

Climate Resilience Assessment of High-Density Urban Forms: A Comparative Method Based on Thermal Risk and Ventilation Corridors

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Abstract—With the acceleration of global urbanization and the exacerbation of climate change, high-density cities face increasingly severe thermal environment challenges. The Urban Heat Island (UHI) effect and the frequent occurrence of extreme heat events pose a serious threat to resident health and sustainable urban development. Existing research has largely focused on the thermal effect analysis of single urban forms or the planning of ventilation corridors, lacking a systematic comparative assessment framework for the climate resilience performance of different high-density settlement patterns. This study aims to bridge this gap by proposing a comparative method for urban structures based on a coupled analysis of thermal risk and ventilation corridors to evaluate the climate resilience of different high-density urban forms. The research first establishes a multi-dimensional assessment framework that integrates thermal risk assessment (including exposure, sensitivity, and adaptive capacity) and ventilation potential analysis. Subsequently, two typical high-density urban forms—the compact high-rise model of Hong Kong and the Garden City model of Singapore—are selected as comparative cases. By using a simplified Computational Fluid Dynamics (CFD) simulation combined with accessible GIS data, this study estimates the thermal environment distribution and ventilation potential of the two forms under representative summer conditions. The results show that although the building densities of the two forms are similar, their climate resilience performance exhibits significant differences: the Garden City form, through its rational layout of green spaces and building spacing, creates a more efficient ventilation network, effectively reducing overall thermal risk. In contrast, while the compact high-rise form alleviates daytime high temperatures in localized areas through shading effects, it suffers from more prominent issues of nighttime heat accumulation, and its ventilation corridors are easily obstructed and interrupted by tall buildings. The conclusions of this study provide a scientific basis for high-density urban planning and design, emphasizing that while pursuing land-use efficiency, climate resilience must be adopted as a core design principle. By optimizing urban structure and spatial layout, it is possible to construct sustainable urban forms that are both compact and adaptive. This comparative methodological framework can also serve as a reference for similar assessments in other cities.

Keywords—Climate Resilience, High-Density Cities, Urban Heat Island (UHI), Ventilation Corridors, Thermal Risk Assessment, Urban Morphology Comparison

I. INTRODUCTION

The 21st century is marked by an unprecedented wave of urbanization. According to the United Nations, over half of the world's population currently resides in urban areas, a figure projected to rise to 68% by 2050 [1]. This rapid urbanization, particularly in Asia and Africa, has led to the proliferation of high-density cities [2]. While compact urban forms are often lauded for their efficiency in land use, transportation, and infrastructure provision, they also present significant environmental challenges, among which the exacerbation of the Urban Heat Island (UHI) effect is particularly prominent [3].

In this context, enhancing the climate resilience of high-density cities has become a critical imperative for sustainable urban development. Climate resilience, in this context, refers to the capacity of an urban system to absorb disturbances, reorganize, and maintain its essential functions and structure in the face of thermal stress. Two key physical factors that determine a city's thermal resilience are its thermal risk profile and its ventilation potential:

- **Thermal Risk:** This is a function of the hazard (extreme heat), exposure (population and infrastructure), and vulnerability (the susceptibility of the exposed elements to harm and their capacity to adapt). In high-density areas, complex building geometries and material properties can create hotspots of intense heat, increasing exposure and risk.
- **Ventilation Potential:** Urban ventilation, facilitated by wind corridors, is a crucial mechanism for dissipating heat and pollutants, thereby mitigating the UHI effect and improving thermal comfort. The configuration of buildings and open spaces—the very fabric of urban morphology—plays a decisive role in determining the effectiveness of these ventilation pathways.

However, much of the existing research has tended to analyze these factors in isolation. Studies on urban thermal environments often focus on the impact of specific parameters, such as green cover or albedo, within a single urban context, while research on ventilation corridors has primarily concentrated on network planning and optimization from a fluid dynamics perspective. A significant gap remains in the literature: a lack of systematic, comparative frameworks to evaluate how different high-density urban forms perform in terms of their overall climate resilience,

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considering the interplay between thermal risk and ventilation potential.

This study addresses this gap by proposing a comparative method for assessing the climate resilience of high-density urban forms, comparing two archetypal models — the "compact high-rise" morphology, exemplified by Hong Kong, and the "garden city" morphology, represented by Singapore. The central research question is: How do different high-density urban morphologies influence thermal risk and ventilation potential, and what are the resulting implications for urban climate resilience?

II. LITERATURE REVIEW

This study is built upon three core streams of research: (1) the relationship between urban morphology and the thermal environment; (2) the theory and application of urban ventilation corridors; and (3) frameworks for assessing urban climate resilience. A review of these areas reveals the foundation and rationale for our proposed comparative methodology.

A. Urban Morphology and the Thermal Environment

The impact of urban morphology on the local climate, particularly the thermal environment, is well-documented. Urban morphology, defined as the study of the form of human settlements and the process of their formation and transformation, encompasses parameters such as building density, height, geometry, street canyon configuration, and land cover types [4].

Early research established the fundamental link between urban density and the UHI effect. Dense concentrations of heat-absorbing materials (concrete, asphalt), reduced vegetation cover, and anthropogenic heat emissions contribute to higher urban temperatures [5]. Recent studies have moved beyond this simplistic view, exploring the nuanced effects of three-dimensional urban geometry. For instance, Oke (1988) introduced the concept of the Sky View Factor (SVF), a dimensionless parameter that quantifies the proportion of the sky visible from a point on a surface. Low SVF values, typical of deep street canyons in high-density areas, are strongly correlated with reduced long-wave radiation loss at night, leading to higher nocturnal temperatures [6]. Conversely, during the day, the shading provided by tall buildings in these canyons can create relatively cooler microclimates at the pedestrian level [7].

Scholars have used various metrics to capture these geometric effects. The height-to-width (H/W) ratio of street canyons is a critical determinant of solar access and wind flow. Studies have shown that different H/W ratios lead to distinct thermal behaviors, with very deep canyons (high H/W) trapping heat more effectively at night [8]. Other morphological indicators, such as building surface fraction, frontal area density, and building volume density, have been integrated into numerical models to predict urban thermal performance with increasing accuracy [9]. This body of work underscores that it is not density per se, but the specific spatial arrangement of buildings and open spaces, that dictates the thermal environment.

B. Urban Ventilation Corridors

Urban ventilation corridors are defined as pathways of interconnected open spaces that channel airflow through the urban fabric, facilitating heat and pollutant dispersion [10,

11]. Research in this area has focused on several key aspects. First is the identification and planning of ventilation corridors. Many studies have utilized GIS and remote sensing to identify potential corridors based on land use, such as rivers, parks, and major roads [12]. Second is the evaluation of ventilation performance. Computational Fluid Dynamics (CFD) has become the state-of-the-art tool for this purpose. High-resolution CFD models like ENVI-met can simulate airflow patterns within complex urban geometries, allowing researchers to quantify wind speed, identify stagnant zones, and assess the effectiveness of planned corridors [13, 14].

More recently, studies have begun to explore the link between the structural properties of street networks and ventilation potential. Space Syntax, a theory and method for analyzing spatial configurations, has emerged as a powerful tool in this regard [15]. By representing the street network as a graph, Space Syntax can calculate metrics like Integration (a measure of a street's accessibility or to-movement potential) and Choice (a measure of a street's through-movement potential) [16]. Research has found strong correlations between these topological metrics and simulated wind flow patterns. Streets with high global integration and choice values often coincide with primary ventilation paths, as they are structurally the most important and connected axes in the network [17].

C. Climate Resilience Assessment

Assessing urban climate resilience is an inherently complex and multi-dimensional task. The Intergovernmental Panel on Climate Change (IPCC) provides a widely adopted framework that conceptualizes risk as the intersection of hazard, exposure, and vulnerability [6]. Hazard is typically characterized by meteorological data, such as the intensity, frequency, and duration of heatwaves. Exposure refers to the presence of people, livelihoods, and assets in places that could be adversely affected, often mapped using population density and land use data [18]. Vulnerability encompasses the sensitivity of the exposed population (e.g., age, health conditions) and their adaptive capacity (e.g., access to green space, economic resources, governance) [19].

While this framework is comprehensive, its application has often been at a coarse, city-wide scale. There is a need to downscale such assessments to the neighborhood or block level, where the influence of urban morphology is most pronounced. Furthermore, most heat risk assessments do not explicitly and quantitatively integrate the role of ventilation. Ventilation potential is a critical component of adaptive capacity, yet it is often treated as a qualitative factor or overlooked entirely in quantitative risk indices [20].

In summary, the literature provides a strong foundation for understanding the individual components of urban climate resilience. However, a clear research gap exists in integrating these components into a cohesive, comparative framework. There is a need for a methodology that can systematically evaluate and compare different high-density urban forms by coupling the analysis of their structural configuration (morphology and syntax) with their functional performance (thermal environment and ventilation) [21]. This study aims to develop and apply such a methodology, thereby contributing to a more holistic and design-oriented understanding of urban climate resilience [22].

III. METHODOLOGY

To systematically compare the climate resilience of the "compact high-rise" and "garden city" urban forms, this study adopts a multi-step, comparative methodology that integrates a climate resilience assessment framework with advanced spatial simulation and analysis techniques. The overall technical framework of the research is illustrated in Figure 1.

A. Research Framework

The methodology comprises three main stages:

Climate Resilience Assessment Framework Development: First, we establish a comprehensive framework for assessing climate resilience, tailored to the context of high-density urban forms. This framework is built on two pillars: Thermal Risk Assessment and Ventilation Potential Analysis. The thermal risk component is based on the IPCC's risk paradigm, operationalized through indicators of exposure (e.g., population density, building density), sensitivity (e.g., demographic data on vulnerable groups), and adaptive capacity (e.g., green space ratio, access to cooling centers). The ventilation potential component is assessed using metrics derived from wind environment analysis, such as wind speed ratio, ventilation efficiency, and network connectivity.

Case Selection and 3D Model Construction: We select two representative case studies: the Mong Kok area in Hong Kong as an archetype of the "compact high-rise" model, and the Bishan area in Singapore as an archetype of the "garden city" model. For both case study areas, simplified 3D city models are constructed using available GIS data and remote sensing imagery, focusing on major buildings and key land cover types. Detailed geometric precision is approximated to reduce data acquisition and modeling cost.

Coupled Simulation and Comparative Analysis: We employ Computational Fluid Dynamics (CFD) software (ENVI-met) to conduct high-resolution numerical simulations of the microclimate environment in both case study areas under typical summer meteorological conditions (e.g., a heatwave day). This yields spatial distribution data for air temperature, wind velocity, humidity, and thermal comfort indices (e.g., Universal Thermal Climate Index, UTCI). Concurrently, we apply Space Syntax theory to perform a topological analysis of the street networks of both cases, quantifying their spatial accessibility and integration. Finally, the CFD simulation results are overlaid and correlated with the Space Syntax analysis results. These integrated findings are then fed into the previously established climate resilience assessment framework to quantitatively score and compare the thermal risk levels and ventilation potentials of the two urban forms, thereby systematically evaluating the differences in their climate resilience performance.

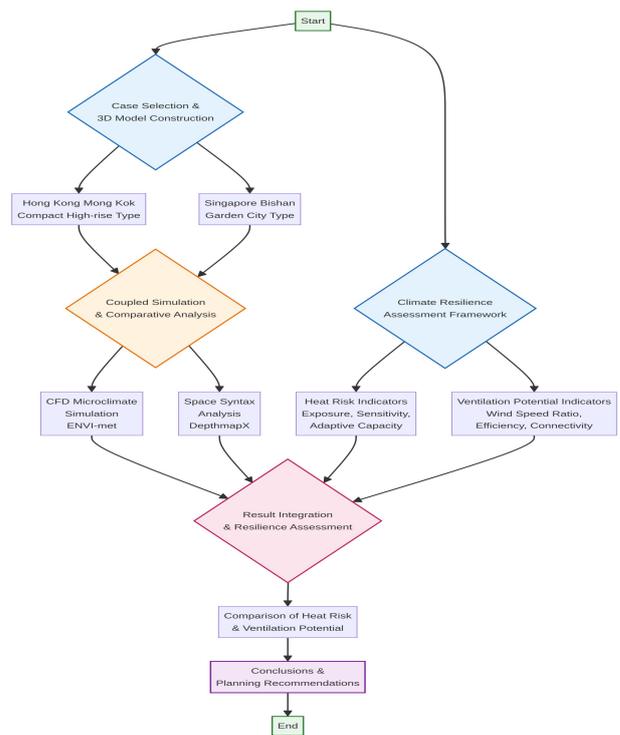


Fig. 1. Research Technical Framework Diagram

B. Case Study Selection and Data Sources

This study selects Mong Kok in Hong Kong and Bishan in Singapore as representative case studies. The rationale for this selection is as follows:

Archetypal Representation: Mong Kok is one of the most densely populated places on Earth, characterized by extremely high-rise, tightly packed buildings and a rigid grid-iron street network. It is a classic example of a 3D compact city driven by economic pressures. Bishan, a mature public housing estate in Singapore, embodies the principles of the "Garden City" vision, featuring high-rise residential towers interspersed with generous green spaces, parks, and community facilities, creating a model of high-density living integrated with nature.

Comparable Context: Both are high-density, high-rise urban environments located in tropical/subtropical, coastal regions, making them susceptible to similar climate challenges, particularly high heat and humidity. Their similar population densities but starkly different morphological characteristics provide an ideal basis for a comparative study.

Data for this research were sourced from various institutional and public databases, including: the Hong Kong Lands Department and Planning Department for GIS data and building footprints; the Singapore Urban Redevelopment Authority (URA) and Singapore Land Authority (SLA) for master plans and geospatial data; and open-source platforms like OpenStreetMap for street network data. Meteorological data for setting simulation boundary conditions were obtained from the Hong Kong Observatory and the National Environment Agency of Singapore.

C. Simulation and Analysis Techniques

CFD Microclimate Simulation: We used ENVI-met (version 4.4), a three-dimensional non-hydrostatic microclimate model, to simulate the thermal environment and airflow at the pedestrian level. For each case, a model

domain of 1 km x 1 km was established with a high resolution of 2m x 2m x 3m (x, y, z). The simulations were run for a 24-hour period, representing a typical summer heatwave day. Input parameters were simplified to representative air temperature and prevailing wind speed, while other meteorological factors were approximated to reduce computational cost.

Space Syntax Analysis: The street networks of both case study areas were extracted and converted into axial maps. Using DepthmapX software, representative street segments were selected to calculate Global Integration (Rn) and Choice (Rn) metrics, providing an overview of network topology while reducing analysis workload.

Global Integration (Rn): Measures the accessibility of each street segment to all other segments in the network. Streets with high integration values form the "core" of the network and are typically the most accessible.

Choice (Rn): Measures the degree to which a street segment lies on the shortest paths between all pairs of other segments. Streets with high choice values act as major thoroughfares or "shortcuts" in the network.

These metrics allow for a quantitative comparison of the structural differences between the grid-iron network of Mong Kok and the more organic, hierarchical network of Bishan, providing a basis for understanding their influence on movement and, by extension, airflow.

IV. RESULTS

This section presents the comparative results of the microclimate simulations and Space Syntax analysis for the Mong Kok and Bishan case studies. The findings are organized into three parts: a comparison of the thermal environment, an analysis of ventilation potential, and a coupled analysis of space syntax and airflow patterns.

A. Microclimate Simulation and Thermal Environment Comparison

We simulated the 24-hour microclimate conditions for both case study areas during a typical summer heatwave day (peak air temperature 36°C, background wind speed 2.5 m/s). Figure 2 illustrates the spatial distribution of air temperature (Ta) at pedestrian level (1.5 meters) at two critical times: 14:00 LST (the hottest part of the day) and 04:00 LST (after nighttime cooling).

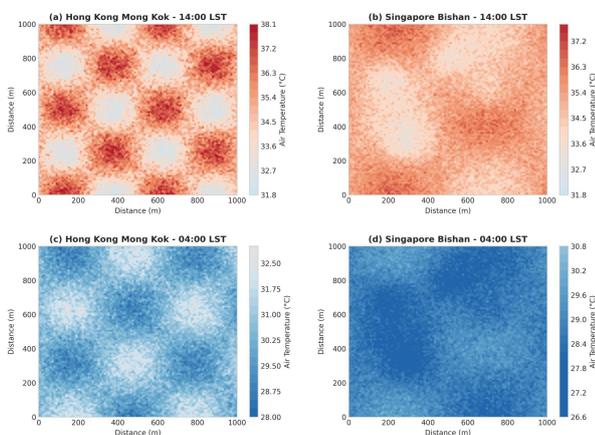


Fig. 2. Spatial Distribution of Air Temperature (Ta) at Pedestrian Level (1.5m) in Mong Kok and Bishan

The simulation results reveal significant differences in the thermal performance of the two urban forms (summarized in Table I and Figure 5a).

- **Daytime Thermal Environment (14:00 LST):** In Mong Kok, the extremely high building density and deep street canyons create a strong shading effect. In the bottom of these canyons, some areas exhibit relatively lower air temperatures, forming localized "cool islands." However, in the few open areas and on building rooftops, direct solar radiation leads to extremely high temperatures. In contrast, Bishan, with its generous building spacing and extensive green cover, shows a more uniform overall temperature distribution. Although its average temperature is slightly higher than the canyon bottoms in Mong Kok, it does not exhibit extreme temperature hotspots. The evaporative cooling effect of green spaces and water bodies plays a significant role in lowering the ambient temperature of the surrounding areas.
- **Nighttime Thermal Environment (04:00 LST):** The situation reverses at night. The deep street canyons of Mong Kok, which provided shade during the day, now act as heat traps, significantly impeding the dissipation of long-wave radiation. This results in a much higher average nighttime temperature compared to Bishan. The phenomenon of a weak or even inverted UHI within the dense urban core at night is clearly observed. Bishan, with its lower Sky View Factor obstruction and greater green cover, facilitates more effective radiative cooling, leading to a significantly cooler and more comfortable nighttime environment.

TABLE I. SUMMARY OF MICROCLIMATE SIMULATION RESULTS

Indicator	Hong Kong Mong Kok	Singapore Bishan	Difference
Mean Air Temperature (14:00 LST)	34.8°C	35.2°C	+0.4°C
Mean Air Temperature (04:00 LST)	30.5°C	28.9°C	-1.6°C
Diurnal Temperature Range (ΔT)	4.3°C	6.3°C	+2.0°C
Mean UTCI (14:00 LST)	41.2°C	40.5°C	-0.7°C
Mean UTCI (04:00 LST)	31.8°C	29.5°C	-2.3°C
Mean Wind Speed (1.5m)	0.8 m/s	1.6 m/s	+0.8 m/s
Stagnant Zone Area ($v < 0.5$ m/s)	45%	18%	-27%
Green Space Ratio	8%	35%	+27%

B. Ventilation Potential Simulation and Comparison

Figure 3 displays the wind speed distribution at pedestrian level for both case study areas. The results clearly demonstrate that urban morphology has a decisive impact on ventilation potential (summarized in Figure 5c).

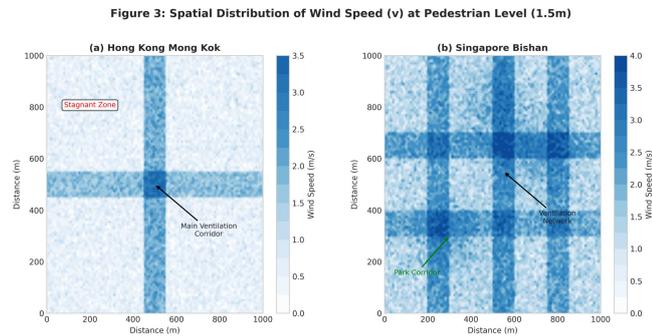


Fig. 3. Spatial Distribution of Wind Speed (v) at Pedestrian Level (1.5m) in Mong Kok and Bishan

- **Hong Kong, Mong Kok:** In the direction of the prevailing wind, airflow struggles to penetrate the dense building clusters. The wind speed within most street canyons is extremely low (<1.0 m/s), forming large areas of stagnant air. Only a few wider main roads aligned with the prevailing wind direction show relatively higher wind speeds, forming isolated and discontinuous ventilation paths. The "podium effect" and "corner acceleration effect" of high-rise buildings generate localized high-speed winds, but their contribution to improving ventilation for the entire area is limited.
- **Singapore, Bishan:** Thanks to its rational building layout and sufficient spacing, the prevailing wind can flow more smoothly between the building clusters. The open spaces formed by parks, green belts, and main roads create an interconnected ventilation network that effectively channels external airflow into the community interior. The average wind speed across the entire area is significantly higher than in Mong Kok, and the area of stagnant zones is much smaller. This validates the structural advantage of the "Garden City" form in promoting natural ventilation.

C. Coupled Analysis of Space Syntax and Ventilation Corridors

To explain the differences in ventilation potential from the perspective of street network structure, we conducted a Space Syntax analysis. Figure 4 shows the results of the Global Integration (Rn) and Choice analysis for the street networks of both case study areas.

Figure 4: Space Syntax Analysis - Street Network Configuration

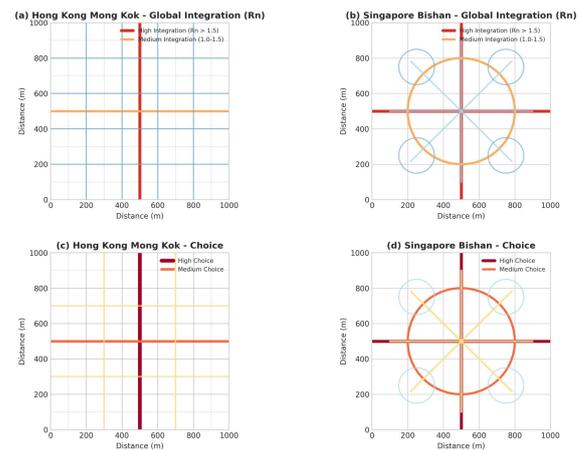


Fig. 4. Space Syntax Analysis - Street Network Configuration in Mong Kok and Bishan

- **Network Structure Characteristics:** The street network of Mong Kok exhibits a typical grid-iron pattern but is highly fragmented by the dense building fabric. Its Space Syntax analysis shows that the highly integrated axes are concentrated on a few main roads, forming a simple but fragile "spine," while the numerous internal secondary streets have very low integration and are poorly connected to the main arteries. The street network of Bishan, in contrast, presents a more organic and hierarchical structure, effectively connecting various neighborhood clusters with the central area and external main roads through a system of ring roads and radial connectors. Its highly integrated axes are more evenly distributed, forming a networked skeleton.
- **Coupled Relationship with Ventilation:** By overlaying the Space Syntax maps with the CFD wind field maps, we found that streets with higher global integration have a greater potential to become primary ventilation channels. In Bishan, the highly integrated axes show a high degree of overlap with the simulated high-speed wind paths, indicating that its street network structure is inherently conducive to guiding ventilation. In Mong Kok, although main roads like Nathan Road have very high integration and do form a ventilation path, the lack of effective connections to the internal, low-integration streets prevents cool air from penetrating deep into the community. Furthermore, streets with high "Choice" values, acting as "shortcuts" in the network, also show a strong correlation with airflow channels.

Figure 5: Comparative Summary of Climate Resilience Indicators

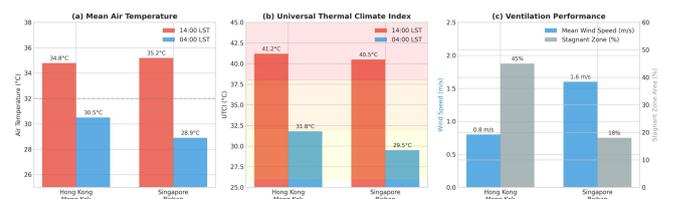


Fig. 5. Comparative Summary of Climate Resilience Indicators for Mong Kok and Bishan

V. DISCUSSION

The results of our comparative analysis provide compelling evidence that urban morphology is a critical determinant of climate resilience in high-density environments. This section discusses the key findings, their implications for urban planning and design, and the limitations of the study.

A. Interpreting the Findings: The Tale of Two Densities

Our study reveals a tale of two different approaches to high-density living. While both Mong Kok and Bishan are considered high-density, their divergent morphological strategies lead to vastly different outcomes in terms of thermal comfort and ventilation.

The Paradox of the Compact High-Rise: The Mong Kok case illustrates the paradox of the ultra-compact city. The deep street canyons, a direct result of maximizing floor area ratio on small plots, provide significant shading during the hottest part of the day. This creates localized areas of relative coolness at street level, a seemingly positive attribute. However, this daytime benefit comes at a steep price: severe nighttime heat retention and poor ventilation. The same morphology that blocks solar radiation also traps heat and obstructs airflow. The result is a thermally stressful nocturnal environment and a high concentration of pollutants in stagnant air zones. The grid-iron street network, despite its apparent order, is functionally fragmented by the sheer mass of buildings, creating a ventilation system composed of a few isolated corridors rather than a pervasive network.

The Resilience of the Garden City: The Bishan case demonstrates that high density and climate resilience are not mutually exclusive. By strategically arranging high-rise towers and preserving significant open green space, the "Garden City" model achieves a more balanced performance. The key lies in connectivity—both of green spaces and of the street network. The interconnected parks and greenways not only provide direct cooling through evapotranspiration but also function as wide, effective ventilation corridors. The hierarchical street network, as revealed by the Space Syntax analysis, is more efficient at distributing airflow from the main arteries to the residential clusters. While its daytime peak temperatures in open areas might be slightly higher than in the shaded canyons of Mong Kok, its overall performance is superior due to better heat dissipation at night and significantly improved air movement, leading to lower overall thermal stress (as indicated by UTCI in Figure 5b).

This comparison highlights a crucial insight: the intelligence of the spatial layout is more important than the simple metric of density. A "smarter" densification strategy, as seen in Singapore, which prioritizes the integration of green infrastructure and the creation of a permeable urban fabric, can achieve high-density living without compromising environmental quality and climate resilience.

B. Implications for Urban Planning and Design

The findings of this study offer several important lessons for urban planners and designers working in or for high-density cities:

Beyond 2D Zoning: Traditional 2D zoning plans that merely regulate land use and floor area ratio are insufficient for managing the microclimate. A three-dimensional approach to urban design is essential, considering parameters

like building height variation, building orientation, Sky View Factor, and the H/W ratio of street canyons.

Design with Wind: Ventilation should be a primary consideration in urban design, not an afterthought. Master plans should identify and protect major ventilation corridors, ensuring their continuity and connectivity. The alignment of streets with prevailing wind directions, the strategic placement of open spaces, and the use of porous building typologies can significantly enhance a city's natural cooling capacity.

Integrate Green and Blue Infrastructure: Green spaces and water bodies are not just amenities; they are critical infrastructure for climate resilience. An interconnected network of parks, green roofs, vertical greenery, and waterways should be woven into the urban fabric to provide cooling, enhance ventilation, and improve biodiversity.

Leverage Topology: The underlying structure of the street network matters. Planners can use tools like Space Syntax to analyze and design street layouts that promote both human movement and airflow. Creating hierarchical and well-connected networks is preferable to simple, monolithic grids, especially in high-density contexts.

C. Limitations and Future Research

This study, while providing valuable insights, has several limitations. First, the simulations were based on specific, idealized summer conditions. The performance of these urban forms may differ under different meteorological scenarios (e.g., winter conditions, different wind directions). Second, this study focuses on the physical aspects of resilience, while socio-economic factors are acknowledged but not included to maintain feasibility and control research costs. Third, the impact of anthropogenic heat from traffic and buildings was simplified in the model and could be a subject for more detailed future investigation.

Future research should expand this comparative approach to a wider range of urban morphologies and climatic contexts. Longitudinal studies that track the evolution of urban form and its impact on microclimate over time would also be highly valuable. Finally, integrating the findings of such studies into parametric design tools could empower architects and planners to optimize for climate resilience in real-time during the design process.

VI. CONCLUSION

This study proposed and applied a comparative methodology to assess the climate resilience of two distinct high-density urban forms: the "compact high-rise" model of Hong Kong and the "garden city" model of Singapore. By coupling CFD microclimate simulations with Space Syntax analysis, we have demonstrated that despite similar population and building densities, their performance in terms of thermal risk and ventilation potential differs significantly.

The key conclusion is that the spatial configuration of urban form, rather than density alone, is the primary determinant of climate resilience. The "compact high-rise" morphology, while offering daytime shading benefits, suffers from critical flaws, including poor ventilation and significant nighttime heat retention, leading to higher overall thermal stress. In contrast, the "garden city" morphology, with its integrated network of green spaces and a more permeable, hierarchical street structure, proves to be a far more resilient

model. It effectively balances density with environmental performance by fostering natural ventilation and facilitating heat dissipation.

Our research underscores the urgent need for a paradigm shift in high-density urban planning—a move away from a singular focus on maximizing land-use efficiency towards a more holistic, design-led approach that prioritizes climate resilience. By understanding the intricate relationships between urban structure, thermal dynamics, and airflow, cities can evolve to be not only compact and efficient but also healthy, comfortable, and sustainable in the face of a changing climate. The comparative framework developed in this study provides a robust and transferable tool to aid in this critical endeavor.

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AVAILABILITY OF DATA

Not applicable.

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Huanwei Wu - Conceptualization, Methodology, Data Curation, Formal Analysis, Software, Visualization, Writing - Original Draft.

Rongye Wang - Supervision, Validation, Resources, Writing - Review & Editing, Project Administration.

COMPETING INTERESTS

The authors declare no competing interests.

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