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Numerical Study on the Summer High-Temperature Climate Adaptation of Traditional Dwellings in the Western Plains of Sichuan, China

Rongjia Li [1], Qiushan Li [1,*], Ishikawa Mikiko [2] and Kabilijiang Wumaier [1]

[1] Sichuan University–The Hong Kong Polytechnic University Institute for Disaster Management and Reconstruction (IDMR), Sichuan University, Chengdu 610207, China; 2021226200008@stu.scu.edu.cn (R.L.); kabil@scu.edu.cn (K.W.)

[2] Department of Integrated Science and Engineering for Sustainable Society, Faculty of Science and Engineering, Chuo University, Tokyo 112-8551, Japan; ishikawa.27@g.chuo-u.ac.jp

* Correspondence: liqiushan@scu.edu.cn; Tel.: +86-156-8099-7814

Abstract: Ongoing global climate change, marked by sustained warming and extreme weather events, poses a severe threat to both the Earth's ecosystems and human communities. Traditional settlements that underwent natural selection and evolution developed a unique set of features to adapt to and regulate the local climate. A comprehensive exploration of the spatial patterns and mechanisms of the adaptation of these traditional settlements is crucial for investigating low-energy climate adaptation theories and methods as well as enhancing the comfort of future human habitats. This study used numerical simulations and field measurements to investigate the air temperature, relative humidity, wind speed, wind direction, and thermal comfort of traditional settlements in Western Sichuan Plain, China, and uncovered their climate suitability characteristics to determine the impact mechanisms of landscape element configurations (building height, building density, tree coverage, and tree position) and spatial patterns on microclimates within these settlements. The results revealed the structural and layout strategies adopted by traditional settlements to adapt to different climatic conditions, providing valuable insights for future rural protection and planning and enhancing climate resilience through natural means. These findings not only contribute to understanding the climate adaptability of Earth's ecosystems and traditional settlements but also offer new theories and methods to address the challenges posed by climate change.

Keywords: nature-based solution; traditional settlement; Linpan in western Sichuan; microclimate; ENVI-met

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1. Introduction

In recent years, the urban heat island (UHI) effect, which is driven by global warming and intensive urbanization, has significantly elevated regional summer temperatures, leading to an increase in the duration and frequency of extreme high-temperature events [1,2]. The impact of urban microclimates on outdoor human comfort, building energy consumption, and heat wave dispersion has been demonstrated [3–5]. As the UHI effect extends towards urban outskirts and rural areas, studies have revealed the substantial risks of high temperatures to the health and safety of outdoor rural residents [6]. Its negative consequences, including reduced thermal comfort [7], increased morbidity rates [8], deteriorating air quality [9], and additional cooling energy consumption [10,11], pose significant challenges to rural residents and their living environments.

Current microclimate research is predominantly focused on urban areas spanning various scales [12]. In contrast, research on the microclimates of rural settlements is relatively limited. Compared with urban areas, rural infrastructure is often more vulnerable and disadvantaged in addressing the impacts of climate change. Rural settlements rely heavily on their external environment and, without the use of mechanical equipment, optimize their location, architectural design, and crop layout to adapt to local climates. Such longstanding indigenous wisdom is a nature-based solution (NbS) that addresses challenges such as UHIs and heat waves by providing cooling services [13,14]. Introduced by the World Bank in 2008 and subsequently incorporated into the United Nations Framework Convention on Climate Change by the World Wide Fund for Nature, NbSs rely on nature-derived and nature-dependent approaches to efficiently solve diverse challenges and simultaneously ensure economic, social, and environmental benefits. Currently, NbSs primarily utilize ecosystems and their services to address social challenges such as climate change, food security, and natural disasters [15]. China's historical planning principles, which emphasize alignment with nature, are a manifestation of NbSs that integrate local traditional wisdom. Improving rural living environments and constructing ecologically livable and beautiful villages are crucial tasks in implementing rural revitalization strategies. Therefore, studying the climate adaptability of traditional rural settlements and exploring NbSs is of paramount importance.

However, existing research on microclimates in rural settlements faces challenges in terms of differences and comparability between Western and Chinese rural settlements. The climate in China boasts a wide range of latitudinal and longitudinal spans, featuring diverse climate types such as tropical, subtropical, and temperate monsoons, temperate continental, and high-altitude cold climates. In contrast, European countries primarily experience temperate maritime, temperate continental, and Mediterranean climates, whereas North American countries are characterized by temperate continental and subarctic coniferous forest climates. This diversity makes the direct application of results from studies on Western rural areas to Chinese rural areas challenging. Owing to the larger residential land area in Western countries and scattered distribution of rural residences, most studies have concentrated on small towns. However, the significant differences in scale, layout, and materials between Western and Chinese rural settlements have weakened the applicability of these studies [16].

The Dujiangyan Water Conservancy Project in Western Sichuan, China, is a famous World Heritage site owing to its irrigation engineering, which has been used for flood control and irrigation since its construction 2200 years ago. Abundant water and flat land helped develop the local agriculture and provide natural conditions for farming in the Land of Abundance [17]. In the process of adapting to nature, the "Chuanxi Linpan" was formed, a traditional settlement that facilitates life and production. This refers to a composite rural residential environment that integrates farmsteads on the Chengdu Plain and hilly areas with surrounding tall trees, bamboo groves, rivers, and peripheral farmland, forming a complex living environment that combines production, daily life, and the landscape [18]. As shown in Figure 1, typically organized around clans, it has courtyard houses, tall arbors, shrubs, and bamboos and externally connects to the fields with a river system, reflecting the Taoist view of ecology [19].

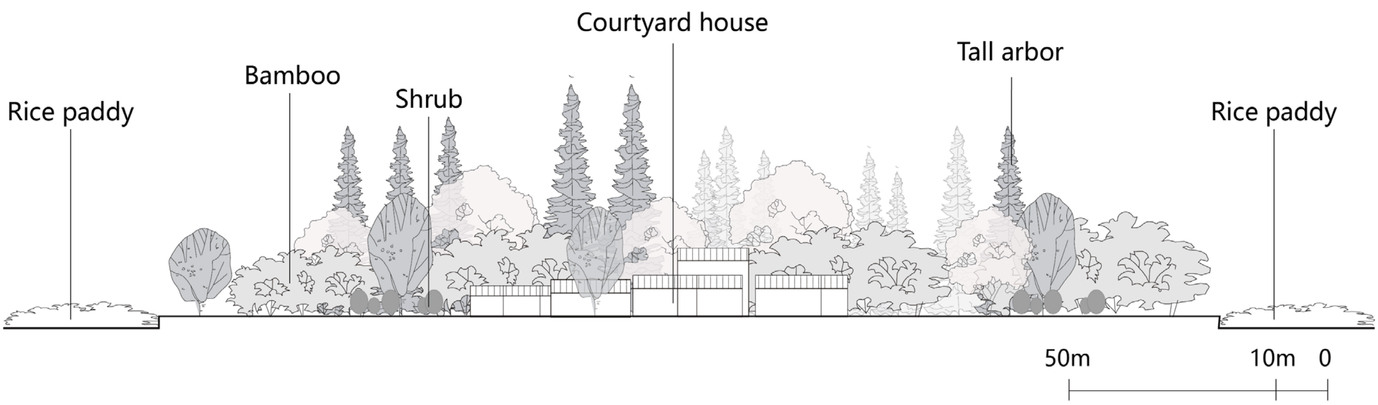


Figure 1. Layout of a Linpan (traditional settlement) in Western Sichuan.

Owing to the absence of hills to block the wind in the Chengdu Plain, tall trees and bamboo protect against the wind. Typically, rural homes often adopt a linear, L-shaped, or concave-shaped layout, and each household has its own courtyard; three to ten households form a small Linpan, ten to thirty households form a medium Linpan, and over thirty households constitute a large Linpan [20]. In addition to the built structures, the open space within a Linpan serves as a transitional semi-open area. This space encompasses natural elements such as the sky, earth, and plants, and their interactions create a distinctive ecological environment in the Chengdu Linpan. This, in turn, generates a mild and comfortable microclimate for the residents [21].

Linpans are not only unique in their form but have also accumulated ecological wisdom over their millennia of development. Their passive design and low-energy consumption are considered NbSs. The arrangement of a long cornice forms a space under the eaves that considers factors such as rain, shade, and ventilation. Deciduous trees provide shade from direct summer sunlight and guarantee access to sunlight during winter. Moreover, recent studies, such as the assessment of land ecological security in the Chengdu Plain Region from 2000 to 2020 by Zhang et al. (2023), highlight the importance of integrating NbSs into regional planning to enhance ecological resilience and sustainability. The ecological strategies embedded in Linpans align with the findings of Zhang et al., emphasizing the critical role of NbSs in maintaining ecological security and promoting sustainable development in traditional and modern settlements alike [22,23].

With the advancement of computer technology and computational fluid dynamics (CFD) software, numerical analysis and computer simulations have become pivotal tools for studying microclimates in human habitats [24]. Among these tools, ENVI-met stands out as a three-dimensional small-scale CFD model that is widely used to simulate microclimatic phenomena within the urban canopy and boundary layers based on interactions among surfaces, buildings, vegetation, and air. It has been extensively and successfully applied to assess microclimates and the human biometeorological impacts of different urban climate design strategies [25]. Microclimate analysis primarily focuses on climate characteristics at the scale of urban blocks, with heights and widths within 0.1 km, and includes meteorological elements such as atmospheric temperature, ground temperature, humidity, wind speed, and thermal radiation near buildings [26]. Furthermore, existing research indicates that variables such as street orientation, building density, floor area ratio, green space density, impervious surface ratio, and sky view factor can considerably influence the local climate [27–30].

Through their study of outdoor thermal comfort in Tunisia, Achour-Younsi and Kharrat [31] proposed that aspect ratio and street orientation are crucial factors influencing urban street canyons. Giridharan et al. [32] analyzed daytime UHI effects in densely populated areas of Hong Kong and found that increasing the surface albedo and floor area ratio and decreasing the sky view factor reduced the UHI index. Furthermore, reducing the impact of buildings is more significant in mitigating the UHI effect, decreasing its temperature increase and duration by approximately 30% [33]. In contrast, artificial surfaces such as walls and impermeable roads have been found to significantly enhance the UHI effect [34]. In terms of vegetation environment, Morakinyo et al. [35] found that leaf area index, tree height, and trunk height most significantly improve outdoor thermal comfort, but the beneficial daytime effects of trees diminish with increasing urban density. Amani-Beni et al. [36] determined that increasing vegetation cover under trees and irrigating grass can effectively reduce temperatures during summer. Yang [37] found that vegetation positively affects the surrounding thermal environment through shading, reflecting shortwave radiation, and transpiration. Increasing the tree coverage provides a more comfortable microclimate than increasing shrubs, making trees a priority when selecting variables [38]. Furthermore, Abdi et al. [39], Atwa et al. [40], and Sahar et al. [41] investigated the mechanisms influencing outdoor microclimates through the types, density, arrangement, and windward direction of different tree species. Wu et al. [42] evaluated four spatial tree layouts in the ENVI-met model of a high-rise residential area in Beijing and found that different spatial arrangements produced different effects by influencing the location of building shadows.

In this study, the microclimate of a traditional settlement, Linpan, in the Chengdu Plain, China, is simulated using hourly monitoring data from meteorological stations, and field measurements were used to validate the model. This study aimed to assess the key factors and indicators influencing the climatic suitability of Linpans by changing the spatial layouts of buildings and trees within them. The main objectives of this research are as follows: (i) elucidate the microclimate environment formed within a Linpan, explore its self-adaptive ability in high-temperature weather, and assess its outdoor thermal comfort; (ii) simulate multiple scenarios for the first time that change the building height, building density, tree coverage, and tree position inside a Linpan using ENVI-met 5.5 software to investigate the influence of a Linpan's configuration on climatic elements such as air temperature, relative humidity, wind speed, and wind direction; and (iii) design strategies for the effective control of thermal comfort to provide a reference for traditional settlement planning.

2. Study Area

The research subject of this study was a traditional settlement in JuYuan Town, Dujiangyan City, QuanShui Village, Cluster 7 (30.971119° N, 103.695207° E) (Figure 2). This settlement has 15 residences clustered together, surrounded by a green barrier made up of tall trees and bamboo, and represents a typical Chengdu Linpan. The Linpan covers an area of approximately 29,328 m^2, making it medium-sized. The predominant tree species are camphor trees, metasequoias, ginkgo trees, paulownias, and bamboo clusters. The architectural forms within this Linpan include one-character, L-shaped, and three-sided enclosed structures. Buildings on the north side face south, whereas those on the south side, which are more compact, primarily face north. This layout reflects the adaptable characteristics of the Linpan arrangement based on local conditions. Meteorological data were measured at a point 1.5 m away from the forest plate from 16 July 2023, 00:00, to 17 July 2023, 00:00. These measurements were used to validate the simulation results (Figure 3E).

Figure 2. Elevated view of the study area.

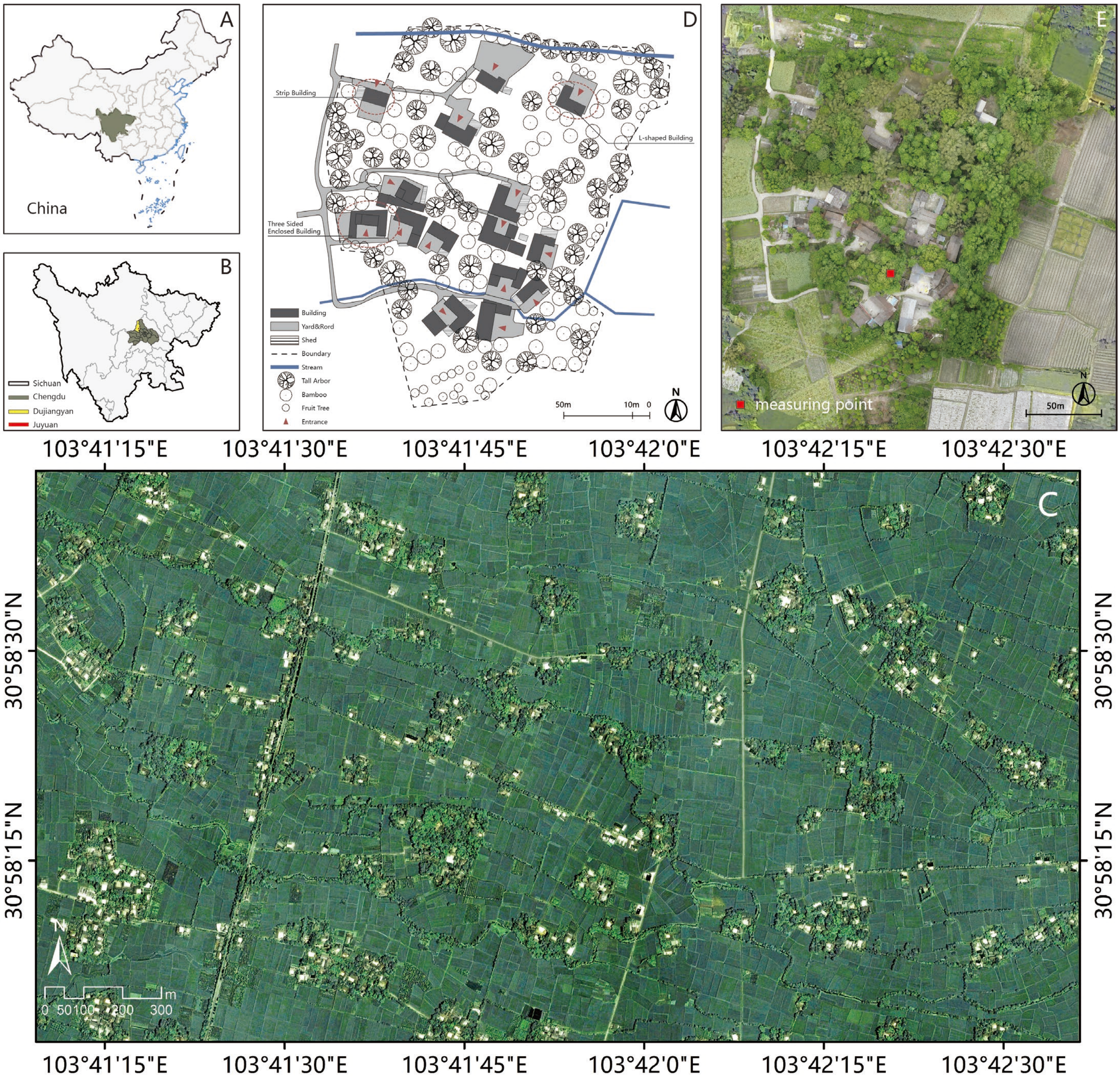


Figure 3. Location map and layout plan of the study area. (**A**) The location of Sichuan Province in China; (**B**) The location of the Linpan distribution area in Sichuan Province; (**C**) Aerial photo of the distribution of Linpan in the field; (**D**) Data model of the simulated Linpan; (**E**) Actual photo of the simulated Linpan (obtained by author used drone photography).

3. Data and Methods

3.1. Simulation Data

For the microclimate simulation, ENVI-MET software was utilized due to its established effectiveness in such analyses. ENVI-MET is a three-dimensional, non-hydrostatic model specifically designed for simulating surface-plant-air interactions in urban environments. It is particularly adept at analyzing the impact of building structures and landscape elements on microclimates, including parameters such as air temperature, humidity, and wind patterns. The extensive validation of ENVI-MET in similar studies underscores its reliability for assessing the microclimatic effects of traditional settlements and their landscape configurations. The strong agreement between the simulated results and the on-site measurements further supports the model's accuracy and credibility in this study. Following the temperature classification method [43], this study defines summer as the period from June to August. The focal month chosen for the investigation was July, specifically targeting days with high temperatures and minimal cloud cover. Consequently, 16 July 2023, a day with a peak temperature of 33.7 °C and 4% cloud cover, was selected as the validation date. Meteorological data (air temperature, relative humidity, wind speed, wind direction, wind angle, visibility, hourly precipitation, average total cloud cover, etc.) in Dujiangyan City, encompassing a 24 h timeframe from 00:00 on 16 July 2023, to 00:00 on 17 July 2023, were sourced from Huiju Data (hz.hjhj-e.com).

3.2. Software Simulation

As shown in Table 1, two distinct input files were defined. First, the environmental elements within the study area, including three-dimensional models of buildings, vegetation, artificial surfaces, water bodies, and soil. Ultimately, a three-dimensional unit model measuring 246 × 236 × 25 m was established, with the dimensions of each unit set to 1 × 1 × 1 m. A 20 m grid extension was also applied externally to the simulation area to mitigate the complex boundary layer effects and enhance stability in proximity to the primary research elements. Second, the climate configuration parameters encompassing the time and climatic environment for model simulation. Hourly air temperature, relative humidity, wind speed, and wind direction data for 16 July 2023, from 00:00 to 24:00, were input for the simulation, which began at 0:00 on the day and was analyzed at 14:00. This time was selected to avoid errors associated with the numerical software and consider the impact of surface radiation during the time of the daily peak air temperature [44]. The measured and simulated values were linearly fitted, and the coefficient of determination and root mean square error were calculated to jointly evaluate the accuracy of the model.

Table 1. Input model data.

Element	Sub-Element	Input Value
Environmental elements	Location	Dujiangyan
	Coordinate Position	30.97° N, 103.69° E,
	Model Dimensions	246 × 236 × 24
	Grid Cell Size	Dx = 1 m, Dy = 1 m, Dz = 1 m
Simulation Date and Time	Start Date	16 July 2023
	Start Time	0:00
	Total Simulation	24 h
Meteorology	Boundary Condition	Simple Forcing
	Air Temperature	Hourly Data From Weather Station
	Relative Humidity	Hourly Data From Weather Station
	Wind Speed	1.6 m/s
	Wind Direction	135° (Southeast)

In the vegetation selection simulation, the Linpan was predominantly characterized by bamboo clusters and tall deciduous trees. Because of the dense and relatively small leaves of bamboo groves coupled with the curvature of the main trunk beyond a certain height, precise morphological control was challenging in the modeling process. To simplify the simulation and account for the substantial impact of individual parameters, deciduous tall trees were selected as surrogates for bamboo. The height distribution of vegetation in the study area primarily ranges from 9 to 15 m. As the cooling effect is more pronounced with a continuous increase in tree height, especially within the range of 8–12 m [45,46], a representative tree height of 12 m was selected for the simulation. This choice was made to streamline the model while acknowledging the significant influence of a singular parameter on the overall simulation. Local 12 m trees were selected for modeling, and LAD values of different heights were assigned according to tree characteristics (Figure 4).

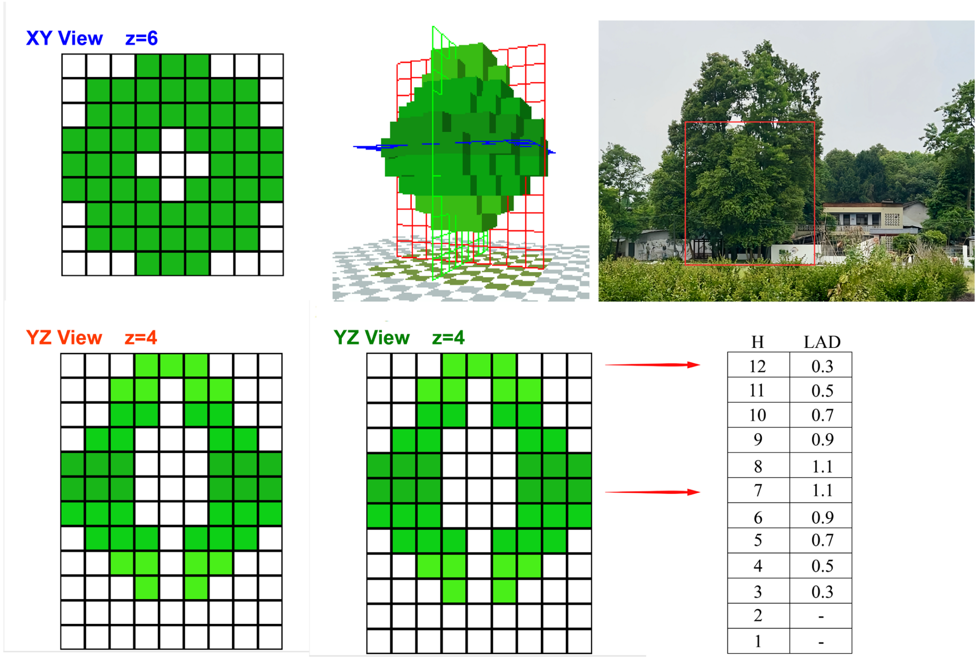


Figure 4. Construction of the Arbor Model.

The physiologically equivalent temperature (PET) is a thermal comfort assessment standard that integrates geographical information [47], climatic parameters, solar radiation, and clothing impact. Thermal comfort levels, classified based on PET, are shown in Table 2.

Table 2. Physiologically equivalent temperature standards.

Physiological Equivalent Temperature (°C)	Human Perception	Physical Stress Levels
<4	Very Cold	Extreme Cold Stress
4–8	Cold	Strong Cold Stress
8–13	Cool	Moderate Cold Stress
13–18	Slightly Cool	Mild Cold Stress
18–23	Comfortable	Non-Heat Stress
23–29	Slightly Warm	Mild Heat Stress
29–35	Warm	Moderate Heat Stress
35–41	Hot	Intense Heat Stress
>41	Very Hot	Extreme Heat Stress

3.3. ENVI-Met Modeling and Validation

This study used unmanned aerial vehicle imagery and on-site reconnaissance observations to analyze the components of the Linpan. Then, an ENVI-MET microclimatic simulation model was developed. By manipulating the four key factors of building height, building density, arbor coverage, and arbor distribution, nine distinct scenarios were devised based on the characteristics of the Linpan. This approach was used to investigate the impact of morphological variations on traditional settlements, as detailed in Table 3.

Table 3. Modeling scenario settings.

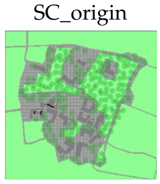
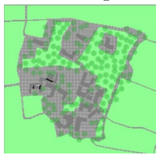
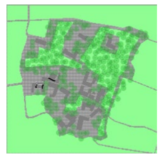
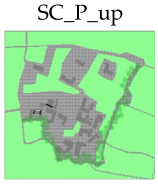
No.	Factors	Characteristics	Model Diagram
1	Original	Modeling of the site's architecture, surface, vegetation, and water system elements according to the results of the site survey	SC_origin 

Table 3. *Cont.*

No.	Factors	Characteristics	Model Diagram
2	Building Height	Height increase of one floor on top of the original forest plate, i.e., one additional single story building (3 m) per building on top of the original forest plate	SC_B_add1 
3		Height increase of two floors on top of the original forest plate, i.e., two additional building single floors (6 m) per building on top of the original forest plate	SC_B_add2 
4	Building Density	Low building density, i.e., removal of L-shaped buildings, monolithic buildings, and all small individual blocks in the original forested area	SC_B_spa 
5		Medium building density, i.e., removal of L-shaped buildings in the original forested area	SC_ B_med 
6	Arbor Coverage	Sparse arbor coverage, reducing arbor to a density of about 40% from the original forested area	SC_P_spa 
7		Sparse arbor coverage, reducing arbor to a density of about 80% from the original forested area	SC_P_den 
8	Arbor Distribution	Full enclosure of the forest plate by trees, i.e., plants surround the building	SC_P_full 
9		Arborvitae upwind and semi-enclosed, arborvitae located windward and upwind	SC_P_up 
10		Arborvitae downwind and semi-enclosed, arborvitae located downwind of the windward side	SC_P_down 

4. Results

A comparison of the simulation results with the measured data revealed a strong hourly correlation between air temperature and relative humidity (Figure 5). At 16:00, a brief spike in air temperature and a decrease in relative humidity occurred, which was hypothesized to be related to the height of the sun descending into the gaps not covered by trees and buildings. After 17:00, the air temperature and relative humidity returned to normal, owing to the sun's further descent, avoiding direct exposure due to obstruction by buildings and vegetation.

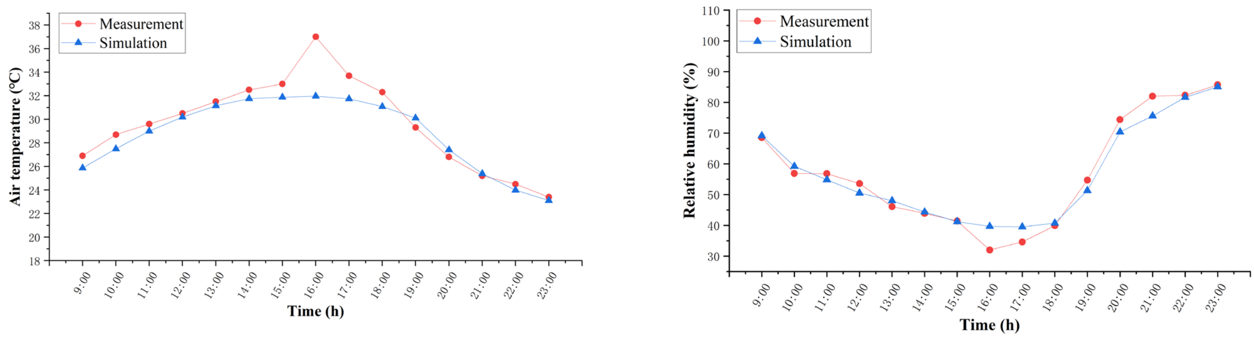


Figure 5. Comparison of simulated results and measured data for temperature and relative humidity.

Figure 6 shows that the coefficient of determination for air temperature and relative humidity are 0.89 and 0.97, respectively, and the root mean square error is 1.04 °C and 2.79%, respectively. According to Tsoka et al. [48], the root mean square error should be <4.3 °C for air temperature and <10.2% for relative humidity. When the root mean square error is smaller and the coefficient of determination is closer to 1, the correlation between the two data groups is more credible; therefore, this ENVI-MET simulation result is considered to be of analytical reference significance.

The simulation results indicate that building height, building density, tree coverage, and tree arrangement all impact the microclimate of traditional settlements. In the visualization of results, air temperature is controlled at a starting point of 29.5 °C, increasing in 0.5 °C intervals; relative humidity is controlled at a starting point of 37.5%, increasing in 1.5% intervals; wind speed is controlled at a starting point of 0.1 m/s, increasing in 0.1 m/s intervals; and wind direction is controlled at a starting point of 0°, increasing in 45° intervals.

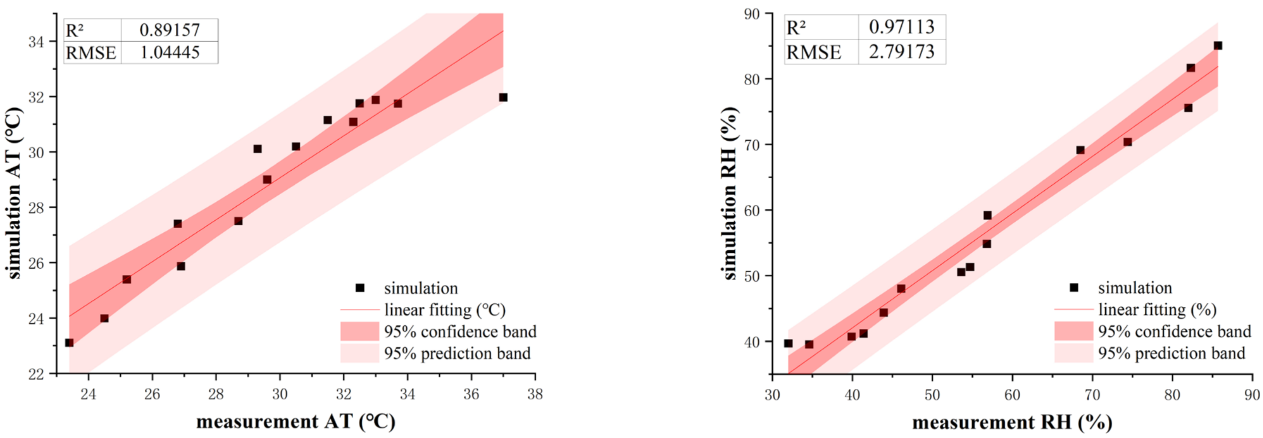


Figure 6. Linear fitting of simulation results to measured data.

4.1. Influence of Building Height on Microclimate

As the building height increased, the overall temperature variation in the settlement remained insignificant, ranging from 0.05 °C–0.46 °C. In contrast, a more noticeable decrease in temperature, approximately 0.6 °C–0.87 °C, was observed around the buildings (Figure 7). An upward trend in relative humidity around the buildings was also evident, increasing by >1.6%, whereas the overall relative humidity of the settlement increased by approximately 0.32–1.6%. The wind speed significantly decreased, forming a large stagnant zone (0–0.2 m/s) around the buildings. Simultaneously, the wind speed in narrow gaps and passages between buildings exhibited a noticeable enhancement, increasing by approximately 0.03–0.19 m/s. The wind direction showed an increased variation area, with the degree of change decreasing with distance from the buildings.

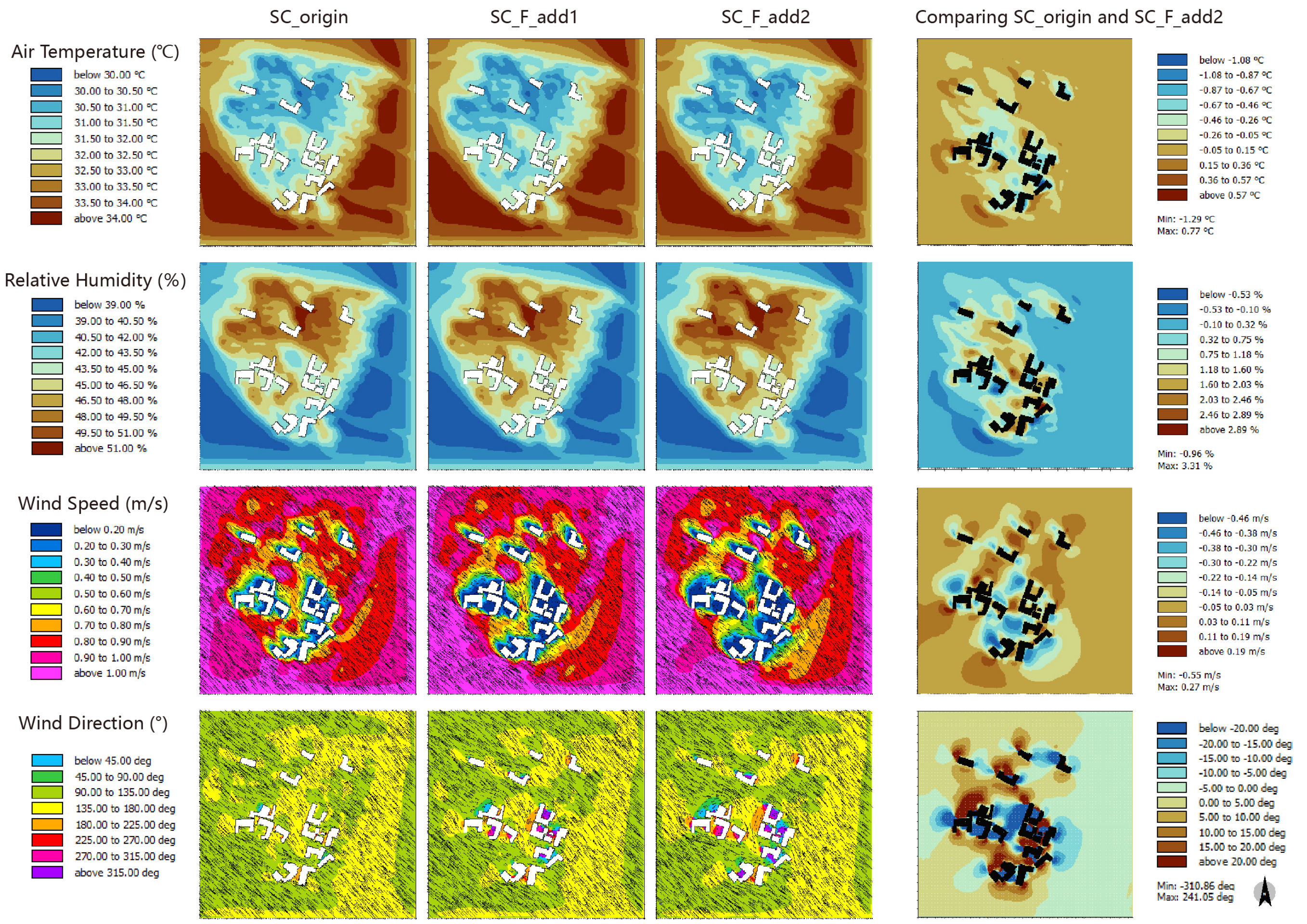


Figure 7. Impact of changes in building height on the microclimate.

4.2. Influence of Building Density on Microclimate

By reducing building density, the temperature within the settlement slightly increased, rising by approximately 0.24 °C–0.8 °C. The high temperatures extended inward along the southeastern wind direction (Figure 8). Changes in humidity within the settlement were insignificant; however, a slight decrease in humidity ranging from 0.15–0.85% was observed at the location where buildings were removed. The wind speed did not significantly change around the preserved buildings, but it increased when the buildings were removed, indicating an influx of air. Although changes in wind direction were not pronounced, the wind direction tended to become more consistent around the removed buildings, especially in the courtyards.

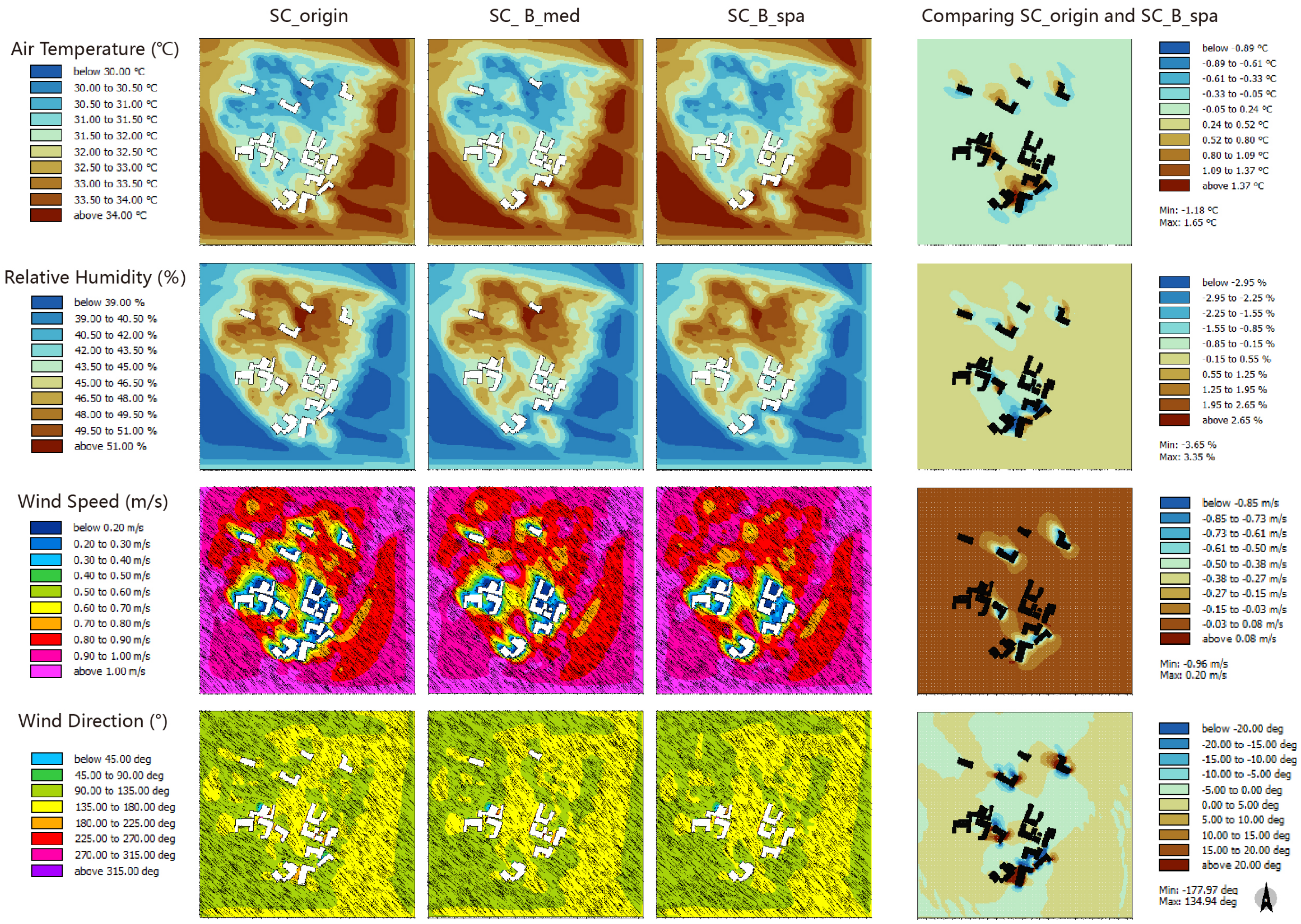


Figure 8. Impact of building density changes on microclimate.

4.3. Influence of Arbor Coverage on Microclimate

The investigation of the impact of tree coverage on the microclimate involved incremental increases (40%, 60%, and 80%). The results revealed a notable reduction in the temperature within the settlement, exhibiting a general decrease of >0.66 °C, with the maximum reduction reaching 2.27 °C (Figure 9). Concurrently, the relative humidity within the settlement considerably increased, by >2.02%, with a maximum increase of 7.05%. The wind speed was noticeably reduced, exhibiting an overall decrease of >0.03 m/s, and in specific areas decreasing by 0.22 m/s. Alterations in wind direction were not pronounced, with only slight variations within 15° observed in areas covered by trees.

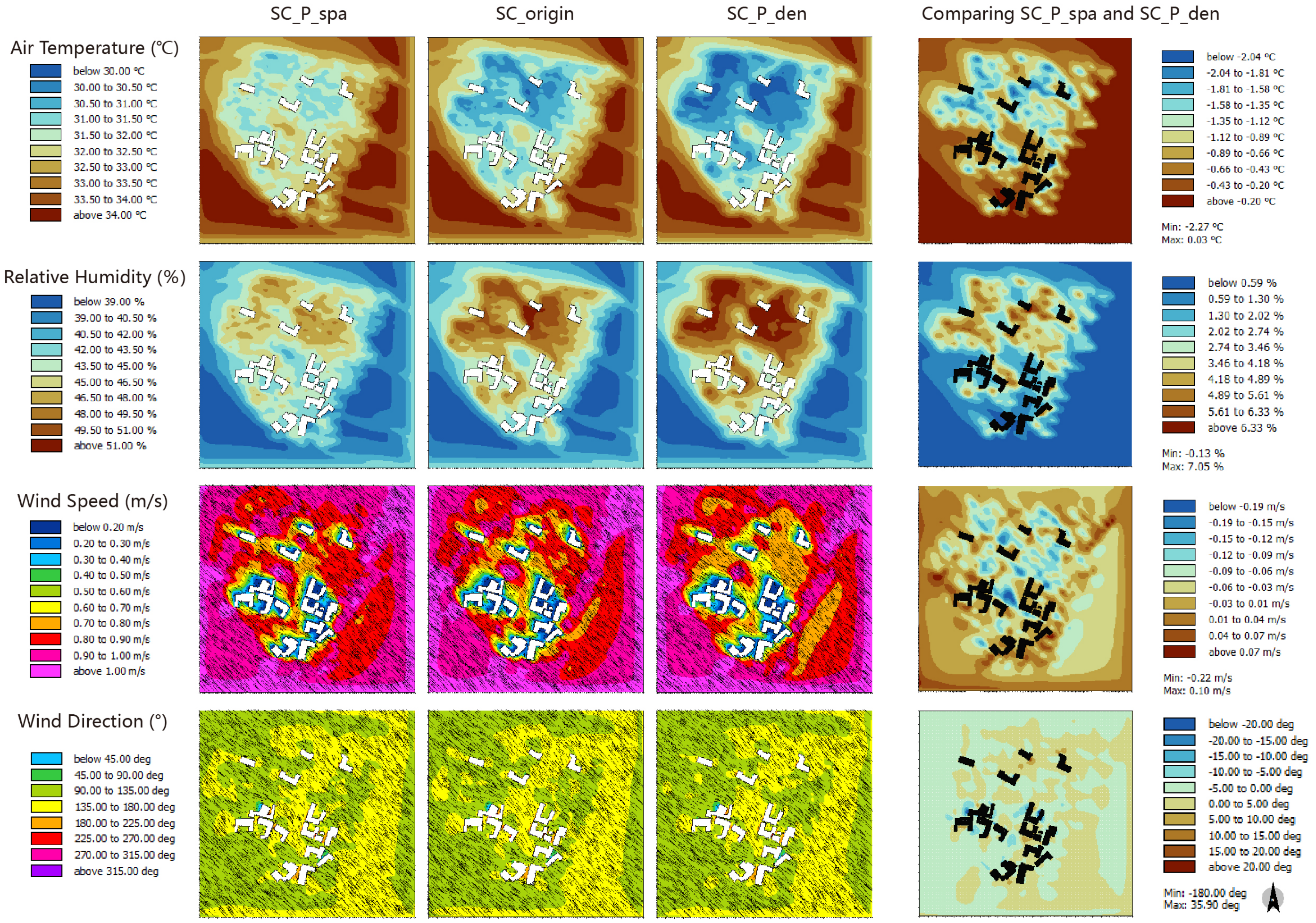


Figure 9. Impact of arbor density changes on the microclimate.

4.4. Influence of Arbor Position on Microclimate

The temperature distribution was varied by modifying the arrangement of the tree enclosures. However, areas with reduced temperatures generally aligned with the position of trees and their downwind directions. Under fully enclosed conditions, a significant temperature reduction was observed around the enclosed trees, contributing to the cooling effects in the upwind direction within the settlement. However, a slight temperature rebound occurred downwind. Under semi-enclosed conditions, trees positioned upwind had a limited range of blocking effects against heat waves, similar to that in the fully enclosed state. Meanwhile, in the downwind direction, heat waves tended to accumulate within the settlement (Figure 10). The distribution of relative humidity also varied, aligning with the position of the trees. It significantly increased in the outer periphery of the settlement under fully enclosed conditions. Meanwhile, wind speed accelerated around areas with tree distribution, and the acceleration effect extended to a certain distance, resulting in the formation of a wind zone around the tree arrangement. The wind direction was minimally affected by the distribution of trees, having slight variations within 30°, which were likely associated with the height of the tree canopy.

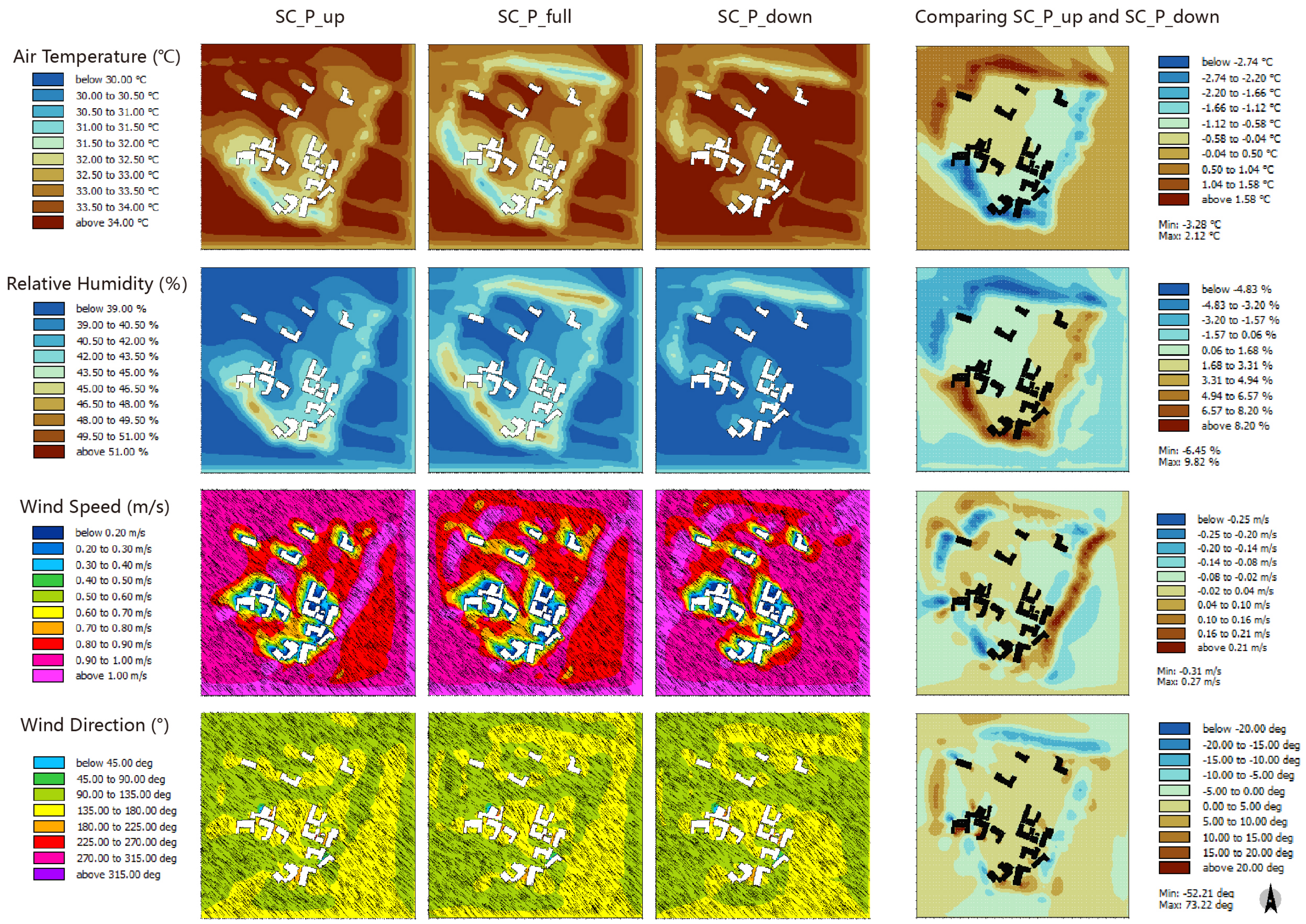


Figure 10. Impact of arbor positioning on the microclimate.

According to the calculated results, the PET value for each scenario reached its highest at 14:00. The graph exhibits a bimodal shape because of the difference between the inside and outside PET values. When the external environment is "very hot" (PET > 41 °C), most of the internal area is also "warm" (29–35 °C). In the simulation, the Linpan can effectively regulate extreme highs. Figure 11 illustrates the ten scenarios, with variations in the height and distribution density of buildings and trees within the Linpan settlement, exhibiting its enhanced adaptability to extreme heat. In scenarios 1–7, distinct temperature concentration areas emerged within the simulation, emphasizing the noteworthy temperature distinction between the Linpan settlement and its external surroundings. The spatial distribution map revealed that the cooling impact within the Linpan settlement primarily resulted from the shading effects produced by buildings and trees. As the building height increased, the shaded area expanded; the shadow positioned northeast of the building led to a significant temperature reduction. Simultaneously, an increase in tree coverage expanded the region of optimal temperatures, although the overall positioning of trees appeared to exert a less visible influence on climate adaptability compared with the initial seven scenarios.

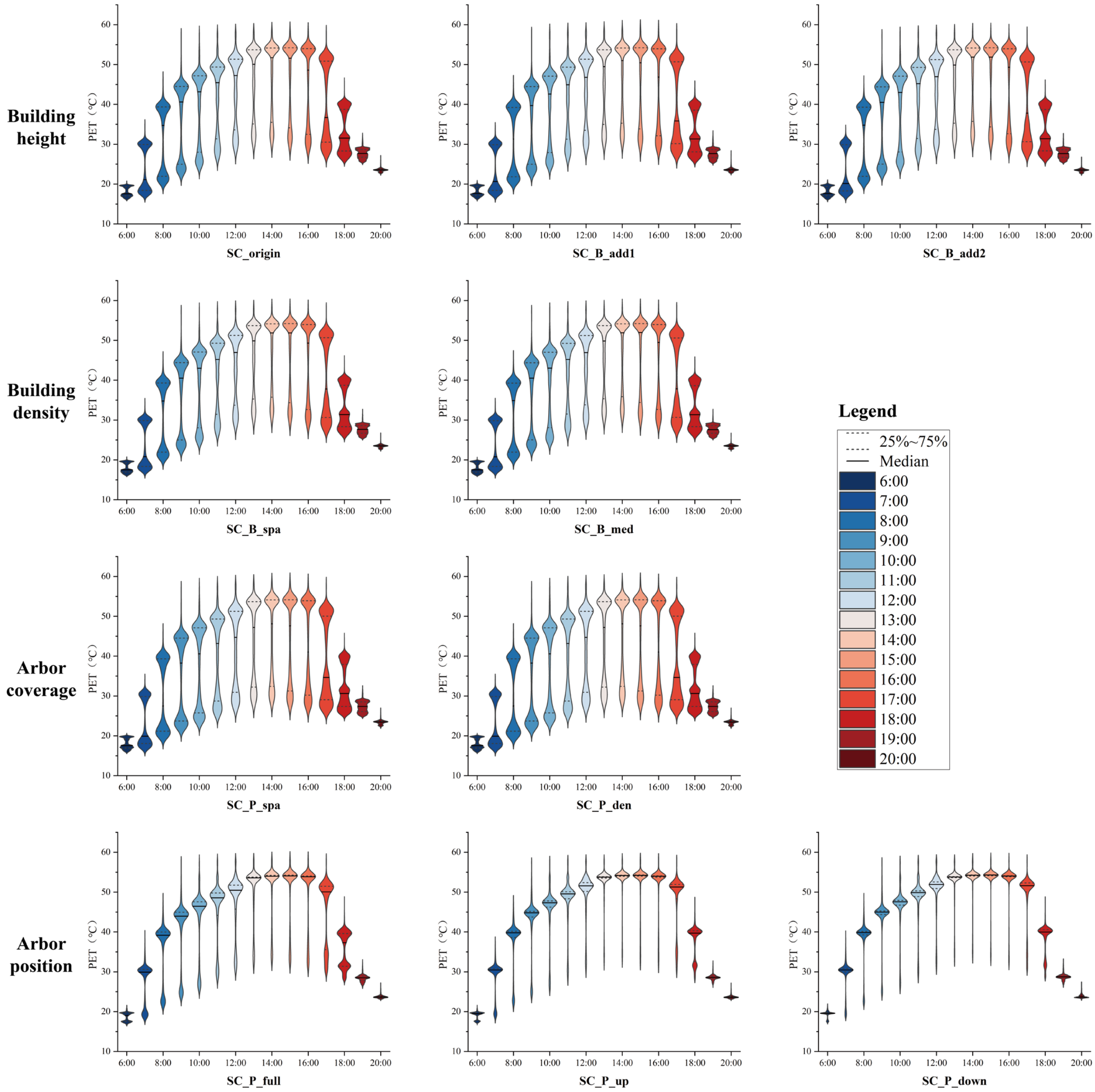


Figure 11. 24 h simulations of PET thermal comfort under nine scenarios.

5. Discussion

The simulation results clearly indicate that Linpans have a cooling effect on the summer environment, with varying degrees of internal influence. These results underscore key factors affecting the Linpan microclimate, as simulated under different scenarios. The outcomes, grounded in benchmark samples and theoretical insights, discuss strategies for Linpan restoration and planning that align with natural processes.

Increasing building height has been shown to impede hot air, induce cooling, and enhance humidity. However, the larger volume of structures can lead to stagnant air around buildings, negatively impacting internal ventilation. Existing research highlights that increased building density tends to correlate with decreased overall wind speed. An optimal building height can create shaded areas, contributing to harmonious rural esthetics; hence, the indiscriminate pursuit of excessively low or high building heights may compromise quality of life and psychological well-being [49]. Furthermore, towering structures may not align with the resident population, resulting in the wasteful utilization of construction resources. Insights from traditional eave designs, which provide shade and manage rainwater, suggest that such features can mitigate temperature extremes and enhance outdoor and indoor comfort.

Changes in building density and height similarly affect microclimates. Both approaches—raising building height and increasing density—expand shaded areas, reducing solar radiation and thus cooling and humidifying the environment. However, this increased volume can also weaken wind speed. In narrow spaces between buildings, wind flow is restricted, leading to higher wind pressure and speed [50]. Effective urban planning in forested areas should incorporate ventilation corridors aligned with prevailing seasonal wind directions to optimize natural light and airflow.

Tree coverage also plays a crucial role in cooling and humidity enhancement, similar to the effects of increased building height. However, excessive tree coverage (over 60%) can reduce wind speed and potentially worsen thermal comfort in still, warm areas [51,52]. In urban settings, higher structures are often promoted to increase shaded areas and lower temperatures. Conversely, in rural areas, strategic tree planting can improve shade, ventilation, and humidity regulation. Effective planning should involve placing trees around buildings and along roadsides while selecting appropriate species to balance summer shade and winter sunlight [53]. Deciduous broad-leaved trees, like ginkgo and dove trees, offer shade in summer and allow sunlight in winter.

The arrangement of trees corresponded to zones affected by temperature reduction and humidity increase. A continuous and dense planting pattern notably hindered external heat waves. However, when this layout was applied to the downwind side of a forested settlement, it impeded the outward flow of internal heat, leading to an increase in the internal temperature [54]. Therefore, the primary roles of tree layout include resisting external heat waves, dissipating internal heat, and introducing wind during calm weather conditions. The arrangement of trees should therefore align with prevailing wind directions to ensure effective heat management and airflow. This strategy also requires a specific analysis of the prevailing wind directions within the settlement to determine the precise arrangement of trees based on the dominant wind directions during summer and winter. For instance, in Dujiangyan City, where northwesterly and southeasterly winds predominate, tree planting should focus on these directions to avoid obstructing wind channels [55].

6. Conclusions

This study investigated the impact of increased building height and tree coverage on the microclimate within traditional rural settlements, emphasizing the positive role of NbSs. Based on ecological principles, these solutions aim to improve the quality of human living environments, mitigate the impacts of extreme weather events on human life, enhance air quality, and promote residential comfort. The findings underscore that while augmenting building height and tree coverage exerts a discernible influence on the microclimate, certain drawbacks also emerge. Elevated buildings can lower temperatures and increase relative humidity but also create stagnant wind areas around the structures, reducing internal ventilation. Increased tree coverage fosters cooling and enhances humidity but may impede airflow, potentially diminishing wind speed. Both heightened buildings and increased tree coverage contribute to the enlargement of shaded regions within settlements.

While various spatial arraignments were observed to influence microclimates, the simulation groups revealed that the cooling effect generated by buildings is less significant compared to that induced by trees. This discrepancy arises from the fact that buildings reflect radiation, which influences shaded areas, whereas trees adeptly sidestep this phenomenon. In summary, NbSs enhance the microclimate in traditional residential settings by enlarging the shaded zones and mitigating direct solar radiation. However, these solutions also hinder wind dynamics, resulting in diminished wind speed. Therefore, in future planning and design endeavors for forested settlements, a judicious equilibrium of these factors is imperative to achieve optimal microclimate effects.

It is imperative to note that the simulation did not account for detailed architectural features, such as eaves, which are crucial for understanding the characteristics of under-eave spaces. Traditional spatial arrangements, which have largely fallen out of use, offered significant environmental benefits compared to contemporary practices. Historical living environment layouts, including tree-lined avenues and shaded public spaces, have been shown to enhance environmental quality and comfort [56]. These factors merit thorough exploration and analysis in future research. Furthermore, the technical methods used in this study can be applied more broadly, and the basic strategies mentioned in our findings can serve as a baseline for human habitat planning. However, specific localized strategies may vary depending on different models, reflecting the unique characteristics of each area.

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