MC2 025
PEOPLE & BUILDINGS
Proceedings of 14th Masters Conference:
London, 15th September 2025

Network for Comfort &
Energy Use in Buildings
http://www.nceub.org.uk

Environmental Design Approaches for Maximising Outdoor Comfort Using Microclimate-Based Strategies in Hyderabad

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Abstract
This study presents microclimate-responsive strategies to enhance outdoor comfort and community engagement at the Dr. Kallam Anji Reddy Memorial in Hyderabad, India, a composite climate site and public building case study. The methodology combined EPW climate data, climate trends, bioclimatic charts, and thermal comfort models (PMV, PET, ASHRAE/IMAC) to assess comfort and identify daily extremes. CFD, radiation, and shading analyses of iterative design proposals demonstrated that rammed earth vertical gardens and a butterfly-shaped ferrocement shade with integrated rainwater collection and cross-ventilation improved evaporative cooling, reduced solar radiation, and enhanced airflow, as confirmed by adjusted bioclimatic charts. Additional benefits included air pollution filtration, noise reduction, biodiversity gains, and support for community food growing. This study demonstrates how in-depth, site-specific hourly microclimate analyses, combined with iterative design investigations enable designers to identify truly optimized interventions that create outdoor spaces that are comfortable and usable all year-round.

1. Introduction
Inclusive public spaces and vibrant urban activity are significant indicators of a city's 'Quality of Life' *(National Institute of Urban Affairs (NIUA), 2024)*.as they sustain neighbourhoods, encourage social interaction, and support health and wellbeing. However, rising global temperatures and intensifying urban heat islands are reducing outdoor comfort and threatening the usability of public environments, making the design of outdoor spaces that are resilient to climate change and centred on human comfort a critical challenge. Outdoor comfort depends on multiple factors, including microclimate, activity, physical design, and human physiology. Hyderabad (17.5062°N, 78.3609°E), the study area, has a composite climate (Kumar and Sachar, 2018) with long hot-dry periods and shorter seasons of high rainfall, humidity, and warmth, which creates a challenge as solutions suited to one season may be unsuitable in another. This study explores how climate data and thermal comfort analysis can optimise microclimate-responsive design at the Dr. Kallam Anji Reddy Memorial. Designed by Mindspace Architects and completed in 2016, the memorial links his workplace to his home through symbolic pathways, indigenous tree avenues, water features, and a central mound, interacting with exhibition spaces reflecting aspects of his life. The site provides a valuable context for studying how architecture and landscape shape microclimate and comfort. The proposed allotment area draws on Dr. Reddy's farming background and the popularity of community gardens, offering recreation, organic produce, and supporting sustainable urban development. The study aims to enhance year-round usability through meditation and gardening spaces by assessing site microclimate, evaluating user needs, and testing strategies that optimise comfort while delivering ecological and social benefits.

2. Methodology
The methodology combines analysis and strategy techniques. Initial observations examined shading patterns, vegetation, topography, noise, and pollution, establishing baseline environmental conditions and identifying potential constraints for outdoor comfort.

Meteorological data were sourced from the 2024 Meteonorm EPW file for Hyderabad Airport, 13.8 km from the site, and hourly climate data were plotted onto a bioclimatic chart, assuming 0.8 clo (winter clothing) and an activity level of 1.3 Met (light office work). Seasonal variations were assessed using thermal comfort models including PMV, PET, and ASHRAE/IMAC to compare international and Indian comfort thresholds, identifying periods of natural comfort and times requiring environmental modification. Digital tools supported detailed microclimate modelling. Shading and solar exposure were analysed with Dr A. J. Marsh's shading masks, wind data interpreted using Climate Consultant, and airflow assessed through CFD simulations in DesignBuilder. Shadow and solar radiation models in SketchUp tested the impact of design interventions on solar loads. Results were synthesised into a "mismatch analysis," highlighting gaps between existing conditions and comfort targets. Four priorities were established: shade and rain protection, temperature regulation, airflow and cooling, pollution mitigation. Potential interventions were iteratively evaluated using case studies, material databases, feedback from CFD, shading, and radiation analyses to refine strategies for seasonal comfort, ecological goals, and user needs.

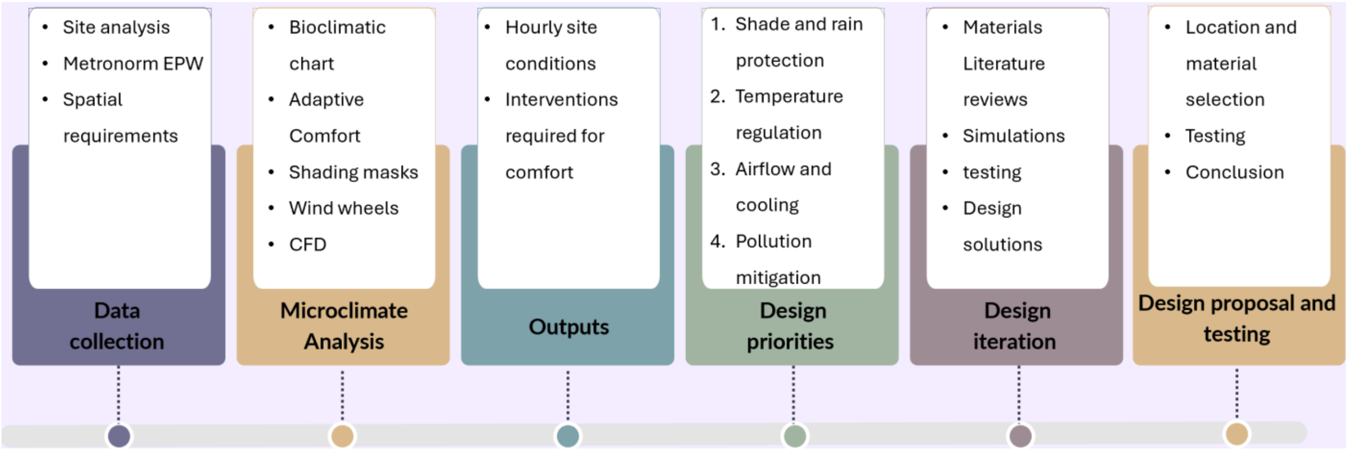

Figure 1: Methodology Workflow

3. Findings

Hyderabad experiences a composite climate, with hot, dry periods from March to May, a humid monsoon season from June to September, and cooler winter months, with average December temperatures below 15 °C. Peak summer temperatures can reach the mid-30s °C, while monsoon rainfall averages 157.8 mm per month, highlighting the need for rain-resistant outdoor interventions. Humidity varies widely throughout the day, influencing thermal comfort and plant growth. Analysis of hot and cold spots indicated a potential 2 °C difference between EPW data and actual site conditions, influenced by nearby man-made lakes. Air quality and noise present additional constraints, as $PM_{2.5}$ concentrations regularly exceed WHO guidelines during the dry season, peaking at 100 µg/m³ between October and May compared with the recommended 15 µg/m³ (WHO, 2021). Dense planting and vegetative buffers can reduce particulate matter and mitigate traffic noise, although unshaded central areas remain acoustically exposed.

Thermal comfort, valuated using hourly climate data and bioclimatic charts, is naturally achieved primarily during winter mornings (October–March), with additional solar gain required to reach 21 °C in the early hours. Outside these cooler mornings, higher wind speeds are beneficial year-round. Summer afternoons would require wind speeds exceeding 5 m/s, beyond recommended comfort levels (Guo et al., 2015, p.228). Humidity should be

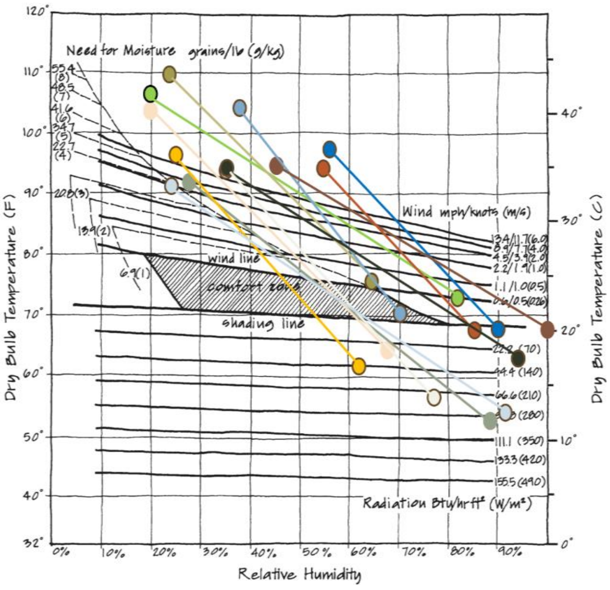

Figure 2 Bioclimatic Chart

increased during dry winter months and low-humidity summer afternoons (March–May), targeting up to 3.9 g/kg using evaporative cooling. Comfort conditions vary sharply within a day; for example, December mornings require 140 W/m² solar gain, whereas afternoons demand cooling with 3.8 m/s wind and added humidity. Data from IMAC and AEEE suggest that occupant comfort thresholds in India exceed those indicated by ASHRAE.

Ultraviolet radiation is consistently high, frequently exceeding a UV Index of eight and reaching twelve at midday between March and September. Reducing solar gain is critical to maintaining human comfort and safety, although most vegetation requires at least six hours of sunlight (Allthatgrows.in, 2024). Shadow studies show that vegetation provides partial shading along site boundaries but leaves central lawns fully exposed. Prevailing winds are mainly from the south and southwest, with additional flows from the west during winter and the monsoon. Overall, site wind speeds are low, insufficient for effective convective cooling. CFD simulations indicate that airflow across central lawns and allotments rarely exceeds 2.1 m/s. To enhance ventilation and prevent overheating, design strategies should channel south-easterly summer winds while mitigating westerly monsoon winds.

3.3 Summary of Key Bioclimatic Issues and Objectives

The site experiences high UV radiation, seasonal variations in thermal comfort, low summer wind speeds, periods of poor air quality, and low humidity during dry winter months and early summer afternoons. To achieve comfortable conditions, air temperatures should be reduced by 4–12 °C in summer and 0.1–4.5 °C during the monsoon, with modest afternoon cooling in winter and winter mornings warmed by up to 4 °C between 07:00 and 09:00. Solar shading strategies should reduce peak UV exposure while maintaining at least six hours of sunlight for vegetation growth. Wind and air movement should be optimised by maximising south-easterly summer flows and blocking westerly monsoon winds, targeting airflow of 4–5 m/s during summer and monsoon periods to support effective convective cooling. Humidity levels should be increased during dry winter months and low-humidity summer afternoons, aiming for up to 3.9 g/kg through passive or evaporative methods. Dense planting and vegetative buffers along site boundaries and sensitive areas can improve air quality and mitigate noise exposure. These objectives are summarised in the table below, which compares observed site conditions with comfort requirements and outlines the corresponding design measures.

	October				Novemeber				December			
	Radiation w/m2	Wind speed m/s	Moisture k/kg	Humidity %	Radiation w/m2	Wind speed m/s	Moisture k/kg	Humidity %	Radiation w/m2	Wind speed m/s	Moisture k/kg	Humidity %
0700	30				110			15	140			16
0800					40			7	70			9
0900		1.1										
1000		1.1				0.8						
1100		2.2				1.1						
1200		4				2				2	2.5	
1300		5.5				4				3.8		
1400		8.9				4				2.2	3.5	
1500		5.5				2				3	3.3	
1600		10				3.8				3		
1700		3.8				2.8				2.2	3.3	
1800		3				2.2				1.8		

		Wind speed required	
	No bioclimatic adjustment		
	Comfort in all areas		0.0—0.6
	Humidity greater than 70%		0.6-1.1
	Moisture required		1.1-2.2
	Radiation required		2.2-4.5
KEY			4.5-8.9
			8.9-13.9
			>13.9

Figure 3: Extract of hourly analysis of Bioclimatic Chart

Table 1. Miss match findings - site conditions available compared to what is required

Topic	When	Targets for comfort	How (Design criteria)
1. Shelter – Sun Rain	All year (06:00–18:00), UV 8–12	UV reduce to ~6; ≥6h sun for planting	Canopies / dappled shade; reduce UV without raising temp
	Jun–Sep (monsoon, 12:00–14:00 peaks)	Rain shelter; resist 100–150 mm/day	Durable roofs; rainwater harvesting; block W winds
2. Temperature	Summer (Mar–May)	Reduce 4–12 °C	Shading; reflective/light surfaces; evap. cooling
	Monsoon	Reduce 0.1–4.5 °C	Shade + ventilation; cooling materials
	Winter AM (Nov–Jan, 07:00–09:00)	Heat +4 °C; +50 to +140 W/m^2	Thermal mass; E-facing morning solar gain
	Winter PM	Reduce ~1.2 °C	Shading + orientation
3. Airflow	Summer AM/PM	Vent. 4–5 m/s (vs ≤2.1)	Channel SE winds; prevent overheating
	Monsoon AM/PM	Vent. 4–5 m/s	Block W winds; cross-ventilation
	Winter PM	Vent. ≤2 m/s	Gentle airflow; avoid overcooling
4. Humidity	Mar–May PM; Dec–Feb AM	+3.9 g/kg; not needed in monsoon/early winter AM	Evap. cooling (fountains, porous walls, irrigation)
5. Pollution	Oct–May (dry season)	$PM_{2.5}$ reduce 175 → ≤40 µg/m^3	Vegetation buffers, vertical gardens, tree planting

2. Design iteration

Potential interventions for shading, ventilation, cooling, and material selection were evaluated using mismatch analysis and climate data. Material properties were compared for their influence on outdoor comfort. Bamboo has an albedo of 0.12, low embodied carbon (0.13 kg CO_2/kg) and embodied energy (2.58 MJ/kg) (Yu, Tan and Ruan, 2011). HDPE canvas has an albedo of 0.20, high UV protection, and embodied carbon of 3.43–3.79 kg CO_2/kg (recycled: 0.90–0.99) with energy of 100–111 MJ/kg (recycled: 26.2 MJ/kg). Trees provide shade, CO_2 absorption, pollution mitigation, and rainwater uptake. Ferrocement has albedo of 0.57 and shows high durability, low embodied energy (2.3 MJ/kg) and carbon (0.29 kg CO_2/kg) (International Finance Corporation (IFC), 2017; Minde et al., 2023), moderate thermal mass (800–2100 J/kg·K; 0.3–1.5 W/m·K) (Greepala et al., 2008), and adaptable ventilation. Shadow studies indicated a north–south orientation was optimal: the west-facing embankment gave protection from sun and monsoon rains, while the east captured morning solar gain. Pitched roof designs were most effective in maximising shade, limiting heat retention, and collecting rainwater. When UTCI exceeds 26 °C, solar radiation has greater impact on outdoor comfort than wind (Ji et al., 2022).

Ventilation corridors, low wind-catching walls, and passive cooling systems were assessed. Fountains cooled up to 4.7 °C (Xue, Gou and Lau, 2015) and provided noise masking, with the noise creating a relaxing effect *(Fernandes and Correia-da-Silva, 2007, p.5)*. Clay pipe walls reduced temperatures by up to 6 °C with medium embodied energy (7.5 MJ/kg) and carbon (0.69 kg CO_2/kg) (International Finance Corporation (IFC), 2017), though they restricted airflow. Living walls reduced temperature by 2.6 °C (Shafiee et al., 2020) and vegetation lowered $PM_{2.5}$ levels by 25% (Mobarhan et al., 2024).

CFD models tested wind wall layouts. The linear design maximised prevailing south-easterly winds (nine months/year), improving airflow along the western wall and maintaining light for plants. The diagonal design channelled eastern winds but reduced plant light and shifted benefits southwards. Gains met comfort

Figure 4 Parallel wind walls CFD

thresholds but were seasonal, indicating mechanical ventilation may still be needed. The western wall remains most suitable for activities due to consistent wind speeds.

Thermal performance of brick, rammed earth, and gabion walls was compared. Brick has the lowest conductivity (1.16 W/m·K) (Brickability, 2024) and a thermal lag of 6.2 hours (YourHome, n.d.), providing good insulation. Rammed earth has a conductivity of 0.87 W/m·K (Thermal Science, 2018), is the lightest at 1540 kg/m³ (Thermal Science, 2018), and has the longest thermal lag of 10.3 hours (YourHome, n.d.), aiding night cooling and planter germination. Gabion walls have a conductivity of 1.7 W/m·K and a density of 2000 kg/m³ (Coventry University, 2017); when built with local stone, they offer low embodied energy and are easy to construct and repair.

Solar analysis shows the east remains shaded until 10:00, while the west receives sun from 07:00, providing adequate winter radiation. North façades experience low solar gains, south façades high gains, while east and west façades receive the most, with west greater than east. To maximise exposure, planters should be placed in south-facing uncovered areas.

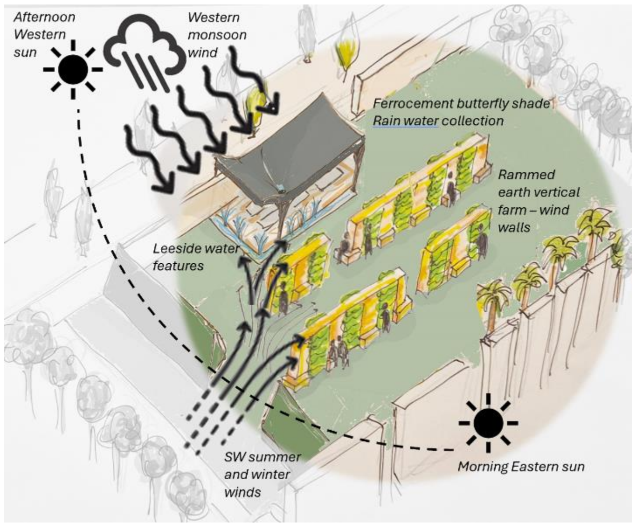

Figure 5 Final Design Diagram

5. Final Proposal

The design uses dense overhead shading to block peak solar radiation year-round, with high-thermal-capacity ferrocement providing cooling, long time lag, and resilience to heavy monsoon rain. A 1 m overhang on north and south ensures consistent shading, while siting along west wall maximises morning solar gain and provides afternoon shade. A butterfly roof collects rainwater, promotes natural ventilation, and prevents long-wave heat build-up. Elevated shading enhances airflow with western monsoon winds, supplemented by jali panels for passive cross-ventilation. Leeside water features cool air, raise humidity for vegetation, create calming soundscapes, reduce noise, and boost biodiversity. Light-coloured, raised timber decking improves ventilation, lowers mean radiant temperature, and reduces UV. Vertical communal gardens act as wind walls, providing evaporative cooling, filtering pollution, enhancing biodiversity, and buffering noise for a tranquil meditation area. Rammed earth wind walls add thermal mass for cooling and warmth for plants in colder conditions, while shaded seating improves comfort. Integrated vertical farming fosters social sustainability, engaging the community in food production and stewardship of green space

	October				Novemeber				December			
	Radiation w/m2	Wind speed m/s	Moisture k/kg	Humidity %	Radiation w/m2	Wind speed m/s	Moisture k/kg	Humidity %	Radiation w/m2	Wind speed m/s	Moisture k/kg	Humidity %
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1700		3.8				2.8				2.2	3.3	
1800		3				2.2				1.8		

Figure 6 Bioclimatic Chart extract – dark green shows intervention improvements

6. Testing

Wind walls had limited effect on overall speeds but successfully redirected airflow toward activity zones, improving ventilation and comfort. Peak winds shifted up the site, allowing fountains in leeward areas to provide evaporative cooling. In the meditation area, summer winds reached 2.78 m/s and monsoon winds 2.43 m/s, with a 2.5 g/kg moisture increase and an additional 280 W/m² of winter morning radiation (excluding green walls and shading). Ferrocement shading reduced peak solar gain, lowering midday loads and limiting UV exposure. Vertical gardens and vegetation provided evaporative cooling and filtration, reducing $PM_{2.5}$ by 25% while maintaining daylight for plants. Rammed earth added thermal mass, retaining heat in cooler months and reducing overheating in hot periods. While comfort improved for most hours, CFD and PET analysis showed extreme summer afternoons with high humidity still exceeded thresholds, requiring adaptive behaviour or limited mechanical support. Iterative testing confirmed that combining passive strategies with microclimate-responsive design measurably enhances outdoor comfort, air quality, biodiversity, and community wellbeing.

7. **Conclusion**

This study demonstrates that detailed microclimate-responsive design strategies can significantly improve outdoor comfort in Hyderabad's composite climate. The research followed a structured process of site climate analysis, identification of heat and wind patterns, evaluation of public space usage, and simulation of passive interventions. By combining ferrocement shading, rammed earth wind walls, water features, and vertical gardens, the proposed strategies reduced heat stress, improved air movement, and enhanced usability of public spaces across seasonal extremes. These passive measures also delivered wider benefits, including improved air quality, biodiversity support, and opportunities for community engagement through activities such as urban gardening and meditation. While passive strategies addressed most comfort needs, extreme summer afternoons and humid monsoon periods still pose challenges, highlighting the need for adaptive behaviours or supplementary mechanical solutions. Overall, this research offers a practical framework for applying climate data and robust comfort analysis to optimise outdoor environments, showing how site-specific, low-energy strategies can create resilient, socially vibrant spaces in composite climates and support healthier, more sustainable cities worldwide

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