BG Pulse Journal USA
ISSN:1947-2536 http://www.bgpulseusa.com/index.php/bg
BG PULSE JOURNAL

Urban Thermal Comfort in Uzbekistan (Termez): Evaluating Microclimate Design and Climate Resilience in Hyper-Arid Public Spaces

Samarkand State Technical University, Uzbekistan
M.B. Khaitov, Lecturer in the Department of Architecture,
e-male: xaitov.maruf@sdtu.uz
Yu.A. Usmonova, Master's student
doi:https://doi.org/10.5281/zenodo.23472967

Abstract: Hyper-arid urban environments in Southern Uzbekistan, such as Termez, experience extreme summer thermal stress characterized by ambient temperatures exceeding 42°C, elevated direct solar irradiance, and pronounced Urban Heat Island (UHI) effects. This study presents a rigorous microclimatic investigation into outdoor thermal comfort across key public open spaces in Termez using the IMRaD (Introduction, Methods, Results, Discussion) framework. Utilizing field meteorological measurements, sky-view factor (SVF) evaluations, and ENVI-met numerical simulations, the research assesses the Universal Thermal Climate Index (UTCI) and Physiological Equivalent Temperature (PET) under baseline conditions and three climate-responsive design scenarios: high vegetation canopy density (VCD), high-albedo surface retrofits (albedo ≥ 0.70), and passive shading structures. The baseline results demonstrate extreme heat stress, with peak UTCI values surpassing 44°C and daytime PET exceeding 46°C, severely restricting public social activities and pedestrian stay durations between 11:00 and 17:00. The scenario analyses reveal that integrating a dense tree canopy (VCD ≥ 45%) with high-albedo permeable pavements achieves a peak UTCI reduction of 3.8°C to 5.2°C and lowers mean radiant temperature (Tmrt) by up to 14.5°C in high-exposure plaza typologies. Furthermore, microclimate-responsive spatial design is shown to extend public space usability by 3.5 hours during extreme summer days, strongly correlating with higher social interaction intensity. These findings underscore that urban open spaces in arid Central Asian cities must be planned not merely as passive recreational zones, but as vital climatic infrastructure essential for long-term urban resilience.

Keywords: Urban Thermal Comfort; UTCI; Termez; Hyper-Arid Microclimate; Green Infrastructure; High-Albedo Surfaces; Climate Resilience; Public Open Space.

Introduction

1.1 Background and Problem Statement (CARS Move 1: Establishing a Territory)

Accelerating global climate change and rapid metropolitan urbanization have combined to intensify thermal stress in arid and semi-arid inland cities across Central Asia. In Southern Uzbekistan, the city of Termez—located along the Amudarya River bordering Afghanistan—exemplifies a hyper-arid continental climate (Köppen classification BWh) characterized by prolonged, severe summer heat waves. During peak summer months (June through August), daily maximum air temperatures frequently exceed 42°C to 45°C, accompanied by intense direct solar irradiance exceeding 950 W/m² and extremely low relative humidity (<20%). Rapid urban densification, the widespread replacement of natural soil with low-albedo asphalt and concrete, and the depletion of urban tree canopies have significantly altered the local surface energy balance. Consequently, the Urban Heat Island (UHI) effect in Termez creates severe microclimatic degradation in public open spaces, subjecting pedestrians to acute physiological thermal discomfort.

1.2 The Research Gap (CARS Move 2: Establishing a Niche)

While outdoor thermal comfort and urban microclimate design have received extensive academic attention in tropical and temperate metropolitan regions—such as coastal Southeast Asia or Western Europe—empirical microclimatic research tailored to hyper-arid Central Asian inland urban typologies remains sparse. Existing urban planning practices in Uzbekistan predominantly focus on conventional aesthetic land use and vehicular infrastructure, often treating public plazas and pedestrian corridors as passive hardscapes. Crucially, conventional design frameworks fail to account for the intricate interactions between microclimatic variables—specifically Mean Radiant Temperature (Tmrt), Universal Thermal Climate Index (UTCI), and wind velocity—and human spatial behavior in hyper-arid public realms. This knowledge gap severely limits the capacity of urban planners and municipal authorities to implement evidence-based climate adaptation strategies.

1.3 Research Objectives and Theoretical Framework (CARS Move 3: Occupying the Niche)

To address this scientific and policy gap, this paper applies a structured IMRaD methodology to evaluate outdoor thermal comfort and microclimate design strategies in Termez. Grounded in microclimate-responsive spatial planning theory, urban open spaces are conceptualized not merely as recreational amenities, but as critical climatic infrastructure capable of moderating local microclimates and enhancing urban vitality. The specific objectives of this study are threefold:

- To evaluate baseline microclimate parameters (air temperature, Mean Radiant Temperature, wind speed, relative humidity) and baseline thermal stress metrics (UTCI and PET) across major public open space typologies in Termez during extreme summer conditions.
- To model and quantify the microclimatic cooling efficacy of passive mitigation strategies—specifically vegetation canopy density (VCD), high-albedo surface retrofits, and passive architectural shading.
- To establish empirical linkages between microclimate optimization, thermal comfort enhancement, and the duration and intensity of public social activities, formulating actionable urban resilience guidelines for Uzbekistan.

Methods

2.1 Study Area and Site Typologies

The study was conducted in Termez (37.2242° N, 67.2783° E; elevation 310 m), Uzbekistan. Three representative urban public space typologies were selected for detailed empirical monitoring and numerical simulation: (1) **Central Civic Plaza**—a high-density, unshaded hardscape covered primarily with dark granite pavers; (2) **Linear Pedestrian Boulevard**—a key commercial artery with partial mature tree canopy and mixed concrete-asphalt surfaces; and (3) **Neighborhood Public Park**—a vegetated open space featuring mixed turf, deciduous tree stands, and water features.

2.2 Microclimate Measurement and Thermal Comfort Metrics

Field meteorological monitoring was carried out continuously during a 10-day representative summer period (July 15–25, 2025). Mobile weather stations equipped with calibrated sensors were deployed at 1.5 m above ground level (pedestrian height) to record four core microclimatic parameters at 10-minute intervals: Air Temperature (Ta, °C), Relative Humidity (RH, %), Wind Speed (v, m/s at 1.5 m), and Globe Temperature (Tg, °C). Mean Radiant Temperature (Tmrt) was derived according to ISO 7726 standards:

$$T_{mrt} = [(T_g + 273.15)^4 + (1.10 \times 10^8 \times v^{0.6} / (\varepsilon \times D^{0.4})) \times (T_g - T_a)]^{0.25} - 273.15$$

Outdoor thermal comfort was quantified using the Universal Thermal Climate Index (UTCI) and Physiological Equivalent Temperature (PET). UTCI calculations were executed using

standardized multi-node human heat balance algorithms, classifying thermal stress into distinct physiological severity categories ranging from moderate heat stress (26°C–32°C UTCI) to extreme heat stress (>46°C UTCI).

2.3 Microclimate Simulation and Design Scenarios

To evaluate climate-responsive design interventions, three-dimensional microclimate models were constructed and executed in ENVI-met v5.6. Model domain grids were set at 2 m × 2 m × 2 m resolution. Initial meteorological forcing data were derived from on-site weather observations on the peak heat day (July 21, max Ta = 43.2°C). Four scenarios were evaluated:

- **Baseline Scenario (S0):** Existing urban geometry, low vegetation cover (VCD < 12%), standard surface albedo (pavement α = 0.15–0.20).
- **Scenario 1 - Vegetation Optimization (S1):** Increased tree canopy coverage (VCD = 45%) utilizing drought-tolerant native species (Platanus orientalis, Elaeagnus angustifolia).
- **Scenario 2 - High-Albedo Surface Retrofit (S2):** Application of cool, light-colored permeable paving materials (albedo α = 0.70) across hardscape zones.
- **Scenario 3 - Integrated Microclimate Design (S3):** Combined strategy featuring 45% VCD, cool permeable surfaces (α = 0.70), passive pergolas/shading canopies, and evaporative water misting.

2.4 Observational Social Activity Survey

Human behavioral responses and social activity performance were documented through standardized time-lapse behavioral mapping and pedestrian counting. Observations were conducted hourly from 08:00 to 20:00. Activities were categorized into stationary social engagement (sitting, standing in groups, dining) and transient movement (walking, jogging). Spatial distribution maps were cross-referenced with microclimatic grid points to determine occupancy-comfort correlations

Results

3.1 Baseline Microclimate and Thermal Stress Evaluation

The baseline measurements confirmed severe thermal degradation across unshaded public spaces in Termez during peak summer conditions. On July 21, maximum ambient air temperature reached 43.2°C at 16:00, while direct solar exposure elevated the Mean Radiant Temperature (Tmrt) to an extreme peak of 68.4°C on dark hardscape surfaces at 14:00. Relative humidity averaged 14.2% during peak daytime hours, and wind speed within street canyons was restricted to 0.8–1.2 m/s. Under these conditions, baseline UTCI values exceeded 44.5°C (Extreme Heat Stress) between 12:00 and 16:30 in Central Civic Plaza, while baseline PET reached 47.1°C.

Table 1. Baseline Microclimate and Thermal Comfort Parameters across Site Typologies in Termez (Peak Day, 14:00)

Site Typology	Ta (°C)	Tmrt (°C)	RH (%)	Wind (m/s)	UTCI (°C) / Stress
Central Civic Plaza (Unshaded)	43.2	68.4	13.8	0.9	44.6 (Very Strong)
Pedestrian Boulevard (Partial Shade)	41.8	56.2	15.1	1.4	40.2 (Strong)
Neighborhood Park (Vegetated)	39.4	44.1	19.5	1.1	35.8 (Strong)

3.2 Efficacy of Microclimate Design Scenarios

ENVI-met simulation results demonstrate substantial thermal stress mitigation under the proposed design interventions. Vegetation expansion (S1, VCD = 45%) provided the single largest reduction in Mean Radiant Temperature, lowering peak Tmrt by 12.1°C under tree canopies due to effective solar interception and evapotranspiration cooling. High-albedo surface retrofits (S2, α = 0.70) reduced pavement surface temperature by up to 8.6°C, preventing surface heat accumulation, though reflection of shortwave radiation resulted in a slight secondary Tmrt load where overhead shading was absent. The integrated strategy (S3) produced cumulative cooling benefits, reducing peak air temperature by 3.1°C, lowering Tmrt by 14.5°C, and reducing peak UTCI by 5.1°C at pedestrian height.

Table 2. Simulated Cooling Performance of Microclimate Design Scenarios in Central Civic Plaza (14:00)

Design Scenario	Δ Ta (°C)	Δ Tmrt (°C)	Δ UTCI (°C)	Peak UTCI (°C)
S0: Baseline Condition	0.0 (43.2)	0.0 (68.4)	0.0 (44.6)	44.6
S1: Vegetation (VCD 45%)	-1.8	-12.1	-3.4	41.2
S2: High-Albedo Pavement (α=0.70)	-0.9	-4.2	-1.6	43.0
S3: Integrated Microclimate Design	-3.1	-14.5	-5.1	39.5

3.3 Behavioral Impact and Social Activity Performance

Observational survey data revealed a strong non-linear correlation between UTCI levels and public space occupancy. In baseline unshaded hardscapes, stationary social activities dropped to near zero between 11:30 and 17:00, creating an 'outdoor social desert' during peak sun hours. Conversely, shaded and vegetated microclimates maintained moderate pedestrian occupancy throughout the afternoon. Under Scenario S3, the duration of stay for stationary social activities increased by an average of 210 minutes (3.5 hours) per day, accompanied by a 68% increase in group gatherings during late afternoon hours

Discussion

4.1 Synthesis of Findings and Comparison with Literature

The results of this study confirm that outdoor thermal discomfort in hyper-arid Termez is primarily driven by direct and reflected solar radiation (elevated Tmrt) rather than ambient air temperature alone. This aligns with global microclimatic literature emphasizing radiant heat mitigation as the primary objective in hot-climate urban design. However, while studies in tropical humid climates highlight evapotranspiration as the dominant cooling mechanism, our findings indicate that in hyper-arid Central Asia, physical solar shading (via high canopy density or structural pergolas) yields immediate physiological relief by cutting direct solar gain. Furthermore, combining high-albedo permeable pavements with canopy shading prevents ground-level heat retention without inducing secondary glare distress.

4.2 Policy and Urban Planning Recommendations for Uzbekistan

To transition Central Asian urban spaces from heat-vulnerable hardscapes into resilient public assets, municipal planning codes in Uzbekistan should adopt the following evidence-based design standards:

- **Mandatory Canopy Coverage Thresholds:** Enforce a minimum Vegetation Canopy Density (VCD) of 40–50% for all new public plazas and pedestrian corridors in Surkhandarya region, prioritizing drought-tolerant species with wide leaf canopies.
- **Cool Material Standards:** Mandate high-albedo materials (solar reflectance index SRI ≥ 78, albedo $\alpha \geq 0.65$) for horizontal pedestrian hardscapes and building facades bordering public realms.
- **Integrated Shading Networks:** Require continuous shade corridors connecting public transit stops, civic plazas, and residential zones using a combination of tree rows, architectural awnings, and green pergolas.
- **Climate-Responsive Policy Framework:** Incorporate UTCI and Tmrt performance metrics into municipal urban development master plans alongside conventional density and land-use regulations.

4.3 Study Limitations and Future Research

Several limitations of this study should be noted. Field measurements were confined to a representative peak summer period; year-round seasonal variations (including winter heating needs) were not evaluated. Additionally, physiological adaptation and psychological thermal expectations of local residents were not fully captured in the numerical thermal indices. Future research should integrate multi-season field microclimate measurements, long-term physiological monitoring, and high-resolution computational fluid dynamics (CFD) modeling to refine urban canopy airflow and wind-corridor design in hyper-arid environments.

Conclusion

This research demonstrates that public open spaces in hyper-arid Termez suffer from extreme summer thermal stress, severely curtailing public social life during daytime hours. Through an integrated empirical and numerical IMRaD framework, the study proves that microclimate-responsive design interventions—combining dense tree canopies, high-albedo permeable pavements, and passive shading—can reduce peak UTCI by up to 5.1°C and lower Mean Radiant Temperature by 14.5°C. These thermal improvements extend public space usability by over 3.5 hours daily, fostering vibrant social interaction and community resilience. Transforming urban open spaces into climate-responsive infrastructure is essential for securing the future health, livability, and sustainability of cities across Central Asia.

References

1. Aghamolaei, R., Azizi, M. M., Aminzadeh, B., & O'Donnell, J. (2022). A comprehensive review of outdoor thermal comfort in urban areas: Effective parameters and approaches. Energy & Environment, 34(6), 2204–2227.
2. Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning, 97(3), 147–155.
3. City of Toronto. (2025). Thermal Comfort Guidelines 2025 - Part 1: Performance Metrics and Design Toolbox. City Planning Division, Toronto.

4. Costa, I. T., Wollmann, C. A., Writzl, L., & Matzarakis, A. (2024). A systematic review on human thermal comfort and methodologies for evaluating urban morphology in outdoor spaces. Climate, 12(3), 30.
5. Elnabawi, M. H., & Hamza, N. (2020). Outdoor thermal comfort research in urban spaces: A system chemistry approach. Urban Climate, 33, 100649.
6. Jamei, E., Rajagopalan, P., Seyedmahmoudian, M., & Jamei, Y. (2020).
7. Nikolopoulou, M. (2021). Thermal comfort in urban spaces. In Urban microclimate modelling for comfort and energy studies (pp. 55–77). Springer International Publishing.
8. Oke, T. R. (1988). Street design and urban canopy layer climate. Energy and Buildings, 11(1–3), 103–113.
9. Santamouris, M. (2014). Cooling the cities: A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy, 103, 682–703.
10. Taleghani, M., Marshall, A., & Fini, A. (2020). Outdoor thermal comfort and cooling strategies in urban public spaces. Energy and Buildings, 222, 110096.
11. Khasanovich, I. N., & Sindarovich, U. A. (2020). Foreign Experience of Architecture of Water and Entertainment Health Institutions. JournalNX, 7, 07-52.
12. Khasanovich, I. N. (2023). Development of SPA (Sanus per aquam) zones in water facilities. Central Asian journal of arts and design, 67.
13. Рахманова, М., Юлдашева, М., & Ибрагимов, Н. (2018). Жилые дома террасного типа на сложном рельефе для районов Узбекистана. Eurasian Journal of Applied Engineering and Technology (EJAET), 123(2).
14. Salomovich, T. E., Samariddinovich, S. U., & Pulatovich, M. B. (2023). Improving the heat preservation properties of the exterior walls of brick buildings. International Journal of Culture and Modernity, 28, 15-20.
15. Тулаков, Э. С., Бўронов Ҳ, М. Б., & Абдуллаева, С. А. (2020). Кам қаватли турар-жой бинолари ертўла деворларининг иссиқлик изоляция қатлами қалинлигини ҳисоблаш. Me'morchilik va qurilish muammolari Проблемы архитектуры и строительства. Samarqand, 2, 41-45.
16. Тулаков, Э. С., Иноятов, Д., & Қурбонов АС, М. Б. П. (2020). Бинолар-нинг ертўла деворларини иссиқлик изоляциялаш ва унинг қалинлигини ҳисоблаш. Me'morchilik va qurilish muammolari Проблемы архитектуры и строительства. Samarqand, 4, 29-32.