Articles

Beating the heat

Cooling landscape measures for typological outdoor spaces in Hong Kong's public housing estates

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ABSTRACT: Rising extreme heat events pose significant threats to human health and pedestrian comfort, calling for climate-responsive design to provide heat-resilient spaces. Accommodating over 40% of Hong Kong's population, cooling public spaces in public housing benefits a substantial portion of the city's residents. Taking Hong Kong's public housing as the targeted urban context, this article illustrates the heat stress faced by residents. Based on a review of outdoor cooling measures for subtropical regions, an inventory including ten feasible measures to cool the typological public spaces, i.e., open, semi-outdoor, and vegetated spaces, is proposed. These measures target key microclimate parameters that improve thermal comfort, e.g., reducing solar radiation, enhancing pedestrian level ventilation, etc. We advocate for the integration of these cooling strategies in future public space design to ensure both spatial diversity and improved thermal comfort, enabling residents to better adapt to increasing future extreme heat conditions.

BACKGROUND

Climate change is leading to an increase in extreme heat events worldwide, posing a challenge to both the urban ecosystem and human well-being [1]. Various health impacts, including cardiovascular, respiratory, and renal diseases are associated with extreme heat events [2], and such impacts are often felt most acutely by vulnerable populations, e.g. the elderly and low-income communities. Besides, reduced thermal comfort directly influences how people use and experience outdoor spaces in daily lives, leading to reduced physical activity, limited social interactions, and diminished quality of life. Therefore, adopting innovative strategies that mitigate such adverse effects of urban overheating and designing outdoor spaces that are both functional and thermally comfortable for occupants is essential to promote social equity and create more inclusive urban environments.

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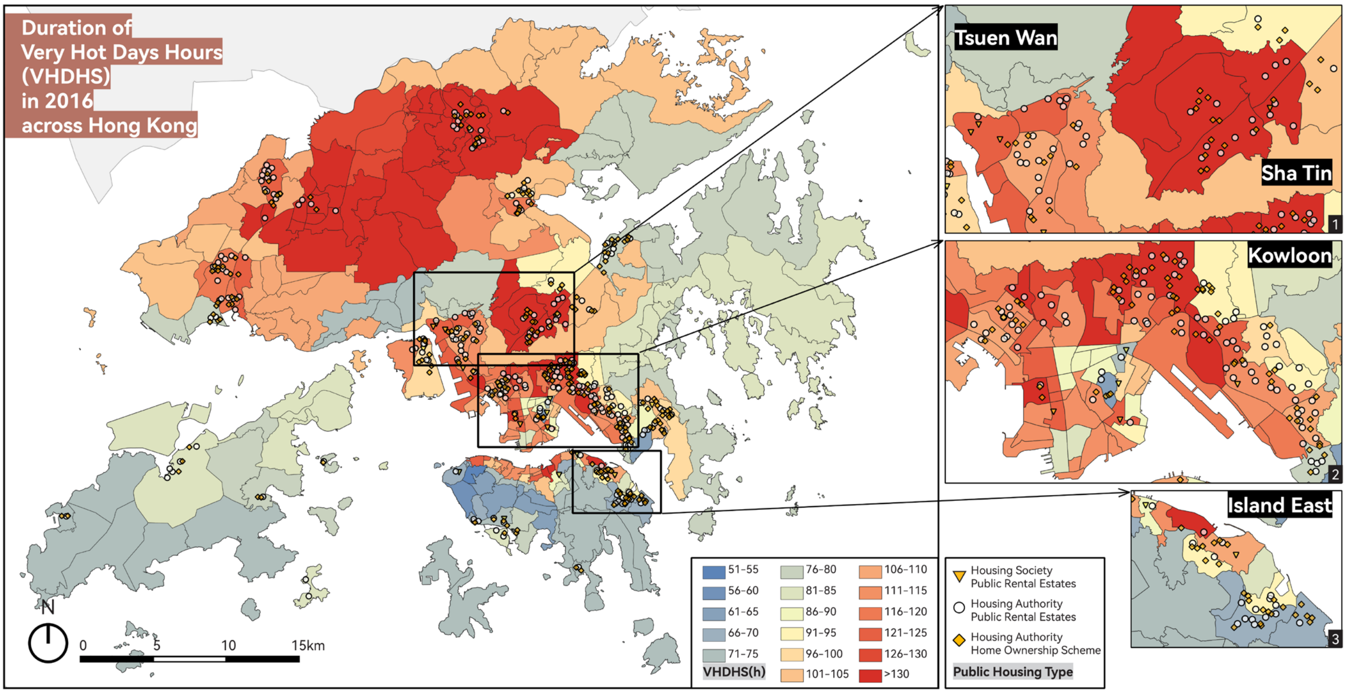


Fig 1. Heat stress across Hong Kong's territory quantified by very hot days hours in 2016 [5] and locations of Hong Kong's Public Housing Estates

Despite more frequent extreme heat in urban areas, providing thermally comfort spaces through urban design remains feasible. Referring to the subjective satisfaction that individuals experience with their thermal environment [3], thermal comfort is influenced by both microclimatic conditions and human factors, with the former encompassing solar radiation, air temperature, humidity, and wind speed, while the latter encompassing clothing insulation and metabolic rate. Therefore, as the microclimate can be influenced by urban morphology, thermal comfort enhancement can be achieved through design interventions, particularly in high-density cities like Hong Kong, where space types and morphology may vary greatly.

Housing provision in Hong Kong is largely supported by Hong Kong's public housing, which accommodates over 40% of Hong Kong's population [4], with developments distributed throughout the territory. These housing estates are home to a significant vulnerable population, particularly elderly residents, who comprise 25% of rental housing households aged over 60 years [4]. The heat stress faced by public housing residents is shown in Fig. 1, which overlaps the locations of public housings and the heat stress assessed by the duration of very hot days hours in 2016 [5]. Among the 485 estates, 153 sites experienced very hot days longer than 120 hours. Incorporating cooling measures to public housing's outdoor spaces may benefit a vast population.

In Hong Kong's public housing estates, open, vegetated, and semi-outdoor spaces are typological spaces commonly found. These spaces feature distinct functions, usage patterns, morphological characteristics, and microclimate conditions. Given the varied characteristics of these spatial typologies, space-specific measures to enhance thermal comfort become essential. Therefore, focusing on the urban context of outdoor spaces in Hong Kong's public housing estates, this article presents an inventory of feasible outdoor cooling measures for typological public spaces, as demonstrated in Fig. 2. These measures are developed based on a review of existing outdoor cooling research in subtropical regions. The development of these measures follows three key principles: evidence-based effectiveness to ensure reliable cooling performance, context-specific applicability to Hong Kong's public housing environments, and implementation feasibility under reasonable cost constraints. Through synthesizing research findings that align with these principles, technical details and practical guidelines

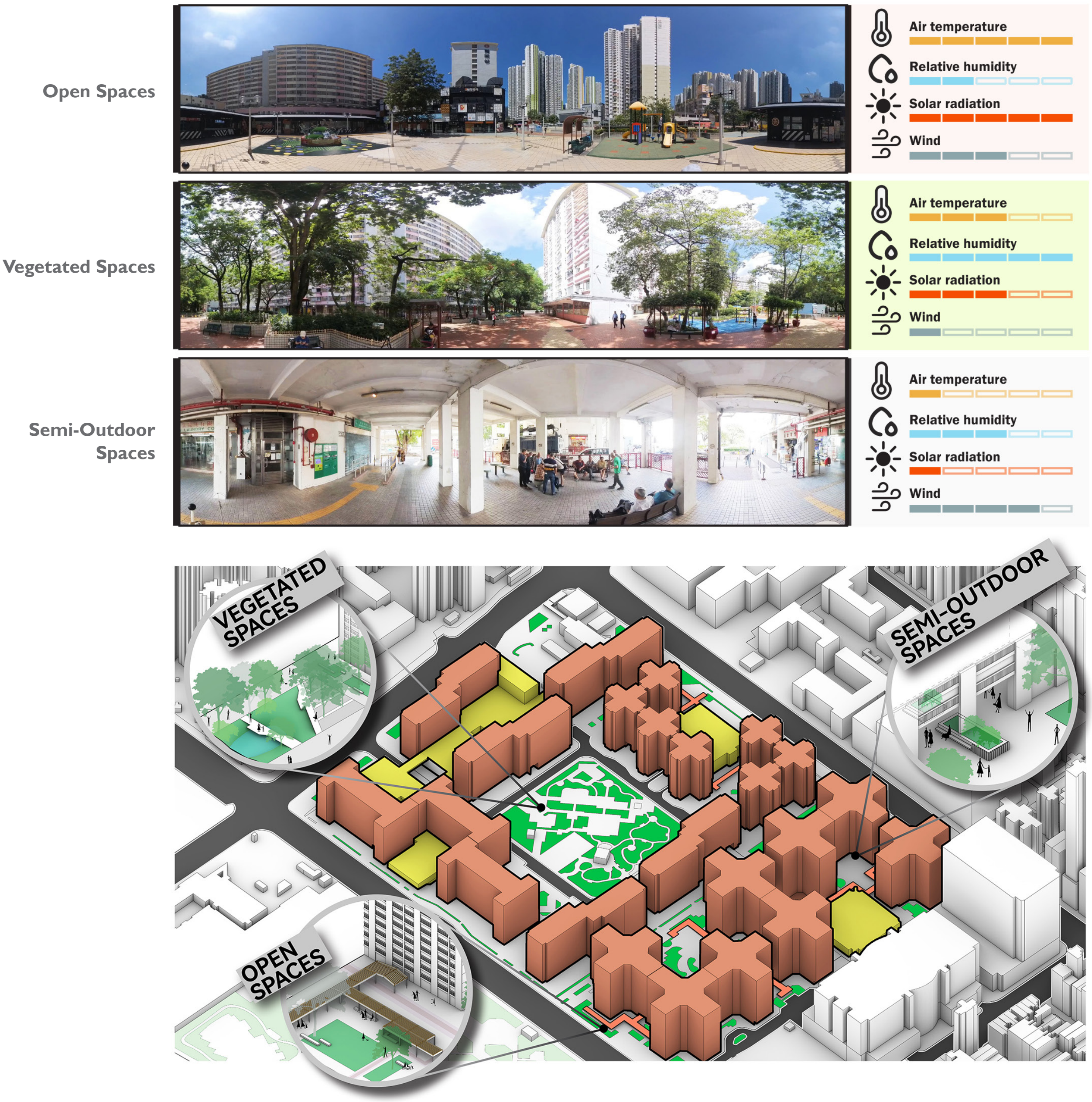


Fig 2. Typological public spaces in PHEs: Open, vegetated, and semi-outdoor spaces, illustrated with Lai On and Lai Kok Estates, and Yee Ching and Yee Kok Courts, Cheung Sha Wan

are illustrated to facilitate intuitive understanding of these measures.

COOLING LANDSCAPE MEASURES FOR OPEN SPACES

Large and unobstructed open spaces in public housing estates are typical spaces for community gatherings, public activities, and all kinds of light to intense outdoor exercise. Due to the openness of these spaces, they are most likely to be exposed to strong solar radiation and feature high air temperature and radiant temperature. Cooling strategies are needed especially under extremely hot summer days. The following five measures can be considered.

Measure 1: Utilizing building shade

Building orientation in relation to solar paths should be strategically considered to optimize shade utilization throughout the year. The seasonal variation of building shade has been demonstrated to significantly impact long-term thermal comfort [6]. In subtropical climates, while building shade is highly beneficial during hot summers, excessive shading in winter may lead to thermal discomfort due to over-cooling. Therefore, the optimal design solution involves positioning open spaces where they can benefit from building shade during summer months while maintaining adequate solar access in winter. This strategic placement ensures year-round thermal comfort by balancing seasonal shading requirements.

Measure 2: Covered walkway

Strategic implementation of covered walkways along primary pedestrian routes connecting buildings and infrastructure serves as an effective cooling measure. Empirical studies in Public Housing Estates have shown that covered walkways can substantially reduce mean radiant temperature by more than 20°C [7]. The cooling performance varies with roofing material selection; opaque materials such as concrete, aluminum, and PVC, as well as glass with transparency exceeding 10%, have demonstrated superior cooling efficacy [8]. To maximize shading effectiveness, the design must account for solar angles during peak heat periods. Beyond thermal comfort benefits, covered walkways offer additional advantages including protection from precipitation and adverse weather conditions, thereby enhancing overall pedestrian comfort and accessibility. The integration of these structures should be considered as a fundamental element in climate-responsive urban design.

Measure 3: High-reflectance pavement material

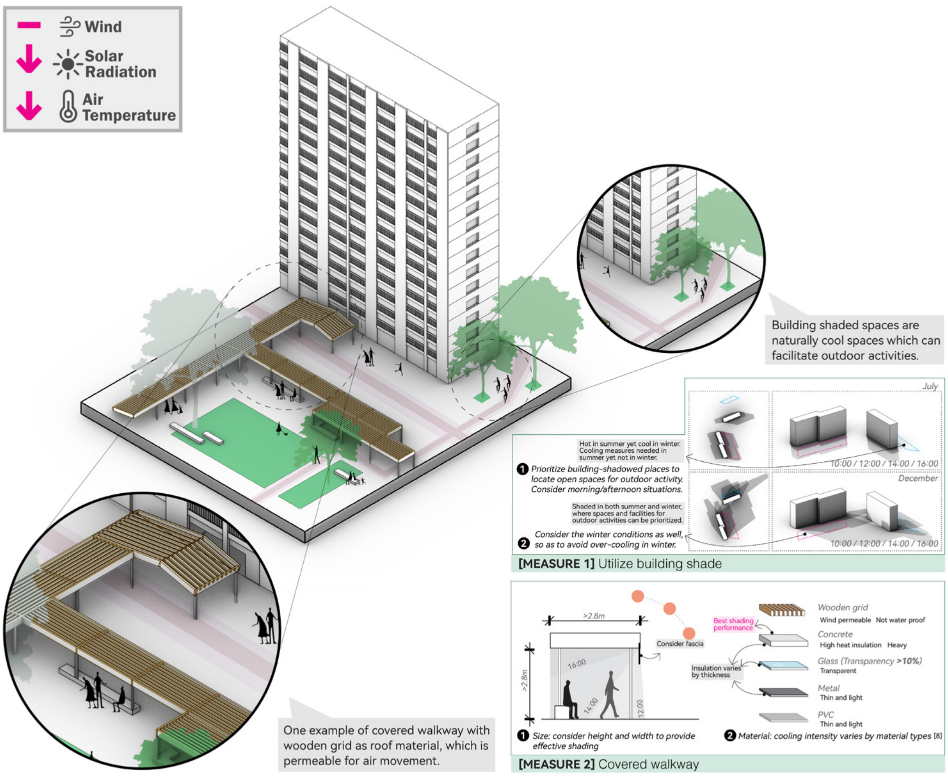
Prioritize high-reflectance pavement material at places that are highly exposed to sunlight, which may minimize the absorption of solar radiation and reflect a significant portion of the sun's energy. Such specialized pavement has a high solar reflectance index, which helps to reduce the surface temperature of outdoor spaces. Reflective pavements used in residential areas have been proved as effective mitigation on extreme heat. High reflectance of these materials may reflect the radiation and reduce the surface temperature of and the radiant temperature above the pavement, especially at noon [9]. Different pavement materials can also influence subject's local skin temperatures, which further determine the perceived thermal comfort of individuals [10]. By reflecting sunlight instead of absorbing it, it helps to keep the sunlight-exposed outdoor areas cooler.

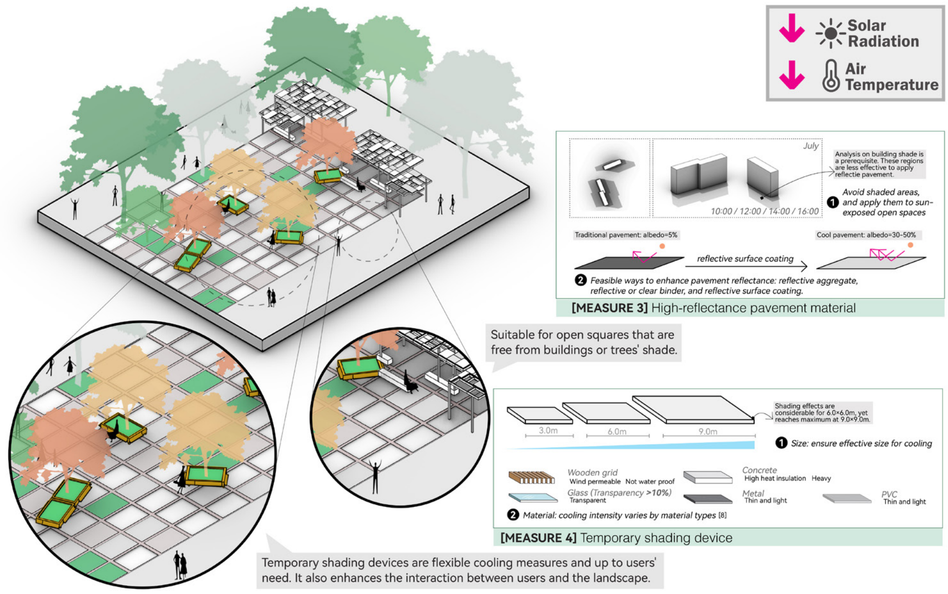
Measure 4: Temporary shading device

Designate landscape structures, such as pergolas, arbors, etc., as temporary shading devices. They feature manually adjustable elements, allowing users to control the amount of shade they need. By simulation, shading provided by opaque materials, such as concrete, aluminum, and PVC, can reduce mean radiant temperature by up to 24 °C. Comparatively, the cooling effect of transparent materials is reduced to 1.4°C. In terms of the size of the shading devices, maximum thermal stress reduction can be reached by devices larger than 9.0×9.0m [8]. The flexibility of their usage patterns ensures optimal comfort in extremely hot weather conditions, and at

Fig 3. Utilizing building shade and covered walkway in open spaces

Fig 4. Applying high-reflectance pavement materials and temporary shading device in open spaces





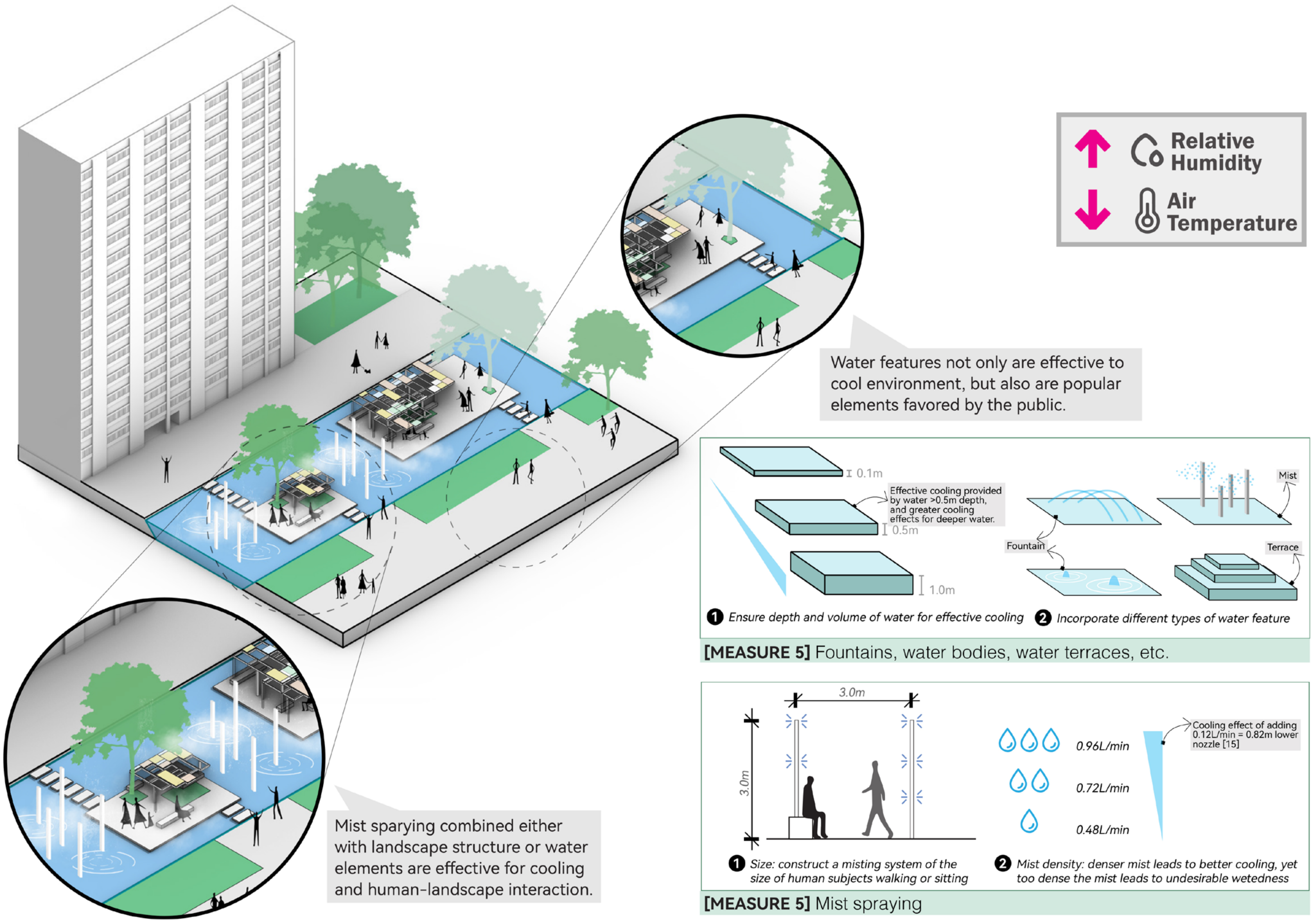
the same time offer multifunctional usage, serving as attractive architectural features that enhance outdoor spaces. By incorporating temporary shading devices, individuals can create comfortable and versatile environments that protect against excessive sun exposure while adding aesthetic value to their surroundings.

Measure 5: Water features

Water features such as fountains, ponds, and other aquatic elements can be strategically incorporated into open squares to provide cooling effects. Water's high heat capacity enables significant cooling during daytime hours, although it can release heat at night. While evaporation contributes to air temperature reduction, its accompanying increase in humidity may partially offset thermal comfort benefits. Research in Hong Kong has demonstrated this effect, with measurements showing notably lower air temperatures in lawn areas adjacent to small ponds [11]. The cooling efficiency of water features depends largely on their volume, as sufficient water mass is necessary to achieve meaningful temperature reduction despite heat storage. Moreover, the morphology of water features also plays a crucial role in their cooling performance. Parametric studies reveal that deeper [12] and more dispersed [13] water bodies are more effective in enhancing thermal comfort.

One special type of water feature that can effectively enhance thermal comfort is mist-spraying. This feature provides active cooling in high-temperature zones, either

Fig 5. Utilizing water features and mist spraying in open spaces



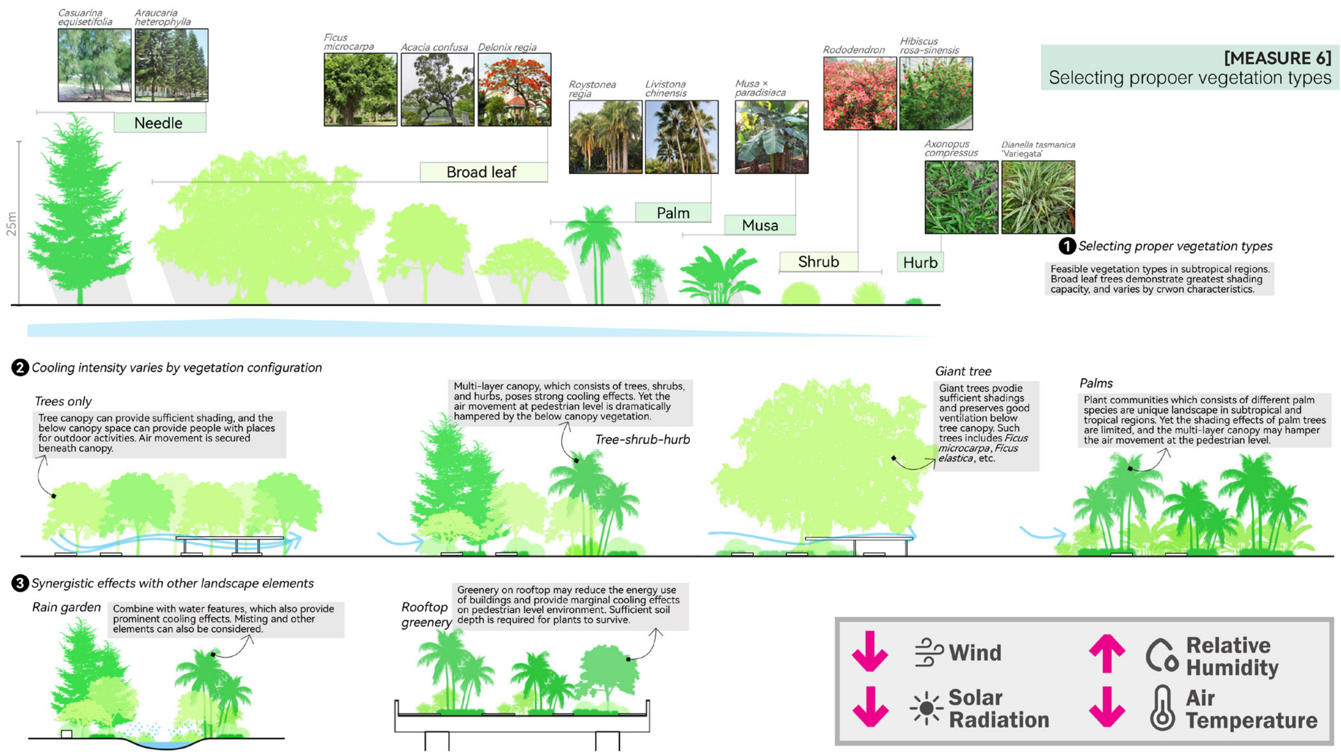


Fig 6. Selecting proper vegetation types and species (Plant image source: http://ppbc.iplant.cn/)

integrated into landscape structures or utilized as standalone devices. This cooling method has proven particularly effective in enhancing thermal comfort under extreme heat conditions, with research demonstrating that even brief five-minute exposures can significantly reduce skin temperature [14]. The cooling efficiency can be optimized through various factors: higher mist density closer to occupants [15], and synergistic combinations with natural wind and shade [16] can maximize thermal comfort benefits. Moreover, mist-spraying systems can be creatively incorporated into interactive landscape features, transforming conventional spaces into engaging environments that offer both heat relief and recreational value. This integration of cooling technology with landscape design creates more enjoyable outdoor spaces while effectively mitigating heat stress.

COOLING MEASURES FOR VEGETATED SPACES

Vegetated spaces in public housing estates encompass diverse typologies, including pocket gardens, tree-shaded squares, and green corridors, serving multiple functions from daily respite to community engagement and recreational activities. While these spaces benefit from vegetation's dual cooling mechanisms - shading and evapotranspiration - they still experience considerable thermal stress. Although demonstrably cooler than exposed open spaces, these vegetated areas continue to face challenging microclimatic conditions characterized by substantial solar radiation exposure, elevated air temperatures, and high relative humidity levels. The complex interaction between these environmental parameters underscores the need for strategic enhancement of vegetation's cooling potential in these communal spaces.

Measure 6: Selecting proper vegetation types and species

As key elements in vegetated spaces, selecting appropriate plant types and species is crucial for optimizing microclimate effects. Different vegetation types - trees, shrubs, and herbs - contribute distinctly to microclimate regulation.

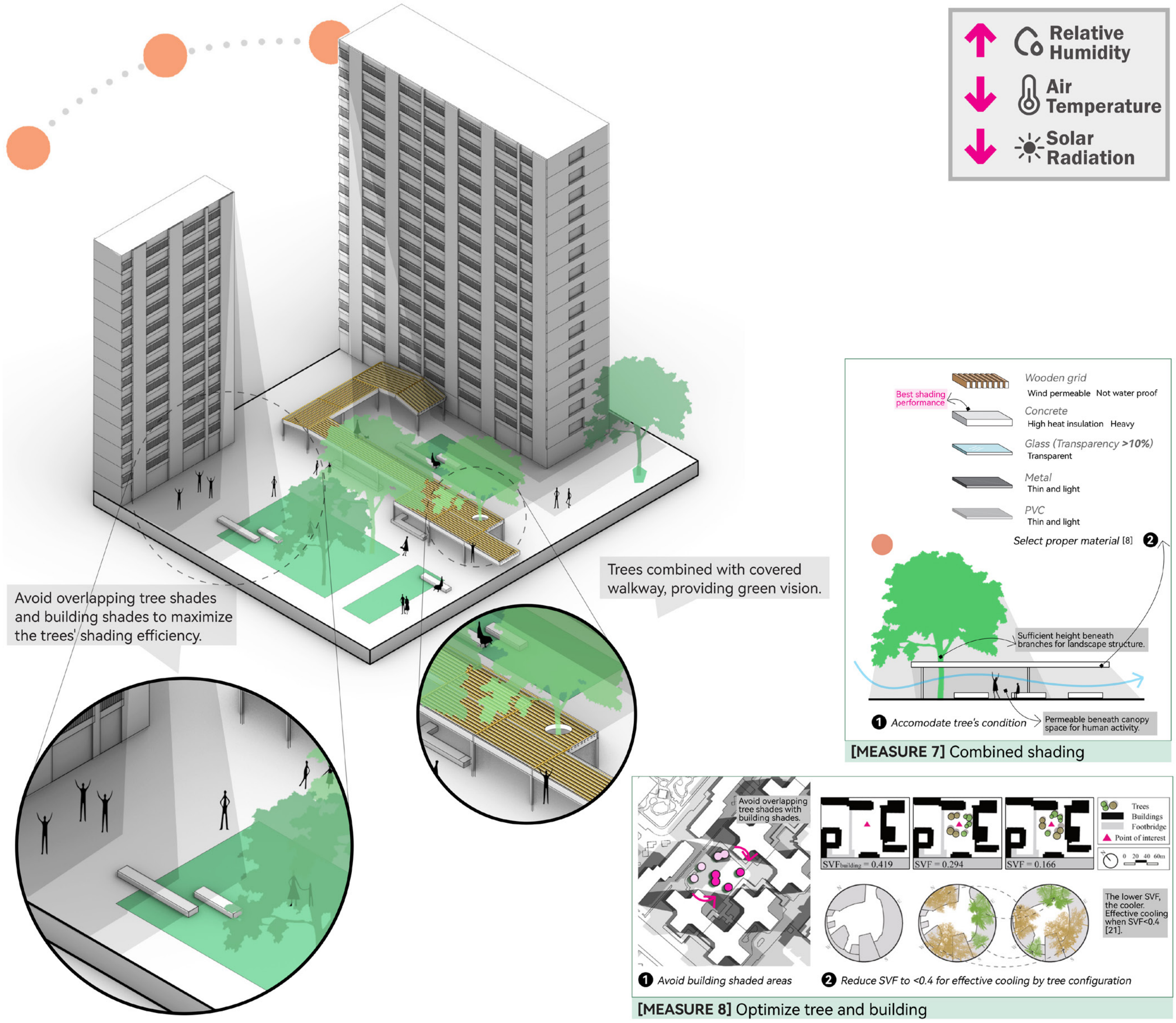


Fig 7. Utilizing combined natural and artificial shading and optimize tree and building in vegetated spaces

Large-crowned trees offer the most significant cooling benefits through shade provision, making them particularly valuable in areas beyond the reach of building shadows. While shrubs and herbs provide less shade, they contribute to cooling through evapotranspiration. Vines serve as excellent complements to existing landscape structures. A review study using meta-analysis demonstrated that canopy density, measured by leaf area index, is the primary determinant of cooling effectiveness [17]. To maximize cooling effects, planners should prioritize species with high leaf area indices and implement multi-layered vegetation arrangements. Research indicates that taller trees with expansive crowns are particularly effective at reducing heat stress [18]. In subtropical climates, multi-layer canopy systems have shown remarkable cooling capacity [19], achieving temperature reductions of up to 5.15°C. However, designers must carefully balance these benefits against potential impacts on ventilation.

Measure 7: Combined shading

The integration of structures and trees can provide both effective shading and recreational facilities, such as pavilions, particularly in areas where large tree planting is constrained by factors like limited soil depth. Field measurements in Hong Kong's public housing estates have demonstrated that tree and artificial structure shading offer comparable cooling effects [7]. Artificial structures can effectively complement trees where crown size and trunk height are difficult to control. This approach is especially valuable in situations that restrict tree growth, such as insufficient soil depth on podiums or rooftops. The combination of vegetation with landscape elements creates cool spaces that deliver both functional benefits and recreational opportunities while maintaining optimal thermal comfort. This integrated approach not only enhances environmental aesthetics but also promotes sustainable design by creating comfortable and inviting public spaces.

Measure 8: Optimizing tree and building

Strategic optimization of tree and building placement maximizes shading benefits, which has been shown to double cooling effects in subtropical Hong Kong [20]. Research in Hong Kong's public housing estates demonstrates that sky view factor serves as a key indicator for configuring buildings and greenery in outdoor spaces. Optimal cooling can be achieved by reducing the sky view factor to below 0.4 through strategic arrangement of buildings and vegetation [21]. Maximizing cooling effects requires prioritizing tree placement in areas beyond building shadows, while avoiding overlap between building and tree shade. Through careful consideration of spatial relationships between trees and buildings, designers can achieve optimal shading patterns and enhance thermal comfort in outdoor environments.

COOLING MEASURES FOR SEMI-OUTDOOR SPACES

Semi-outdoor spaces, defined by their partial enclosure within buildings or architectural structures, encompass pilotis, corridors, shelters, and shaded terraces. These areas serve as vital communal spaces, primarily designed to accommodate daily activities such as resting and light exercise. While these spaces benefit from natural shading that reduces direct solar radiation and subsequent heat stress on occupants, careful consideration must be given to ventilation patterns and visual quality to ensure optimal environmental comfort.

Measure 9: Enhancing porosity, connectivity, and volume

Enhancing the porosity, connectivity, and volumetric characteristics of semi-outdoor spaces can significantly enhance natural ventilation and thermal comfort conditions. Research has demonstrated a clear correlation between the morphological features of these spaces and their microclimate conditions. The height-to-depth ratio emerges as a critical parameter,

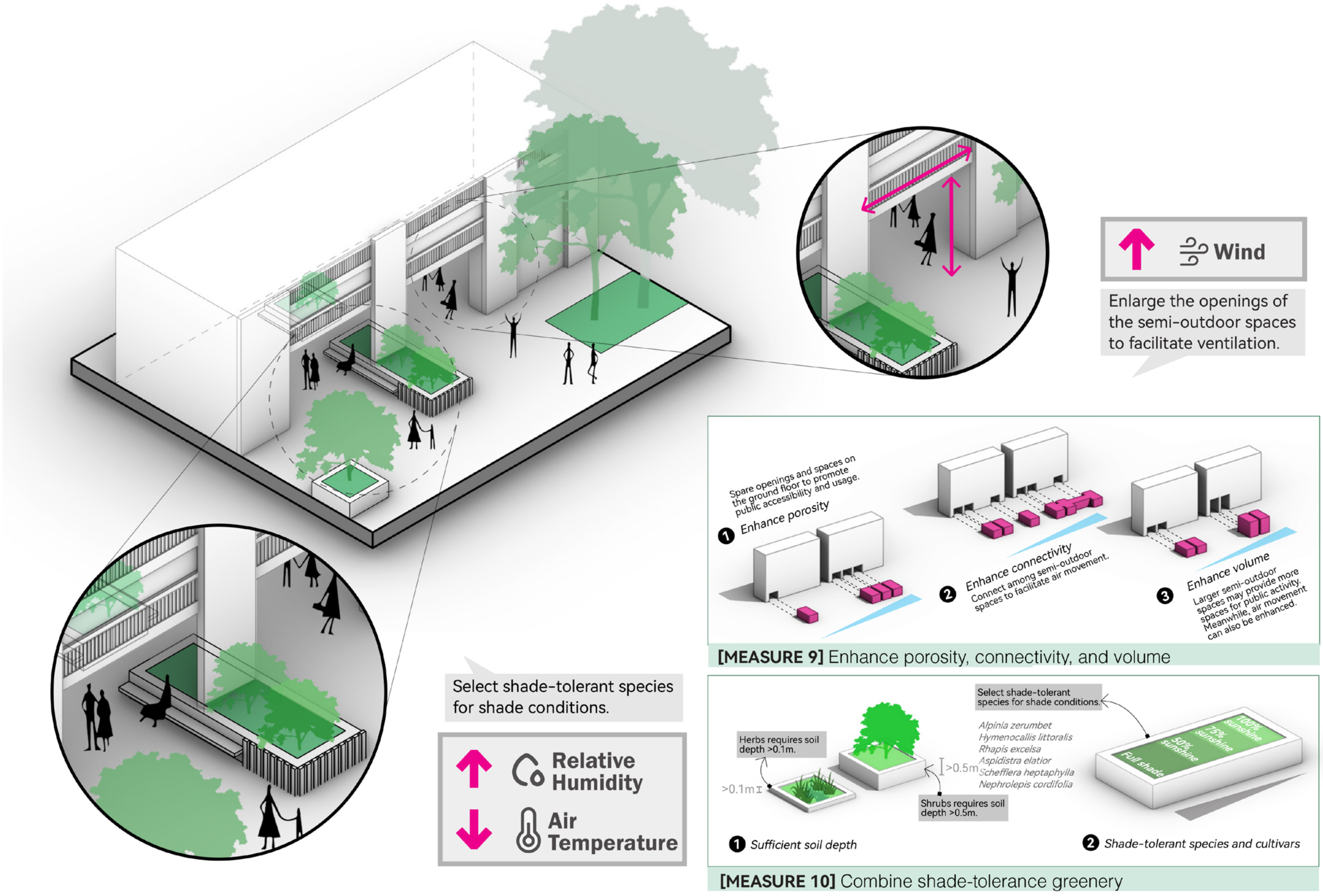


Fig 8. Enhancing porosity, connectivity and volume and combine shade-tolerance greenery in semi-outdoor spaces

with higher ratios corresponding to increased mean radiant temperature and wind velocity [22]. Priority should be given to enhancing airflow through the strategic design of horizontal and vertical breezeways, as improved wind velocity has been shown to substantially contribute to thermal comfort in these areas [23]. Additionally, careful consideration of solar angles is essential in determining sunlight penetration patterns and their impact on spatial comfort. Through thoughtful optimization of these design elements, semi-outdoor spaces can better serve their intended functions while encouraging increased user activity and engagement, ultimately enhancing the overall environmental experience.

Measure 10: Combining shade-tolerance greenery

Strategic incorporation of vegetation in semi-outdoor spaces through green walls, planters, and containers can enhance both cooling effectiveness and visual quality. These planted elements contribute to evaporative cooling, with research confirming their efficacy in increasing relative humidity and reducing mean radiant temperature [22]. Species selection should be carefully tailored to the specific solar radiation conditions within these semi-outdoor environments. Beyond their physical cooling effects, vegetation also offers psychological benefits, as studies have shown that the mere presence

Table 1 Summary of the 10 feasible cooling landscape measures

Space type	Cooling measure	Implementation feasibility	Design complexity	Maintenance requirements	Cost
Open Spaces	Utilizing building Shade	+ + +	+	+	+
	Covered Walkways	+ + +	+ +	+	+ +
Semi-outdoor Spaces	High-reflectance pavement	+ +	+	+	+ +
	Temporary shading devices	+ +	+ +	+ + +	+ +
	Water features	+	+ + +	+ + +	+ + + +
Vegetated Spaces	Plant selection	+ +	+ +	+ +	+ +
	Combined shading	+ +	+ +	+ +	+ + +
	Optimizing tree and building	+ + +	+ +	+	+
Semi-outdoor Spaces	Enhancing porosity and connectivity and volume	+ + +	+ +	+	+
	Shade-tolerant Greenery	+ +	+ +	+ +	+ +

of green elements can positively influence perceived thermal comfort [24]. When selecting plants, emphasis should be placed on shade-tolerant species that can thrive in reduced light conditions, ensuring sustainable growth and long-term viability. This integration of vegetation not only provides practical thermal benefits but also enriches the aesthetic experience through the natural beauty of carefully curated greenery.

CONCLUSION

The escalating challenges posed by extreme heat events in urban environments, particularly within the high-density context of Hong Kong's public housing estates, necessitate the implementation of innovative yet pragmatic cooling strategies. This article presents a feasible inventory of ten evidence-based cooling measures, specifically tailored for subtropical regions. These measures, as summarized in Table 1, accompanied by practical implementation guidelines, provide urban designers and planners with a robust framework for creating thermally resilient public spaces.

Despite the measures demonstrating high adaptability to public housing developments, their practical implementation faces varying challenges in terms of feasibility, design complexity, maintenance requirements, and cost, as summarized in Table 1. For instance, early intervention at the building design stage might be needed, in particular for building shade utilization (Measure 1), tree-building optimization (Measure 8), and building porosity enhancement (Measure 9), which may limit their application in existing developments. Water features (Measure 5) and temporary shading devices (Measure 4), while offering interactive elements for the public, face challenges due to their high construction and maintenance costs, as well as durability concerns. However, given their current rarity in public housing estates, strategic implementation of these features could pioneer innovative approaches to outdoor thermal comfort enhancement. Therefore, a selective combination of these strategies, prioritizing those with higher feasibility while strategically implementing more resource-intensive measures in key locations, may offer the most practical approach for public housing developments.

As cities globally confront intensifying urban heat stress, the systematic integration of these cooling strategies through evidence-based design not only enhances thermal resilience and livability but also advances the broader goals of urban sustainability and social equity. This approach represents a crucial step toward creating more climate-adaptive and inclusive urban environments for future generations.

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