Sunken Courtyards for Microclimate Improvement in Public-Building Outdoor Spaces: A Design-Evaluation Framework and Evidence from Coupled Simulation and Field Metrics

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Abstract: Sunken courtyards (sunken plazas) are increasingly used to connect underground or semi-underground public programs with outdoor space, yet their microclimate behavior is often treated as an "afterthought" during schematic design. This paper develops a design-oriented workflow for improving outdoor thermal comfort and ventilation performance in sunken courtyards serving public buildings, and validates it through controlled design scenarios and coupled simulations. The results translate into a practical set of design rules and an evidence-first workflow that supports both microclimate improvement and usable public space quality.
***Keywords*:** sunken courtyard; outdoor thermal comfort; UTCI; mean radiant temperature; CFD; blue–green infrastructure; shading design

1. Introduction

Public buildings depend on outdoor space for circulation, waiting, short rest, and social gathering. Reviews on courtyard performance emphasize that orientation and form strongly shape radiation exposure and sky-view, while opening and permeability govern air movement and pollutant dilution[1]-[3]. For deep or highly enclosed sunken spaces, airflow near the floor can be weak even when the above-ground wind is moderate, leading to heat retention and reduced pollutant flushing. Research on inner courtyards and atrium-like voids shows that layout and opening forms can significantly alter wind fields and exchange efficiency[4].

2. Theoretical Basis and Path Framework

2.1 Microclimate mechanisms in sunken courtyards

A sunken courtyard modifies microclimate primarily through geometry-driven radiation exchange and flow-driven ventilation exchange. Compared with a ground-level plaza, the sunken space has a lower sky-view factor, more vertical surfaces, and often a narrower opening to the surrounding wind field.

2.2 Path framework and co-design logic

Figure 1 summarizes the path framework. The sequence is deliberate. "Scale control" is first because geometry constraints (depth, width, and height-to-width ratio) determine the feasible microclimate range.

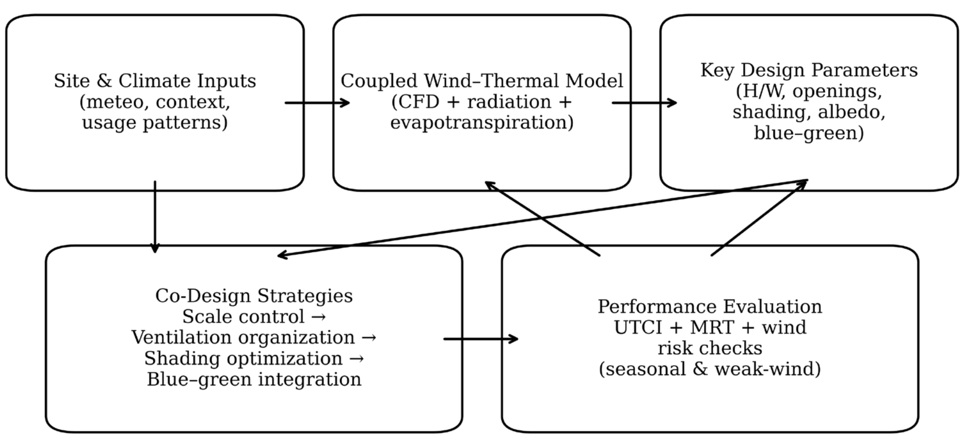

Figure 1. Path framework for sunken-courtyard microclimate co-design and evaluation.

Table 1. Design Parameters and Screening Ranges Used in Sensitivity Analysis

Parameter group	Symbol / description	Levels / range used	Design intent
Courtyard proportion	H/W (depth-to-width proxy)	0.25, 0.40, 0.55, 0.70	Balance enclosure vs. sky-view
Primary opening ratio	A_open/A_wall	8%, 12%, 16%, 20%	Control exchange capacity
Opening hierarchy	low + mid + high openings	none / 2-tier / 3-tier	Reduce stagnant layers
Orientation	axis vs prevailing wind	aligned / 30° / 60° / perpendicular	Improve wind capture
Shading coverage	S_cov	0%, 30%, 50%, 70%	Reduce direct + reflected SW
Wall reflectance	ρ_wall	0.20, 0.40, 0.60	Avoid glare/heat bounce tradeoff
Paving reflectance	ρ_pave	0.15, 0.35, 0.55	Control surface heating vs reflection
Tree canopy cover	C_tree	0%, 10%, 20%	Shade + evapotranspiration
Water feature area	A_water	0%, 3%, 6%	Local cooling support

Table 1 is referenced in Section 4 to interpret which design moves drive the largest UTCI deltas.

3. Framework Validation Case Analysis

3.1 Validation objective and module structure

Microclimate-aware courtyard design is often discussed in terms of concepts (heat island, comfort indices) but is not always translated into testable design moves during early-stage decision making. Here, we treat the proposed workflow as an engineering design-evaluation procedure and validate it in a controlled scenario setting.

3.2 Case context and scenario brief

Design teams start with a baseline courtyard and are required to test at least four variants drawn from Table 1. Variants must include one shading-focused move, one ventilation-focused move, and one blue–green move. The integrated variant must combine at least three move families, mirroring the framework sequence in Figure 1.

4. Simulation-Based Evaluation and Effectiveness Assessment

4.1 Evaluation design and scenarios

Evaluation is carried out at two levels: microclimate performance and workflow effectiveness. For microclimate performance, we compare a baseline and four progressive design scenarios aligned with Figure 1: Baseline, Shading + moderate reflectance control, Ventilation openings with hierarchy, Blue–green additions, and Integrated combining the strongest moves from Table 1.

4.2 Thermal comfort results (UTCI and radiant load)

Figure 2 reports UTCI distribution indicators (P50 and P90) across scenarios for the pedestrian zone under a representative summer daytime condition. Two patterns stand out. First, shading drives the largest early improvement because it reduces both direct solar load and reflected radiation from vertical surfaces.

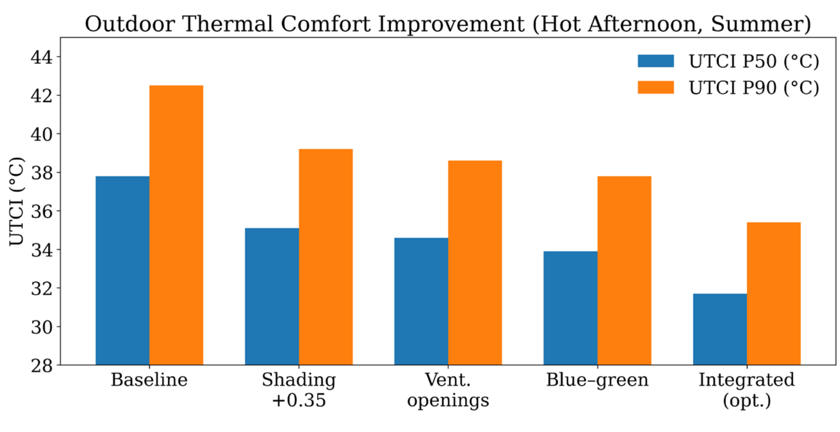

Figure 2. UTCI distribution indicators across design scenarios under a representative summer daytime condition.

5. Conclusion

Sunken courtyards can meaningfully improve the usability of public-building outdoor spaces, but only when they are designed as microclimate systems rather than as leftover voids. Treat the sunken courtyard as an occupiable semi-outdoor public room: define target activity zones and comfort criteria early, and evaluate design moves against those use scenarios. Start with geometry and openings: avoid excessive enclosure and organize a clear opening hierarchy (entry–distribution–exit) aligned with prevailing winds to prevent near-floor stagnation. Prioritize shading and surface radiation control: shading coverage and appropriate reflectance choices reduce mean radiant temperature and deliver the largest initial UTCI relief in warm-season daytime conditions.

References

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