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Adaptive Planning for Old Residential Communities Around Parks Under High-Temperature Conditions: A Case Study of the East Side of Xingqing Palace Park, Xi'an

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Abstract. Against the backdrop of global warming and exacerbating urban heat island effects, heat waves have significantly impacted residents' lives and urban development. Enhancing the thermal adaptability of urban spaces through systematic planning has become an urgent task. Existing research often focuses on isolated technologies and lacks multidimensional resilience integration at the community scale, thereby constraining the efficacy of urban planning. This research employs a case study of the old urban area surrounding Xingqing Palace Park in Xi'an and adopts a methodology that integrates theoretical framing, methodological development, and empirical validation. It establishes a "spatial strategies–thermal adaptation goals" framework with four dimensions—resistance, adaptation, recovery, and learning. A localized adaptive planning strategy centered on "guiding the park's cool-island effect into the communities" is proposed, and its efficacy is quantitatively verified through ENVI-met microclimate simulations. Finally, an integrated "park–community" adaptive planning and governance model is presented, offering a transferable "Xi'an solution" to enhance livability during heat waves in similar Chinese urban contexts.

Keywords: Heat Waves, Park Cool Island, Adaptive Planning, Microclimate Simulation, ENVI-met, Xi'an

1. Introduction

Rapid urban development, characterized by the continuous expansion of impervious surfaces, has squeezed out green ecological spaces.Coupled with escalating anthropogenic heat emissions from human activities, regional thermal stress continues to intensify. According to the IPCC Sixth Assessment Report, the intensification of climate change is leading to more frequent extreme weather events, a trend that seriously threatens urban public health and safety.

In this context, China's 14th Five-Year Plan and its Long-Range Objectives Through 2035 emphasize the integration of health objectives into urban development and shifting focus from expansion to the regeneration of existing urban stock. Upgrading old residential communities, which often feature single land uses, insufficient facilities, and pronounced vulnerability to high

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temperatures,has become a critical priority. In many neighborhood landscape plans, suboptimal functional zoning and fragmented green-space layouts constrain ecological benefits and negatively impact residents' health and quality of life [1].

For old communities adjacent to parks, a key challenge lies in how to leverage their locational advantages via systematic spatial planning to enhance climate adaptability amid extreme heat, thereby addressing both urban regeneration strategies and climate challenges. This study aims to integrate the park cool-island effect with the renewal of old communities, and propose a new paradigm for climate-adaptive planning at the micro (community) scale. It presents a "park–community collaboration" optimization pathway for Xi'an and similar cities, and provides an operational template for multi-department collaborative governance.

2. Theoretical foundations and the associated framework

2.1. Climate-adaptive planning based on urban resilience theory

Urban resilience theory provides a new planning paradigm for addressing the uncertainties of climate change. Originating from Holling's work in systems ecology and subsequently refined by numerous scholars, it is defined by Gomes Ribeiro and Pena Jardim Gonçalves as encompassing four dimensions:resistance, recovery, adaptation, and transformation [2-3]. This perspective emphasizes that urban resilience is a comprehensive, systemic effort requiring coordination across ecological, economic, social, and technological dimensions.Accordingly, the core of urban planning must shift from pursuing static ‘ultimate blueprints’ to dynamic ‘adaptive processes’.

Climate-adaptive planning aims to address and mitigate the impacts of climate change.Ye Zuda proposed integrating the concept of climate-resilient urban adaptation into China's urban and rural planning management systems [4]. Given the complexity and diversity of climate adaptation, coupled with its context-dependent methodologies and pathways, no universally applicable technical approach exists [5]. For old communities near parks, their greatest advantage lies in proximity to a natural cool-island resource; therefore, targeted spatial interventions that leverage this resource are key to improving their thermal adaptability.

2.2. Current research status domestically and internationally

2.2.1. Studies on park cool-island effects

Domestic and international studies have conclusively demonstrated that urban parks generate a ‘cooling island effect’ that not only improves local microclimates but also extends cooling benefits to surrounding neighbourhoods. Spronken-Smith and Oke's California study found that parks with extensive green spaces and tall trees exhibit more pronounced cooling effects [6]. Upmanis et al.'s Swedish research observed maximum temperature differentials of up to 5.9°C between parks and surrounding areas during summer, with benefits extending to zones 1100 metres beyond park boundaries [7]. Su and other scholars in their study of 17 parks in Guangzhou, concluded that parks with larger water bodies demonstrated superior cooling effects [8]. However,existing research predominantly focuses on park interiors, with insufficient exploration of collaborative mechanisms between parks and their thermally vulnerable surrounding neighborhoods.

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2.2.2. Old-community renewal and climate adaptation

At the community scale, climate-adaptive planning practices have a longer history abroad ,while they have only recently gained traction in China.Song Ruochen emphasised through micro-renewal theory that spatial transformations of contemporary older residential areas should prioritise the renewal of public spaces and landscape environments [9]. Wei Fang et al. proposed that informal green spaces could serve as effective pathways for the renewal of older residential areas [10].

Overall, current research tends to emphasize either macro strategies or singular technological interventions, lacking a systematic integration of multiple measures through a spatial-planning lens to synergistically enhance thermal adaptation. In particular, how to implement integrated planning that couples old-community renewal with adjacent park ecological resources remains a significant gap.

In summary, existing research exhibits two key gaps: firstly, studies on park cooling islands tend to prioritise internal rather than external aspects, neglecting planning guidance for surrounding neighbourhoods. Meanwhile, research on the renewal of older residential areas is conducted in isolation, failing to effectively utilise adjacent park ecological resources.Secondly, there is a lack of a systematic theoretical framework and technical methodology to guide the planning of integrated ‘park-residential area’ systems, thereby optimising the spatial transmission and synergistic enhancement of cooling island benefits.

3. Research mechanism for adaptive planning

3.1. A four-dimensional goal system for adaptive planning

Grounded in resilience theory, this study advances the concept of ‘coordinated planning’, viewing parks and adjacent old communities as an integrated system. The planning goal is to use spatial strategies to guide the permeation and diffusion of the park’s cool-island effect into heat-vulnerable communities, thereby systematically enhancing community thermal resilience. To this end, the study translates adaptive planning for ageing neighbourhoods into a four-dimensional target system. Each dimension defines its scientific essence, spatial representation, and quantitative indicators, providing guidance for planning evaluation and formulation:

Enhancement capacity: The community's ability to receive, amplify, and retain the park's cooling benefits. Spatially, this involves creating efficient cool-air corridors and internal cooling retention elements. It can be quantified by reductions in the attenuation rate of park-cooling intensity (°C per 100 m).

Accessibility: Ensuring residents can safely and comfortably reach and use the park during heat events. This is achieved through continuous shaded walkways and thermally comfortable entrance nodes, measurable via improvements in Physiologically Equivalent Temperature (PET).

Maintenance capacity: The ability to sustain basic community services under heat stress (e.g., water/power supply, community services). This can be measured by the number of functional interruptions of key facilities on extreme-heat days.

Learning Capacity: The system's ability to monitor thermal environments, assess strategy performance, and adapt dynamically. This emphasizes coordinated responses between park management and community governance, measurable by the number of times strategies are adjusted annually (times/year).

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3.2. Spatial strategy framework

To achieve the four-dimensional goals outlined above, this study establishes a targeted spatial strategy framework. Strategy selection adheres to the principles of 'spatial coordination'(strengthening park–community spatial linkages) and 'community feasibility'(accommodating the constraints of old communities, such as limited space, complex tenure, and limited funds). The strategies are categorized as follows:

Cool-Corridor Guidance Strategy: Create pathways for the cool air from parks to penetrate communities. Core strategies involve constructing shaded connecting corridors (extending park greenways into residential areas) and optimising street valley ventilation (guiding prevailing summer winds through rational building layouts).

Interface Optimisation Strategy: Soften hard boundaries between parks and residential areas to facilitate lateral penetration of cooling benefits.Core strategies include transforming perimeter walls with greenery (increasing vertical greening coverage) and cooling entrance nodes (equipping them with shade structures and misting devices).

Internal Adjustment Strategy: Upgrade the community's own thermal regulation capacity to synergize with external cool sources. Core strategies encompass greening vacant spaces (utilizing idle land to supplement green areas), providing flexible shading (adding sunshade equipment to activity areas), and applying high-reflectance paving (replacing some hard surfaces).

Smart Governance Strategy: Enhance the system's perception and response capabilities through technological empowerment and mechanism innovation. The core measure involves establishing a community heat risk monitoring network with low-cost sensors and developing digital platforms to support data-driven decision-making and public participation.

3.3. The "strategies–goals" association matrix

A spatial strategies–adaptive planning goals association matrix is constructed to illustrate how each strategy leverages the park's cooling effects and enhances community thermal adaptation, thereby transcending a simple checklist approach.

3.3.1. Mechanism tracing

Grounded in resilience theory, two primary pathways are identified: a biophysical pathway, which involves direct local climate regulation, and a social-behavioral pathway, which achieves indirect effects through the optimization of functionality and accessibility.

3.3.2. Matrix presentation

Consistent with the aforementioned mechanisms, the correlation matrix presented in Table 1 illustrates the inherent associations among certain strategies. ●●● indicates a strong association, ●●○ a medium association, ●○○ a weak association, and ○ no direct association.

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Table 1. Example correlation matrix of spatial strategies and adaptive planning objectives

Strategy	Enhancement Capacity	Accessibility	Maintenance	Learning Capacity	Key Mechanism
Shaded linkage corridors	●●●	●●●	●●○	○	Forming cold air guidance channels to enhance shaded pedestrian spaces.
Perimeter Wall Greening	●●○	●●○	●○○	○	Promotes visual and ventilation connectivity, enhancing cooling benefits penetration.
Entrance Node Cooling	●●○	●●●	●●●	○	Enhances park entrance comfort, encouraging park usage.
Green Spaces in Interstitial Areas	●●●	●●○	●○○	○	Increases internal community cooling capacity, supplementing cooling benefits.
Community heat-risk monitoring	○	●○○	○	●●●	Data-driven park-residential area emergency response coordination.

3.3.3. Application rules

Strategy Prioritization: Prioritize strategies with strong or medium associations across multiple goals.

Gap-Filling: Address identified weak dimensions (e.g., maintenance capacity) with targeted strategies.

4. Verifying strategy effectiveness: ENVI-met microclimate simulations

ENVI-met microclimate simulations are used to assess the impact of spatial planning strategies on mitigating heat in old residential communities. This approach precisely models key parameters, including air temperature, wind speed, the Universal Thermal Climate Index (UTCI), and the Physiologically Equivalent Temperature (PET). ENVI-met is particularly effective for evaluating the complex impacts of spatial elements such as vegetation and water bodies on local microclimates. It effectively simulates the spatial spillover effects of park cooling islands and environmental responses following strategic interventions, which aligns closely with this study's requirement for quantitative validation of multiple strategies.

Output indicators are described as follows:

Air Temperature: A core metric that directly reflects heat island mitigation effectiveness (i.e., enhancement capacity).

Physiological Equivalent Temperature (PET): Integrates factors such as air temperature, radiation, humidity, wind speed, and human activity to translate human thermal sensation into an equivalent temperature (unit: °C), making it directly relevant to accessibility.

Universal Thermal Climate Index (UTCI): Suitable for assessing thermal stress responses in extreme heat environments, UTCI serves as an effective complement to the PET index, jointly characterizing a strategy’s contribution to enhancing human comfort.

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5. Xi'an case study: adaptive planning for the core area east of Xingqing Palace Park

5.1. Area profile and rationale for selection

The study area, located in Beilin District, is situated to the east of Xingqing Palace Park. It is bounded by Dongfang Xingzuo Community to the north, Xingqing Wharf to the south, the park's east wall (adjacent to Longqubao Community) to the west, and Xingqing Garden Community to the east, covering an area of approximately 0.35 km². This area typifies a coupled park–community system characterized by several pronounced challenges:

Prototypical Spatial Types and Acute Heat Conflict: Within a compact area, a cool-island (the park), a transition zone (park east wall and Shiyuan Road), and high-temperature old communities (Shiyuanfang, Longqubao) coexist. Dense building layouts and poor building thermal performance exacerbate the paradox of ‘being near a cool source but unable to benefit from it,’ making the situation particularly acute.

The thermal environment is worsened by cumulative heat emissions and pronounced spatial isolation. Specifically, heat from traffic and commercial activities is compounded by perimeter walls and compact layouts, which not only block cool air from the park but also discourage residents from accessing it.

Fragmented Cool-Island Linkages and Intensified Internal Heat Islands: Internal greenery consists mainly of low shrubs with limited canopy coverage, failing to effectively capture and dissipate the park’s cooling effects; furthermore, extensive impervious pavements exacerbate heat accumulation.

5.2. Selecting and localizing spatial strategies

Guided by the principle of channelling cold sources,this study proposes the following localised spatial strategies to effectively direct the park's cooling effect into the surrounding communities:

Cool Corridor Guidance Strategy: Establish a shaded central corridor(featuring species such as Sophora japonica and Ficus microcarpa)along the route from the park's west gate to the main entrance of Longqubao Residential Area. Create a "cool-alley system" within neighborhood passageways using trellised greening and movable planters to guide cool air deeper into the community.

Cooling Key Nodes Strategy: Develop pocket parks at park–community interfaces equipped with shade pavilions, misting devices, and seating. Transform internal leftover or idle spaces into tree-dominated micro-green spaces or community gardens to add shade and evapotranspirative cooling points.

Optimizing Boundary Interfaces Strategy: Replace solid park perimeter walls with permeable ecological walls incorporating vertical greening (e.g., Boston ivy) to enhance ventilation and visual connectivity. Implement night-time heavy vehicle restrictions on adjacent roads like Xingqing West Road and Shiyuan Road during summer to reduce heat emissions. Regulate vendor layouts to avoid concentrated heat release.

5.3. Localized revision of the strategies–goals matrix

Based on the specific design scope for the case area, the generic association matrix is revised as shown in Table 2.

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Table 2. Localized strategies–goals matrix (Xingqing east core area)

Strategy	Enhancement	Accessibility	Maintenance	Learning Capacity
Primary shaded corridor	●●●	●●●	●●○	○
Community cool-alley system	●●●	●●○	●○○	○
Interface node retrofit	●●○	●●●	●○○	○
Perimeter Wall Greenery Enhancement	●●○	●●○	●○○	○
Optimisation of Activity Spaces	●○○	●●○	●○○	●●●

5.4. Verifying strategy effectiveness

5.4.1. Microclimate validation via ENVI-met simulation

To quantify the effectiveness of the strategies, the ENVI-met software was used to simulate the combined effect of the 'Perimeter Wall Greenery Enhancement + Primary Shaded Corridor' strategy bundle. Owing to constraints in research resources and time, the simulation focused on this core combination to verify its fundamental physical effectiveness, providing a basis for these representative and high-priority measures.

Simulation settings were as follows:

Date: 15 July 2025 (a typical high-temperature day)

Duration: 12 hours (06:00–18:00)

Key Output Periods:15:00 (peak temperature, reaching 42°C),17:00 (residents travel peak period)

Output Metrics: Air Temperature (potential air temperature), PET (Physiological Equivalent Temperature), UTCI (Universal Heat Climate Index)

Simulation results are presented as shown in Figure 1.

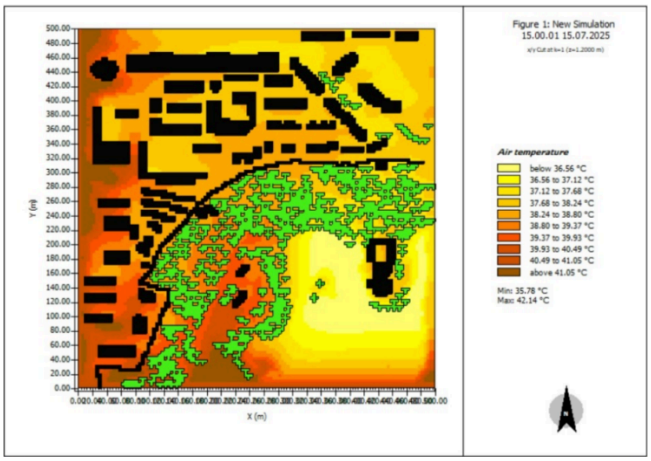

Figure 1. Air temperature simulation results view (15:00 after strategy implementation)

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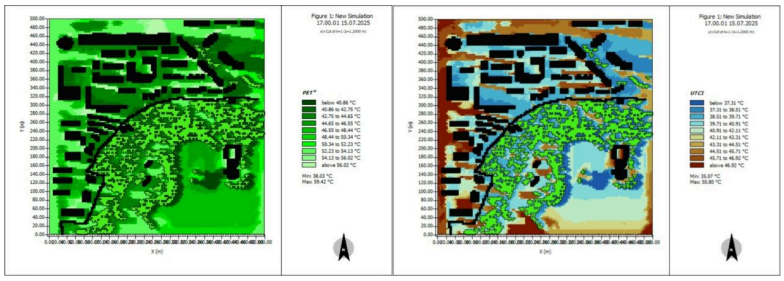

Figure 2. PET and UTCI simulation results view (17:00 after strategy implementation)

5.5. Key indicators before vs. after implementation (ENVI-met results)

Simulation results are presented in Table 3. The combined strategy of 'Perimeter Wall Greenery Enhancement + Primary Shaded Corridor' effectively reduces air temperature by 4.17°C during typical high-temperature afternoon periods, demonstrating its efficacy in reducing near-surface temperatures and mitigating the urban heat island effect. PET decreased by 2.92°C, indicating the strategy effectively enhances pedestrian thermal comfort. UTCI decreased by 2.28°C, demonstrating a reduction in overall heat stress levels and improved adaptive capacity. Analysis of the data reveals that this strategy significantly improves the thermal environmental conditions of the community, enhancing its resilience and adaptive capacity to extreme high-temperature weather.

Table 3. Comparison of key microclimate indicators before and after strategy implementation

Indicator	Baseline	Strategy	Δ(Change)	Δ (%)
Air Temperature(°C)	42.63	38.46	-4.17	−9.78
PET(°C)	45.07	42.15	-2.92	−6.48
UTCI(°C)	42.43	40.15	-2.28	−5.37

6. Discussion

6.1. Summary

This study utilizes the vicinity of Xi'an's Xingqing Palace Park as an empirical case to address pronounced issues, such as fragmented thermal environments, cumulative heat emissions, and disjointed spatial connections. It establishes a spatial strategy system centered on 'guiding the park's cooling effect to permeate the community', encompassing measures such as primary and secondary tree-lined corridors, optimised interface nodes, permeable green walls, and heat source regulation. Validation through ENVI-met simulationsfor the combined 'Perimeter Wall Greenery Enhancement + Primary Shaded Corridor' strategy demonstrates that this approach significantly enhances community thermal comfort and resilience during high-temperature afternoons. Empirical results validate the effectiveness of the 'park-residential integration' collaborative renewal model, providing a replicable "Xi'an solution" for mitigating urban heat and improving the liveability of older residential areas.

6.2. Limitations and future directions

Limitations of this study include the following: although ENVI-met was locally calibrated, it cannot fully encapsulate all complex factors, such as detailed anthropogenic heat emissions, which can lead

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to discrepancies between simulated and measured results. Long-term, continuous monitoring was not feasible due to resource constraints. Analyses primarily relied on data from typical high-temperature days. Furthermore, current simulations focus solely on one core strategy combination. Future work should systematically validate remaining strategies and their synergistic benefits.

Building upon the findings and limitations of this study, future research may deepen exploration in three areas: Firstly, future work should integrate multi-scale modeling techniques to couple mesoscale climate models with neighborhood microclimate simulations, while incorporating IoT technology to establish a long-term monitoring and feedback mechanism. Secondly, expanding into the social and governance dimensions to investigate 'park-community' collaborative governance mechanisms and associated policy instruments. Thirdly, advancing model standardisation and dissemination by applying this framework and methodology to case studies across diverse climatic zones and spatial configurations, progressively developing toolkit-based technical guidelines.

7. Conclusion

This study investigated enhanced climate adaptation for aging neighborhoods adjacent to urban parks, following a logical progression from theoretical framework development and methodological research to empirical application. Key conclusions are as follows:

Theoretically, it constructs a thermal-adaptive planning framework and a four-dimensional goal system (encompassing enhancement, accessibility, maintenance, learning) for 'park–old community'systems. It establishes a paradigm centered on "guiding cool-island effects into communities" and provides a strategies–goals matrix to facilitate systematic optimization.

Methodologically, it defines a technical pathway that combines microclimate simulation with strategy verification. By generating multi-indicator outputs (e.g. temperature, PET, UTCI) using ENVI-met, it enables quantitative assessment of planning interventions, thereby enhancing the scientific rigor and foresight of the planning process.

Practically, the Xi'an case study validates the integrated park–community co-renewal model. Through the integration of spatial and governance measures, it helps alleviate the paradox of 'proximity to a cool source without receiving its benefits,'offering a replicable model for similar urban renewal contexts.

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