Study on Thermal Comfort in Historical Districts of Canal Ancient Towns

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Abstract. The thermal environment of tourist attractions, particularly in regions with hot summers and cold winters, significantly impacted visitor experiences and revenue. This study applied the microenvironment simulation software ENVI-met to analyze the thermal environment of historic streets and alleys under different conditions. Using simulation analysis, the paper revealed the effects of water bodies, shading, and wind speed. Key findings included: water bodies reduced temperatures by over 3°C in waterfront areas; shading in public spaces, such as pavilions and tree planting, lowered temperatures by about 2°C; and increased wind speed enhanced thermal comfort.Particularly in areas near water bodies, the combination of mechanical ventilation and the cooling effect of water bodies can effectively improve thermal comfort in historical districts. The research on Xiaohe Street highlighted the need for more shading facilities and mechanical ventilation to improve the thermal environment in ancient towns. Future studies will further analyze the impact of street and building layouts on thermal conditions, providing recommendations for environmental improvements.

Keywords: Canal Historical District, Thermal Comfort; Ancient Towns, ENVI-met

1 Introduction

Zhejiang Province has a long history and preserves many traditional villages and towns. By the end of 2023, it had 20 historic cultural cities, 94 famous towns, 218 famous villages, and 107 historic cultural districts, ranking first in the country. Following the implementation of policies such as "Beautiful Countryside" and "Beautiful Towns," the government has also introduced projects like the revival of ancient towns, aiming to promote the high-quality development of Zhejiang's traditional villages and towns and achieve common prosperity.[1]Traditional towns are not only important carriers of historical and cultural heritage but also living spaces for large populations. Additionally, they are popular destinations for cultural tourism.[2]According to statistics, traditional towns attract a large number of tourists. The three towns of Wuzhen, Nanxun, and Xitang alone receive more than 35 million

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visitors annually. Located in an area with hot summers and cold winters, Zhejiang experiences uncomfortable summer heat in its ancient towns. However, summer is also the traditional peak season for tourism, and visitors' perceptions of thermal comfort directly impact their travel experience, which in turn affects their willingness to return. Therefore, improving the thermal comfort of historical districts in ancient towns is very important. Additionally, since a large number of residents live in these ancient towns, enhancing the quality of the outdoor living environment reflects the high-quality development of urban construction in Zhejiang Province.

2 Literature Review

Urbanization has led to high population density, resulting in increasingly severe urban heat island effects. Since the 1970s, scholars worldwide have conducted extensive research on urban microclimates. Ali Katal and colleagues found a significant increasing trend in the duration of indoor overheating in three Canadian cities.[3] Studies have shown that extreme weather in summer and winter can affect human health.[4] Early scholars used methods such as field measurements of temperature, humidity, and other parameters to analyze urban thermal environments.[5] Nowadays, the combination of computer simulations and field measurements began to be used. Research on thermal environments has mainly focused on public spaces such as urban parks.[6] Some scholars have also studied rural thermal environments.[7] Research on outdoor thermal environments at a micro scale has mainly focused on people's perceptions of thermal comfort in courtyards.[8]With economic development, the tourism industry has become a major source of revenue for many countries and regions. As the fastest-growing industry globally, it is must to conduct in-depth discussions and research in various aspects. Studies have found that climatic conditions are a major factor influencing tourism, and changes in climate determine the popularity of tourist destinations.[9] Moreover, tourists are more concerned about the climate than local residents, as climatic factors directly affect their travel plans.[10] Therefore, thermal comfort in tourist destinations has become a focal point for researchers. Wang et al. studied alpine glacier tourism in southwestern China. Hamilton et al. evaluated the tourism climate in Germany [11] It can be seen that much research focuses on the climatic comfort of natural landscapes, while studies on the thermal comfort of historical districts for tourism are relatively scarce. Similar studies have revealed that the thermal environment is influenced by the characteristics of urban underlying surfaces, Urban geometry and vegetation distribution both affect thermal comfort.[12] Historical districts in ancient towns are usually located in the urban core, where land is crowded and the environment is suboptimal. These districts contain many valuable ancient buildings, making it challenging to alter the overall layout of the area. The main difficulty of this study is to propose effective design strategies to improve the living environment under various constraints.

3 Research Methodology

3.1 Research Subjects

Xiaohe Street Historic District in Hangzhou is a traditional area rich in history and cultural atmosphere, located in the Gongshu District along the Beijing-Hangzhou Grand Canal.(Fig.1) Xiaohe Street carries abundant canal culture and urban memories. The district preserves numerous traditional residences from the Ming and Qing dynasties, mostly brick-wood structures, showcasing the distinct characteristics of the Jiangnan water town.The buildings in the district are closely packed, with green bricks and black tiles, and the architectural style of whitewashed walls and black tiles harmonizes with the canal's waterscape, creating a unique historical panorama. Xiaohe Street not only retains its historical appearance in architecture but also continues the traditional canal culture.(Fig.2)

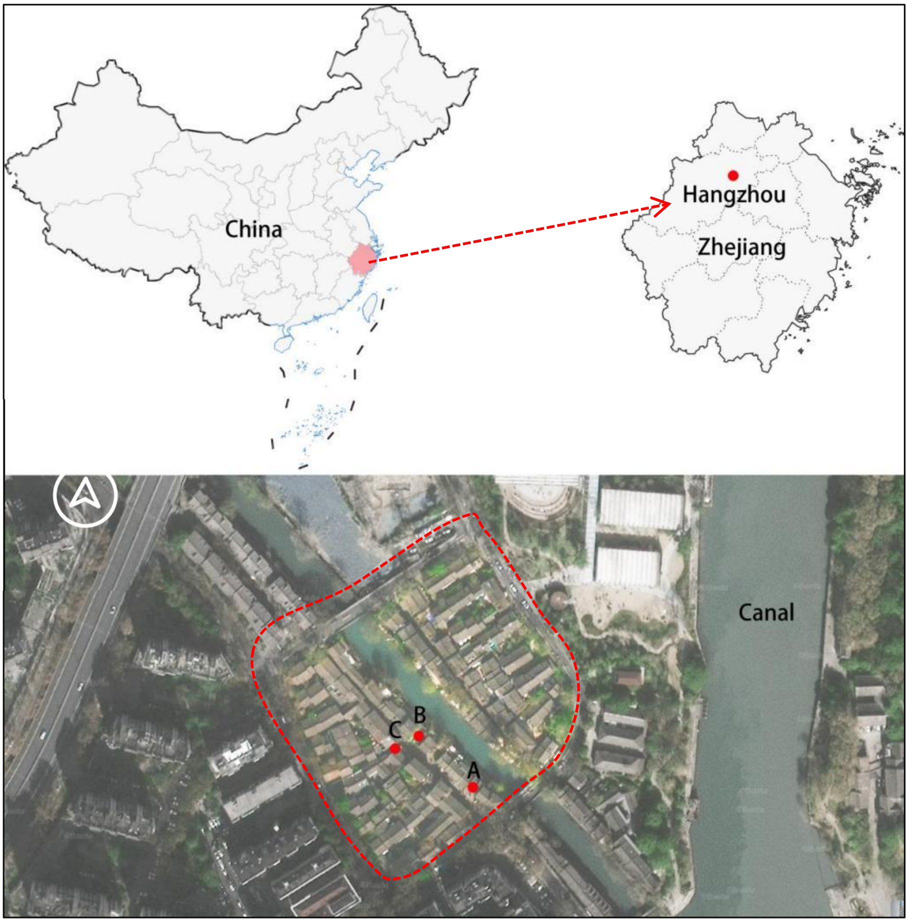


Fig. 1. Location Map and Measurement Point Distribution

Fig. 2. Scenic Views of Xiaohe Street

Within the district, there are many traditional craft shops, teahouses, and antique shops, where visitors can experience authentic Jiangnan charm. Additionally, Xiaohe Street is a major venue for traditional festive activities in Hangzhou. During significant holidays, the district hosts a variety of folk activities, attracting numerous residents and tourists.

3.2 Research Framework

This study focuses on the typical ancient town historic district of Xiaohe Street. First, a field measurement of the microclimate is conducted to explore the basic microclimate characteristics and the variation patterns of thermal environment parameters during the summer (July). This provides fundamental data for the verification and quantitative simulation of microclimate simulation software. Next, the selection and validation of the microclimate simulation software are carried out to ensure the reliability and sensitivity of the chosen numerical simulation software and the simulation settings used in this study. Finally, a quantitative simulation of landscape elements in Xiaohe Street is performed to analyze the effects of water body area, vegetation, shading facilities, and mechanical ventilation on the thermal environment. Based on the simulation results, effective design strategies are proposed to improve the thermal comfort of the historic districts in ancient towns.

3.3 Simulation Software Selection

ENVI-met is is designed to study the thermal stress relationships between building surfaces, vegetation, and air. The software uses a three-dimensional non-hydrostatic fluid dynamics model. In the horizontal direction, ENVI-met adds nesting grids around the simulation area as a buffer zone to reduce the influence of lateral boundary effects on the simulation results. Vertically, ENVI-met requires that the vertical height of the three-dimensional model be at least twice the height of the tallest building in the area (i.e., $Z \geq 2Hmax$) to eliminate the impact of top boundary effects on the simulation results.Due to its ability to effectively simulate the relationships between landscape greening, outdoor thermal environments, and buildings.

3.4 Field Measurements

Table 1. Equipment parameters.

KAN-WS01 Handheld meteorological monitoring instrument meteorological parameters				
Measurement elements	Measuring range	Accuracy	Resolution ratio	Unit
Wind speed	0~40	±0.3	0.1	m/s
Atmospheric temperature	-20~50	±0.3	0.1	℃
Relative humidity	0~100%	±3%	0.1	%
Atmospheric pressure	300~1100	±0.3	0.1	hPa

The experiment was conducted on July 2, 2024, at Xiaohe Street in Hangzhou. The instrument parameters are listed in Table 1. The measured point is located at point B (see Fig. 1 for details), with a height of 1.5 meters above the ground and no obstruction within 3 meters. The ground is paved with granite slabs. The experiment took place from 9:00 AM to 8:00 PM, with data recorded every hour. Subsequently, simulations were performed using ENVI-met, with the simulation parameters listed in Table 2. Meteorological data were sourced from a nearby weather station in Hangzhou. A comparison of the test data and simulation results is shown in Figures 3 and 4.

Table 2. Model input in Envi-met.

Category	Simulation Parameters	Values Used
Simulation Parameters	Date	July.24,2023
	Time	9:00-18:00
	Total Time	10h
	Boundary Condition	Simple Forcing
	Wind Speed at 10 m	2.7 m/s (summer)
	Wind Direction	202.5 (summer)
	Roughness Length	0.01
	Initial Relative Humidity	weather station data
	Initial Air Temperature	weather station data
Material Setting	Buildings	Absorption of Roof tile: 0.5
		The albedo of walls for buildings: 0.3
	Pavements	The albedo of Granite pavement gray: 0.6
Greenery Setting	Cylindric (Conifers)	Heart-shaped,medium trunk, dense, medium (15m)

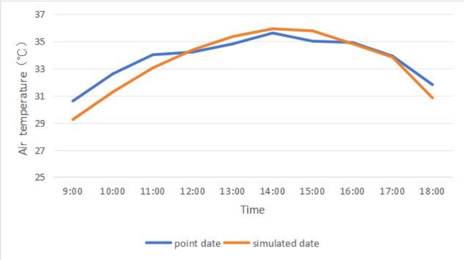


Fig. 3. Temperature Comparison Chart

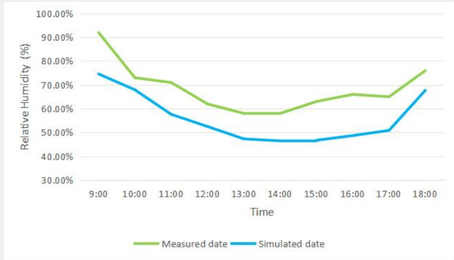


Fig. 4. Humidity Comparison Chart

The validation of this simulation was conducted using temperature and humidity. The accuracy of the simulation was evaluated using RMSE and MAPE. RMSE is used to measure the error between the simulated values and the measured values. According to recent studies on the accuracy of ENVI-met simulations, it is generally accepted that the RMSE for air temperature (Ta) between measurements and simulations should not exceed 1.31, and the MAPE should not exceed 5%.[13] After calculations, the RMSE value in this model is 0.81°C, and the MAPE value is 2.0%. The ENVI-met model's applicability and accuracy were evaluated by performing a linear regression analysis between the measured and simulated data. The linear regression results showed.[14]Detailed data can be seen in Figures 3 and 4.

$$RMSE = \sqrt{\frac{1}{r}\sum_{i=1}^{r}\left(y_i^{'} - y_i\right)^2} \tag{1}$$

$$MAPE = \frac{1}{r}\sum_{i=1}^{r}\frac{\left|y_i^{'} - y_i\right|}{y_i} \times 100\% \tag{2}$$

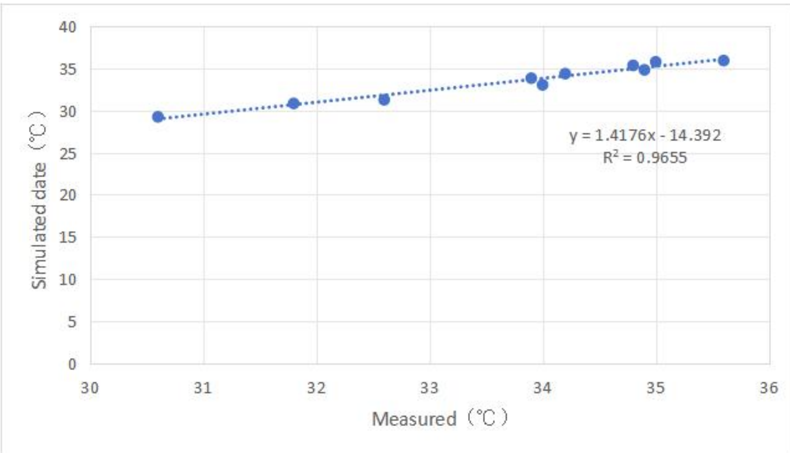


Fig. 5. Correlation Analysis

4 Result

4.1 Influence of the Canal Water Body

The study of the thermal environment in the streets and alleys of canal ancient towns requires quantitative analysis. This paper first simulates the impact of the canal water body on the temperature of the streets and alleys. The simulation results show that the water body can effectively reduce the temperature of the streets and alleys. At 2:00 PM, the hottest time of the day in summer, the temperature around the water body is 3-5°C lower than that of the streets. By comparing the temperature and humidity at monitoring point B (Fig.6-7), it was found that the temperature in the streets and alleys around the canal is lower, but the humidity difference is not significant. Therefore, under the same conditions, the ancient towns along the canal have better thermal comfort. (Fig.8) Previous studies have shown that larger water bodies have a greater impact on site temperature. Additionally, the shape of the water body influences how temperature changes are distributed across the site. This aspect will be explored further in future research.[15]

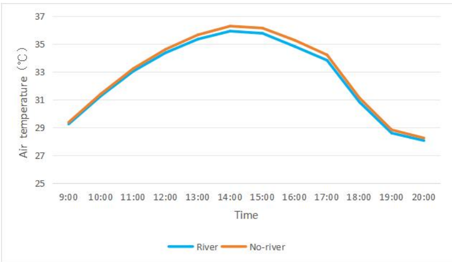


Fig. 6. Temperature Comparison Chart

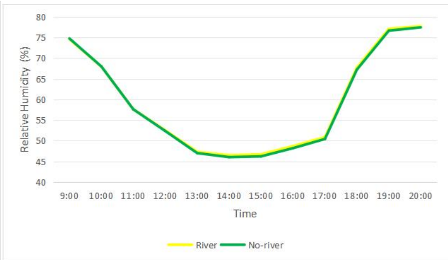
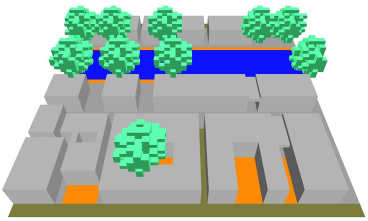
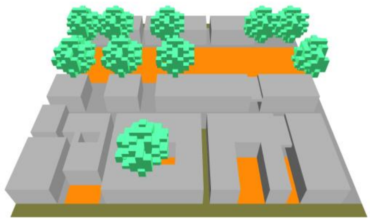


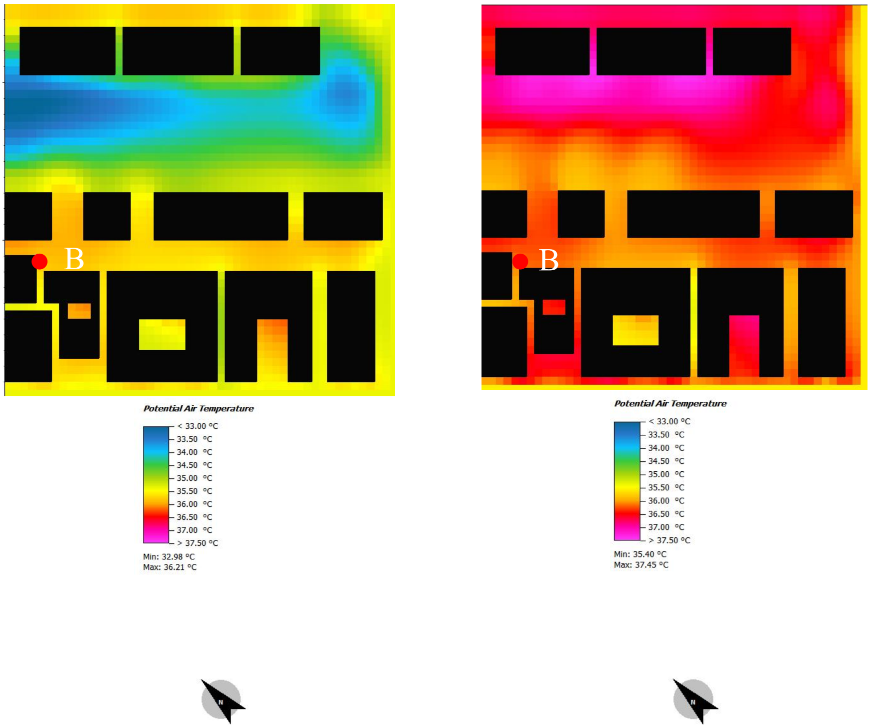
Fig. 7. Humidity Comparison Chart



Case1 model



Case2 model



Case1 Simulation Results Case2 Simulation Results

Fig. 8. Simulation Analysis of the Canal Water Body's Impact on Street Temperature

4.2 Shading Facilities and Trees

The main areas where tourists gather in the canal historical district are the streets and public spaces. This study first conducted field measurements in key public spaces and found that summer temperatures are very high, resulting in poor comfort levels. Comparing monitoring points A and B (Fig.9), it was found that point A, which is located under a pavilion, had a temperature nearly 3°C lower than point B (Fig.10), demonstrating the effective cooling impact of shading.

Fig. 9. Monitoring Points A and B

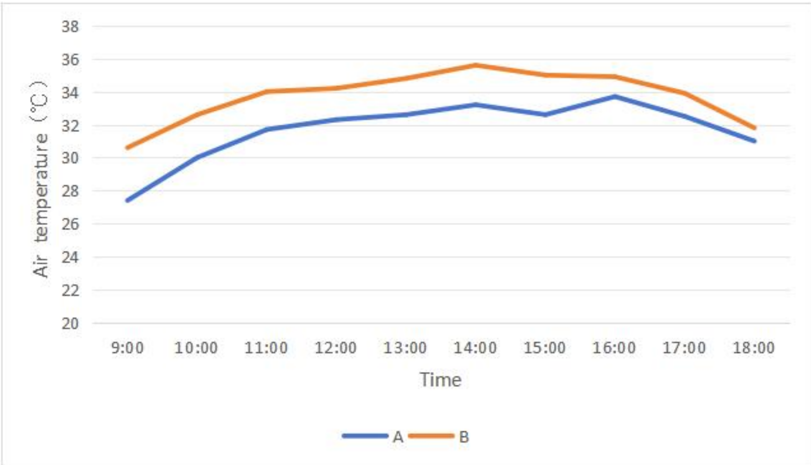


Fig. 10. Temperature Comparison Chart for Monitoring Points A and B

Simulation analysis indicates that setting up a pavilion near monitoring point B would result in a significant shading effect. The installation of shading pavilions can also indirectly reduce the surrounding temperature, enhancing the comfort of the streets and alleys. Additionally, planting trees in courtyards can lower the ambient temperature by approximately 2°C (Fig.11). Previous studies have found that tall trees have the most significant cooling effect. So choosing locally common evergreen broad-leaved trees is a better landscape strategy.[16]

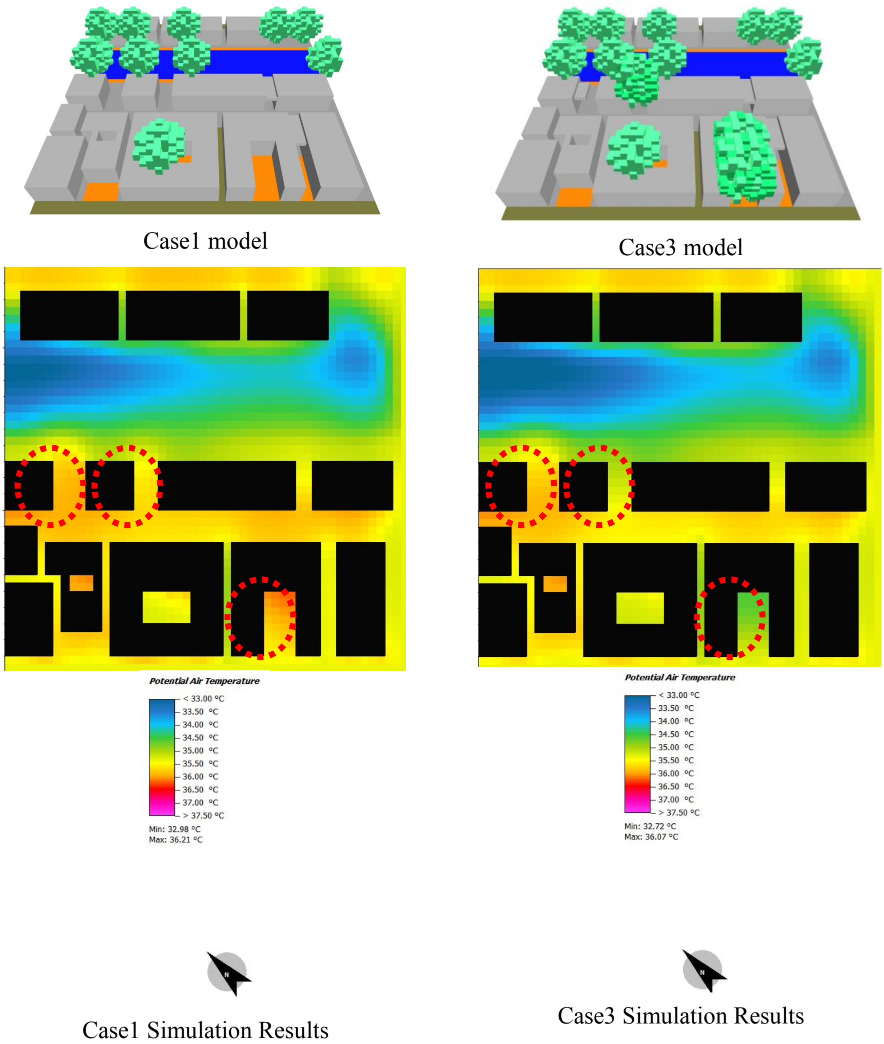
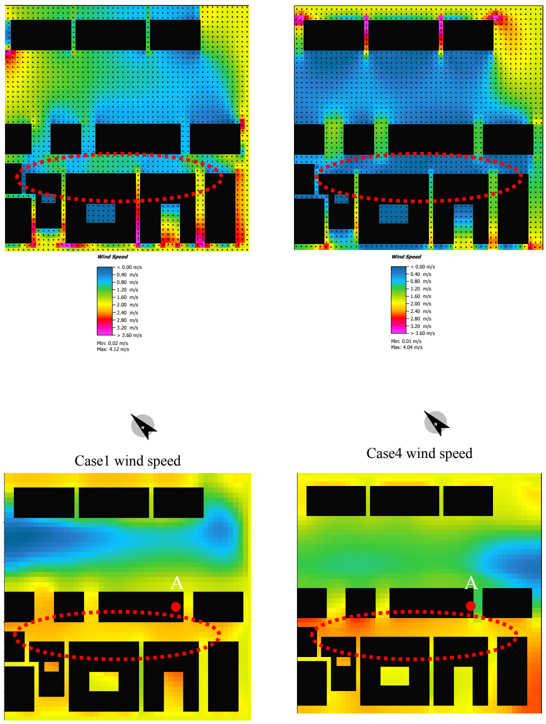


Fig. 11. Simulation of the Impact of Shading Facilities and Trees on the Thermal Environment

4.3 The Impact of Ventilation

The Envi-met simulation study indicates that the temperature within a street canyon is influenced by wind direction and speed. In Case 1, the wind speed on the south side of the street is higher than in Case 4, which helps prevent heat accumulation and lowers the air temperature in the street canyon (Fig. 12).


Wind Speed
Case1 wind speed
Case4 wind speed
A
A

Case1 Simulation Results   Case4 Simulation Results

Fig. 12. Comparison of Simulations with Different Wind Directions

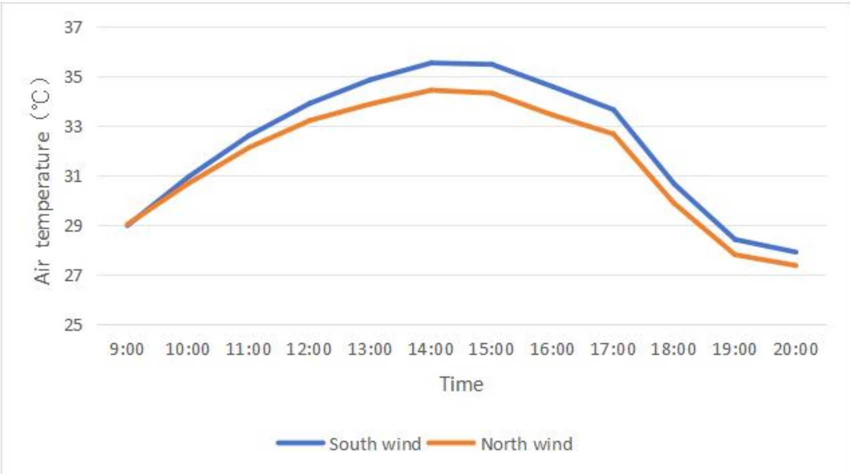


Fig. 13. Comparison of Temperature at Monitoring Point A Under Different Wind Speed Conditions

By comparing the temperature and wind speed at monitoring point A, it was found that the wind speed at monitoring point A in Case 4 is higher, resulting in a lower temperature (Fig.13). During the period from 14:00 to 15:00, the temperature difference is about 2°C. Therefore, in areas with poor natural ventilation, enhancing mechanical ventilation can reduce the temperature in the street canyon. Particularly in areas near water bodies, the combination of mechanical ventilation and the cooling effect of water bodies can effectively improve thermal comfort in historical districts.

5 Discussion and Conclusion

The thermal environment of tourist attractions is a current hot topic in the cultural and tourism industry. Especially in areas with hot summers and cold winters, research has found that the deterioration of the thermal environment affects visitors' experiences and directly reduces the revenue of tourist attractions, making this study highly significant. This paper examines the thermal environment of streets and alleys in historical districts under different conditions. Through simulation analysis of various conditions, the effects of water bodies, shading, and wind speed on the thermal environment are revealed. The conclusions are as follows:

①Numerous studies indicate that water bodies significantly impact the climate. Consequently, the canal has a cooling effect on ancient towns, with temperatures in waterfront areas being over 3°C lower than in other areas.

②In tourist areas, shading in public spaces is crucial. Simulation results show that setting up pavilions by the water and planting trees in courtyards can reduce the ambient temperature by about 2°C.

③Wind speed is an important factor affecting thermal comfort. The combined effects of water bodies, shading, and wind enhance thermal comfort. This study found that wind can blow cool air from above the water body onto the streets. Particularly in areas near water bodies, the combination of mechanical ventilation and the cooling effect of water bodies can effectively improve thermal comfort in historical districts.

The investigation of Xiaohe Street revealed a lack of shading facilities in public spaces, suggesting the addition of pavilions or more tree planting. Analysis of the spatial morphology of the historical district shows that the narrow streets and dense building distribution reduce wind speed and cause heat accumulation. Therefore, in tourist areas, mechanical ventilation should be combined with water bodies to enhance ventilation. Cooling mist should be installed at densely populated public space nodes to improve thermal comfort. Future research will analyze the impact of the layout of streets and buildings on the thermal environment, providing suggestions for improving the thermal environment in ancient towns.

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