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The Influence of Tree Planting Layout on the Wind Environment of Residential Areas in Hangzhou and Optimization Strategies

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Abstract: With the continuous advancement of the sustainable development concept, optimizing the urban living environment has become one of the core goals of urban planning and construction in China. To enhance the ecological benefits and living comfort of residential areas, the reasonable planting distance between trees and buildings has become an important factor that cannot be ignored. By combining on-site cases, through on-site investigation and numerical simulation, this paper explores the impact of tree planting distance on the building environment and further proposes optimization schemes to avoid the negative effects of excessive tree shading and wind blocking of buildings, while ensuring the ecological functions of trees in beautifying the environment and purifying the air. The research results provide theoretical support and practical basis for the future design of residential area green landscape, promote the application of the concept of sustainable urban greening, and make positive contributions to improving the quality of life of residents and the urban ecological environment.

Keywords: Tree Landscape; Planting Spacing; Numerical Simulation; Wind Environment Optimization; Residential Area.

1. Introduction

With the acceleration of urbanization in China, cities are confronted with multiple challenges such as the environment, resources, and climate. Particularly, in the context of increasing building heights and densities, the changes in urban microclimate and the deterioration of wind environment have become increasingly prominent. Against this backdrop, the concept of "ecological garden city" has emerged as an important direction for promoting sustainable urban development, emphasizing the creation of harmonious and healthy living environments. As an essential part of cities, residential areas' wind environment comfort directly affects residents' quality of life and health. With the rising demands for living environments, how to improve the wind environment of residential areas through reasonable greenery layout has become one of the current research hotspots. At the national and local levels, a series of policy documents have been issued, such as the "Green Building Evaluation Standard GB/T 50378-2019", highlighting the importance of microclimate regulation and wind environment optimization, aiming to provide theoretical basis and implementation guidance for the planning and design of urban residential areas. Urban green spaces, as an effective means to improve microclimate and regulate local wind environment, their configuration directly influences the comfort and sustainability of residential areas. Based on this, this paper aims to deeply explore the impact of tree layout design on the wind environment of residential areas, and through analyzing the optimization paths of tree configuration, provide scientific support and practical basis for building more comfortable and healthy urban residential areas.

Currently, there are many studies on the impact of plant configuration forms and green space layout on the wind environment. In the research conducted by Lv Xiangcui and Gao Wenwen at Tianjin Chengjian University, the changes in wind speed and pressure fields at pedestrian height around building clusters were explored, and a comparison was made between the current situation and the optimized tree layout [1]. Lin Ding and others from Fuzhou University used CFD technology to reproduce four tree planting scenarios in typical urban deep street canyons [2]. Chang Le from Xi'an Polytechnic University studied the impact of different greenery layout patterns on outdoor wind environment through CFD software simulation and on-site measurement methods [3]. Zhang Yuanyuan from Shenyang Jianzhu University, based on survey results, selected 20 typical Shenyang citizen squares and studied the impact of square greening on the wind environment from aspects such as the degree of boundary greening enclosure, opening form, and the length and width of windbreak forests [4]. Dongjin Cui et al. took urban street canyons as the research object and analyzed the impact of street morphology and layout on the wind environment [5]. In addition, Xiaoyu Ying et al. set up multiple office building cluster layouts and simulated and analyzed the relationship between these layouts and the outdoor wind environment. The study found that the outdoor wind environment of the multi-court layout was more comfortable than that of the overall court layout [6].

In recent years, the role of trees in the residential environment has also received extensive attention, especially in the research on improving microclimate, regulating wind environment, enhancing ecological benefits, and improving living quality. Domestic and international research shows that trees not only play a significant role in beautifying the environment and improving air quality but also effectively regulate temperature, mitigate the urban heat island effect, and improve the wind environment, etc. Abroad, especially in Europe and America, scholars have concentrated on studying the impact of trees on the climate regulation of residential areas. For instance, Salmond et al. demonstrated that urban greening through the shading and transpiration of trees effectively reduces the temperature in urban centers, thereby alleviating the heat island effect [7]. Hedblom et al. further explored the improvement effect of trees on the urban wind environment, pointing out that trees not only provide good wind barriers for residents but also regulate air flow, enhancing the comfort and livability of residential areas [8]. Additionally, Tyrvainen et al. found that trees planted along streets can significantly reduce the noise level in surrounding areas, improving the living environment [9].

In China, with the advancement of urban greening and ecological civilization construction, research on the impact of trees on the residential environment has gradually increased. Domestic research mainly focuses on the regulation of microclimate and the mitigation of urban heat island effect by tree planting configuration. For instance, Sun Xiang et al. found through field investigation that trees can effectively lower temperatures, especially in summer. Reasonably arranged green belts can reduce the surface temperature of buildings and decrease the load of air conditioning usage [10]. Li Jianhua et al.'s research indicates that the regulation effect of trees on the wind environment is multi-faceted. The layout of trees should be optimized based on factors such as climate conditions, wind speed, and humidity. Particularly in tropical and subtropical regions, trees can effectively block hot winds and enhance wind comfort. However, in cold regions, overly dense greenery may affect lighting and heating efficiency [11].

Trees play a significant role in improving the wind environment of urban pedestrian areas, reducing residential energy consumption, and regulating the microclimate and wind speed of residential areas. Badamchizadeh et al. utilized a Computational Fluid Dynamics (CFD) model to analyze the improvement effect of trees on the wind environment of urban pedestrian areas. The study showed that trees effectively improve the wind environment at the pedestrian level through wind barrier effects [12]. Taha et al. explored the wind barrier and shading effects of trees and found that trees can significantly reduce residential energy consumption, especially in heating and cooling [13]. Additionally, Hong et al. also pointed out that the planting location and species of trees have a significant impact on the microclimate and wind environment of residential areas. Reasonable tree configuration can provide important shading and wind speed regulation effects for residents [14]. Although some preliminary studies have shown that reasonable tree spacing can regulate local wind flow and reduce wind pressure on buildings, specific numerical standards and spatial layout strategies remain unclear, lacking systematic theoretical models and experimental data support. Therefore, this paper combines field cases, through a combination of on-site investigation and numerical simulation, to optimize the impact of tree planting distance on the building environment and further propose planting schemes to avoid the negative effects of excessive shading and wind flow obstruction of buildings by trees.

2. Materials and Methods

(1) Regional Overview

The research area is located in Xixing, Binjiang District, Hangzhou. The selection of the research area follows these criteria: it has been under construction for over 15 years, the vegetation types in the public spaces of the residential area are diverse, and they have reached a mature growth stage. The area is also frequented by residents. In recent years, Hangzhou, as a city that has attracted much attention, has increasingly focused on the construction of human settlements. Therefore, this study selects a residential area in Binjiang District, Hangzhou as the object of optimization research.

This residential area was constructed by Hangzhou Urban Construction Comprehensive Development Corporation. The total building area is 43,000 square meters, the total land area is 56,000 square meters, and there are a total of 1,387 residential units. The green coverage rate of the residential area is approximately 35%. The west side of the area is adjacent to the Construction River, the south side is close to Beitang Road, the north side is next to Binxing Road, and the east side is Qianmo Road. The residential buildings are multi-story buildings, totaling 32 buildings, each with 6 floors, which are mid-to-low-rise buildings. Through the satellite plan (Figure 1), it can be observed that the building layout of the residential area adopts a parallel arrangement of slab buildings, extending from east to west.

Figure 1. Survey the satellite map and current photos of the residential area

Through on-site investigation of the current greenery situation in the residential area, the main types of trees planted between the buildings in the community were statistically analyzed, and the results are shown in Table 1. The vegetation in this community is diverse, with rich layers and vigorous growth.

According to the frequency table of plant application (Table 2) obtained through on-site investigation, the plant types with higher application frequencies in green spaces are mainly evergreen plants. Among them, the dominant tree species are camphor and osmanthus, which are respectively the city tree and city flower of Hangzhou and have been widely used in landscaping. As for deciduous plants, they are mainly concentrated in tree species such as Sapindus mukorossi and late cherry.

(2) Research Methods

The current Computational Fluid Dynamics (CFD for short) integrates fluid mechanics, numerical calculation and computer graphics, and is widely used to simulate and analyze the characteristics of fluid flow. CFD technology can handle the complex flow of fluids at different speeds. By constructing turbulence models, setting appropriate parameters and boundary conditions, it can numerically simulate the velocity field, temperature field and concentration field of fluids in a specific space. Such simulations not only reveal detailed information about fluid flow but also visually display the flow state. The CFD simulation software used includes but is not limited to ENVI-MET, FLUENT and PHOENICS, etc. These software have been widely applied in landscape architecture and many other fields. PHOENICS has demonstrated its reliability and effectiveness in terms of openness, flexibility, CAD integration, handling of moving objects, model selection, algorithm diversity, multi-body simulation, VR interface, grid processing, teaching resources, automatic convergence control, detail processing and VR enhancement functions, making it a widely used simulation software.

Table 1. Statistics of Main Tree Species in the Residential Area

No.	Name	Latin Name	Family	Genus	Growth Type
1	Camphor Tree	Cinnamomum camphora	Lauraceae	Cinnamomum	Evergreen Tree
2	Osmanthus fragrans	Osmanthus fragrans	Oleaceae	Oleaceae	Evergreen Tree
3	Elaeocarpus decipiens	Elaeocarpus decipiens	Elaeocarpaceae	Elaeocarpaceae	Evergreen Tree
4	Loquat	Eriobotrya ja pnica	Rosaceae	Eriobotrya	Evergreen Tree
5	Magnolia denudata	Yulania denudata	Magnoliaceae	Magnoliaceae	Evergreen Tree
6	Ligustrum lucidum Ait	Ligustrum lucidum Ait.	Oleaceae	Ligustrum	Evergreen Tree
7	Red Maple	Acer palmatam	Aceraceae	Acer	Deciduous Tree
8	Trident Maple	Acer palmatam	Sapindaceae	Acer	Deciduous Tree
9	Sapindus mukorossi	Sapindus mukorossi	Sapindaceae	Sapindus	Deciduous Tree
10	Koelreuteria paniculata	Koelreuteria paniculata	Sapindaceae	Koelreuteria	Deciduous Tree
11	Ginkgo biloba	Ginkgo biloba	Ginkgoaceae	Ginkgo	Deciduous Tree
12	Purple Leaf Plum	Prunus cerasifera	Rosaceae	Prunus	Deciduous Tree
13	Japanese Cherry	Prunus serrulata	Rosaceae	Prunus	Deciduous Tree
14	Chinese Elm	Ulmus parvifolia	Ulmaceae	Ulmus	Deciduous Tree
15	Chinese Tulip Tre	Liriodendron chinense	Magnoliaceae	Liriodendron	Deciduous Tree
16	Black Locust	Robinia pseudoacacia	Fabaceae	Robinia	Deciduous Tree

(3) Evaluation Indicators

Wind speed has a significant impact on residents' comfort. In urban residential areas, especially in densely populated regions, abnormal fluctuations in wind speed may negatively affect residents' quality of life and health. Appropriate wind speed helps promote air circulation, improve air quality, lower environmental temperature, and enhance the comfort of the living environment. Therefore, using wind speed as an evaluation indicator can effectively guide the planning of residential areas, landscape design, and the improvement of air quality. The wind speed dispersion index reflects the amplitude of wind speed variation within a specific area. In cases of high wind speed dispersion, the difference in wind speed is significant, which may lead to the formation of extreme wind environments such as vortices or strong winds, increasing the environmental discomfort in residential areas. Therefore, using wind speed dispersion as one of the evaluation indicators aims to prevent the instability of the wind environment and avoid extreme wind phenomena that may pose potential hazards to residents' lives and building structures.

Table 2. The application frequency of trees in the surrounding green spaces

Application Frequency	Evergreen Trees	Deciduous Trees
80%<F≤100%	Osmanthus	Sapindus mukorossi
60%<F≤80%	Camphor	Acer palmatum, Cherry blossom, Prunus cerasifera
40%<F≤60%	Ligustrum	Liriodendron chinense, Koelreuteria paniculata, Ginkgo bilob
20%<F≤40%	Magnolia grandiflora, Elaeocarpus decipiens	Acer rubrum, Ulmus pumila
0%<F≤20%	Loquat	Acer rubrum

In summary, this paper uses wind speed data at pedestrian height (1.5 meters) and combines it with wind speed dispersion to evaluate the wind environment under different tree planting scenarios.

Table 3. Interaction between pedestrian comfort and wind speed

Evaluation Indexes	Wind Environment Requirements	
Wind Speed	0≤V≤1m/s	Uncomfortable, the area is a still wind zone
	l≤V≤2m/s	Comfortable, suitable for outdoor rest and children's play areas
	2≤V≤5m/s	Comfortable zone
	V≥5m/s	Uncomfortable, the area is a strong wind zone
Dispersion	If the wind speed dispersion value is large, it indicates that the wind speed difference within the area is significant, and the wind speed changes drastically, increasing the possibility of vortex formation or extreme wind environments.	

3. Results and Analysis

(1) Field Measurement of Wind Environment Data

The experiment was conducted at noon on June 27, 2024. The wind speed was measured using the Zhongbiao GM8902+ digital handheld anemometer. The monitoring points were set at a height of 1.5 meters above the ground, mainly observing a 5-level wind from the southeast. The measurement lasted from 11:00 to 14:00, approximately 3 hours. The observation time at each measurement point ranged from 5 to 10 minutes, and it was ultimately decided that each point would be measured for 4 minutes, totaling about 2 hours. Wind speed data were collected synchronously and in real-time at all monitoring points, with data recorded every 5 seconds within each minute to calculate the average wind speed for that minute. The 1-minute average wind speed measurement was repeated three times, with a 3-minute break between each measurement. The average wind speed obtained from these three measurements was taken as the final wind speed at each monitoring point. The wind was at its strongest during the experiment, and wind speed measurements were continuously carried out.

Figure 2. Distribution map of test points within the community and handheld anemometer GM8902+

The measured wind speed and average wind speed data at each measuring point after processing are shown in the following figure:

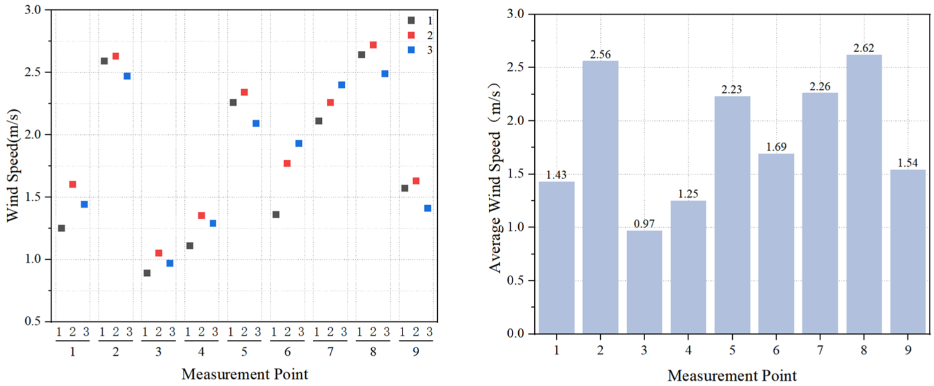

Figure 3. The measured wind speed and average wind speed at each measuring point

(2) Simulation and Field Measurement Verification

To simulate the outdoor wind environment, a model of the buildings and green areas in Yingchun South Garden was first constructed. This residential area consists of 32 six-story buildings. Since the focus of this study is on the outdoor wind environment, the external details of the buildings were ignored and they were simplified as rectangular blocks during modeling. Plant modeling was based on the field investigation results and divided into evergreen small trees, evergreen trees, and deciduous trees. Their tree heights and crown widths were set respectively, and finally imported into the PHOENICS software. The dimensions of the computational domain were set to 1100×1400×90. The wind direction was determined by combining the prevailing wind direction in Hangzhou and the wind direction on the day of the simulation, which was southeast. The grid was divided into 100×120×80. The buildings were represented using the BLOCKAGE method, and the green areas were represented using the FOLIAGE method. The standard k-ε model was selected as the turbulence model, and the power law exponential function was used as the wind profile function. The ground roughness was set to 0.25, and the number of iterations was 1000. To verify the accuracy of the software and parameter settings, the wind speed data obtained from the simulation will be compared with the actual observed data.

To accurately capture the fluctuations of the monitoring point data and calculate their average values, a pedestrian-level wind speed contour map at a height of 1.5 meters (Figure 6) was adopted. The obtained average values were compared and analyzed with the field measurement data. During the field measurement process, the measured data might be influenced by unpredictable factors, resulting in certain deviations between the simulation results and the field measurement data. To verify the accuracy of the simulation results, a comparative analysis was conducted between the simulation values and the field measurement data. When evaluating the simulation accuracy, the root mean square error (RMSE) was selected as the evaluation index, and the detailed results are shown in Figure 5.

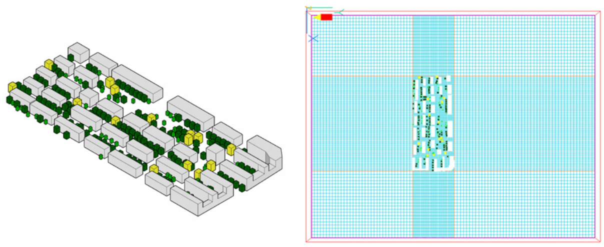

Figure 4. Modeling and Simulation Grid Settings for Yingchun South Garden

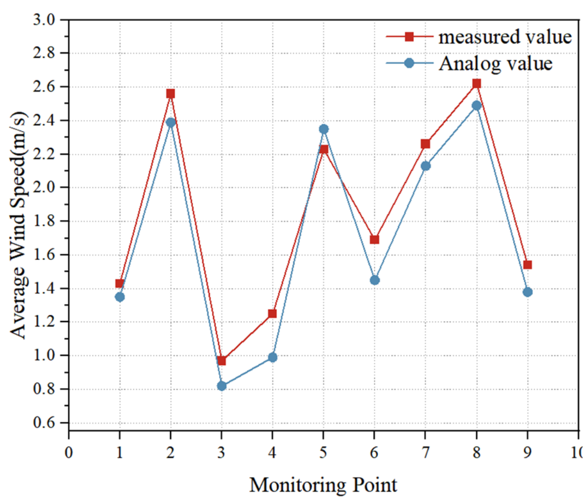

Figure 5. Comparison of wind speed simulation results with actual measurement values

In the field of wind environment simulation research, it is generally believed that when the root mean square error (RMSE) is less than 0.20 m/s, the simulation results are acceptable. In this experiment, the calculated RMSE was 0.1368542 m/s, which is below the standard threshold of 0.20 m/s. Therefore, this indicates that the simulation conducted using the Phoenics software, along with the applied model and parameters, can effectively reflect the characteristics and trends of air flow in residential areas.

(3) Current Wind Environment Analysis

Based on the analysis results of the wind speed cloud map, it can be observed that the vegetation coverage in this residential area is good, with an average wind speed of 1.83, which meets the standard for suitable wind speed for outdoor activities. Despite this, there are still large areas of calm zones within the region. The extreme values of wind speed are 4.69 m/s (maximum) and 0.23 m/s (minimum), indicating significant fluctuations in wind speed distribution. In the statistical analysis of wind speed distribution, the area proportion of calm zones is 23.37%, while that of strong wind zones is 5.83%. Further analysis shows that at the breathing height of pedestrians, the area proportion of comfortable wind speed zones is 45.61%, indicating that the wind speed conditions in most areas are suitable for residents' outdoor activities. However, the coefficient of variation is 84.76%, suggesting that the airflow within the wind field is unstable. The wind speed around buildings is relatively low, possibly due to the influence of vortices and obstacles. The wind speed at the top is higher, indicating that the wind accelerates above the buildings. The wind speed between buildings is moderate, forming a wind channel effect, while the wind speed near the ground is relatively low. Wind speed accelerates or decelerates in different areas due to the blocking and guiding effect of buildings, demonstrating typical urban wind effects. Abnormal wind speed phenomena in local areas still need attention, as these areas may have excessively high or low wind speeds, thereby affecting residents' outdoor activity experience.

The areas with higher wind speeds in the figure are concentrated at the main entrance on the north side of the community, while others are scattered in the vortex zones around various buildings. The through-flow zones are formed by the wind from the external open space flowing into narrow areas, with generally low wind speeds, which is not conducive to the diffusion of air pollutants. After entering through the main gate, the wind is divided into eastward and westward airflows by the vegetation at the entrance and flows towards each building, forming multiple small vortices within the building complex. These vortices not only affect the stability of the wind field but may also lead to a decline in air quality in local areas. Especially in the vortex zones, the wind speed is low, and the air flow is poor, making it easy for pollutants to accumulate, posing a potential threat to residents' health. Additionally, although the wind speed in the through-flow zones is moderate, due to the narrow space, air exchange is not smooth, which is also not conducive to the diffusion of pollutants.

It is worth noting that the greenery and vegetation within the community have a certain impact on the wind environment. The presence of vegetation can reduce wind speed, decrease wind impact force, increase air humidity, and improve microclimate. Especially in summer, the green spaces can provide residents with cool resting areas, enhancing the comfort of the living environment. However, in the current greenery layout of the community, the distribution of vegetation is not uniform, resulting in limited improvement of the wind environment. Therefore, in future greenery planning, the impact of vegetation on the wind environment should be fully considered, and green spaces should be rationally laid out to achieve better microclimate regulation effects.

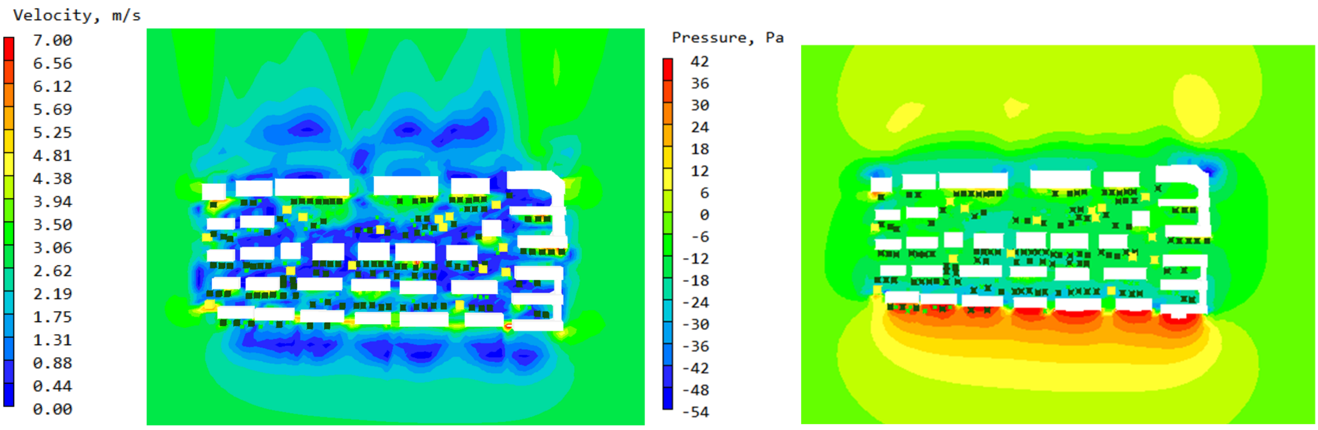

Figure 6. Simulation results of the current wind environment model of the residential area

4. Tree Planting Optimization Strategies

(1) Optimization Strategies

During the on-site investigation, it was found that the distance between the trees and the buildings in the residential area was too close, which affected the daily lighting of the ground floor residents and was also unfavorable for the air circulation inside and outside the buildings. Therefore, appropriately adjusting the planting distance between the trees and the buildings can effectively improve the outdoor wind environment. If trees are planted perpendicular to the wind direction, they can effectively block the wind; if they are planted parallel to the wind direction, they can help guide the wind direction. In view of the problems existing in the wind environment of this residential area, the planting of the trees in the green space should be adjusted. Therefore, based on the simulation cloud map, sample points A, B, and C with lower wind speed in the community (Figure 7) were selected for corresponding planting adjustments.

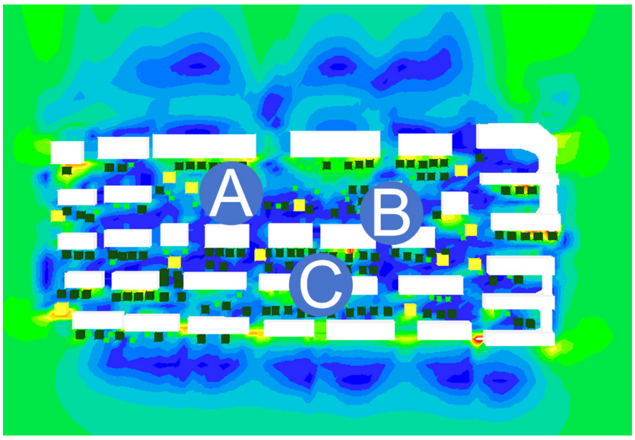

Figure 7. Improve the distribution of sample points

Sample point A, located at the entrance of the community, has formed a distinct still air zone due to the obstruction of buildings and the lack of tree planting. In such areas, the low wind speed and poor air circulation can easily lead to air stagnation, affecting the comfort of the surrounding environment. To improve the wind environment in this area, it is recommended to plant trees parallel to the wind direction at the entrance. The presence of trees can effectively impede wind speed and utilize the wind speed increase effect on their sides to guide the wind flow to divert laterally. In this way, the wind speed can be effectively guided from the north to the south, enhancing the wind flow in the area between buildings, alleviating the still air phenomenon, and thereby improving the air circulation at the community entrance.

Sample point B, located in the open area within the community, has formed a relatively strong wind zone due to insufficient vegetation coverage, with high wind speed, which can cause discomfort to people. The existence of strong wind areas often affects the daily activities and outdoor leisure environment of the surrounding residents. Therefore, it is recommended to plant trees perpendicular to the wind direction in this area. The branches and leaves of the trees can effectively slow down the wind speed. At the same time, the introduction of vegetation can not only improve the wind speed but also increase air humidity, further optimizing the microclimate conditions and reducing the dryness caused by high wind speed, creating a more pleasant community environment. The ecological benefits of trees can also promote air freshness, providing a healthier living space for community residents.

Sample point C, located in the narrow passage between building clusters, has relatively moderate wind speed but obvious air stagnation due to poor air circulation. To address this issue, it is recommended to plant trees on both sides of the passage to form a wind tunnel effect. The planting of trees can not only guide the wind flow but also promote the circulation of air, avoiding the formation of vortices, thereby enhancing air circulation and improving air quality. Through this approach, the air circulation in the passage can be effectively increased, reducing air stagnation and creating a fresher living environment.

Through a reasonable tree planting strategy, we can effectively regulate the wind environment in residential areas, enhance the ecological quality of the living area, and provide residents with more comfortable and healthy living conditions. When choosing tree species, priority should be given to those with excellent wind resistance and ecological benefits. For instance, camphor and osmanthus, as evergreen trees, not only have high ornamental value but also can significantly reduce wind speed. Simulation studies show that the optimal planting distance for camphor trees is 6 meters from buildings. This configuration can achieve the peak wind speed while keeping the wind speed fluctuation at the minimum, thereby enhancing the stability of the wind field. At this distance, human comfort is also maximized, and the fluidity and exchangeability of the wind are significantly improved. The planting distance for osmanthus trees should be 4 to 6 meters, especially around 4 meters, which can achieve a relatively ideal layout effect. Within this range, osmanthus vegetation can not only increase the average wind speed but also enhance the stability of the wind field, improving the external wind environment of the residential area and thereby increasing residents' comfort. On the other hand, deciduous trees such as Sapindus and late cherry blossoms can reduce the obstruction of the tree canopy to the wind in winter, facilitating wind penetration. Moreover, these tree species can provide rich ecological services, such as air purification and increased biodiversity, further enhancing the overall environmental quality of the residential area.

To alleviate the impact of strong winds at the entrance of the residential area on residents, a row of tall deciduous trees, such as ginkgo or Sapindus, can be planted. Simulation studies have shown that at a planting distance of 6 meters, although the wind speed does not reach its peak, the wind speed dispersion significantly decreases, indicating a significant improvement in the stability of the wind field and effective suppression of vortex formation. Such a layout can effectively guide air flow, improve the comfort of the wind environment in the residential area, and avoid discomfort caused by excessive or insufficient wind speed. Therefore, a planting distance of 6 meters may be a better choice for Sapindus vegetation in improving the external wind environment of the residential area. This configuration not only provides shade in summer but also allows sunlight to pass through in winter, while effectively reducing wind speed.

Inside the residential area, to promote air flow in the still air zone, low shrubs and ground cover plants can be added to form "wind channels" to guide air flow. In the vortex and through-flow zones, planting trees with wind-absorbing effects, such as Zelkova or purple leaf plum, can also effectively reduce vortex formation and further improve air quality. Through these comprehensive planting strategies, not only can the wind environment of the residential area be optimized, but also the overall ecological benefits and living comfort can be enhanced.

After simulation analysis, the results show that the south side of the building is most suitable for planting sun-loving plants, including large trees that can grow up to 11-12 meters and medium-sized shrubs about 1.5 meters tall. In contrast, due to insufficient light on the north side, it is more suitable for planting shade-tolerant medium-sized trees (6-8 meters in height) and medium-sized shrubs. Such a plant configuration can well adapt to the weak light environment, and when selecting tree species, their air purification effect and pollutant absorption capacity, among other ecological benefits, should also be taken into account.

(2) Analysis of Wind Environment Before and After Optimization

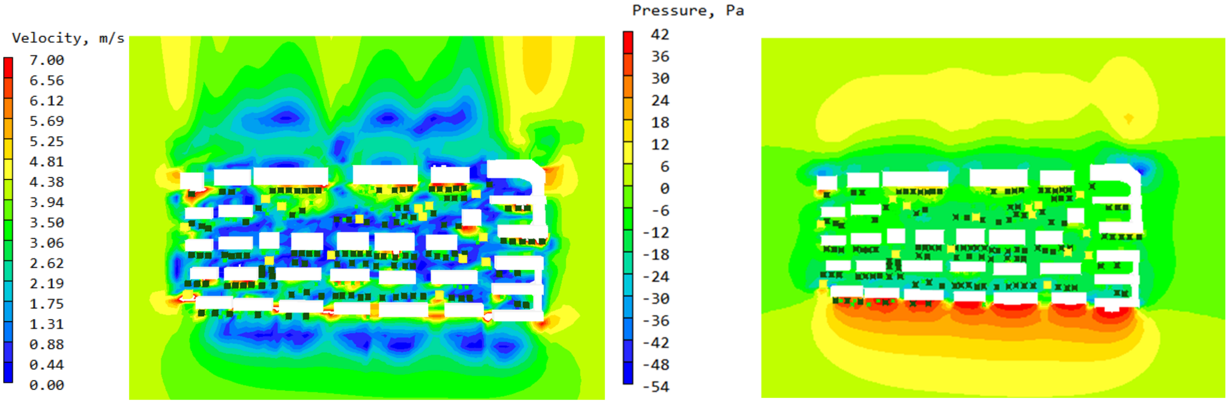

Figure 8. Optimized simulation results of the residential area

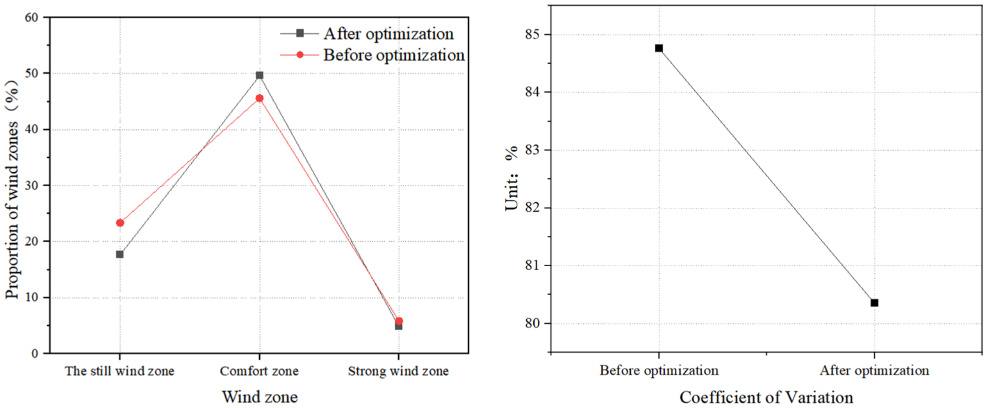

Figure 9. Comparison of wind speed and dispersion before and after optimization

According to Figure 8, the airflow characteristics at the breathing height of pedestrians in the residential area were optimized by adjusting the spatial layout of trees to improve the unsuitable wind field areas. Under the condition that other environmental factors remained unchanged, the wind environment of the residential area after optimization in Figure 9 was significantly improved. The wind speed became more stable, and the problem of excessively high local wind speed was effectively alleviated. The overall average wind speed in the residential area increased to 2.67 m/s, the area of still wind within the residential area decreased to 17.64%, the proportion of the comfort zone rose to 49.63%, and the coefficient of variation, or wind speed dispersion, dropped to 80.35%. The stability of the wind field in the residential area was effectively controlled, promoting air circulation within the residential area and reducing vortices and dead zones caused by building obstructions. As a result, the air quality of the entire residential area was significantly improved.

In the optimized layout, trees not only beautified the environment but also became the key factor in regulating the microclimate of the residential area. Especially in winter, by rationally arranging tall trees as windbreaks, the cold northerly wind was effectively blocked, making the internal temperature of the residential area relatively milder. Meanwhile, in summer, the branches and leaves of the trees provided necessary shade for pedestrians, reducing the discomfort caused by direct sunlight. Additionally, the optimized tree layout promoted air circulation within the residential area, reduced the occurrence of still wind areas, and was conducive to improving air quality, creating a healthier and more comfortable living environment for residents.

5. Conclusion

Through on-site investigation of the residential area Yingchun South Garden in Binjiang District, Hangzhou City, and simulation research on the outdoor wind environment of the residential area using simulation software, the actual measurement data were compared with the simulation data to determine the accuracy of the simulation software. To observe the influence of different types of trees at various planting distances on the wind field around buildings and explore the impact of tree planting distances on the building environment, and further propose optimization schemes to avoid the negative effects of excessive tree shading on buildings and wind flow, while ensuring the ecological functions of trees in beautifying the environment and purifying the air. Through the above research, the following conclusions were drawn: This study deeply explored the tree planting layout and its impact on the wind environment of the residential area Yingchun South Garden in Binjiang District, Hangzhou City, and proposed corresponding optimization strategies. By combining on-site measurement data with computer simulation technology, this study verified the accuracy of the simulation software in simulating the wind environment of the residential area, providing a theoretical and practical basis for subsequent related research. The research results emphasized the key role of tree planting in improving the microclimate of the residential area and proposed an optimization scheme for tree planting that aims to balance ecological benefits and the needs of the building environment. The conclusions of this study not only provided a scientific basis for improving the wind environment of Yingchun South Garden but also offered a reference model for optimizing the wind environment of other residential areas. It is hoped that this study will stimulate further attention from the academic and practical communities to the wind environment and tree planting layout of residential areas, promote research progress in this field, and contribute to creating a more livable urban environment for humans.

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