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THE IMPACT OF URBAN GEOMETRY AND BUILDING CONFIGURATION ON OUTDOOR THERMAL COMFORT IN DA NANG CITY

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INTRODUCTION

1. Research Rationale

The Urban Heat Island (UHI) effect, characterized by elevated temperatures in urban areas, poses significant heat-related health risks and imposes a heavy burden on urban cooling energy systems. The adverse effects of UHI are particularly exacerbated in coastal cities within hot and humid tropical climates. As a representative coastal city under such climatic conditions, Da Nang is currently facing severe challenges related to the intensification of UHI and heat stress driven by climate change. Given the projected scenarios of heatwaves escalating in both intensity and duration, there is an urgent need to develop solutions to improve outdoor microclimate conditions in this region, thereby mitigating health risks for the workforce and the broader community.

Thermally comfortable outdoor spaces are essential not only for facilitating physical activities and promoting public health but also for fostering social interaction and enhancing urban vitality. The degree of thermal comfort directly dictates the frequency of outdoor space utilization; a more favorable thermal environment significantly encourages public participation in outdoor activities. Consequently, this behavioral shift indirectly reduces the reliance on indoor mechanical cooling systems, thereby conserving energy and alleviating the burden on the urban power grid during extreme heatwaves. In the face of intensifying climate change and the UHI effect, optimizing outdoor thermal conditions has emerged as a fundamental objective for achieving sustainable urban development and improving the overall quality of life.

Since outdoor thermal comfort can be predicted during the early design stages, static geometric parameters such as orientation, building height, and building configuration are of paramount importance in climate-responsive design. Specifically, orientation governs airflow patterns and direct solar radiation, whereas

building height and configuration dictate the shading area, thereby significantly reducing the mean radiant temperature (Tmrt) within the urban canyon. To quantify the spatial geometry between adjacent building blocks, Oke (1988) introduced the concept of the "urban canyon aspect ratio" (H/W), defined as the ratio of building height to street width. This parameter fundamentally drives urban microclimatic characteristics, and its cooling efficacy has been extensively validated through empirical field measurements and numerical simulations across diverse climatic regions.

However, the magnitude of the impact exerted by orientation, building height, and configuration is highly contingent upon local climatic conditions. To date, there remains a notable paucity of comprehensive quantitative research evaluating these geometric parameters within the specific microclimatic context of Da Nang. Unlike adaptive mitigation strategies such as urban vegetation or surface materials, building geometry is inherently static and practically irreversible once construction is complete, yet it possesses profound passive cooling potential. Consequently, investigating the thermal mitigation efficacy of spatial configurations is an imperative prerequisite for optimizing building forms. This research will ultimately serve as a foundational framework for enhancing outdoor thermal comfort across the city.

2. Research Objectives

The overarching aim of this dissertation is to establish a scientific foundation for climate-responsive architectural design and spatial organization tailored to Da Nang’s specific climatic conditions, ultimately enhancing outdoor thermal comfort and urban quality of life. To achieve this, the specific research objectives are outlined as follows: (1) To analyze the impact of geometric parameters, specifically building height and orientation, on the urban canyon microclimate; (2) To assess the influence of high-rise buildings on the microclimate of adjacent areas; (3) To investigate

microclimatic variations across diverse building configurations and massing scenarios; (4) To quantify the cooling efficacy of urban greening strategies (i.e., integrated green infrastructure and urban trees) applied within the existing urban morphology; and (5) To propose architectural design and spatial organization guidelines aimed at optimizing outdoor thermal comfort in street canyons.

3. Research Object and Scope

This research primarily focuses on evaluating the impact of building orientation, height, and configuration on the microclimate at the pedestrian level. The scope of the study is established within the following specific delimitations:

- **Spatial Scope:** The study investigates urban canyon models formed between two adjacent building blocks. Street orientations are categorized into four main axes, while building heights are determined relative to street widths to ensure strict compliance with current architectural management regulations.
- **Temporal Scope:** The investigations are conducted under typical hot season climatic conditions to assess the worst-case thermal scenarios of the year.
- **Analytical Focus:** The research delves into the interactions among the urban canyon aspect ratio (H/W), street orientation, building configuration, and the presence of high-rise buildings. Urban greening solutions are incorporated as an auxiliary variable to verify their passive cooling efficacy.
- **Evaluation Parameters:** The final conclusions are derived from a comparative analysis of variations across three core microclimatic indices among the simulated scenarios: air temperature (Ta), mean radiant temperature (Tmrt), and Physiologically Equivalent Temperature (PET).

4. Research Methodology

This research adopts a comprehensive methodological framework comprising four primary methods: (1) Literature review and theoretical analysis, (2) Field

measurements and data collection, (3) Microclimate simulation and model validation utilizing ENVI-met, and (4) Statistical data analysis. Specifically, the literature review serves to systematize the theoretical foundation, synthesize current research trends, and pinpoint existing research gaps. Field measurements and data collection are conducted to construct the empirical input database and validate the reliability of the computational model. Furthermore, microclimate simulations employing ENVI-met enable the quantitative assessment of microclimatic variations driven by diverse geometric parameters. This phase specifically extracts three core thermal variables: air temperature (Ta), mean radiant temperature (Tmrt), and Physiologically Equivalent Temperature (PET). Finally, statistical analysis is applied to process the extensive simulation outputs to identify characteristic patterns and correlations, thereby establishing a robust foundation for proposing architectural design solutions that optimize outdoor thermal comfort.

5. Significance of the Study

This research contributes to elucidating the efficacy of manipulating urban geometry as a strategy to modulate outdoor thermal comfort in Da Nang City. Furthermore, it establishes a theoretical and methodological foundation for future in-depth studies, facilitating the integration of supplementary passive cooling strategies such as urban vegetation, surface materials, and water bodies. From a practical perspective, the guidelines and recommendations derived from this study will serve as a valuable reference for architects and urban designers. These findings provide them with evidence-based insights to systematically consider crucial morphological parameters that govern outdoor thermal comfort within the specific climatic context of the city.

7. Main Contributions of the Dissertation

Based on the analytical results, this research offers several original contributions to academic knowledge, methodological approaches, and practical applications, detailed as follows:

- **Geometric Optimization Thresholds:** Optimizing building height (urban canyon aspect ratio) and orientation plays a pivotal role in improving outdoor thermal comfort in Da Nang City. An H/W ratio of 2.5 (the maximum permissible limit for local streets) yields the most significant thermal improvement. Furthermore, an H/W ratio of 2.0 emerges as a minimum threshold; aspect ratios below this level induce severe thermal disadvantages.
- **Orientation Performance:** The North-South orientation is identified as the most favorable axis for outdoor thermal comfort. Conversely, the East-West axis is the most adverse; notably, even increasing the H/W ratio to 4.5 remains insufficient to provide complete shading across the East-West street surface, thereby necessitating the integration of supplementary passive cooling strategies.
- **Microclimatic Role of High-Rise Buildings:** Although high-rise buildings may locally obstruct wind flow, they exhibit a profound capacity to intercept solar radiation, thereby effectively lowering air temperatures in adjacent street canyons.
- **Building Configuration Strategies:** Regarding massing, the application of low-rise sprawling forms across the entire plot reveals significant limitations. This typology is deemed the most detrimental to outdoor thermal comfort, as it fails to generate an adequate shadow footprint for street shading while heavily encroaching upon land suitable for vegetation. Instead, adopting a perimeter block configuration with an H/W ratio exceeding 2.0 proves to be a highly effective strategy. This form provides expansive shading for street surfaces and liberates the ground level for landscape greening.

- **Retrofitting Fixed Morphologies:** For existing urban areas with irreversible spatial morphologies, intensifying tree planting along sidewalks is identified as the most effective retrofitting intervention for noticeable thermal mitigation.

8. Structure of the Dissertation

The dissertation comprises three primary chapters, structured as follows: *Chapter 1*: Literature Review on Outdoor Thermal Comfort. *Chapter 2*: Theoretical Framework and Research Methodology. *Chapter 3*: Results, Discussions, and Climate-Responsive Design Guidelines

9. List of Abbreviations

The following key concepts and terms are consistently utilized throughout this dissertation: Physiologically Equivalent Temperature (PET), Urban Canyon Aspect Ratio (H/W), Outdoor Thermal Comfort (OTC), Mean Radiant Temperature (Tmrt), Dry Bulb Temperature (Ta).

CONTENT

Chapter 1. LITERATURE REVIEW ON OUTDOOR THERMAL COMFORT AND INFLUENCING FACTORS

1.1. Current State of Research on Outdoor Thermal Comfort

In the context of complex climate change and the intensifying Urban Heat Island (UHI) effect, ensuring thermally comfortable outdoor spaces has become an imperative necessity in urban areas. To address this demand, numerous strategies aimed at improving outdoor thermal comfort have been proposed and implemented globally. Among these, four passive cooling strategies are widely recognized for their proven efficacy and extensive application, including: (1) configuring urban geometry, (2) integrating urban vegetation, (3) applying reflective materials, and (4) incorporating water bodies. Each strategy modulates the microclimatic environment

through distinct physical mechanisms, generating specific cooling effects contingent upon the urban context.

Manipulating urban geometry serves as a crucial strategy for enhancing outdoor thermal comfort, leveraging the capacity of built structures to provide solar shading and regulate airflow patterns. Within the urban environment, these structures exhibit significant diversity in shape and scale, thereby generating a wide array of distinct urban geometries. For thermal environment investigations, the urban geometry of a specific area is typically characterized and quantified using fundamental geometric parameters, notably the urban canyon aspect ratio (H/W), street orientation, and the Sky View Factor (SVF). The H/W ratio delineates the cross-sectional profile of a street canyon, defined as the proportion of building height (H) to street width (W). This ratio fundamentally dictates the spatial openness, as well as the canyon's capacity to receive solar radiation and facilitate wind penetration. Similarly, the Sky View Factor (SVF) serves as a critical indicator reflecting the openness of an urban space. This dimensionless metric quantifies the fraction of the visible sky hemisphere from a fixed observation point, with values ranging from 0 to 1. Consequently, areas characterized by a low SVF indicate a high degree of sky obstruction, and vice versa.

The integration of urban vegetation represents another highly effective strategy for mitigating elevated temperatures and ameliorating microclimatic conditions. Trees facilitate air temperature reduction primarily through the mechanisms of shading, evapotranspiration, and solar energy absorption. Specifically, the shading mechanism significantly attenuates incoming shortwave radiation from reaching the surfaces beneath the tree canopy, thereby maintaining these surface temperatures considerably lower than those in unshaded, exposed areas.

Furthermore, the application of reflective materials constitutes a vital strategy for reducing surface temperatures, leveraging their inherent capacity to reflect solar

energy. These materials are characterized by their ability to reflect radiation across the entire solar spectrum, particularly within the visible and near infrared thermal wavelengths, rather than absorbing this energy as conventional materials do. This mechanism effectively diminishes heat accumulation and substantially lowers the surface temperatures of these materials. Compared to conventional building materials, which typically reflect merely 5 to 15% of solar radiation, reflective materials exhibit superior thermal performance, demonstrating the capability to reflect up to 65% of incoming solar energy.

As a final mitigation strategy, the incorporation of water bodies, facilitates air temperature reduction primarily through their high heat capacity and the process of evaporation. Natural water bodies, such as lakes, rivers, and ponds, possess the capacity to absorb a substantially greater amount of solar radiation compared to conventional urban materials like concrete or asphalt, without experiencing a significant increase in their own temperature. This thermodynamic property enables water features to effectively sequester heat, thereby lowering the temperature of the surrounding ambient environment.

To date, the four aforementioned strategies for enhancing outdoor thermal comfort have been extensively investigated across diverse climatic regions. Although these strategies universally demonstrate the capacity to mitigate air temperatures and improve outdoor thermal comfort, their actual efficacy is highly contingent upon a multitude of contextual conditions, yielding heterogeneous results in practice. In an effort to synthesize and evaluate the relative effectiveness of these interventions, Lai et al. (2019) conducted a comprehensive comparative analysis of the cooling performance across these four strategies. The synthesized results regarding the maximum reductions in air temperature and the PET index for each respective strategy are presented in Figure 1.1.

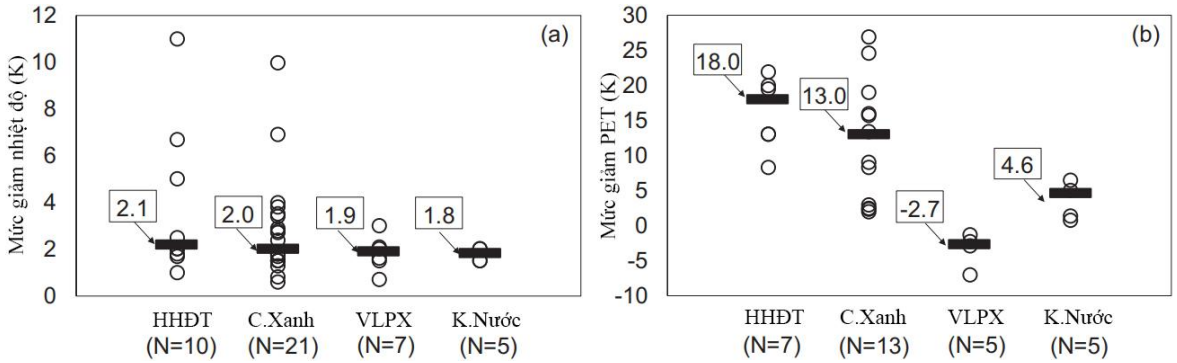


Figure 1.1: Mean reductions in (a) air temperature and (b) PET achieved by the four cooling strategies: urban geometry, vegetation, reflective surfaces, and water bodies. (Source: Lai et al., 2019)

The findings of the study indicate that among the four prevalent strategies for enhancing outdoor thermal comfort, manipulating urban geometry yields the most comprehensive efficacy, demonstrating a consistently high capacity to reduce both air temperature and PET. The integration of vegetation also delivers substantial cooling effects, particularly concerning tree species with expansive canopies and when combined with street canyons of appropriate proportions. Ground level greenery, such as grass lawns, provides minimal thermal mitigation for the space directly above them, given their inability to intercept direct solar radiation. Similarly, while water bodies offer a certain degree of temperature reduction, their overall cooling performance remains relatively modest because they cannot shield the environment from solar exposure. Notably, the application of reflective materials produces a counterproductive outcome, elevating PET values in the surrounding ambient environment rather than decreasing them. Due to their property of reflecting incoming solar radiation, these materials inherently increase the mean radiant temperature, thereby causing a severe deterioration of thermal comfort conditions within urban spaces.

1.2. Studies on Outdoor Thermal Comfort in Vietnam

Research concerning outdoor thermal comfort represents a relatively nascent field, having emerged only in recent decades driven by advancements in heat transfer

physics and computational technology. Consequently, academic publications addressing outdoor thermal comfort have only experienced a substantial surge in recent years. In Vietnam, despite numerous reports documenting elevated temperatures in major cities, research publications focusing on mitigation strategies remain notably limited. To quantify this literature, Fong et al. (2019) conducted a comprehensive review reporting on the current state of outdoor thermal comfort research across Southeast Asian countries, including Vietnam. According to their synthesized findings, the vast majority of studies are concentrated in Malaysia (10 studies) and Singapore (6 studies). Other nations recorded three or fewer studies, specifically Indonesia (3), Vietnam (1), and Thailand (1), whereas the remaining countries reported no publications. The study by Fong et al. highlighted a significant disparity in the volume of outdoor thermal comfort research among Southeast Asian nations. Countries with more advanced economies such as Malaysia and Singapore recorded a predominant number of investigations, while developing nations, including Vietnam, produced very few academic publications in this field. Crucially, this literature review exposes a distinct research gap and a profound scarcity of investigations within the developing urban areas of Vietnam, where numerous coastal cities such as Da Nang are experiencing increasingly pronounced impacts of urban microclimate issues.

1.3. Identified Research Gaps and Proposed Approaches

In Vietnam, investigations concerning outdoor thermal comfort remain relatively constrained, particularly when juxtaposed with other Southeast Asian nations such as Malaysia and Singapore. This represents a substantial research gap, notably within the context of major metropolitan areas like Hanoi, Ho Chi Minh City, and Da Nang, which are currently enduring severe impacts from ongoing climate change and the urban heat island effect. Although numerous reports have documented escalating temperatures driven by the urban heat island phenomenon

and global climate shifts in these cities, dedicated studies aimed at ameliorating outdoor thermal comfort remain exceedingly scarce. The prevailing deficit in empirical research concerning the optimization of the outdoor thermal environment poses significant challenges in formulating appropriate adaptation strategies to combat climate change.

Specifically in Da Nang, although numerous studies have reported on heat stress and the urban heat island phenomenon, the volume of research publications dedicated to enhancing outdoor thermal comfort remains exceedingly limited. There is a conspicuous absence of systematic quantitative analyses examining the complex interactions among the urban canyon aspect ratio, street orientation, tall buildings, and overall building configurations. As Da Nang undergoes rapid urban development and strives to establish itself as a highly livable city, ameliorating the living environment and optimizing outdoor thermal comfort emerge as pressing imperatives. Given its status as an expanding urban center confronting profound challenges associated with climate change and the urban heat island effect, comprehensive and empirical investigations into thermal environment optimization are strictly essential. Such studies are required to establish a robust scientific foundation for developing highly effective adaptation strategies against increasingly complex climatic fluctuations.

Chapter 2. THEORETICAL FRAMEWORK AND RESEARCH METHODOLOGY

2.1. Practical Background

Da Nang City, situated in the central region of Vietnam with coordinates ranging from 15°55’19” to 16°13’20” North and 107°49’11” to 108°20’20” East, serves as a crucial port city and is classified among the three largest metropolitan areas nationwide. The city experiences a tropical monsoon climate, characterized by two distinct seasons: the rainy season spanning from September to March and the

dry season lasting from April to August. In recent years, the municipality has undergone rapid urbanization. The expansion of new urban developments has significantly altered the land use patterns of the city. Concurrently, the municipal population has witnessed a substantial surge, escalating from 568,000 residents in the year 2000 to 1,125,000 in 2020, with projections anticipating the two million mark by 2030. This demographic boom drives an escalating demand for housing and infrastructure, thereby significantly intensifying the Urban Heat Island phenomenon across the city. According to research conducted by Linh (2015), the Urban Heat Island effect has elevated temperatures in densely built districts of Da Nang by 4 to 6 degrees Celsius compared to their rural surroundings. Furthermore, functioning as a central coastal city, Da Nang endures severe impacts from global climate change. Driven by these climatic shifts, the frequency of hot days and warm nights is increasing, the hot season is substantially prolonging, and extreme heat events are occurring with greater regularity. Consequently, local residents face a critical risk of heat stress in the absence of robust strategies aimed at ameliorating outdoor thermal comfort.

Amidst the context of escalating temperatures induced by urbanization and climate change, integrating urban vegetation and optimizing urban geometry are widely recognized as two prerequisite strategies for ameliorating outdoor thermal comfort. Although the critical role of vegetation in mitigating air temperatures is entirely undeniable, current urban planning realities in Vietnamese cities, notably Da Nang, present a severe challenge. The proliferation of a specific urban geometry characterized by densely built, low elevation tube houses has exerted profound pressure on the local microclimate, compelling green spaces to yield to extensive concrete surfaces. Specifically, the contemporary urban landscape is heavily dominated by adjacent townhouses with exceptionally high building densities, occupying a remarkably massive proportion of the total residential land area (Figure

2.1). As the land available for greenery is drastically curtailed to accommodate these closely packed, low profile building blocks, the capacity of urban surfaces to absorb incoming solar radiation increases significantly. This spatial transformation fundamentally exacerbates the Urban Heat Island phenomenon and induces prolonged thermal discomfort for the urban population.

Figure 2.1: The contrast in land coverage proportions between high density tube house typologies and low density developments within the existing urban fabric, exemplified by the case of An Hai Ward, Son Tra District, Da Nang City. (Source: Google Earth)

2.2. Research Methodology

This research employs four primary methodological approaches, specifically: comprehensive literature review and theoretical analysis; empirical survey and data collection; microclimate simulation and model validation utilizing the ENVI met software; and statistical data analysis. Among the aforementioned approaches, the simulation method assumes the most pivotal role. It serves as the primary computational instrument to generate quantitative results, thereby establishing the foundational evidence for the conclusions drawn in this study. To accurately replicate real world conditions, the ENVI met model is employed, which is an advanced computational program explicitly designed to simulate and calculate outdoor microclimatic parameters. The investigated scenarios are systematically categorized into four principal groups of variables. The initial group comprises 20 scenarios dedicated to examining urban canyon morphology. These scenarios involve the

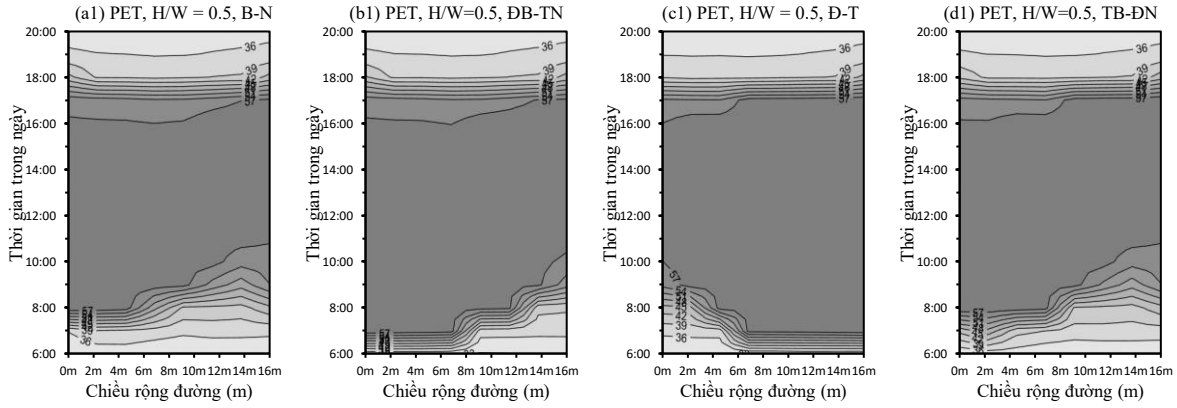
systemic variation of the aspect ratio, specifically H/W values ranging from 0.5 to 2.5, across four cardinal street orientations to evaluate thermal comfort fluctuations governed by the geometric configuration of the canyon. The second group, consisting of 4 scenarios, investigates the thermodynamic impact of adjacent tall building clusters on the thermal comfort zones within neighboring street canyons. Furthermore, the third group encompasses 3 scenarios that delve into the spatial organization paradigm by contrasting three distinct architectural typologies. Specifically, the compared variables include a sprawling development model characterized by low elevation and high surface coverage density; a perimeter block model featuring structures aligned along the plot boundary with reduced building density; and a concentrated model represented by a compact tall tower situated at the core of the site. Finally, the fourth group introduces 4 greenery intervention scenarios applied to the existing baseline while retaining the original building massing. These interventions encompass green facades, green roofs, intensified tree planting, and a fully integrated greening solution."

Chapter 3. RESEARCH FINDINGS AND CLIMATE RESPONSIVE DESIGN GUIDELINES

3.1. Impacts of Urban Canyon Aspect Ratio

The geometric proportions of the street canyon directly influence the duration and intensity of solar radiation incident upon the street surface, thereby regulating the Physiological Equivalent Temperature (PET) within the canyon. Figure 3.1 illustrates the distribution of PET zones across four cardinal street orientations, corresponding to three canyon aspect ratio scenarios of 0.5, 2, and 2.5. Increasing the canyon aspect ratio serves as a highly effective passive intervention, facilitating a synchronous reduction of extreme heat PET zones across all street orientations. The cooling efficacy reaches its optimal level at the highest canyon aspect ratio of H/W = 2.5, where the radiation shielding capacity is maximized. Compacting the urban

spatial form by increasing the H/W ratio can thus be considered an effective strategy for controlling severe PET zones within the canyons. Furthermore, the absolute difference data between the two extremes of the aspect ratio spectrum, specifically 0.5 and 2.5, demonstrates a robust capacity to diminish exceptionally hot PET zones at elevated canyon proportions. Upon examining intermediate aspect ratio levels, the spatial extent of high PET zones exhibits a progressive reduction that is directly proportional to incremental increases in the aspect ratio. As the aspect ratio is sequentially elevated across the thresholds of 1, 1.5, and 2, the occurrence frequency of PET zones exceeding 54°C diminishes uniformly across all street orientations, registering mean values of 54.4 percent, 49 percent, and 39.6 percent, respectively. Nevertheless, within the increment from 2 to 2.5, the capacity to mitigate hot PET zones declines abruptly and becomes statistically negligible. The H/W ratio threshold of 2 can therefore be identified as a technical saturation point, at which the structural shading capacity approaches its absolute limit. Continuing to elevate building heights to achieve an H/W ratio of 2.5 no longer yields commensurate benefits regarding thermal comfort optimization.



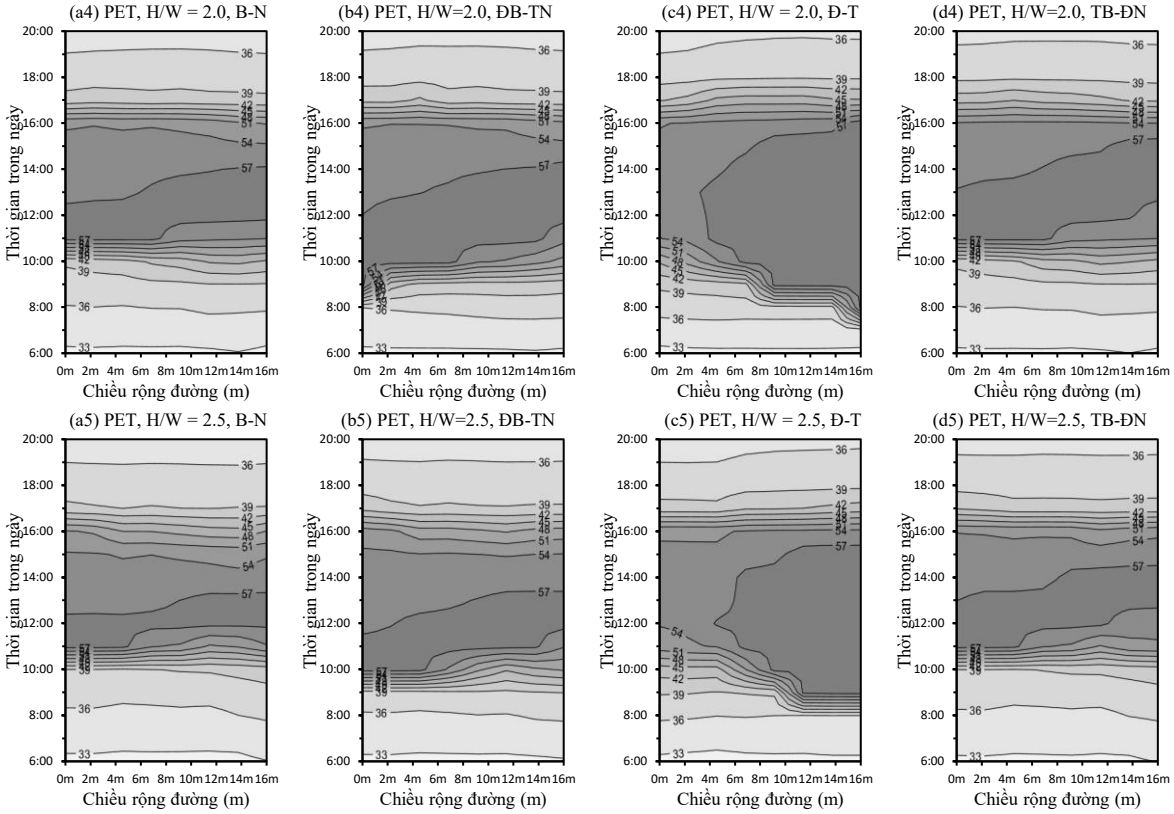


Figure 3.1: Spatial and temporal variations of PET across five canyon aspect ratios corresponding to four street orientations: (a) the North to South axis, (b) the Northeast to Southwest axis, (c) the East to West axis, and (d) the Northwest to Southeast axis.

3.2. Impacts of High-rise Buildings

Elevating building height contributes to expanding the shadow footprint, thereby diminishing the solar radiation received at the surface level and mitigating the escalation of PET. Along North-South streets in Da Nang during the summer, high-rise buildings can generate substantial shading zones in the morning and afternoon; however, this capacity diminishes markedly around 12:00 noon, a time when the sun is positioned near the zenith. Conversely, along East-West street axes, an evident shadow asymmetry occurs between the two sides of the canyon: the northern side is entirely exposed to direct solar radiation for almost the entire daytime duration, whereas the southern side remains better protected, even when the sun reaches its peak elevation. The spatial and temporal distribution of the Physiological

Equivalent Temperature (PET) across the three canyon typologies is illustrated in Figure 3.2.

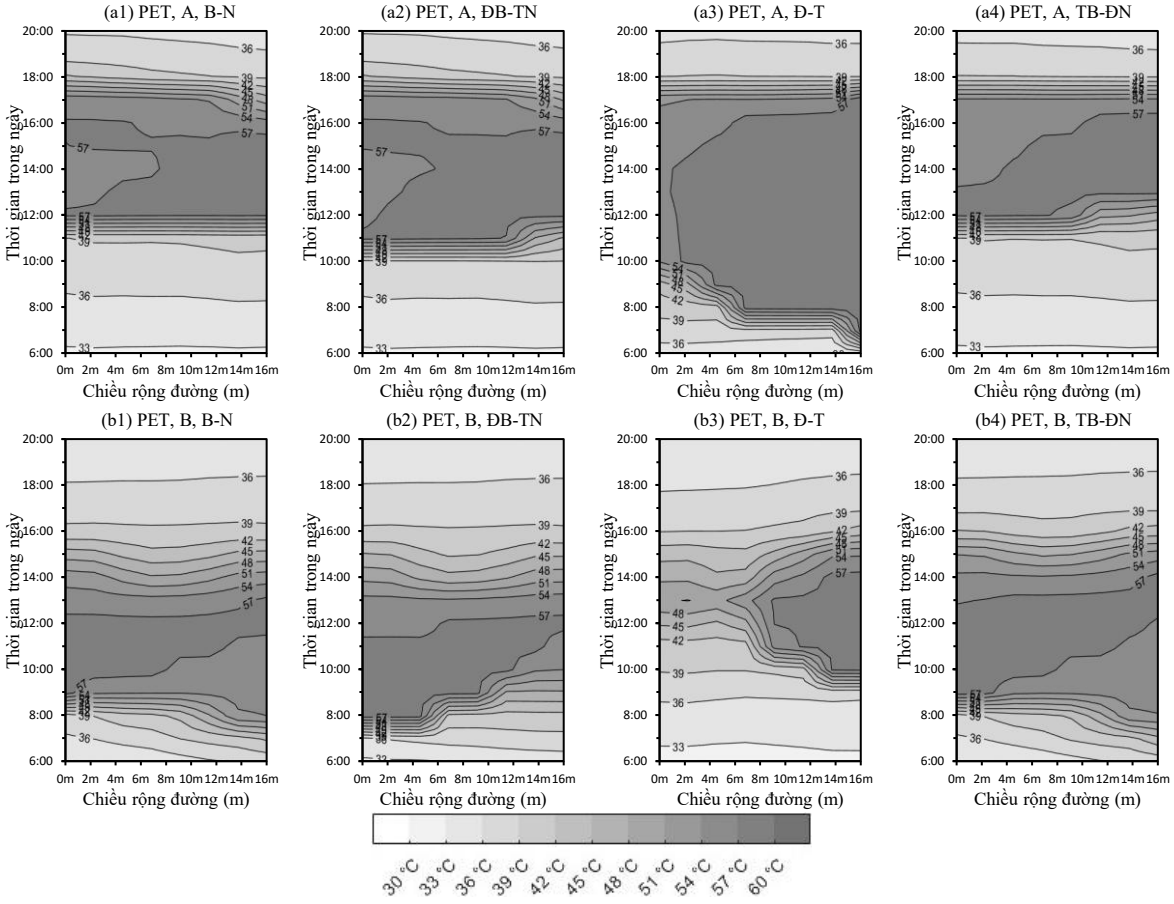


Figure 3.2: Spatial and temporal variations of PET at (a) street surface A and (b) street surface B across four street orientations.

In canyon model A, the shading effect generated by high-rise buildings during the morning assists in maintaining a relatively stable PET profile. However, this thermal advantage is no longer evidently sustained into the afternoon. Conversely, in the three B canyons, where high-rise structures intercept solar radiation during the afternoon, the severe PET zones within this timeframe are significantly ameliorated. Along the East-West orientation, the discrepancy in extreme PET zones between canyon A and canyon B is exceptionally pronounced. In canyon A, where high-rise buildings are positioned on the southern flank, the radiation shielding efficacy of these structures remains largely limited. The primary reason is that locating high-rise

buildings on the south fails to shade the northern street surface during the majority of the daytime. In contrast, within canyon B, the shadow footprint cast by high-rise buildings on the northern flank effectively shields the southern street surface throughout the day, thereby restricting heat accumulation and facilitating a drastic reduction in hot PET zones.

3.3. Impacts of Building Configuration

The spatial configuration of building massing plays a crucial role, significantly influencing outdoor thermal comfort conditions within urban canyons. The sprawling low-rise model covering the entire site is identified as the most detrimental to outdoor thermal comfort (Figure 3.3). The shadow footprint generated by this typology is insufficient to shield the street surface; this deficiency, coupled with a severe lack of natural land area for vegetation, significantly elevates local air temperatures. Transitioning the model to a compact tower configuration increases the available land area for greenery, thereby enabling this scenario to substantially improve air temperatures compared to the sprawling low-rise model. Nevertheless, owing to its open geometric structure, the tower typology fails to maintain a stable shadow zone, which results in a greater fluctuation amplitude for the mean radiant temperature. In contrast to the two aforementioned scenarios, the perimeter block configuration with an H/W ratio of 2 generates canyons characterized by lower and more stable air temperatures and mean radiant temperatures throughout the majority of the daytime. This H/W = 2 scenario emerges as the optimal configuration for outdoor thermal comfort, as its PET values consistently remain at the lowest level among the three investigated typologies.

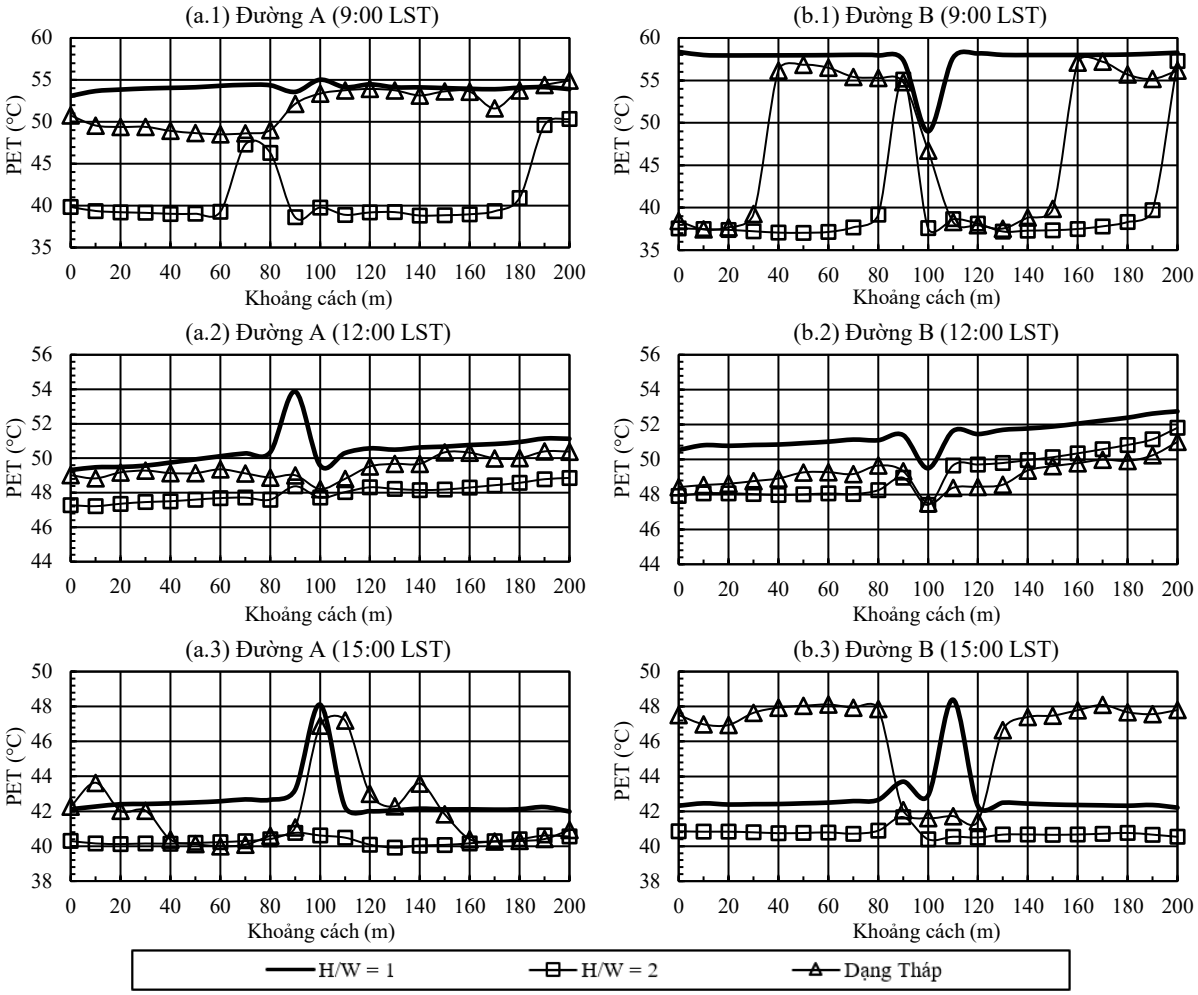


Figure 3.3: Distribution of PET across the three scenarios at 9:00, 12:00, and 15:00 LST along (a) Street A and (b) Street B.

3.4. Impacts of Urban Vegetation on the Existing Urban Areas

The final scenario is contextualized within a typical low-rise residential neighborhood to investigate the efficacy of greenery modification strategies applied to the existing urban fabric. The augmentation of street trees emerges as a highly effective strategy for mitigating extreme daytime PET values, primarily owing to the shading capacity of the tree canopy (Figure 3.4). Meanwhile, green facades exhibit maximum efficacy during nighttime hours by functioning as a thermal insulation layer. This intervention prevents building walls from accumulating heat during the daytime and subsequently emitting longwave radiation back into the environment, thereby facilitating rapid spatial cooling after sunset. In contrast, green roofs are

identified as the least effective strategy regarding thermal sensation at the pedestrian level. They produce negligible changes in the temperature profile relative to the baseline condition due to a complete lack of shading provision for ground level surfaces.

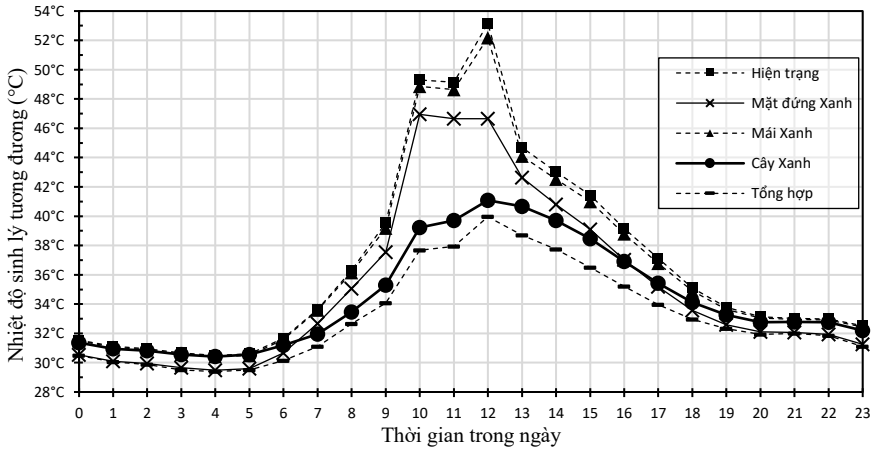


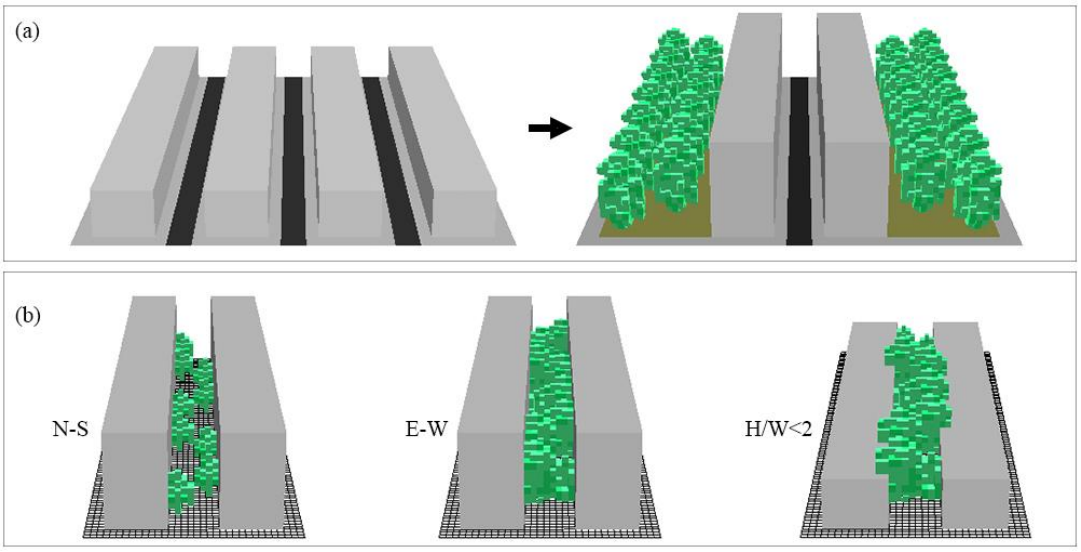
Figure 3.4: Diurnal variations of Physiological Equivalent Temperature (PET) across five scenarios: baseline vegetation, green facades, green roofs, tree augmentation, and the integrated scenario.

3.5. Climate Responsive Design Guidelines for Street Canyons in Da Nang

3.5.1. Guidelines Based on Street Orientation and Urban Canyon Aspect Ratio

The practical application of the canyon aspect ratio can be regarded as a spatial approach, facilitating the reduction of building coverage density and the restoration of natural green spaces to the urban environment. In contrast to the sprawling low-rise urban development model that excessively consumes land resources, a vertical spatial compaction strategy achieved through building mass consolidation significantly liberates surface land for vegetation. Furthermore, when high-rise building masses are planned based on the optimal H/W ratio, they establish a mutually beneficial passive shading mechanism. This mechanism directly prevents solar radiation from reaching surfaces with high thermal capacity, such as asphalt pavements and sidewalks, thereby strictly minimizing exposure duration and heat accumulation levels during peak hours.The shading and shadow casting efficacy of

the buildings fundamentally depends on the orientation and the aspect ratio of the street canyon. These are recognized as two critical urban geometric parameters that profoundly influence the variation of the outdoor thermal environment under the climatic conditions of Da Nang. For street axes that permit alternating shadow footprints on the surface throughout the daytime, the H/W = 2 ratio is considered the minimum threshold to ensure outdoor thermal comfort. Any aspect ratio levels below this threshold prove detrimental to outdoor thermal comfort conditions.



Hình 3.1: Design guidelines based on the urban canyon aspect ratio: (a) Mitigating sprawling residential configurations characterized by low canyon aspect ratios and high building coverage density, substituting them with structures at an optimal ratio to liberate land resources for vegetation; (b) Canyon aspect ratios of H/W ≥ 2 are identified as optimal; meanwhile, East-West street orientations and lower aspect ratio configurations necessitate maintaining high vegetation density to ensure adequate shading against direct solar radiation

3.5.2. Design Strategies for Linear High-rise Blocks

Under the climatic conditions of Da Nang, shading coverage plays a crucial role in ameliorating thermal comfort conditions. Increasing building height expands the shaded area, thereby broadening the radius of the optimal thermal comfort zone in the vicinity. Nevertheless, a design paradox warrants attention: while the PET amelioration efficacy is strictly confined within the boundaries of the shaded zone, the airflow obstruction impact of high-rise buildings exerts a substantially broader

spatial influence. Therefore, in scenarios involving continuous linear high-rise developments, augmenting massing porosity or fragmenting the building facade constitutes a necessary design requirement. In this context, adapting the architectural morphology towards a 'podium and tower' configuration yields optimal microclimate efficacy. Establishing a podium corresponding to the $H/W \geq 2$ threshold, combined with the strategy of rhythmically fragmenting the upper tower masses, creates corridors for natural ventilation to penetrate deeply into the inland areas. This design strategy holds particular significance for North-South street axes adjacent to the seafront. The spatial integration of the podium with the opposing building row sustains optimal street canyon proportions ($H/W \geq 2$); this simultaneously ensures the thermal environment quality within the canyon and prevents the 'wind wall' phenomenon against sea breezes blowing inland.

3.5.3. Guidelines for Spatial Building Configuration

In urban environments, the sprawling development model with a high surface coverage ratio is significantly depleting the land allocated for green infrastructure systems. In response to this situation, intervening in building massing through a vertical spatial compaction strategy is considered an effective approach. Additionally, calculating shadow trajectories to shield surfaces with high thermal mass, such as asphalt roads and pavements, by utilizing the passive shading mechanism of buildings, can be considered the first step in controlling heat accumulation. The study recommends replacing sprawling low-rise structures with linear building models with controlled heights to establish an optimal street canyon geometry. This massing strategy not only ensures the maintenance of the required green space area on-site but also maximizes the mutual shading effect of the buildings on surrounding radiation-absorbing surfaces. In terms of spatial composition, the massing solution can adopt a closed perimeter block model with uniform height. When two building blocks are aligned along the same axis and

spaced apart, they form an internal urban canyon with an optimal geometric ratio threshold of H/W ≥ 2. Thanks to the mutual shading effect between the two building strips, the core space enclosed between the blocks consistently maintains the necessary amount of shade, helping to shield surfaces from direct solar radiation and ensuring a better thermal comfort environment.

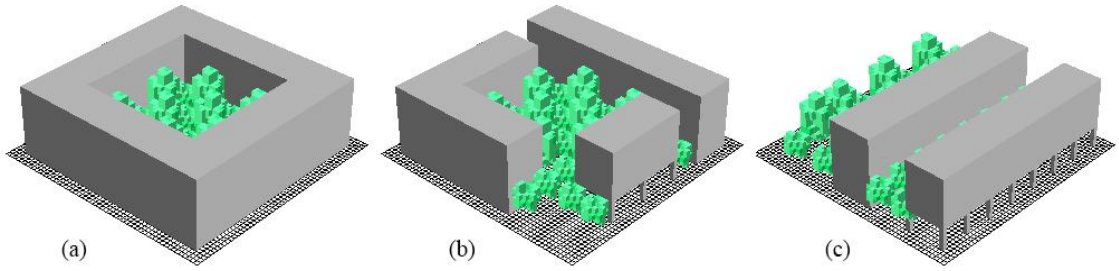


Figure 3.5: Massing design guidelines: Reduce sprawling low-rise structures, promote building forms with an H/W = 2 ratio and low building density: (a) Perimeter block, (b) Discontinuous perimeter block, and (c) Paired blocks.

3.5.4. Guidelines for building solid-void elements

Based on the research results, establishing a setback between two building blocks at a distance equal to half the building height is a prerequisite for maintaining the ideal street canyon ratio. Although effective in improving thermal comfort, maintaining two continuous, solid architectural volumes inadvertently creates an enclosed canyon, generating visual-psychological pressure and reducing the quality of spatial perception. To resolve the conflict between microclimatic performance and visual experience, the study proposes several massing compositions that play a decisive role in optimizing the shaded area on the surrounding ground environment. The first category relates to modifications on the building envelope surface. The presence of protruding elements such as balconies, overhangs, sun-shading louvers, or green vertical facades all help increase the passive shading area on the surrounding ground space. In cross-section, these protruding components re-establish a new width distance between the two building blocks, thereby allowing the main body of the building to be set back further inward while still maintaining the original canyon

ratio. Alongside the modification of the building envelope, the flexible utilization of architectural voids is also an important spatial organization solution. When a void is integrated at the base, the space acts as a transitional buffer zone between the interior and exterior of the building. This area can become a public space, helping to increase social interaction. On the other hand, when the voids are shifted to higher floors, the building mass will develop in a stepped (or terraced) form, creating the premise for organizing garden spaces right within the building. At a more radical level of intervention, the design can apply the solution of completely freeing up the ground floor plan. In this scenario, the building mass can be elevated using a column system (pilotis), allowing the spaces at the front and back of the building to be interconnected. This is an optimal scenario, as it can create open spaces for natural ventilation for the pedestrian area.

3.5.5. Design orientation for retrofitting existing street canyons

For existing street canyons, the challenge of climate adaptation is no longer about reorienting streets or reorganizing building massing, but rather applying selective interventions to the pre-existing urban morphology. The highest retrofitting priority is assigned to East-West oriented axes, particularly in segments with high pedestrian volume, concentrated commercial activities, or intensive public space utilization. This is followed by Northwest-Southeast street canyons, due to the fact that hot zones in these areas are prolonged until the late afternoon. Finally, for North-South oriented routes, improvement strategies should focus on increasing shading during the hours of peak solar altitude, rather than on widespread interventions. In street canyons with a low geometric ratio ($H/W < 1.5$), or those with buildings on only one side of the street, increasing the density of sidewalk trees is the most optimal intervention solution. The shading mechanism provided by tree canopies helps to significantly mitigate the amount of direct solar radiation reaching the pavement surface below.

3.5.6. Study limitations and future research

The primary focus of this study is the analysis of urban geometric factors within the climatic context of Da Nang city. Other elements, such as specific vegetation types or the incorporation of water bodies, were not addressed in this research. Therefore, more in-depth studies are required to evaluate the impact of these elements across specific street canyon ratio scenarios.

Additionally, due to the relatively complex characteristics of wind directions during the hot months in Da Nang, the study established a default assumption where the wind direction is perpendicular to the street axis in the urban canyon scenarios. During the hot months of the year (from June to August), morning wind directions in the city exhibit significant fluctuations. Given this difficult-to-control uncertainty, to minimize confounding variables and ensure consistency when comparing different street orientations, the study opted to isolate this factor by assuming a wind direction that is constantly perpendicular to the street axis across all simulation scenarios. Consequently, to fully assess the influence of this aerodynamic factor, further research is needed to investigate the specific impacts of varying wind directions within each street orientation scenario.

Finally, to assess the comprehensiveness and feasibility of the derived results, the temporal limitations of the model require further consideration. Aiming to focus on the challenge of improving the thermal environment, all input parameters and investigated scenarios were established based on summer climate data, utilizing June, the hottest month, as the representative case. Consequently, to translate the current research findings into a set of flexible urban design guidelines, future studies need to broaden the temporal scope of the assessment.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study aims to evaluate the impact of street orientation and building height on outdoor thermal comfort at the pedestrian level in Da Nang. The conclusions of this study are drawn from simulation results, utilizing input microclimate parameters from June, the hottest month of the year in Da Nang.

The urban canyon ratio significantly influences the thermal indices within street canyons in Da Nang. Increasing the canyon ratio helps reduce air temperature, with the effect being most pronounced at noon. An increase in the canyon ratio also reduces the frequency of hot Tmrt and PET zones within the canyon. The highest canyon ratio (H/W = 2.5) yields the best improvement in thermal comfort. Conversely, H/W ratios below 2 consistently result in the most adverse conditions for outdoor thermal comfort.

Street orientation also has a significant impact on air temperatures in the urban canyons of Da Nang. Among the four street orientations, the North-South (N-S) orientation is recorded as the most favorable for outdoor thermal comfort. The two intermediate orientations, Northeast-Southwest (NE-SW) and Northwest-Southeast (NW-SE), exhibit many similarities to the N-S orientation, as buildings in these directions alternately shade the street surface throughout the day. Conversely, the East-West (E-W) orientation is considered the most disadvantageous among the four.

Regarding high-rise buildings, increasing their height helps expand the shaded area, thereby reducing direct solar radiation and mitigating temperature elevation. Canyons shaded by high-rise buildings during the morning or afternoon both record an effective reduction in hot Tmrt and PET zones. Nevertheless, in E-W oriented canyons, a distinct asymmetry in the hot PET zones is evident between the northern and southern street surfaces adjacent to the high-rise building.

The configuration of building massing also affects the outdoor thermal comfort conditions in adjacent street canyons. The low-rise building model uniformly distributed across the entire site is considered the most adverse for outdoor thermal comfort. When transitioning the model to a compact tower configuration, the land area allocated for greenery increases, thereby allowing this scenario to significantly improve the air temperature compared to the sprawling low-rise model. The perimeter block scenario with an H/W ratio greater than 2 generates canyons with lower and more stable air temperatures and mean radiant temperatures (Tmrt) for the majority of the day. This is also the most optimal scenario for outdoor thermal comfort, as the PET values in this case consistently remain at the lowest level among the three studied scenarios.

Finally, increasing vegetation is considered an effective solution to enhance thermal comfort under fixed urban geometric conditions. Meanwhile, the implementation of green facades has limited cooling effects in the morning but facilitates better cooling at night by preventing the walls from accumulating heat during the day and releasing long-wave radiation back into the environment at night. The use of green roofs is deemed the least effective strategy for improving thermal sensation at the pedestrian level, resulting in almost no change in thermal values compared to the baseline scenario, as they cannot provide shading for the street surface.

Recommendations

Regarding the urban canyon ratio, under the summer climatic conditions of Da Nang, H/W = 2.5 (the highest ratio) yields the best improvement in thermal comfort. Furthermore, the H/W = 2.0 threshold can be considered the minimum required level; ratios falling below this mark cause significant disadvantages for outdoor thermal comfort zones. Specifically for the East-West (E-W) orientation, even at the highest

ratio (H/W = 2.5), this threshold remains insufficient to mitigate the hot PET zones along this street orientation.

Regarding high-rise buildings, models such as the podium-tower configuration can deliver substantial solar radiation shielding efficiency while simultaneously allowing wind flows to pass through the structures. Podiums designed at an H/W ratio greater than 2, combined with the spatial interruption of the tower volumes above, not only ensure an optimal environment within the street canyon but also create corridors for natural ventilation to penetrate deep inland.

Regarding building massing, the application of a sprawling low-rise development model across the entire site reveals numerous limitations. Instead of being spread evenly across the site area, arranging buildings along the perimeter with an H/W ratio greater than 2 is considered an effective strategy. This approach allows the structures to cast a sufficiently wide shadow footprint to shield the street surface, while freeing up the ground-level space for the development of landscape greenery.

For urban areas with a fixed spatial morphology, increasing vegetation along the sidewalks is identified as the intervention method that yields the most pronounced effectiveness.

LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

1. Anh, N. H., & Dung, N. T. K. (2024). Impact of street orientation and canyon aspect ratio on outdoor thermal comfort in coastal low-rise residental areas. *National Scientific Conference*, ACEAT2024, ISBN 978-604-82-8109-0, pp. 276-282.

2. Anh, N. H., & Dung, N. T. K. (2025). Impacts of urban canyon aspect ratio and street orientation on microclimate and outdoor thermal comfort in Da Nang, Vietnam. *Journal of Construction*, ISSN 2734-9888, October 2025, pp. 66-70.

3. Anh, N. H., & Dung, N. T. K. (2025). Influence of building height on microclimate and outdoor thermal comfort: The case of Da Nang, Vietnam. *Journal of Construction*, ISSN 2734-9888, November 2025, pp. 65-69.