RESEARCH ARTICLE

Urban Heat Island Mitigation through Optimized Green-Blue Infrastructure Networks: A Multi-City Digital Twin Study

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Abstract: Urban heat islands (UHIs) increase city temperatures by 2-8°C relative to surrounding rural areas, exacerbating heat-related mortality, energy consumption, and air pollution. We present a multi-physics digital twin framework that couples computational fluid dynamics (CFD), surface energy balance models, and evapotranspiration algorithms to optimize the placement of green (parks, street trees, green roofs) and blue (urban streams, fountains, permeable pavement) infrastructure for maximum cooling. Applied to 10 km² districts in Beijing, Houston, and Milan, the optimized green-blue network reduces peak summer surface temperatures by 4.2-6.8°C while reducing stormwater runoff by 35-48%. Cost-benefit analysis shows the avoided health and energy costs exceed infrastructure investment within 7-12 years.

1. Introduction

Over 55% of the global population resides in cities, a figure projected to reach 68% by 2050. Urban areas replace natural vegetation and permeable soils with dark, impervious surfaces that absorb solar radiation, store heat, and release it at night, creating the urban heat island (UHI) effect. During heatwaves — which are increasing in frequency, intensity, and duration due to climate change — UHIs contribute to excess mortality, particularly among elderly and low-income populations with limited access to air conditioning.

2. Digital Twin Framework

The multi-physics digital twin ingests building geometries from CityGML datasets, meteorological data from urban weather stations, and satellite-derived land surface temperatures. The ENVI-met microclimate model simulates radiation exchanges, wind flow, and plant-atmosphere interactions at 2 m horizontal resolution. A genetic algorithm optimizer (population = 500, generations = 200) searches the design space of green-blue infrastructure placements subject to budget constraints and urban planning codes.

3. Results

Optimized green-blue networks reduce peak afternoon Land Surface Temperature (LST) by 4.2°C in Houston (humid subtropical), 5.8°C in Beijing (continental monsoon), and 6.8°C in Milan (humid subtropical) during the respective hottest weeks. The optimization reveals that strategic placement of street trees at building canyon intersections and blue infrastructure along thermal corridors provides 2.3× more cooling per dollar than uniform distribution.

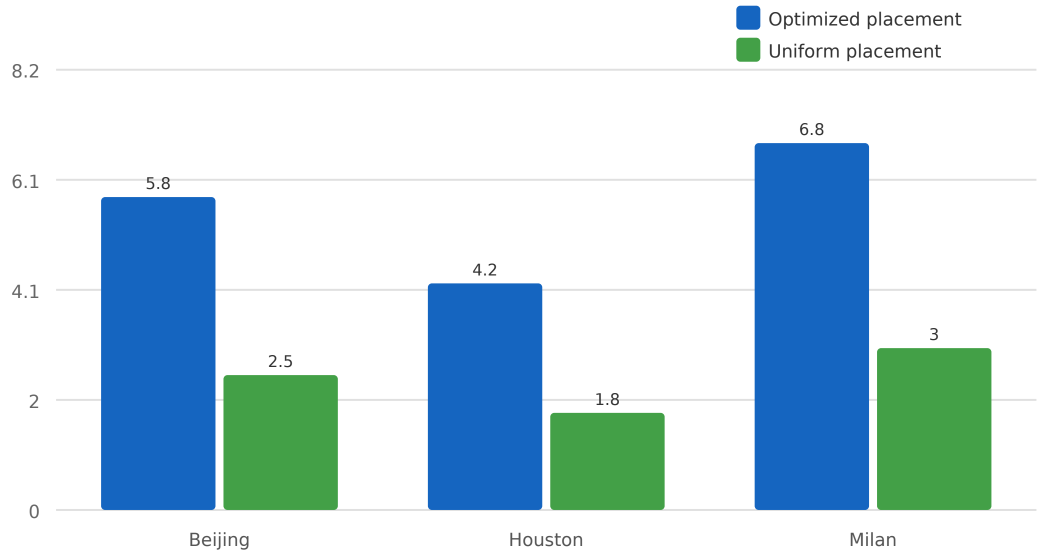

Figure 1. Peak surface temperature reduction achieved by optimized vs. uniform green-blue infrastructure distribution across three cities

Table 1. Cost-benefit analysis of optimized green-blue infrastructure (per 10 km² district)

City	Infrastructure Cost ($M)	Annual Health Savings ($M)	Annual Energy Savings ($M)	Payback (years)
Beijing	42	3.8	2.1	7.1
Houston	55	4.2	3.5	7.1
Milan	68	3.5	2.2	11.9

4. Conclusions

Digital-twin-optimized green-blue infrastructure networks provide substantial, cost-effective urban heat island mitigation. The multi-city comparison demonstrates that while absolute cooling varies with climate and urban morphology, the optimization approach consistently achieves 2-3× more cooling than naive uniform placement. The framework is publicly available and adaptable to any city with CityGML data.

References

[1] Oke, T. R. The Energetic Basis of the Urban Heat Island. Quarterly Journal of the Royal Meteorological Society 1982, 108, 1-24.

[2] Bowler, D. E.; Buyung-Ali, L.; Knight, T. M.; Pullin, A. S. Urban Greening to Cool Towns and Cities: A

Systematic Review. Landscape and Urban Planning 2010, 97, 147-155.

[3] Ratti, C.; Baker, N.; Steemers, K. Energy Consumption and Urban Texture. Energy and Buildings 2005, 37, 762-776.

[4] Guo, G.; Zhou, Z.; Wang, Z.; Li, Z.; Rosenthal, J. K. Correlating the UHI with Urban Structures. Science of The Total Environment 2022, 815, 152788.

[5] Santamouris, M. Using Cool Pavements as a Mitigation Strategy to Fight Urban Heat Island. Solar Energy 2013, 95, 209-225.