Resilience through Built Morphology: A CFD-Based Evaluation of Wind-Driven Urban Heat Island Adaptation in Residential Blocks of Bangalore

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Abstract - Rapid urban densification in Indian cities has intensified Urban Heat Island (UHI) effects, particularly at the residential block scale where everyday life unfolds. While conventional mitigation strategies emphasize vegetation, material substitution, and technological add-ons, the role of built morphology in regulating airflow and enabling convective heat dissipation remains underexplored. This research positions residential block morphology as an active climatic infrastructure capable of influencing wind behaviour and, by extension, urban thermal resilience.

The study comparatively evaluates two morphologically contrasting residential urban blocks in Bangalore: a high-density compact configuration (Case A) and a low-density porous configuration (Case B). Computational Fluid Dynamics (CFD) simulations were conducted using Vayu Pravaah to analyze air velocity magnitude and static pressure distribution across multiple vertical sections under identical wind conditions (300° from North, 15 m/s reference velocity).

Results indicate that compact morphologies generate strong windward pressure build-up, deep leeward suction zones, and extended stagnation pockets, thereby limiting airflow penetration and pressure equalization. In contrast, porous configurations demonstrate distributed airflow pathways, reduced aerodynamic resistance, and improved internal ventilation continuity. The findings establish wind behaviour as a measurable intermediary linking built form to convective heat dissipation potential.

The study contributes a morphology–ventilation–resilience framework that repositions architectural configuration as a foundational climate adaptation strategy at the urban block scale.

Keywords: Urban Heat Island, Built Morphology, CFD Simulation, Wind Behaviour, Ventilation Efficiency, Urban Resilience.

1.INTRODUCTION

Urban Heat Island (UHI) intensity has become a defining environmental challenge in rapidly growing cities such as Bangalore. As densification increases and built mass expands, urban microclimates are increasingly shaped by architectural form rather than natural terrain. Traditional research has primarily examined surface temperature mapping and vegetation coverage; however, airflow regulation through spatial configuration remains insufficiently theorized at the residential block scale.

Built morphology influences wind penetration, pressure gradients, stagnation zones, and wake formation. These aerodynamic conditions directly affect convective heat dissipation, which is critical for reducing localized thermal accumulation. If airflow is obstructed due to compact massing and limited spacing, heat removal becomes inefficient, intensifying thermal stress. Conversely, porous configurations can enable wind circulation and pressure equalization.

This study evaluates how two contrasting residential morphologies mediate wind behaviour and explores how these aerodynamic outcomes contribute to Urban Heat Island resilience. By using CFD-based simulation under controlled environmental parameters, the research establishes wind behaviour as a measurable performance indicator linking architectural configuration to thermal adaptation.

2. Body of Paper

2.1 Research Context and Conceptual Framework

The research adopts a morphology–ventilation–resilience framework in which built form acts as the primary spatial determinant influencing wind behaviour. Wind behaviour is assessed through two measurable variables: velocity magnitude (m/s) and static pressure distribution (Pa).

These aerodynamic outputs determine ventilation efficiency and convective heat dissipation capacity.

Built Morphology
↓
Wind Behaviour (Velocity + Pressure)
↓
Ventilation Efficiency
↓
Convective Heat Dissipation
↓
Urban Heat Island Resilience

This framework positions wind behaviour as the measurable intermediary between architecture and thermal performance.

2.2 Study Area and Case Selection

Two residential urban blocks in Bangalore were selected based on contrasting morphological characteristics.

Case A: High-density, compact urban block
Case B: Low-density, porous urban block

Both blocks are comparable in overall site scale but differ significantly in built coverage, spacing, and mass continuity. Simulations were conducted under identical boundary conditions to isolate the effect of morphology on airflow behaviour.

Figure 1: Case A: High Density

Figure 2: Case B: Low Density

2.3 Simulation Environment and Parameters

Simulations were conducted using Vayu Pravaah CFD software under the following parameters:

- Wind direction: 300° from North
- Reference wind velocity: 15 m/s
- Reference wind height: 4 m
- Surrounding environment: Villages (as per simulation setting)

Multiple horizontal sections were analyzed at varying Z-normal positions to examine vertical airflow variation:

0.01 m
~1.5–2 m (pedestrian height)
~3–4 m
~5–6 m
~7–8 m

2.4 Velocity Magnitude Analysis – Case A

Ground-level velocity contours (0.01 m) indicate strong obstruction at windward edges and extensive low-velocity stagnation zones within interior spaces.

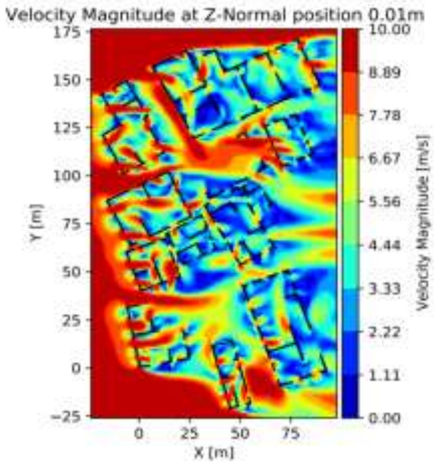

Figure 3: Velocity Magnitude at 0.01m

At pedestrian height (~1.89 m), airflow penetration remains limited, with elongated wake zones forming behind closely spaced masses.

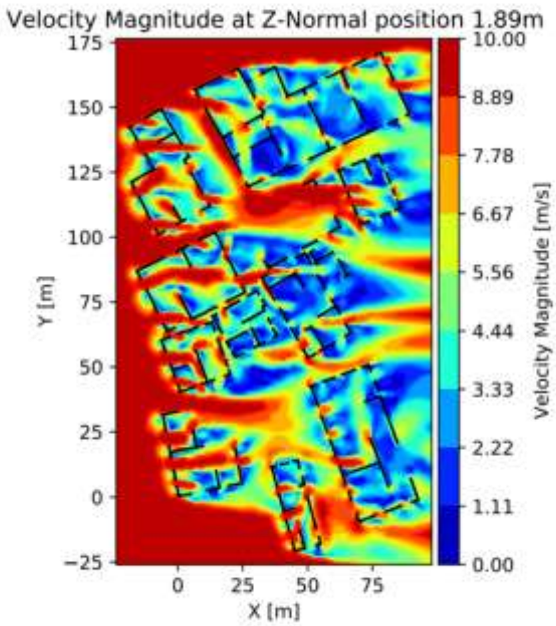

Figure 4: Velocity Magnitude at 1.89m

At higher sections (~3.76 m and above), high-velocity streams remain primarily confined to outer corridors, while internal regions exhibit reduced ventilation continuity.

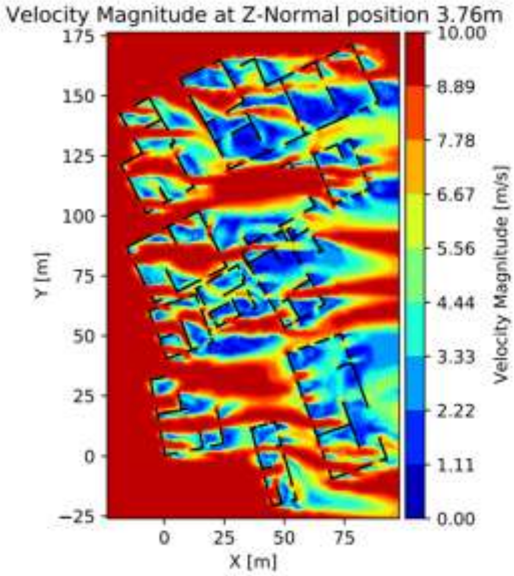

Figure 5: Velocity Magnitude at 3.76m

The compact morphology demonstrates repeated flow interruption, persistent stagnation pockets, and reduced ventilation efficiency.

2.5 Pressure Distribution Analysis – Case A

Pressure contours reinforce velocity findings. Strong windward compression zones form along exposed façades.

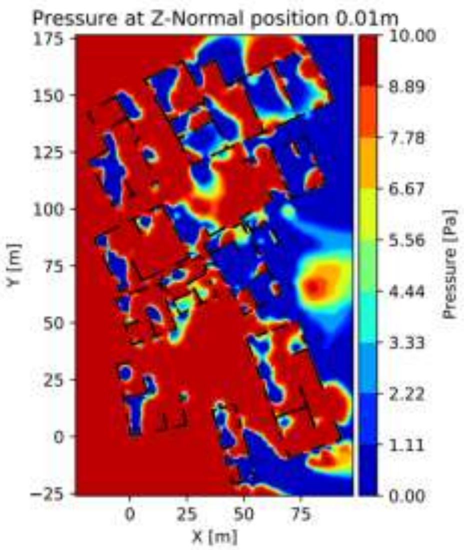

Figure 6: Pressure at 0.01m

Deep negative pressure regions develop within leeward wake zones, indicating sustained aerodynamic resistance.

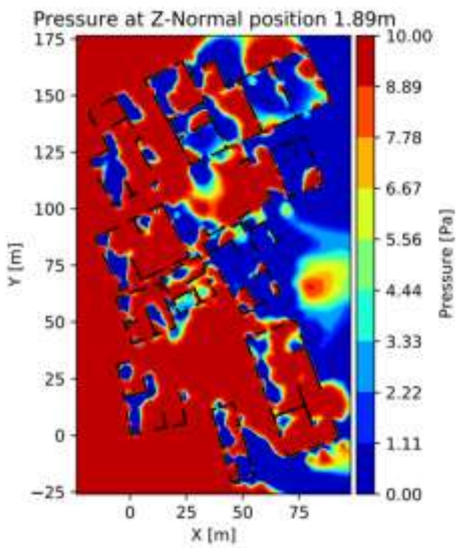

Figure 7: Pressure at 1.89m

Persistent pressure gradients across vertical sections indicate limited pressure equalization and reduced internal airflow exchange.

2.6 Velocity Magnitude Analysis – Case B

Ground-level velocity contours demonstrate clear wind penetration pathways through open corridors.

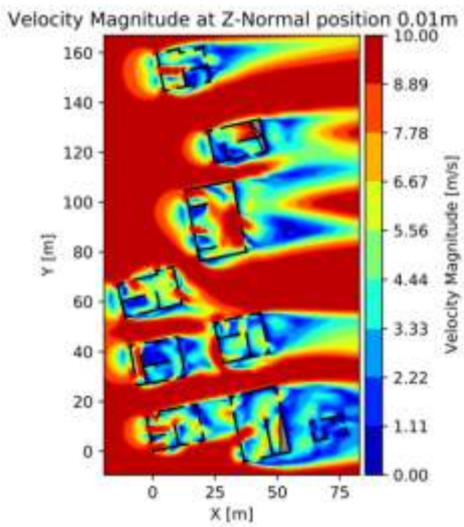

Figure 8: Velocity Magnitude at 0.01m

Wake regions are localized and discrete rather than continuous. At pedestrian height (~1.68 m), airflow continuity remains strong.

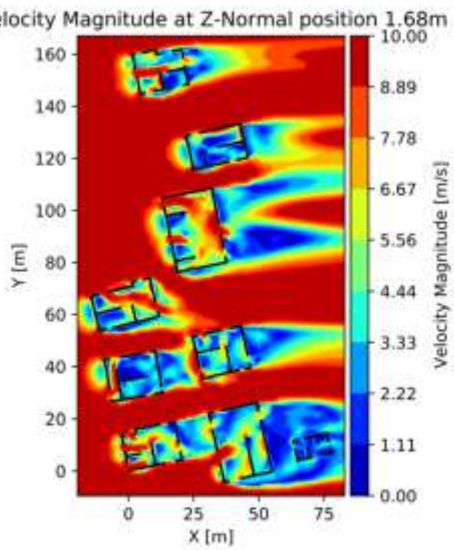

Figure 9: Velocity Magnitude at 1.68m

At higher elevations, velocity fields become smoother, with sustained directional continuity across the block.

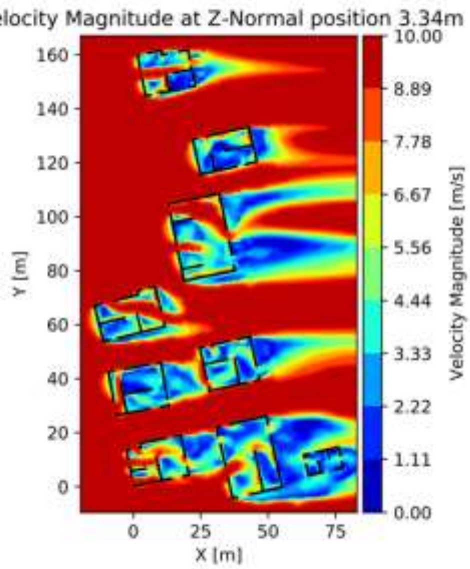

Figure 10: Velocity Magnitude at 3.34m

The porous configuration demonstrates distributed airflow, minimal stagnation, and improved ventilation performance.

2.7 Pressure Distribution Analysis – Case B

Windward pressure build-up remains concentrated along the exposed boundary, but interior pressure gradients equalize rapidly.

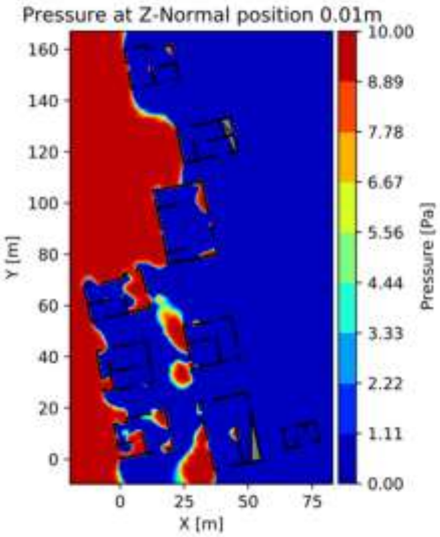

Figure 11: Pressure at 0.01m

Leeward suction zones remain localized and do not extend deeply into interior areas.

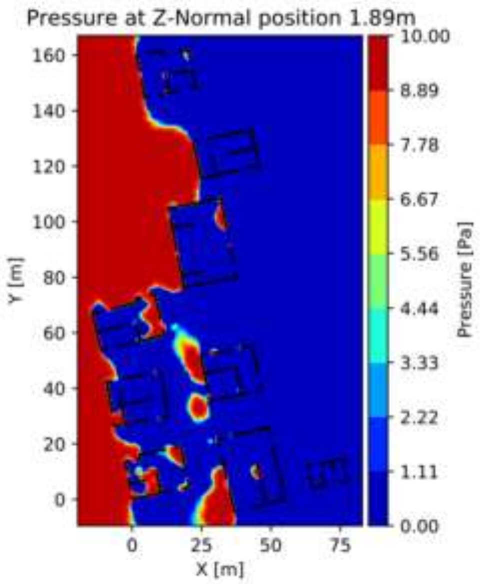

Figure 12: Pressure at 1.89m

At upper sections (~5.63 m and ~7.51 m), pressure fields become vertically diffused and largely uniform, indicating enhanced aerodynamic continuity.

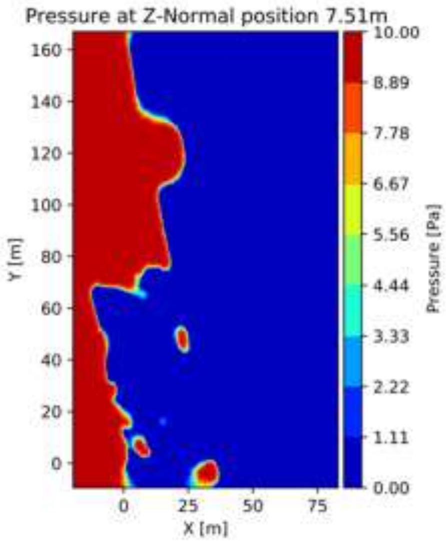

Figure 13: Pressure at 7.51m

2.8 Comparative Discussion

Case A demonstrates:

• Strong windward pressure build-up
• Deep and extended wake zones
• Persistent stagnation pockets
• Limited airflow penetration
• Reduced pressure equalization

Case B demonstrates:

• Distributed airflow corridors
• Reduced aerodynamic resistance
• Localized wake formation
• Faster pressure equalization
• Improved ventilation continuity

These differences confirm that morphology significantly influences aerodynamic behaviour. Wind velocity and pressure distribution operate as measurable indicators of block-scale convective performance.

The findings support the argument that built form is not a passive background but an active environmental regulator. Compact mass continuity increases flow separation and stagnation, whereas spatial porosity enhances wind penetration and heat dissipation potential.

3. CONCLUSIONS

This study establishes built morphology as a measurable climatic infrastructure capable of influencing wind behaviour and Urban Heat Island resilience at the residential block scale.

CFD-based analysis demonstrates that compact high-density morphologies generate sustained aerodynamic resistance, extensive stagnation zones, and limited ventilation efficiency. In contrast, porous configurations enable distributed airflow pathways, improved pressure equalization, and enhanced convective heat dissipation potential.

By positioning wind behaviour as the measurable intermediary linking architecture to thermal performance, the research proposes a morphology–ventilation–resilience framework applicable to block-scale retrofitting strategies.

The findings reinforce the role of architects in climate adaptation, demonstrating that spatial configuration, density distribution, and mass articulation can significantly influence environmental performance without reliance solely on technological add-ons or vegetation-based interventions.

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