Study on the Optimization Design of Landscape Morphology for Climatic Comfort in Rural Mountain-Forest Scenic Areas Based on the Climate-Ecological Compensation Function: A Case Study of the Western Sichuan Bamboo Sea Scenic Area, Chengdu

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ABSTRACT Global warming intensifies heat exposure in rural mountain-forest scenic areas of humid-hot regions, making landscape morphology optimization important for improving climatic comfort. Taking the Western Sichuan Bamboo Sea Scenic Area as a case, this study integrates field measurements of temperature, humidity, and wind speed with thermal-response questionnaire surveys to characterize local microclimatic conditions. Improvement directions are identified by analyzing three spatial components: impacted areas, regulation spaces, and ventilation and cold-air corridors. Based on the climateecological regulation principle, targeted strategies are proposed for different spatial types, including building-layout optimization for impacted areas, bamboo-tree intercropping for regulation spaces, and construction of a green open-space system for ventilation and cold-air corridors. These strategies are designed to regulate air temperature, humidity, and wind speed and to improve thermal comfort through a source-corridor-sink microclimate-control mechanism. The findings provide scientific support and practical guidance for climate-comfort-oriented landscape morphology design in rural settlements and mountain-forest scenic areas, and offer a reference for environmental sensing-based spatial planning in humid-hot regions.

INDEX TERMS climatic comfort, landscape morphology, climate-ecological regulation, rural scenic areas, environmental sensing

I. INTRODUCTION

WITH the continued increase in global greenhouse gas emissions, global warming has intensified; compared with 1850–1900, the global mean surface temperature rose by 1.1 °C during 2011–2020 [1]. It is anticipated that over the next 20 years the global mean temperature will increase by 0.2 °C per decade [2]. Statistics indicate that from 1961 to 2007 the annual mean temperature in the southwestern forest region of China increased by approximately 0.71 °C [1]. Owing to weak airflows in mountain forests, humid-hot summer climates cause physiological and psychological discomfort for residents and visitors. How to lower air temperature within rural mountain–forest scenic areas and maintain comfort for living and recreation during summer is an urgent problem. This is compounded by the presence of temperature-sensitive industries like manufacturing, which relies on these regions for its labor force. Buildings and rural towns can be regarded as volumetric elements within a large open landscape; rural landscape morphology design concerns the spatial layout of rural landscapes and their buildings, providing a design-oriented methodology for addressing these rural and industrial issues [3].

Since 2000, China's PET (Physiological Equivalent Temperature) has increased by 0.26–0.28 °C per decade, with a more pronounced trend in rural areas than in urban cores and urban expansion zones, indicating an escalating heat-exposure risk for rural residents [4]. Scholars have used the ENVI-met software to verify optimal spatial configurations of the Linpan settlements in western Sichuan, offering guidance for the design of outdoor thermal environments in rural areas of the Chengdu Plain [5]. Taking the Western Sichuan Bamboo Sea Scenic Area as a case, this study elaborates the connotation of landscape morphology design and the construction of a climatic-comfort system. Based on an analysis of the site's microclimatic characteristics, it proposes optimization pathways for climatic comfort, with the aim of providing a theoretical foundation and practical guidance for subsequent climate-comfort-oriented landscape morphology design.

II. INTEGRATION OF CLIMATIC COMFORT AND LANDSCAPE MORPHOLOGY DESIGN

A. CLIMATIC COMFORT

The concept of climatic comfort emphasizes that, in environments where people live and engage in activities, climatic conditions should reach a state that makes individuals feel comfortable. This concept is particularly relevant in high-exposure work settings, such as the industry, where worker health and productivity are directly linked to ambient temperature and humidity. It concerns not only the comfort of human perception but also ecological balance and environmental sustainability. The theoretical foundations of climatic comfort primarily derive from multiple disciplines—including meteorology, physiology, psychology, and environmental science [6]—which provide a scientific basis for research on climatic comfort, encompassing studies of human perception, quantitative analyses of climatic conditions, and the impacts of environmental factors on human health [7]. The principal factors influencing climatic comfort are air temperature, humidity, wind speed, and solar radiation. The ideal temperature for a comfortable sensation is 20 °C; at the same air temperature, people may experience different thermal sensations due to physical factors (e.g., humidity and wind speed), physiological factors (e.g., skin temperature and activity intensity), or psychological factors [6] (Figure 1).

B. LANDSCAPE MORPHOLOGY DESIGN

Landscape morphology design refers to a design concept and methodology constructed through landscape linkages and coexisting in integration with the overall spatial order. Contemporary planning and design primarily respond to rapid socioeconomic development and accelerated urbanization, focusing on the refinement of "functional space"—that is, spatial planning and design initiated from the functional requirements of daily life and human activities. In contrast, the formation of traditional rural space relies more on the presence and development of the natural environment and landscape, emphasizing the expression of landscape space and the primacy of borrowing from the landscape to achieve optimal harmony between humans and nature [8]. The core concern of Chinese geomancy (fengshui) is the selection and treatment of the residential environment: the maxim of "observing wind and water" in practice entails choosing higher ground, seeking shelter from wind, avoiding hazards, orienting toward sunlight, ensuring ventilation, and preventing dampness to meet site-selection needs in the natural environment [9]. In antiquity, understandings of residential and subsistence space were not grounded in the demands of individual space or the creation of spaces that satisfy all functions of communal living; rather, they followed and accommodated the configurations of the external heaven-and-earth environment, emphasizing harmony among heaven, earth, and humanity, and thereby determining the spatial contours for internal behaviors and livelihood activities (Table 1).

TABLE 1. Three dimensions of landscape form design

Environment Type	Characteristic	Scale	Manifestation
Natural environment	Natural landscape	Macro-scale	Mountains, forests, rivers, lakes, grasslands
Habitable environment	Landscape space	Meso-scale	Spatial contours of behavioral and subsistence activities
Subsistence environment	Landscape borrowing and treatment	Micro-scale	Choosing higher ground, sheltering from wind, avoiding hazards, orienting toward sunlight, ventilation, moisture control

A rural space is not only an organic combination of material space and behavioral space; it also exhibits characteristics of spatiotemporal development and evolution, with these three dimensions being inseparable, mutually interacting, and co-evolving. Rural space integrates material and immaterial dimensions: beyond the commonly emphasized plan morphology and three-dimensional visual expression, it must also account for human behavioral space and the influences of the settlement's own temporal evolution on spatial configuration. Landscape morphology should be understood as a multidimensional, integrated space— formed by the organic fusion of material composition, human behavioral space, and temporal–evolutionary space (Figure 2). Its spatial sequence and assemblage, the accretion of historical and cultural layers over time, and the permeation of human behavior through evolutionary processes jointly constitute an organic spatial system oriented toward harmony between humans and nature.

C. CLIMATIC-COMFORT-ORIENTED LANDSCAPE MORPHOLOGY DESIGN

Climatic-comfort-oriented landscape morphology design is a planning approach that centers on improving the microclimate and enhancing human comfort by scientifically arranging landscape elements to address specific climatic conditions. Its core lies in leveraging the synergistic effects of natural components—such as topography, water bodies, vegetation—and built structures to regulate temperature, humidity, and wind environments, thereby creating pleasant outdoor spaces. Their relationship is manifested in three aspects.

(1) Climatic comfort uses landscape morphology design as its vehicle, emphasizing full consideration of climatic influences on human comfort during planning and design, and improving climatic comfort through the optimization of landscape form. As the daily activity setting for villagers,

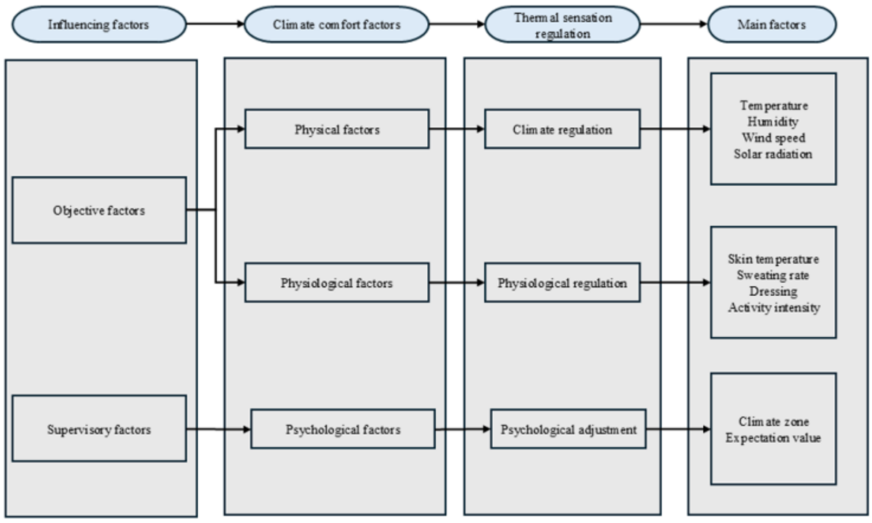

FIGURE 1. Three factors of comfortable climate

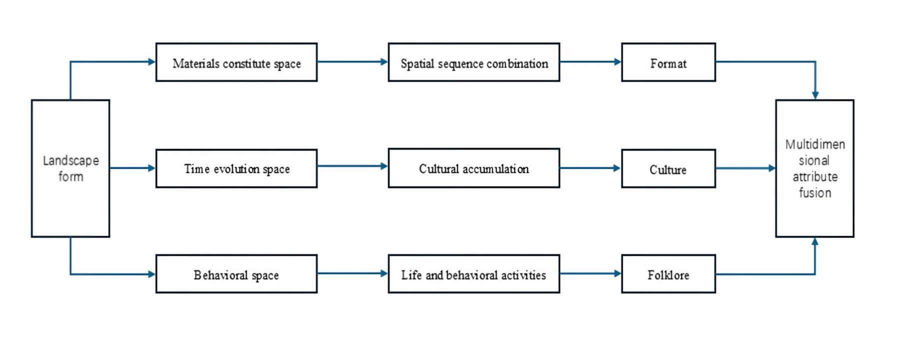

FIGURE 2. Analysis framework of landscape morphological attributes

the spatial environment can be optimized by harnessing favorable climatic resources and mitigating adverse conditions, thus improving the overall quality of rural space and residents' quality of life. For example, rational design of building orientation, spacing, and height can enhance ventilation and daylighting, reduce energy consumption, and improve outdoor comfort, while avoiding large continuous building masses that create heat-accumulation zones and exacerbate the heat-island effect. A climatically comfortable rural environment can elevate overall form and attractiveness; appealing landscapes, agreeable climates, and comfortable living conditions help attract talent and investment, thereby promoting economic development and social progress.

(2) Landscape morphology design adopts climatic comfort as a scientific criterion. As a complex and multidimensional process, landscape form design increasingly takes climatic comfort as a key standard in response to rising expectations for quality of life. The core is to optimize the spatial environment through landscape form so as to improve outdoor thermal comfort, including spatial layout, vegetation selection, water-feature design, material choice, and adaptive architecture. Vegetation plays an essential role in climatic regulation: selecting species suited to local conditions provides shading and cooling and improves air quality.

Water bodies substantially influence the surrounding microclimate; for example, fountains or ponds reduce air temperature through evaporation while increasing humidity, thereby enhancing thermal comfort. Using materials with low thermal conductivity reduces heat absorption and release, helping maintain a comfortable temperature range, while reflective materials limit solar-radiation absorption. Passive strategies—such as building layout, window configuration, and shading devices—maximize natural light and ventilation and reduce energy use. In addition, green roofs, green walls, and rain gardens can markedly improve the microclimate while providing shading, cooling, and stormwater management; these strategies also reduce energy consumption and carbon emissions, advancing sustainability.

(3) Both climatic comfort and landscape morphology design are human-centered. The climatic comfort concept optimizes the spatial environment via landscape form to make it more suitable for habitation and activity. It addresses not only the modulation of physical parameters such as temperature and humidity but also human thermal responses, requiring full consideration of physiological needs, such as appropriate temperature ranges and comfortable humidity levels, to ensure comfort and enjoyment in outdoor settings.

Attention to psychological needs is likewise essential: creating a pleasant environmental atmosphere enhances psychological comfort and well-being. Landscape morphology design is similarly human-centered.

As a synthesis of the artificial and the natural, landscape form constitutes a visible material space and a carrier of social activities. Design must fully consider behavioral habits and needs, such as the provision of walkways, resting areas, and recreational facilities, to accommodate human activities. It should also attend to psychological experience and cultural identity by cultivating landscapes with local characteristics that strengthen residents' sense of belonging and cultural recognition. In sum, both climatic comfort and landscape morphology are people-oriented and must comprehensively account for physiological, psychological, and social needs to ensure scientific rigor and human-centered design.

The "climate-ecological regulation function" in this study, grounded in ecological regulation services and urban climate regulation theory, refers to the synergistic interaction between the Impacted Area, Regulation Space, and Ventilation & Cold-Air Corridors achieved through landscape form optimisation. This facilitates beneficial regulation of microclimate (temperature, humidity, wind), ultimately enhancing human comfort.

Its core mechanism comprises: Regulation Space generates cold sources/fresh air $\rightarrow$ Corridors facilitate low-resistance transport $\rightarrow$ Impacted Area experiences improved thermal environment, forming a "source- corridor-sink" regulatory closed loop.

III. METHODOLOGY FOR CONSTRUCTING THE CLIMATIC COMFORT SYSTEM

A. SYSTEM COMPONENTS: IMPACTED AREA + COMPENSATION SPACE + AIR-GUIDANCE CORRIDOR

German scholar Kress was the first to propose an evaluation standard for the climatic functions of the underlying surface based on the operating laws of local circulation; according to climatic function, the underlying surface is divided into impacted area, compensation spaces, and air-guidance corridors [10].

Impacted Area typically refers to an area (e.g., a settlement) that exhibits higher air temperatures than its surroundings (e.g., bamboo forests), thereby forming a "heat-island-effect space." Its distribution within bamboo forests is uneven and often appears as building clusters with limited greenery. Surface covers in such spaces are predominantly high–heat-capacity materials such as concrete and asphalt, which absorb solar radiation and subsequently release heat to the atmosphere, producing a heat-island effect. This effect intensifies in summer due to stronger solar radiation and weakens in winter as solar radiation diminishes.

Because pressure differences arise between the windward and leeward sides of individual buildings, stagnant- wind zones tend to form within building clusters; thus, the area's overall ventilation and air-exchange capacity needs to be enhanced.

Compensation space generally denotes zones within the local wind-circulation system that generate clean or cold air, as well as local climate-resource and climate-sensitive areas; these spaces play a vital role in mitigating heat-island effects and improving the microclimate. Compensation spaces can be categorized into two types. The first reduces the thermal air mass within an impacted area or improves its air quality; it mainly occurs inside the impacted area as an adjacent functional space and can alleviate hot air masses there through positional relationships and air-exchange processes. The second promotes air circulation within the impacted area; its primary function is to secure sources of cold air for the impacted area, such as natural mountains capable of generating local circulation.

As air-flow conduits, air-guidance corridors may utilize existing arterial roads, rivers, parks, greenbelts, high- voltage transmission corridors, contiguous recreational lands, and other open areas as corridor carriers; even under stable weather conditions they facilitate air movement [11]. These corridors transport fresh air from compensation areas to action areas. Based on the thermodynamic characteristics and air quality of the transported air masses and their source regions, air-guidance corridors can be classified into ventilation corridors, cold-air corridors, and fresh-air corridors [12], among which cold-air corridors are the most effective at alleviating heat-island effects. In general, the flow velocity of cold air is proportional to terrain steepness and to the area of the cold-air generation region.

B. CONSTRUCTION PRINCIPLES: ADHERING TO THE CLIMATE-ECOLOGICAL COMPENSATION FUNCTION

The operational effectiveness of the climate-ecological compensation function depends on factors such as the relative positions of compensation spaces and impacted area, the climatic-function level and area of compensation spaces, and the surface roughness, length, width, edge conditions, and obstacles within air- guidance corridors [10]. The core area of the Western Sichuan Bamboo Sea covers 3.3 km2, with agricultural and forestry land accounting for 85%. Areas permitted for construction include urban land and rural residential land; the land-use categories comprise urban land, rural residential land, woodland, orchard land, and cropland. Aside from urban and rural residential land, the extensive forested areas serve as cold-air generation zones, while Zhaogou and the meandering valley river on the western side function as air-guidance corridors (Figure 3).

IV. MICROCLIMATIC CHARACTERISTICS OF THE SCENIC AREA

Measurements of microclimatic factors in the scenic area included four parameters: air temperature (°C), relative humidity (%), black-globe temperature (°C), and wind speed (m/s). The instrument models used for each thermal-environment indicator include Taiwan AZ-8778, Taiwan TES-1333 and America Kestrel 5500.

Monitoring devices were mounted on tripods in the field at a height of 1.5 m. Temperature and humidity were read every 5 minutes, with four instantaneous readings cross-recorded at each measurement; wind speed was automatically logged every 1 minute. The basic information on measurement points is provided in Table 2.

Table 2. Measurement point number and location

Measurement Point ID	Photo	Space Type
Bamboo Forest 1		Roadside
Bamboo Forest 2		Terrace
Bamboo Forest 3		Waterside
Bamboo Forest 4		Waterside
Bamboo Forest 5		Waterside
Bamboo Forest 6		Roadside
Bamboo Forest 7		Valley
Bamboo Forest 8		Valley

A. WIND SPEED

Influenced by mountainous terrain, the bamboo-forest scenic area exhibits a high frequency of calm conditions and generally low wind speeds, with marked local variation in wind direction and speed under different landforms. The terrain between Zhaogou and Jinjigou is a northwest–southeast–oriented valley, and the prevailing wind direction aligns with the stream. A flat intermontane terrace on the northwest side of Zhaogou allows smooth airflow and thus higher wind speeds. Near the settlement in a concavity on the northern slope above Zhaogou, the terrain is enclosed and the calm-wind frequency reaches 100%. To the west and east of Zhaogou lies a broad basin where wind speeds are relatively higher. As shown in Table 3, the mean wind speed within the scenic area is below 0.5 m/s; calm conditions are particularly evident in summer.

TABLE 3. Microclimate measurement results of the scenic area

Season	Stat	Air Temperature (°C)	Relative Humidity (%)	Black-Globe Temperature (°C)	Wind Speed (m/s)
Summer	Mean	30.7	85.0	31.2	0.4
Summer	Max	37.6	99.9	39.7	3.8
Summer	Min	26.4	61.6	19.9	0.0
Autumn	Mean	18.8	85.5	18.8	0.4
Autumn	Max	27.3	97.2	29.0	6.7
Autumn	Min	7.3	66.4	14.9	0.0
Winter	Mean	8.7	78.6	8.7	0.4
Winter	Max	13.2	99.9	12.2	4.9
Winter	Min	3.7	47.4	3.5	0.0

Stat abbreviations: Mean = mean value; Max = maximum; Min = minimum.

B. AIR TEMPERATURE

At eight recreational nodes within the bamboo-forest scenic area, users were randomly sampled and completed paper questionnaires each hour to ensure full temporal coverage at all spaces. Subjective thermal responses were evaluated using the ASHRAE seven-point Thermal Sensation Vote (TSV) and a five-point thermal comfort scale.

Survey Period: The research was conducted during July and August (summer months), covering the full daily period from 9:00 to 18:00 (including relatively low-humidity periods in the morning and evening, rather than focusing solely on the midday heat).

Sample Characteristics: A total of 320 questionnaires were distributed, with 286 valid responses collected, achieving an effective response rate of 89.4%. Respondents comprised three groups: rural residents (62%, long-term local residents adapted to high-temperature/humidity conditions with higher heat tolerance), tourists (28%, short-term visitors with relatively lower heat tolerance), and workers (10%, long-term local employees possessing some degree of heat adaptation).

Data validation: Cronbach's α coefficient was employed to assess questionnaire reliability, yielding $\alpha = 0.87$ (> 0.8), indicating strong internal consistency. Concurrently, KMO analysis confirmed validity with KMO=0.76 (> 0.7), demonstrating suitability for factor analysis and establishing a robust statistical foundation for the research data. The specific characteristics of the respondents are distributed as shown in Table 4:

TABLE 4. Distribution of Respondent Characteristics

Respondent Type	Sample Size	Percentage	Average Residence/Stay Duration	Heat Tolerance (1–5 scale, 5 being highest)
Rural Residents	177	62%	$\geq$10 year	4.2
Tourists	80	28%	$<$ 7 day	2.8
Industry Workers	29	10%	$\geq$3 year	3.9

In summer, the proportion of thermally neutral evaluations (TSV = 0) was 28.1%; warm-side evaluations (TSV $>$ 0)

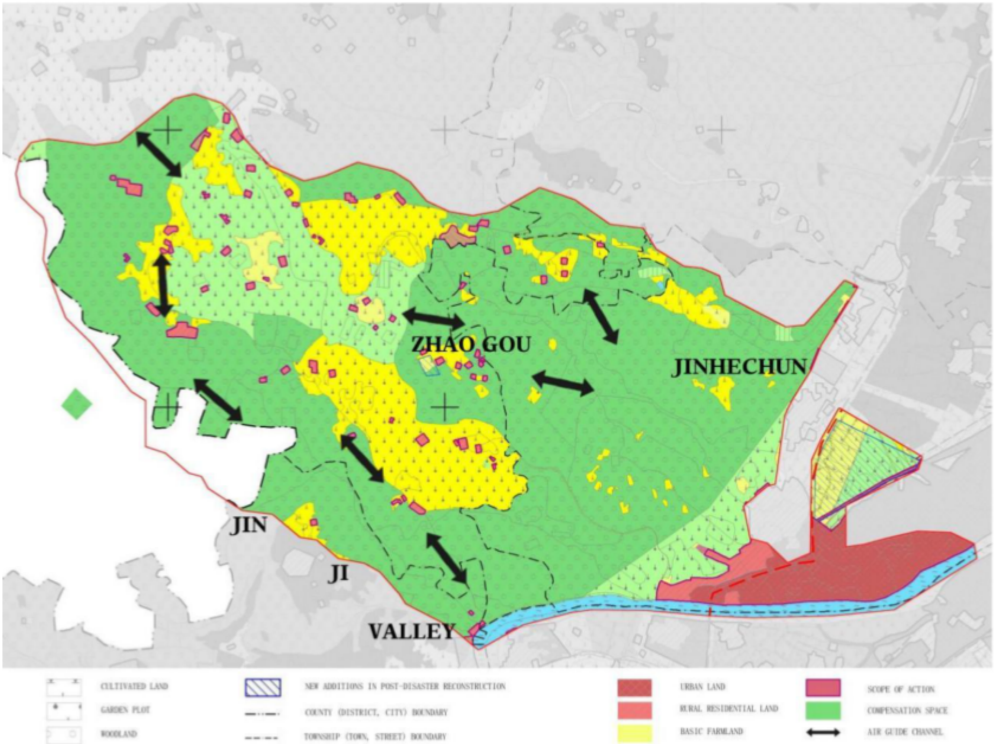

FIGURE 3. Schematic diagram of climate and ecological compensation in Western Sichuan Bamboo Sea

accounted for 41%, with "very hot" (TSV = 3) comprising 26.7%, indicating a warm bias in summer sensation.

The share of "comfortable" votes ranked autumn (66.9%) > winter (55.9%) > summer (21.0%), and the share of "very comfortable" votes ranked autumn (16.1%) > winter (11.8%) > summer (3.5%), confirming that summer thermal comfort is poorest. As shown in Table 3, summer conditions are hot, with a maximum air temperature of 37.6 °C and a black-globe temperature of 39.7 °C, leading to poor perceived comfort.

It should be noted that the neutrality rate in summer TSV (28.1%) does not contradict the high temperature and humidity data: Rural residents and workers exhibit higher heat tolerance (average scores of 4.2 and 3.9 respectively). These two groups accounted for 35.2% of neutral TSV votes, which elevated the overall neutrality rate. This outcome precisely reflects the climate adaptation characteristics of the local long-term resident population, consistent with observed high-temperature and high-humidity environmental conditions.

C. RELATIVE HUMIDITY

Soils in the mountainous area are covered by tall bamboo; due to short periods of insolation, the soil surface is less exposed to direct sunlight, resulting in lower air and soil-surface temperatures than in non-bamboo areas. Conversely, canopy shading produces a near-surface air layer with higher humidity than in non-bamboo areas, typically 15–30% higher. Wind speed within this layer is also low and often calm. Consequently, under conditions unfavorable to soil evaporation, evaporation from bamboo soils is markedly reduced and the relative humidity (RH) of the air is higher. In Chengdu, where the scenic area is located, RH generally remains 75–85% throughout the year; in bamboo stands, RH can reach 99.9% in both summer and winter, with a mean summer RH of 86%. Field observations indicate that pure bamboo forests (compensation spaces) exhibit an average summer humidity of 88%, exceeding the upper limit of comfortable humidity (80%). However, optimisation through intercropping with camphor trees enhances canopy ventilation while reducing surface evaporation. Simulation results demonstrate that humidity can be reduced to 76–78% (Table 4), meeting human comfort standards. Consequently, the core function of compensatory space is not "dehumidification", but rather "regulating high humidity within comfortable ranges" to prevent the oppressive sensation caused by excessive moisture.

V. OPTIMIZATION PATHWAYS FOR CLIMATIC-COMFORT-ORIENTED LANDSCAPE MORPHOLOGY

A. IMPACTED AREA — OPTIMIZING BUILDING LAYOUT

Rural courtyard houses are common in bamboo-forest zones and typically feature either open or enclosed courtyards. The thermal environment inside a courtyard generally outperforms that outside, with a pronounced ameliorative effect on the microclimate. Shading is the most direct and effective means to prevent direct solar exposure and reduce air temperature. Although shaded spaces tend to exhibit relatively stable thermal conditions, shading performance varies with shading type, spatial configuration, orientation, and the scale of buildings or landscape elements, leading to differences in outdoor thermal environments.

Horizontal shading (e.g., vegetation, eaves, pavilions) and vertical shading (e.g., courtyard walls, alleys) have time-dependent effects and are suited to managing solar radiation from different heights and angles. Natural ventilation is another means of improving courtyard thermal conditions. The semi-open courtyard layout employs an 8-metre building separation distance (referencing the local solar access spacing coefficient of 1.2), complemented by 1.0-metre-wide horizontal sunshades. This configuration enhances natural ventilation, increasing courtyard wind speeds by 0.15–0.2 metres per second. Combined with ENVI-met simulations, the average summer temperature is projected to decrease by 1.5°C (Table 5).

TABLE 5. Results presented

Scenario	Average temperature (°C)	Average wind speed (m/s)	TSV neutral rate (%)	Comfort improvement
Baseline	30.7	0.4	28.1	-
Optimisation 1	29.2	0.55	35.6	26.7%
Optimisation 2	28.5	0.42	38.2	35.9%
Optimisation 3	30.1	0.68	33.4	18.9%
Comprehensive	27.8	0.72	45.3	61.2%

Key finding: 'The comprehensive optimisation scenario reduces average summer temperatures by 2.9°C, increases wind speeds by 0.32 m/s, and elevates TSV neutrality rates from 28.1% to 45.3%, validating the strategy's effectiveness.'

B. COMPENSATION SPACE — BAMBOO–TREE INTERCROPPING

In bamboo ecosystems, the low density of leaf coverage, together with the hollow culms of bamboo, results in low biomass, which weakens the cooling function of bamboo stands as compensation spaces. Bamboo–tree intercropping is a mixed management model that combines bamboo with arbor species and delivers both ecological and economic benefits. For example, in Anji, Zhejiang, moso bamboo is mixed with Chinese fir, with the latter maturing in about twenty years; in Pu'er, Yunnan, Dendrocalamus sinicus is intercropped with tea, and bamboo shade improves tea quality. Through appropriate species matching and fine management, bamboo–tree intercropping can achieve the sustainable management goal of "supporting the long term with the short term" and "using bamboo to support trees." Within the bamboo area there are at least twelve bamboo species, with Cizhu as the principal species. It is recommended to plant native tree species such as camphor and teak, and to avoid shallow-rooted, fast-growing species that compete strongly with bamboo, such as eucalyptus. For bamboo species with strong lateral spread, such as moso bamboo, regularly cut underground rhizomes and excavate barrier trenches 1–2 m from tree trunks. Young trees require shade, which can be provided by bamboo; after canopy closure, conduct pruning to ensure adequate light within the bamboo stand.

C. AIR-GUIDANCE CORRIDORS — FORMING A GREEN OPEN-SPACE SYSTEM

Topographic relief and landform have major effects on the generation and movement of cold air; cold air tends to accumulate in valleys, while surface cover—particularly vegetation—strongly influences cold-air flow. Vegetation increases surface roughness and can reduce airflow velocity; therefore, measures should be taken to expand ventilation channels. For example, convert the orchard on the intermontane terrace northwest of Zhaogou to cropland to reduce resistance to cold-air flow; likewise, replace bamboo stands on the valley slopes west of Zhaogou—an important ventilation corridor—with grassland to enlarge the area for cold-air movement and enhance transpiration, thereby creating a green open-space system. Here, Green Open Space (GOS) refers to open areas within forests that are not covered by canopy and are dominated by natural or semi-natural vegetation, including grassland, cropland, shrubland, greenways, and wetlands. When arranged along the prevailing wind direction, intra-forest open spaces can function as wind corridors that guide fresh air inward and increase transpiration, thereby reducing relative humidity.

D. VERIFICATION OF OPTIMISATION STRATEGIES

To quantitatively validate the effectiveness of the landscape form optimisation strategies proposed earlier in improving microclimate and thermal comfort, this study employed the ENVI-met 5.0 tool—commonly used in outdoor microclimate modelling—to construct a microclimate model of the study area and conduct multi-scenario comparisons.

1) Model Parameter Configuration

Model parameters were determined based on field survey data and observational results from the West Sichuan Bamboo Sea Scenic Area, ensuring authenticity and fidelity:

1. Baseline Data: Initial climate conditions for the model were set using field-observed summer averages: mean temperature (30.7°C), relative humidity (85%), and wind speed (0.4 m/s);

2. Landscape Element Parameters: Bamboo forest height set at 8–10m, building density at 0.3, soil type defined as sandy loam, and vegetation coverage at 85%. All parameters align with the actual landscape characteristics of the study area.

2) Scenario Design

This study designed five comparative scenarios, using the 'Baseline Scenario' as a reference to validate the effectiveness of individual spatial optimisation strategies and integrated strategies. Variable settings and simulation indicators for each scenario are as follows:

Baseline Scenario: Based on the current landscape configuration of the scenic area (no optimisation measures), in-

dicators include summer average temperature (°C), average wind speed (m/s), and TSV neutrality rate (%);
Optimisation Scenario 1 (Impacted Area Optimisation): Variable involves adjusting building layout within the Impacted Area (building spacing set to 8m with 1.0m horizontal shading), indicators identical to Baseline Scenario;
Optimisation Scenario 2 (Regulation Space Optimisation): Variable involves bamboo-tree intercropping configuration within Regulation Space (camphor tree planting density set at 30 trees/hm2, retaining original bamboo forest density); indicators identical to baseline scenario;
Optimisation Scenario 3 (Ventilation & Cold-Air Corridors Optimisation): Variable being Ventilation & Cold-Air Corridors – construction of green open spaces (corridor width set at 15m, bamboo forests within 10m on both sides replaced with herbaceous vegetation); indicators consistent with baseline scenario;
Comprehensive Scenario: Simultaneous implementation of optimisation strategies for Impacted Area, Regulation Space, and Ventilation & Cold-Air Corridors, with indicators consistent with the baseline scenario.

VI. CONCLUSION

By shifting the focus of climatic-comfort design from urban settings to rural architecture and landscapes, particularly those supporting the workforce of local industries such as manufacturing, this study provides scientific principles and standards for landscape morphology. Conceptualizing the design system as comprising impacted area, compensation spaces, and air-guidance corridors, the climate-ecological compensation function clarifies how these spaces interact and influence one another. Within the domains of climate and thermal comfort, the climate-ecological compensation function elucidates the nature of climate generation, convergence, and transport, offering a deeper understanding of local microclimate formation.

Through the application of compensatory air masses, climatic-comfort-oriented landscape morphology design advocates a dynamic, compensatory framework in which climate emerges naturally from the design network rather than being introduced solely from external air masses; this approach ensures that microclimatic considerations and design processes remain closely linked to local environmental conditions and practical needs. The emphasis within the climate-ecological compensation function on cold air, fresh air, and ventilation corridors aligns with core design principles—cooling, dehumidification, and ventilation. By embedding ecological compensation into design thinking, designers can create climatically comfortable and morphologically stable systems that adapt flexibly to the needs of different populations and to changing environmental conditions. This is crucial for improving the living and recreational comfort of rural residents and industry laborers in humid–hot regions, offsetting the heat impacts of rural mountain-forest environments. The findings of this study focus on the composite scenario of "rural mountainous forest scenic areas + rural settlements" and do not address the microclimate characteristics of high-density industrial parks.

Future research could be conducted specifically on "recreational spaces attached to industrial parks" to broaden the scope of application.

AUTHOR CONTRIBUTIONS

Conceptualization –Lulu Fan and Fan Zhang; methodology – Lulu Fan and Fan Zhang; investigation – Lulu Fan and Fan Zhang; writing-original draft preparation – Lulu Fan and Fan Zhang. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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