human comfort within dormitory areas located in regions characterized by severe cold climates, approached from a biomechanical perspective. The objective is to accurately identify the factors influencing human habitation, thereby facilitating enhancements in the comfort of the living environment through informed design interventions.

The campus environments of higher education institutions are increasingly garnering attention from diverse stakeholders. Among the various factors influencing outdoor comfort, the wind environment is particularly significant and warrants greater consideration from planning architects. This study utilizes meteorological data from Hohhot City as the foundational parameters and examines the winter wind environment characteristics of three distinct building form group layouts, employing a biomechanical perspective based on the research data. This study employs PHOENICS hydrodynamic simulation software to investigate the relationship between conventional building morphology, spatial arrangement, and the wind environment within the university dormitory sector of Hohhot. It focuses on analyzing the potential impacts of dynamic changes in the wind environment on human thermoregulation mechanisms and cardiovascular system responses. Based on the simulation results, an optimization strategy is formulated with the aim of enhancing the winter living comfort of university dormitories located in cold climate regions through scientific and reasonable architectural design interventions, thereby creating a more superior environmental condition for students' physical and mental health and academic development. This research not only holds profound academic value in the field of architecture but also provides a new perspective and expands the application prospects for interdisciplinary research in the fields of biomechanics and human physiology.

2. Method

Buildings are situated within an open natural wind field, where the airflow is impeded by the structures, resulting in alterations to the flow direction. The presence of multiple buildings can lead to various aerodynamic phenomena, including the wind cyclone effect, wind tunnel effect, narrow tube effect, wind funnel effect, and enclosure effect [20–24]. As obstructions to the wind, buildings modify the surrounding wind field, which is influenced by the characteristics of the local airflow. The outdoor wind environment surrounding a cluster of buildings is affected by factors such as building orientation, architectural form and massing, as well as the spacing and arrangement of the buildings within the group [25,26]. Given that typical human activities occur at a height of 1.5 m, this study focuses on analyzing the wind environment at this elevation outside the buildings [27].

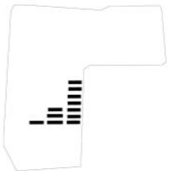
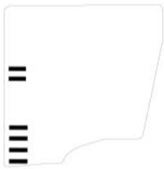
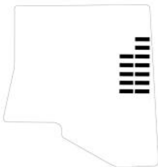
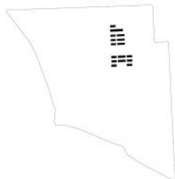
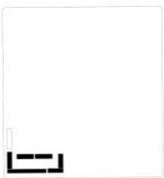
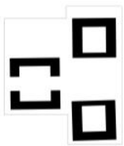
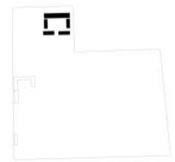
Computational Fluid Dynamics (CFD) represents an integration of computer technology and numerical computation methodologies. Its fundamental principle involves employing numerical solutions to address the differential equations governing fluid flow, thereby enabling a realistic simulation of flow field dynamics in air [28]. The advancement of computer technology has significantly accelerated the development of fluid mechanics software since the 1960s. Among these, PHOENICS, a general-purpose CFD software developed by CHAM in the United Kingdom, is designed to simulate processes such as heat transfer and fluid flow [29]. PHOENICS modeling is characterized by its rapid implementation and seamless integration with widely utilized construction software, demonstrating a high level of professionalism [30]. It features a grid module that facilitates clear and intuitive division of the calculation domain, as well as grid configuration and other settings. The simulation outcomes can be represented in a straightforward and visually comprehensible manner. Consequently, PHOENICS was chosen for this study, and the specific methodology is outlined as follows: Initially, AutoCAD software was employed to create a model, which was then exported in STL format, specifically for the research area. The simulation object is situated within a 3-m unit calculation grid, while the surrounding area is designated as a 10-m unit calculation grid. The inlet boundary is defined as a velocity inlet boundary, where the wind speed diminishes near the ground, resulting in a gradient wind. The equation governing the urban gradient wind is presented as follows.

$$V_Z = V\left(\frac{Z}{10}\right)^a$$

In this context, V denotes the wind speed measured at a height of 10 m, expressed in meters per second (m/s); V_Z signifies the wind speed at an elevation of Z, also in meters per second (m/s); and Z indicates the specific height at which the wind speed is being evaluated.

Hohhot is situated in the Tumut Plain in northern China, specifically in the central-western region of the Inner Mongolia Autonomous Region. The city experiences a typical continental climate characteristic of the Mongolian Plateau, marked by prolonged, cold, and arid winters, as well as dominant northwesterly winds. Hohhot lies within the trajectory of dust and sand storms, and during the spring season, the interaction of alternating cold and warm air masses contributes to its susceptibility to windy and dusty conditions [31,32]. This study investigates the adverse effects of high wind speeds, characterized by gusty sand and dust, on outdoor environments during low-temperature conditions. Specifically, it aims to analyze the most detrimental wind speed conditions for pedestrians in dormitory areas during winter. To this end, the average wind speed recorded in April has been identified as the most unfavorable for simulating comfort levels in the wind environment of college and university dormitory areas, which are primarily frequented by pedestrians. In April, the prevailing wind direction is from the northwest, with an average wind speed of 2.7 m/s.

Table 1. A schematic representation of the dormitories at various colleges located in Hohhot.

Forms	Layout Diagram				
Row	 Hohhot Vocational College	 Inner Mongolia North Vocational and Technical College	 Inner Mongolia Electronic Information Vocational and Technical College	 Inner Mongolia Chemical Industry Vocational College	 Inner Mongolia Normal University (Shengle Campus)
Diagonal	 Inner Mongolia Medical University (Jinshan Campus)	 Inner Mongolia University (South Campus)			
Enclosed	 Inner Mongolia University (North Campus)	 Inner Mongolia University (East Campus)	 Inner Mongolia University of Technology (Xincheng Campus)		
Hybrid	 Inner Mongolia Agricultural University (West Campus)	 Inner Mongolia Agricultural University (East Campus)	 Inner Mongolia Normal University (Saihan Campus)		

This research investigates the correlation between various types of external space plans and spatial enclosure within dormitory settings, utilizing the metric of plan permeability (L/C) as an indicator. An analysis of 24 student dormitory buildings across colleges and universities in Hohhot revealed that the typical monolithic depth of these dormitory structures ranges from 15 to 16 m, with lengths between 60 and 80 m, a height of approximately 18 m, and a common configuration of 5 to 6 floors, indicating that the majority of the dormitories are multi-storey buildings. External spatial configurations can be categorized into three main types: the enclosed category, which is defined by square shapes; the semi-enclosed category, encompassing U-shaped, H-shaped, and L-shaped designs; and the semi-open category, represented by I-shaped forms. It is important to note that the semi-enclosed category includes U-shaped, H-shaped, and L-shaped configurations. Among these, I-shaped forms are the most common, accounting for 71% of the total building types, followed by L-shaped structures at 18%, U-shaped forms at 8%, while other configurations constitute a negligible percentage. The primary configurations of college dormitory layouts chosen for the integration of the aforementioned three principal monolithic building forms include: Row, Diagonal, Enclosed, and Hybrid (refer to **Table 1**).

3. Results

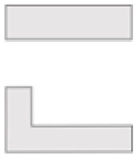
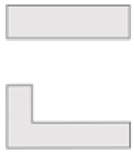
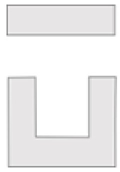
Given that the hybrid configurations and arrangements of dormitory buildings in Hohhot are both variable and limited in number, this research concentrates on the outdoor wind environmental conditions associated with row, diagonal, and enclosed layouts. The simulation of the dormitory area is predicated on a medium-sized cluster of dormitory buildings, specifically comprising 7 to 9 structures, located within the universities of Hohhot. Adjacent buildings, serving as the smallest unit of layout, constitute the fundamental components of the university dormitory area. The quality of their wind environment has a direct influence on the wind field surrounding these dormitory units and may function as a secondary wind source, thereby affecting both the comfort of the outdoor environment and the energy efficiency of the buildings. In the examination of the spatial configuration of group buildings, an initial simulation and analysis of the wind environment is conducted under various enclosure patterns of neighboring structures. This investigation aims to elucidate the relationship between the characteristics of adjacent buildings and the resulting wind conditions. The study involves the establishment of three distinct building forms: an I-shaped structure measuring 88 m in length, 45 m in width, and 18 m in height; an L-shaped building with identical dimensions of 88 m in length, 45 m in width, and 18 m in height; and a U-shaped building measuring 68 m in length, 51 m in width, and 18 m in height.

3.1. Simulation analysis of the outdoor wind environment surrounding adjacent buildings

3.1.1. Examination of the outdoor wind environment of adjacent I-shaped buildings

The study involves the utilization of I-shaped, L-shaped, and U-shaped building units for the purpose of configuration. The north side of the I-shaped building unit is examined solely in terms of its north-south orientation, ensuring that the spacing between buildings adheres to the daylight standards for dormitory buildings as well as fire safety regulations. The various layout configurations are presented in **Table 2**. Additionally, the wind environment is assessed by designating the prevailing winter wind direction as coming from the northwest, particularly when the I-shaped buildings are integrated with other building types.

Table 2. Combination of adjacent I-shaped buildings.

mode	**A**	**B**	**C**	**D**
Layout Diagram				

In Mode A, the interaction between two identical building types reveals that when aligned at a 45° angle to the prevailing wind direction, significant wind speed variations occur. Specifically, at the southwestern corner of the two rows of buildings, there is a marked increase in wind speed, reaching approximately 3.2 m/s, attributed to corner wind effects. The airflow within the passageway between the buildings is notably efficient, which may hinder wind protection during winter months. Analysis of the wind pressure distribution indicates that the windward side of the front row of buildings experiences higher wind pressure. Consequently, it is recommended that the airtightness of the enclosures for the rooms located on the windward side of the front row be enhanced (refer to **Figure 1**).

In Mode B, the interaction between an I-shaped building and an L-shaped building, as illustrated in the wind speed cloud diagram, reveals that the corner wind significantly enhances wind speeds at the south-west corner of the one-character building and the north-east corner of the L-shaped structure. This phenomenon results in the convergence of two airflows, which collectively generate an accelerated airflow directed eastward. Additionally, a small wind shadow area is present at the shaded corners of the L-shaped building, rendering it less amenable to utilization. Furthermore, corner winds are also observed at the south-west corner of the L-shaped building. To mitigate these effects, it is advisable to implement greenery or wind barriers at the windward corner of the building and at the openings between the two structures. The wind pressure cloud map indicates that wind pressure is elevated at one-third of the windward side on the left side of the front building, with a corresponding high-pressure zone also identified in the western section of the L-shaped building (refer to **Figure 1**).

In Mode C, the interaction between the I-shaped and L-shaped buildings reveals notable wind patterns as depicted in the wind speed cloud map. Specifically, corner wind phenomena are observed at the southwest corner of the I-shaped building and the southwest corner of the northwest section of the L-shaped building, with peak wind speeds reaching approximately 2.8 m/s. Furthermore, the average wind speed within the semi-enclosed space is lower than that observed in the B mode configuration. Analysis of the wind pressure cloud diagram indicates that high-pressure areas are predominantly located on the windward side of the I-shaped building, particularly within the left third and at the concave corners of the L-shaped building. It is advisable to implement effective thermal insulation measures in these critical areas (refer to **Figure 1**).

In Mode D, the interaction between an I-shaped building and a U-shaped building results in the formation of a corner wind at the southwest corner of the front row of structures, as indicated by the wind speed cloud map. The wind speed is observed to increase and flow eastward along the windward channel created by the two rows of buildings. Notably, the wind speed exiting the notch of the U-shaped building experiences a significant increase, leading to the development of an accelerated airflow with a maximum velocity exceeding 3.2 m/s on the eastern side of the U-shaped structure. The wind pressure cloud diagram reveals that wind pressure is elevated on the left side of the windward face of the front row of buildings, as well as on the western side of the U-shaped building. Consequently, it is imperative to consider measures for cold protection and thermal comfort in the rooms located in these areas (refer to **Figure 1**).

In conclusion, the implementation of the D mode, which integrates both I-shaped and U-shaped architectural designs, results in an expanded static wind zone within the university dormitory area. This configuration leads to a more moderate wind speed, thereby enhancing the overall comfort experienced by individuals in the vicinity.

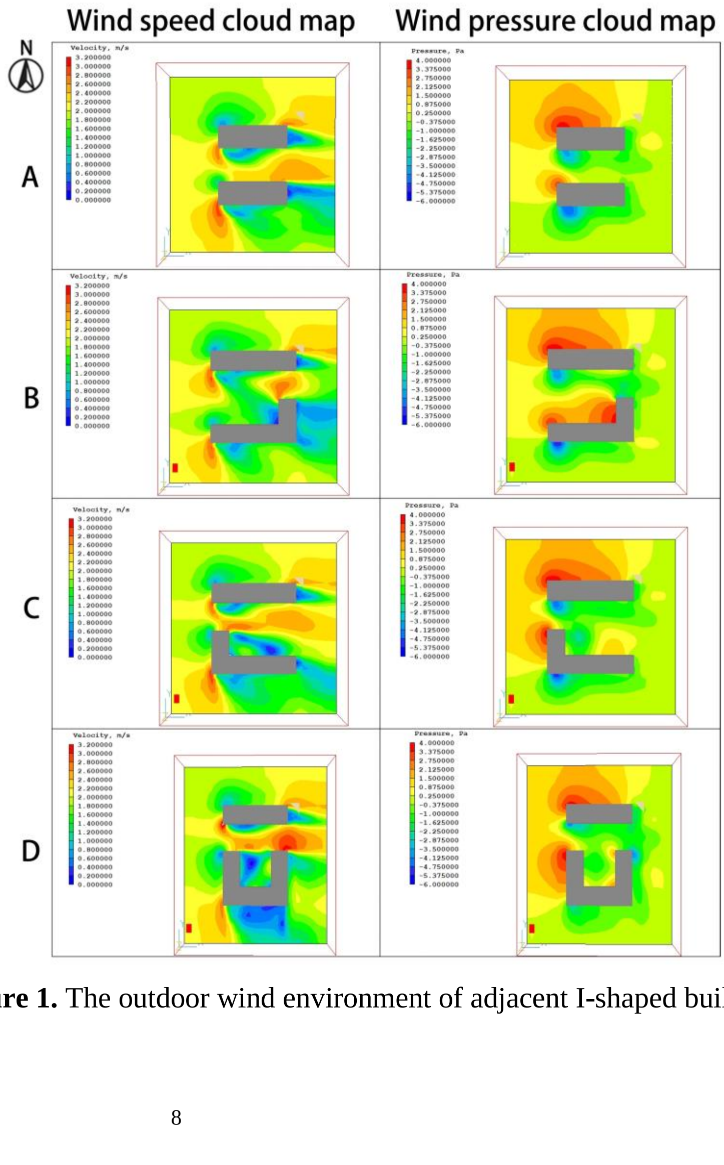
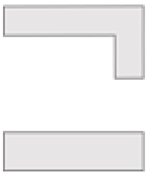
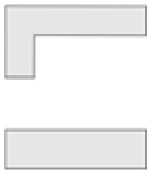
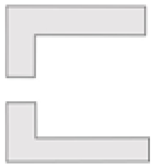
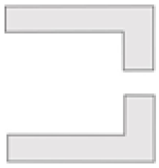
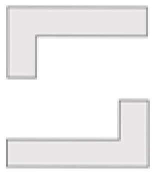


Figure 1. The outdoor wind environment of adjacent I-shaped buildings.

3.1.2. Examination of the outdoor wind environment of adjacent L-shaped buildings

The L-shaped building unit is integrated with the I-shaped, L-shaped, and U-shaped building units, respectively. The L-shaped building unit located on the northern side is exclusively oriented towards the north and south. Furthermore, the spacing between buildings adheres to the daylight standards applicable to dormitory buildings as well as the required fire safety distances. The various layout configurations are presented in **Table 3**, and the analysis of the wind environment is conducted with the prevailing winter wind direction set from the northwest.

Table 3. Combination of adjacent L-shaped buildings.

mode	**A**	**B**	**C**	**D**	**E**
Layout Diagram					

In Mode A, the interaction between the L-shaped building and a single-row building results in the formation of corner winds at the southwest and northeast corners of the L-shaped structure, as indicated by the wind speed cloud map. This phenomenon leads to a significant increase in wind speed at these corners, directing airflow into the channel situated between the two rows of buildings. The presence of the rear row of buildings obstructs this airflow, resulting in a change in wind direction and the establishment of accelerated airflow within the interstitial space between the two rows. The wind pressure cloud diagram reveals that the high-pressure zone is predominantly located on the northern side of the windward face of the front row of buildings, suggesting that insulation measures should be implemented in this area (refer to **Figure 2**).

In Mode B, the integration of the L-shaped building with the I-shaped structure results in a wind environment that resembles that of Mode A, as indicated by the wind speed cloud map. This phenomenon is influenced by corner wind dynamics, with accelerated airflow moving eastward along the wall after encountering obstruction from the rear row of buildings. Analysis of the wind pressure maps reveals that the northwest corner of the L-shaped building experiences elevated wind pressure values. To mitigate the adverse effects of excessive wind pressure on the building, it is advisable to strategically position greenery or wind barriers in designated areas in front of the structure (refer to **Figure 2**).

In Mode C, the integration of two L-shaped structures results in a wind speed cloud map that indicates a more enclosed building environment, leading to a more stable internal wind field, with the exception of corner winds that develop at the southwest corner. The configuration of the leeward side of the rear building, the eastern side of the front building, and a designated range of wind shadow zones at the concave corner is advantageous for mitigating winter winds. Furthermore, the wind pressure map reveals that the northwest corner of the rear building experiences the highest wind pressure values, necessitating the implementation of insulation measures in this specific area of the structure (refer to **Figure 2**).

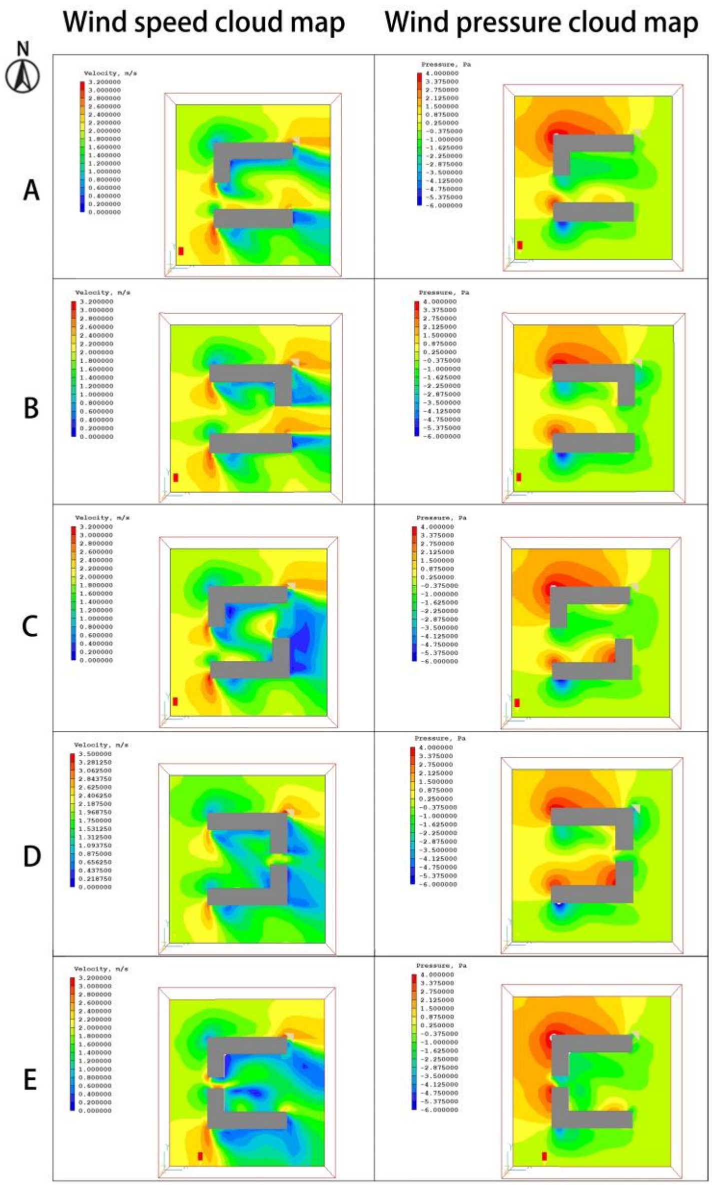


Figure 2. The outdoor wind environment of adjacent L-shaped buildings.

In Mode D, the integration of the L-shaped structures results in a more stable internal wind field, as indicated by the wind speed cloud map, which shows an average wind speed of approximately 1.8 m/s and the absence of vortex areas within the interior. This stability is advantageous for addressing environmental health concerns. Analysis of the wind pressure maps reveals that the windward side of the first row of buildings and the concave corners of the second row exhibit the highest wind pressure values. Consequently, it is imperative to focus on wall treatment and component design in these specific areas (refer to **Figure 2**).

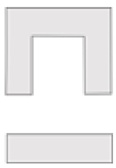
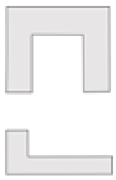
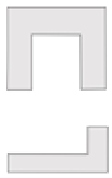
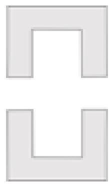
In Mode E, the interaction between two L-shaped buildings results in the formation of corner winds in the southwest corner, situated between the front and rear rows of buildings, with a peak wind speed of approximately 3.2 m/s, as indicated by the wind speed cloud map. Additionally, a minor wind shadow area is observed within the recessed corners of the first row of buildings, while a more extensive wind shadow area is present on the eastern side of the rear row of buildings. The wind pressure cloud map reveals that the first row of buildings in the northwest corner experiences elevated wind pressure values, suggesting the necessity for effective wind proofing and insulation measures (refer to **Figure 2**).

In conclusion, the implementation of C and E mode layouts results in an expanded quiet wind zone within the university dormitory area. Consequently, students traversing this area experience an enhanced level of physical comfort, rendering it more conducive to outdoor activities during the winter season.

3.1.3. Examination of the outdoor wind environment of adjacent U-shaped buildings

The U-shaped building monoliths are integrated into I-shaped, L-shaped, and U-shaped configurations, with the U-shaped monoliths positioned on the northern side, while maintaining the previously mentioned conditions. **Table 4** presents each layout configuration and provides an analysis of the wind environment associated with the U-shaped adjacent building combinations.

Table 4. Combination of adjacent U-shaped buildings.

mode	**A**	**B**	**C**	**D**
Layout Diagram				

In Mode A, the interaction between a U-shaped building and a monolithic structure results in a wind flow pattern characterized by a 45° angle relative to the building, leading to a corner wind effect at the southwest corner of the U-shaped structure. This phenomenon occurs as the wind is obstructed by the adjacent rear building, causing it to flow parallel to the wall and continue along its surface. It is crucial to consider the design of wall elements in these areas to mitigate wind noise generated by the friction between high-velocity winds and the wall surfaces. Additionally, a wind shadow area is present within the concave corner of the U-shaped building, which may be utilized for outdoor activities. Wind pressure maps indicate that high-pressure zones are predominantly located on the windward sides of the west and north elevations of the U-shaped building, with the highest wind pressure values observed at the northwest corner (refer to **Figure 3**).

In Mode B, the interaction between the U-shaped and L-shaped buildings results in a wind speed distribution that indicates elevated wind velocities at the northeast corner of the U-shaped structure, attributed to corner winds. This area experiences a blockage from the rear section of the L-shaped building, leading to a significant increase in wind speed at the corner of the L-shaped building, which subsequently directs the airflow towards the east. Additionally, the southwest corner of the L-shaped building generates corner winds, suggesting the necessity for the implementation of vegetation or wind barriers in this vicinity. Furthermore, the concave corners of the U-shaped buildings create zones of wind shadow, which are beneficial for mitigating winter winds; however, it is essential to monitor these areas to prevent the accumulation of pollutants (refer to **Figure 3**).

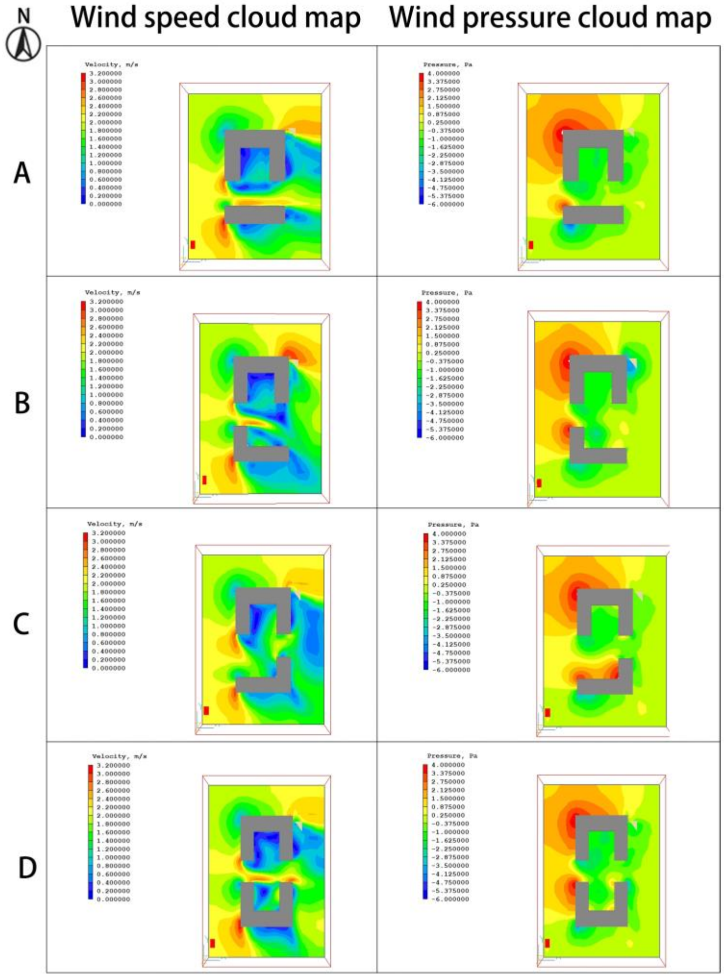


Figure 3. The outdoor wind environment of adjacent U-shaped buildings.

In Mode C, the interaction between the U-shaped and L-shaped buildings results in the formation of corner winds at the southwest corner of both structures, as indicated by the wind speed cloud map, with a peak wind speed of approximately 3.2 m/s. The wind shadow region located in the concave corner of the U-shaped building constitutes half of the total area. Furthermore, the wind pressure maps reveal elevated wind pressure levels at the northwest corner of the U-shaped building and at the concave corner of the L-shaped building (refer to **Figure 3**).

In D mode, the interaction between two U-shaped buildings results in the formation of corner winds at the southwest corner of the U-shaped structure, as indicated by the wind speed cloud map. This phenomenon leads to an increase in wind speed, which is further amplified after the wind is obstructed by the rear row of buildings. Consequently, this alteration in wind dynamics has a notable impact on the accessibility of the two rows of buildings. To mitigate the effects of increased wind speed, it is advisable to implement landscaping or wind barriers at the left opening.

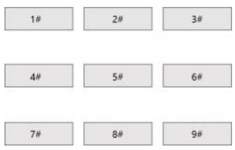
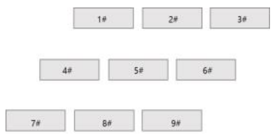
The wind shadow region located within the notch of the U-shaped building is substantial, thereby enhancing wind protection during the winter months. Analysis of the wind pressure distribution, as illustrated in the accompanying wind pressure cloud diagram, indicates that the northwest corner of the front row of buildings, along with the western side of the rear row, exhibits elevated wind pressure levels. Consequently, it is imperative to reinforce thermal insulation and wind protection strategies in these specific areas (refer to **Figure 3**).

In conclusion, the outdoor wind conditions during winter are optimized when utilizing a combination of U-shaped buildings alongside other architectural forms in proximity to the layout. Furthermore, the B layout configuration demonstrates superior performance compared to the C layout. Specifically, it is advisable to limit the size of the openings on the western side of the building ensemble to enhance the suitability of the building arrangement for the Hohhot region.

3.2. Examination of wind environment simulation for groups of I-shaped buildings

The sample was drawn from the dormitory of Inner Mongolia Medical University, which has dimensions of 60 m in length, 20 m in depth, and 18 m in height. The dormitory buildings are designated as Building 1 through Building 9, with spacing arranged to comply with daylight and fire safety standards. The design accounts for the prevailing winter winds, which typically come from the northwest. In the PHOENICS simulation, a grid unit size of 3 m was established for calculations. The wind environment was modeled separately for three configurations: row-row, diagonal-row, and enclosed layouts of the monolithic buildings (refer to **Table 5**).

Table 5. Schematic diagrams of the different layout forms of I-shaped buildings.

	Row	**Diagonal**	**Enclosed**
Layout Diagram			

I-shaped buildings are arranged in rows: the wind speed cloud diagram indicates that wind predominantly enters the dormitory complex from the west and north sides. The east-west corridor between the buildings exhibits effective ventilation, resulting in a higher average wind speed. The presence of the rear buildings provides shelter to the 1# and 3# buildings, causing corner winds to generate a penetrating airflow within the east-west corridor. Notably, the wind speed between the 2nd and 5th buildings exceeds 2.8 m/s, reaching its peak, which contributes to a lower level of comfort during winter months that necessitates improvement. Furthermore, the wind pressure map reveals that the north side of Buildings 1 and 3 serves as a convergence point for high-pressure areas, with the maximum wind pressure value exceeding 4 Pa. Consequently, it is advisable to enhance the thermal insulation and protection of the rooms located on the windward side of the dormitory complex to mitigate cold exposure (refer to **Figure 4**).

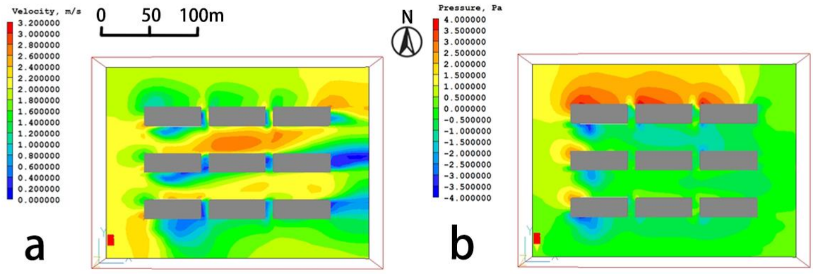


Figure 4. Simulation of wind environment with I-shaped buildings arranged in rows.
Note: a: wind speed cloud map; b: wind pressure cloud map.

I-shaped buildings are arranged diagonally: the wind speed cloud map indicates the presence of a corner wind phenomenon in the southwest corner of Building 4, where the maximum recorded wind speed reaches 3.8 m/s. To enhance human comfort, it is advisable to mitigate wind speeds in this area. Additionally, the presence of the back row of buildings creates a narrow tube effect between the second and third rows, resulting in elevated wind speeds within this channel, which is detrimental to wind protection during the winter months. The wind pressure cloud map reveals an increase in wind pressure values in certain regions on the northern side of Buildings 4 and 7. To prevent the infiltration of cold winds, it is essential to reinforce the thermal insulation and protective measures of the rooms located on the windward sides of the north and west facades of these buildings. Furthermore, a diagonal layout is found to be more advantageous for the overall wind environment compared to a linear row arrangement (refer to **Figure 5**).

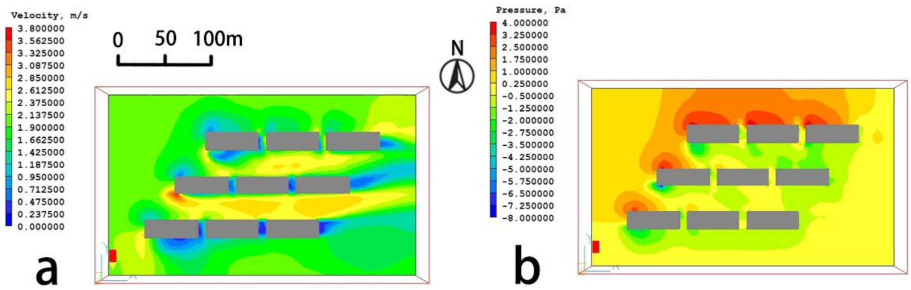


Figure 5. Simulation of wind environment with diagonally arranged I-shaped buildings.
Note: a: wind speed cloud map; b: wind pressure cloud map.

I-shaped buildings are arranged in an enclosed formation: the wind speed map illustrates that airflow enters the building complex via the gap situated between Building 1 and Building 4. The passage between Building 1 and Building 3 exhibits a funneling effect, leading to elevated wind speeds, albeit with a restricted area of influence. Additionally, corner winds are detected in the northeast corner of Building 3 and the southwest corner of Building 4, where the maximum recorded wind speed reaches 2.8 m/s. The enclosed layout exhibits a lower average wind speed in comparison to alternative configurations, resulting in a substantial area of wind shadow that is conducive to outdoor activities during the winter months. However, the limited air circulation within the enclosed space hinders the dispersion of pollutants, thereby adversely impacting air quality. In the design of the enclosed layout, it is imperative to consider the strategic placement of openings and the incorporation of green landscaping to enhance the wind environment. Wind pressure maps indicate that high-pressure zones are predominantly located on the western and northern sides of the complex, necessitating an enhancement of the airtightness of the enclosure structure in the rooms situated on the windward side (refer to **Figure 6**).

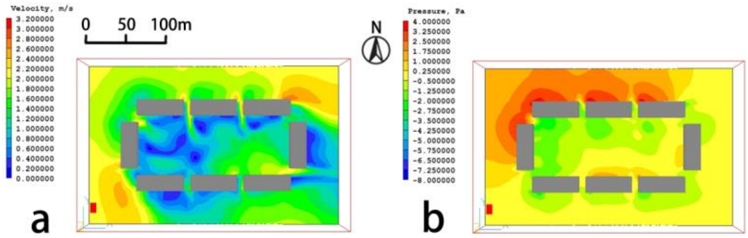


Figure 6. Simulation of wind environment with enclosed, arranged I-shaped buildings.

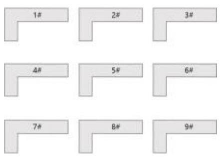
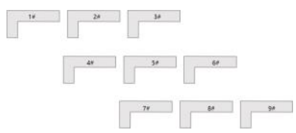
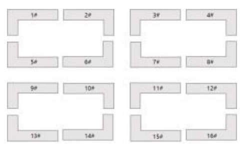
Note: a: wind speed cloud map; b: wind pressure cloud map.

In conclusion, the I-shaped building configuration demonstrates greater efficacy when utilizing an enclosed layout. This design is more effective than both the Row and Diagonal column layouts, as it provides superior resistance to wind forces. Consequently, it is particularly well-suited for the winter wind conditions prevalent in Hohhot.

3.3. Examination of wind environment simulation for groups of L-shaped buildings

The study focuses on the dormitory structure located on the southern campus of Inner Mongolia University, which measures 88 m in length, 45 m in width, and 18 m in height. The individual dormitory buildings are designated as Building 1 through Building 16. The L-shaped configuration of the building complex was modeled with the wind direction oriented towards the northwest (refer to **Table 6**).

Table 6. Schematic diagrams of the different layout forms of L-shaped buildings.

	Row	**Diagonal**	**Enclosed**
Layout Diagram			

L-shaped buildings are arranged in rows: the wind speed cloud diagram indicates that the L-type building configuration effectively creates wind shielding at the corners of the wind shadow area, which is advantageous for winter wind protection. This arrangement is suitable for activities within the site. The presence of the narrow tube effect between buildings 1 and 2 results in increased wind speed due to airflow dynamics, with the maximum wind speed recorded at the southeast corner of building 2 reaching 3.2 m/s. Furthermore, the wind speed in the east-west channels formed by the second and third rows of buildings is lower than that of the first row, suggesting that the wind environment in these latter two rows is more favorable. The southern aspect of the third row of structures exhibits a substantial wind shadow zone, which may be utilized for outdoor activities. Analysis of the wind pressure maps indicates that the wind pressure on the windward side of the first row of buildings is elevated, with a maximum wind pressure exceeding 4.0 Pa. Consequently, it is imperative to consider measures for cold-proofing and heating in the rooms located on the windward side of the buildings situated in the first row and on the western side (refer to **Figure 7**).

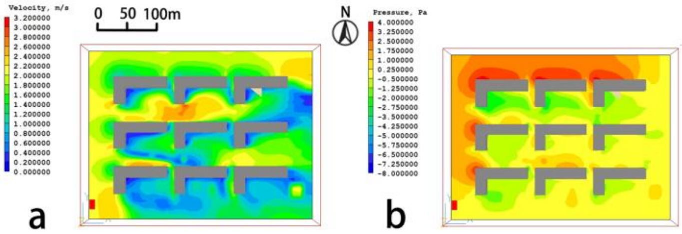


Figure 7. Simulation of wind environment with L-shaped buildings arranged in rows.

Note: a: wind speed cloud map; b: wind pressure cloud map.

L-shaped buildings are arranged diagonally: the wind speed cloud map indicates the presence of corner wind phenomena at the southwest corner of Building 1 and the northeast corner of Building 3. This level of wind speed can create a noticeable draft for pedestrians, thereby diminishing their comfort. Additionally, the southwest corner of Building 4 and Building 7 also experiences corner wind effects, although the impact in this area is relatively minor. Conversely, the northern side of Building 7 and Building 8 exhibits higher wind speeds due to the constricting effects of the surrounding structures, which may hinder wind protection during winter months and adversely affect outdoor activities. In general, L-shaped buildings exhibit a specific range of wind shadow areas at their shaded corners, which enhances the winter wind protection for the building complex. This characteristic allows for the strategic arrangement of outdoor activities within the confines of the wind shadow area. Furthermore, a diagonal layout can create an expanded wind protection surface along the periphery of the building, effectively mitigating wind impact on the interior of the complex and contributing to a more stable wind pressure and wind speed within the premises. The wind pressure analysis indicates that high-pressure zones are predominantly located on the windward side of the first row of buildings, necessitating careful consideration of insulation and heating measures for the rooms situated in these areas (refer to **Figure 8**).

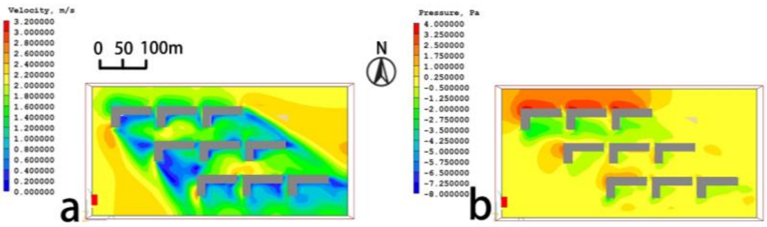


Figure 8. Simulation of wind environment with diagonally arranged L-shaped buildings.

Note: a: wind speed cloud map; b: wind pressure cloud map.

L-shaped buildings are arranged in an enclosed formation: The wind speed map indicates that the phenomenon known as the narrow tube effect results in elevated wind speeds within the east-west corridor formed by two rows of buildings. High-velocity airflow is directed from these openings towards the wind shadow areas. To mitigate the impact of high-speed winds entering enclosed spaces and to enhance human comfort, it is advisable to implement strategic planting of trees or the installation of wind barriers in these critical locations. From the perspective of the entire building complex, the wind field within the second row of enclosed spaces exhibits greater stability, characterized by an extensive wind shadow area, which is conducive to the placement of outdoor activity areas within the enclosed spaces. The wind pressure distribution map indicates that high-pressure zones are predominantly located on the windward side of the northwestern sections of the complex. Consequently, it is imperative to consider measures for cold-proofing and heating the rooms situated in these areas (refer to **Figure 9**).

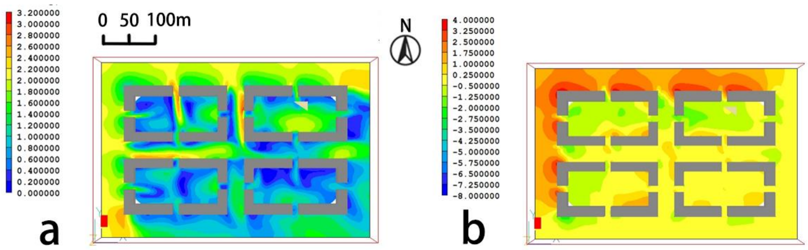


Figure 9. Simulation of wind environment with enclosed, arranged L-shaped buildings.

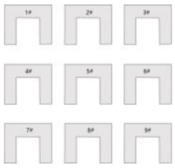
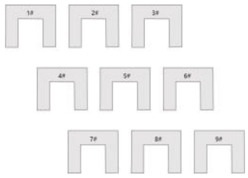
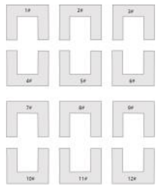
Note: a: wind speed cloud map; b: wind pressure cloud map.

In conclusion, the L-shaped building configuration features an enclosed design that maximizes the internal static wind zone and provides optimal wind protection during the winter months. Nevertheless, this enclosed arrangement may result in inadequate internal ventilation. Upon evaluating the necessity for summer ventilation, it is determined that a diagonal layout is the most efficient design for L-shaped building clusters.

3.4. Examination of wind environment simulation for groups of U-shaped buildings

The dormitory structure located on the West Campus of Inner Mongolia University of Finance and Economics was chosen as a representative sample for the wind environment simulation of a U-shaped monolithic building, based on a study of student dormitories at universities in Hohhot. The dimensions of the building are approximately 68 m in length, 51 m in depth, and 18 m in height. The monolithic sections of the building are designated sequentially from 1# to 12#. The wind environment simulation for the U-shaped building is conducted in three configurations: row, diagonal column, and enclosure layout (refer to **Table 7**).

Table 7. Schematic diagrams of the different layout forms of U-shaped buildings.

	Row	Diagonal	Enclosed
Layout Diagram			

U-shaped buildings are arranged in rows: The wind speed map indicates a significant presence of wind shadow areas within the concave corner of the U-shaped building, which facilitates wind protection during the winter months. This spatial configuration allows for the potential arrangement of outdoor activities in the concave corner. However, the semi-enclosed nature of this space results in inadequate air circulation, leading to difficulties in the dispersion of pollutants and a subsequent deterioration in air quality. Therefore, it is essential to enhance the wind environment in the concave corner through the integration of vegetation and landscaping elements. Additionally, the first two rows of east-west channels experience an intensified wind speed due to the narrow tube effect, which adversely impacts pedestrian comfort in the area. Wind pressure maps indicate that the windward side of the initial row of buildings on the northern side of the complex, as well as the western side of the buildings, exhibit elevated wind pressures, with maximum values exceeding 4.0 Pa. Consequently, it is imperative to implement protective measures for the rooms located in these areas to mitigate the effects of cold and heat (refer to **Figure 10**).

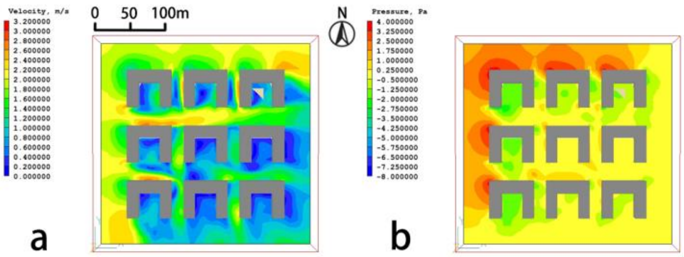


Figure 10. Simulation of wind environment with U-shaped buildings arranged in rows.

Note: a: wind speed cloud map; b: wind pressure cloud map.

U-shaped buildings are arranged diagonally: The wind speed cloud diagram indicates that the southwest corner of Building 1, Building 4, Building 7, and the northeast corner of Building 3 create a corner wind phenomenon due to obstruction by the first row of buildings. In this scenario, the wind speeds around Building 1 and Building 3 are notably higher, exhibiting a broader area of influence. The north-south passage situated between Building 1 and Building 3 experiences an intensified wind speed due to the narrow tube effect, with peak wind speeds reaching approximately 2.9 m/s. To mitigate these wind speeds, it is advisable to implement wind barriers or green plantings in these locations and openings on the windward side. Additionally, significant wind shadow areas are typically found in the concave corners of U-shaped buildings, which can be strategically utilized for outdoor activities in conjunction with site planning. The wind pressure map reveals that high-pressure zones are predominantly located on the windward side of the first row of buildings on the northern side, necessitating careful consideration of the airtightness of the enclosure structures in these areas. In comparison to a row layout, the wind field within the building group exhibits greater stability, while a diagonal layout offers enhanced protection for the interior of the building group (refer to **Figure 11**).

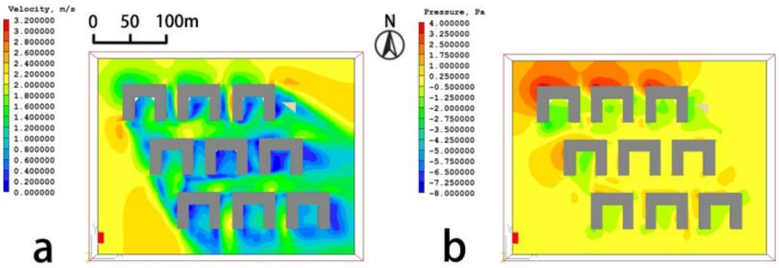


Figure 11. Simulation of wind environment with diagonally arranged U-shaped buildings.

Note: a: wind speed cloud map; b: wind pressure cloud map.

U-shaped buildings are arranged in an enclosed formation: The wind speed cloud diagram indicates that the northeast corner of Building 3 and the southwest corner of Building 10 create a corner wind phenomenon. To mitigate this issue, it is advisable to implement vegetation or install wind barriers in these specific locations to decrease wind speed. Additionally, the wind entering through the openings of the first row of buildings is directed towards the interior of the complex, resulting in increased local wind speeds along the north-south corridor due to the constricting effect of the narrow passage. Therefore, it is recommended to position wind barriers on the windward side of these openings to further reduce wind speed. From the perspective of the wind environment surrounding the entire building complex, it is observed that the airflow velocity between the openings of each individual building is minimal. Furthermore, within the enclosed area of the U-shaped building, the wind speed is notably low, resulting in sluggish airflow and inadequate air circulation. This condition renders the enclosed space suitable for the establishment of outdoor activity and relaxation areas. However, it is imperative to maintain environmental hygiene within this space and to implement appropriate vegetation planting to enhance the wind environment. The wind pressure analysis indicates that the high-pressure zones are predominantly located on the windward side of the northwest corner of the building complex, necessitating careful consideration of the airtightness of the enclosure structure in these areas (refer to **Figure 12**).

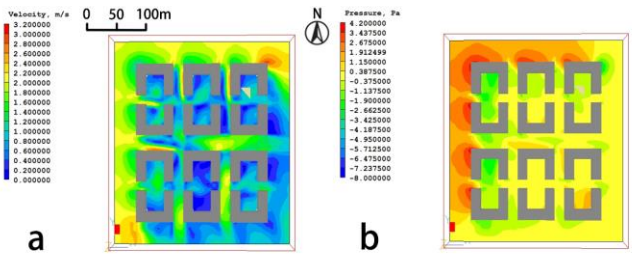


Figure 12. Simulation of wind environment with enclosed, arranged U-shaped buildings.

Note: a: wind speed cloud map, b: wind pressure cloud map.

In conclusion, the U-shaped building configuration utilizes an enclosed design that provides optimal wind protection during the winter months. Nevertheless, taking into account the necessity for ventilation in the summer, the diagonal layout is deemed to be the most effective arrangement for the U-shaped building group.

4. Discussion

4.1. The correlation between architectural layout and wind environment

The wind environment surrounding a building exhibits significant variability due to differing architectural layouts. Typically, there are three primary configurations for a building complex: row, diagonal, and enclosed. The row layout tends to be more systematic and structured; however, the flow field within the complex can fluctuate considerably depending on the angle of wind projection. In the context of university dormitories located in colder regions, it is advisable to enhance the enclosure of the building to the greatest extent possible. By utilizing closed and semi-closed inner courtyard spaces, the building can effectively shield these areas, thereby creating a more favorable outdoor wind environment.

Research examining the wind dynamics in relation to adjacent structures indicates that the internal wind field exhibits optimal stability when L-shaped buildings are situated in conjunction with other L-shaped buildings. This configuration is particularly effective in mitigating the penetration of cold winds during the winter season.

An analysis of three representative building configurations—namely, the Row, Diagonal, and Enclosed layouts—across various arrangement scenarios has revealed that the adoption of row and column layouts significantly improves the internal ventilation of monolithic building clusters. This configuration leads to the formation of corner wind phenomena on the windward side and at the corners, which subsequently influences the airflow experienced by the buildings located in the rear rows. Furthermore, L-shaped buildings demonstrate superior performance compared to monolithic structures due to their shading effects; however, similar corner wind patterns emerge at the corners, thereby affecting the internal wind environment of the complex. In contrast, the average wind speed within U-shaped building clusters is comparatively lower, resulting in a more favorable overall wind environment than that observed in monolithic buildings.

The implementation of a diagonal layout in architectural design facilitates the creation of an expanded wind surface along the periphery of the building. In comparison to linear and L-shaped structures, the diagonal configuration of a U-shaped building offers enhanced protection for the interior spaces. This design results in a more stable wind pressure environment surrounding the internal areas, thereby promoting effective wind protection during the winter months.

The utilization of an enclosed layout facilitates the creation of a relatively confined space due to its strong enclosure, resulting in a stable wind field within this area and the potential for the establishment of a static wind zone. In winter, the wind field within the enclosed space exhibits greater stability compared to that of row-row and inclined-row configurations, thereby optimizing the mitigation of cold winter winds. However, this layout is susceptible to the narrow tube effect at the openings, which can lead to inadequate air circulation within the enclosed space, hindering the expulsion of pollutants. Consequently, it is imperative to implement effective windproof measures at the openings, while also incorporating greenery and landscaping within the space to enhance the overall wind environment.

An examination of the wind environment surrounding adjacent structures, in relation to the selection of layout configurations for three representative building forms, indicates that the winter wind conditions are most favorable when an L-shaped building is paired with another L-shaped building. By considering the building layout as a variable and analyzing factors such as wind speed and wind pressure, it can be inferred that when the building is configured in an I-shape, an enclosed layout is superior to both row and diagonal arrangements. The enclosed layout demonstrates the most significant obstruction to wind flow, thereby providing effective resistance against cold winds during the winter season. In the case of an L-shaped building unit, the enclosed configuration exhibits the largest internal wind shadow zone during winter, thereby enhancing protection against winter winds. However, when evaluating summer ventilation comprehensively, the diagonal layout proves to be more advantageous than the enclosed layout. Conversely, for a U-shaped building monolith, the enclosed layout offers significant enclosure, resulting in a minimal wind speed ratio, which is beneficial for winter wind protection. Nonetheless, this configuration is less effective for summer ventilation and may contribute to air pollution within the enclosed space. Taking into account both summer ventilation and the comfort of the wind environment, the diagonal layout emerges as the optimal choice.

4.2. The impact of wind speed, wind direction, and wind environment changes on human physiological functions and their importance

When exploring the impact of wind environments in severe cold region university dormitories on human comfort and physiological health, it is crucial to delve into the complex mechanisms through which wind speed, wind direction, and changes in the wind environment affect human physiological functions, and to analyze these using biomechanical principles. This is vital for optimizing architectural design.

4.2.1. The impact of wind speed from a biomechanical perspective

From a biomechanical perspective, the most direct impact of wind speed on the human body is the increased efficiency of convective heat exchange with the air. In cold climates, the human body loses heat through radiation, convection, and conduction, and an increase in wind speed significantly accelerates the process of convective heat loss, leading to a rapid drop in body temperature. This drop in body temperature not only affects human comfort but may also trigger a series of physiological issues.

Specifically, when wind speed increases from a stationary state to a certain velocity, convective heat loss from the human body surface increases exponentially. According to relevant literature, when wind speed increases from a stationary state to 5 m/s, the perceived temperature can plummet by about 10 ℃. For university students residing in severe cold regions like Hohhot, prolonged exposure to such wind speed conditions places significant stress on the body’s thermoregulatory mechanisms. Especially when wind speed exceeds the range that the human body can tolerate, it may lead to hypothermia, peripheral circulatory disorders, frostbite, and other physiological problems.

Simulation data from this study shows that in the diagonal layout of Type I building clusters, the wind speed in specific corners reaches up to 3.8 m/s. Based on biomechanical principles, under such wind speed conditions, convective heat loss from the human body surface increases significantly, thereby threatening students' thermoregulatory capabilities. Long-term exposure to such environments may have long-term negative effects on students' physiological health.

4.2.2. The complex impact of wind direction and wind pressure on human physiology

Changes in wind direction not only affect the distribution of wind speed but also exert complex effects on the human body by altering wind pressure. Wind pressure is the pressure exerted by air flow on the surface of an object. For the human body, changes in wind pressure can lead to respiratory discomfort, skin irritation, and even changes in eardrum pressure.

In narrow passages or corner areas between buildings, due to the wind acceleration effect, wind pressure may significantly increase. This high-wind pressure environment directly affects the human respiratory system by increasing respiratory resistance, leading to increased respiratory frequency and reduced oxygen intake. At the same time, high wind pressure may also irritate the skin, causing discomfort or pain.

The wind pressure contour analysis in this study shows that wind pressure is higher on the windward side and in corner areas in various building cluster layouts. For example, in the diagonal layout of I-shaped building clusters, certain areas on the north side of Buildings 4 and 7 have wind pressure values exceeding 4 Pa. According to biomechanical principles, such high-wind pressure environments not only adversely affect the human respiratory system and skin but may also affect hearing by altering the pressure difference inside and outside the eardrum.

Furthermore, changes in wind direction also affect the efficiency of heat exchange on the human body surface. When the wind direction is perpendicular to the human body surface, convective heat loss is most efficient; whereas when the wind direction is parallel to the human body surface, convective heat loss is relatively lower. Therefore, in architectural design, it is crucial to consider changes in wind direction reasonably to optimize the wind environment.

5. Conclusion

This study employs biomechanics as a foundational framework and utilizes PHOENICS hydrodynamics simulation software to systematically analyze the wind environment of a dormitory complex in Hohhot. The research examines various configurations of adjacent buildings, focusing on their type and layout. Through comprehensive simulations, the study establishes a general correlation between the architectural arrangement of the building complex and the resulting wind environment. The findings indicate that the optimal wind conditions are achieved with L-shaped buildings in proximity to one another. Furthermore, the most effective layout for an I-shaped building group is characterized by an enclosed formation, while a diagonal arrangement is preferable for L- and U-shaped building groups.

Based on the aforementioned conclusions, the optimization strategy for the arrangement of building groups is delineated as follows: the diagonal layout configuration is advantageous as it creates an extensive wind protection surface along the periphery of the structure. This arrangement aligns the edges of the building group parallel to the prevailing wind direction, thereby mitigating the impact of corner winds on the rear row of buildings. Furthermore, this layout facilitates an even distribution of wind shadow areas among the buildings. Conversely, the enclosed layout exhibits the highest degree of enclosure, resulting in a relatively confined space with a stable internal wind field. However, it is imperative to consider summer ventilation when evaluating the overall layout of the building complex. This study explores the relationship between three distinct types of neighboring building configurations and three primary forms of group building layouts in relation to the winter wind environment. It is important to note that the research does not consider additional factors that may affect student housing in higher education, such as the orientation of group buildings, the individual building design, and the extent of spatial openness. Furthermore, the building forms and layouts analyzed in this paper represent an idealized model, which allows for predictions and analyses in typical scenarios; however, actual projects are likely to exhibit greater complexity, necessitating dynamic analysis and validation against empirical data. Future research should delve deeper into these aspects to facilitate the development of a sustainable, low-energy, and comfortable outdoor wind environment within the dormitory area of Hohhot University.

Author contributions: Conceptualization, WT and DL; methodology, WT and DL; software, WT and DL; validation, WT, DL and WW; formal analysis, WT; investigation, WT; resources, WT and WW; data curation, WT and DL; writing—original draft preparation, WT; writing—review and editing, WT; visualization, WT and DL; supervision, WT; project administration, WW; funding acquisition, WW. All authors have read and agreed to the published version of the manuscript.

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