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Climate-Resilient High-Rise Design in Bangladesh's Real Estate Sector: A Parametric Numerical Study of Wind-Load, Thermal, Flood, and Urban Heat Island Performance

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ABSTRACT

Bangladesh's high-rise building stock is expanding rapidly, yet the climate hazards these buildings will face over their service life (cyclonic wind, extreme heat, urban flooding, and an intensifying urban heat island, UHI) are usually assessed separately, if at all. Each hazard sits in its own literature with its own benchmarks, so developers and design teams have no single, comparable evidence base for deciding which resilience measures to adopt first. This paper addresses that gap. Its novelty is to bring the four hazards into one building-level, code-referenced framework and to quantify all of them on a common test case, so that their relative magnitudes and design implications can be read side by side. A representative 20-storey Dhaka residential tower was analysed with four transparent parametric models: wind load, envelope cooling load, plinth freeboard, and UHI trend. The analysis is supported by a documented literature-selection protocol, Monte Carlo uncertainty analysis, and benchmark verification. The results indicate that the higher BNBC 2020 basic wind speed raises design wind actions by roughly a quarter relative to the BNBC 1993 value (both evaluated with the BNBC 2020 procedure) by roughly a quarter relative to BNBC 1993. Passive and fully integrated envelope packages reduce peak sensible cooling load by about one-half and three-quarters, respectively. A modest increase in plinth level above the city's embankment standard substantially lowers the likelihood of flood exceedance, and Dhaka's UHI could more than double by 2060 on current trends. Interpreted alongside a practitioner vignette, these findings support a three-tier framework (code-compliant baseline, passive-design enhancement, and integrated climate-adaptive design) that domestically financed projects can adopt incrementally. Because the study rests on a single representative building and has not been validated against instrumented data, the figures indicate order of magnitude and design direction rather than project-specific values. The framework and the openly documented calculation procedure are, however, transferable to other monsoon-delta cities.

INTRODUCTION

Dhaka is building up, not out, and it is doing so under conditions that most of the international climate-resilient design literature was not written to address. Land scarcity has already pushed developers toward taller structures on constrained footprints (Intech Properties, 2025; Kopotakkho Homes, 2025). What gets less attention is that most of these buildings go up without any structured, quantified accounting of the hazards they will face over a fifty- to hundred-year service life: urban flooding and waterlogging, a heat island that keeps intensifying, and cyclonic wind loading that reaches well inland of the coastal belt (Building360, 2026).

This paper addresses that gap in two ways. First, it reviews the international literature on passive thermal design, climate-responsive envelopes, and wind- and flood-resistant structural detailing for high-rise buildings, and sets that evidence against Bangladesh's specific hazard profile and its evolving building code. Second, and this is where the paper departs from most local work on the topic, it puts numbers on four of the questions that synthesis raises, using a single representative Dhaka high-rise as the test case. How much extra wind load does BNBC 2020 actually add at each storey compared with the 1993 code? How much peak cooling load does a passive or fully integrated envelope realistically remove against a code-compliant baseline? What finished plinth elevation does a documented flood level imply once a reasonable climate allowance is added? And how is Dhaka's markedly seasonal urban heat island likely to move if its currently reported trend continues? Existing reviews tend to treat heat, wind, and flood resilience as three separate literatures, each checked against its own international benchmark, and rarely put a number on all of them for the same building. This paper's central contribution is to bring them together as one compound-hazard problem, quantified rather than merely described, with the uncertainty of each estimate made explicit. The resulting framework is built deliberately so that it does not assume a project has the budget or the client mandate for full certification from day one. A practitioner vignette drawn from the author's ongoing structural design vetting and quality-control work on high-rise and industrial projects around Dhaka runs through the paper. The three-tier framework that comes out of it is meant to help developers and design teams sequence climate-resilient measures within the cost and regulatory constraints most of them actually face.

LITERATURE REVIEW

Climate-resilient and climate-responsive design has grown into a substantial international literature over the

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past decade, largely because sustainability and resilience turned out to be related but distinct goals: a building can be energy-efficient without being resilient to the specific hazards of its site, and the reverse also holds (Al-Kodmany, 2022). Most of this literature, though, is anchored in developed-market case studies (certified skyscrapers in mature regulatory environments with established green-finance mechanisms). Comparatively little of it addresses how climate-resilient principles translate into the cost, material, and regulatory constraints of a developing high-rise market like Bangladesh's. The procedure used to identify and select the sources reviewed below.

High-Rise Construction and Compound Climate Exposure in Bangladesh

Bangladesh is among the most climate-vulnerable countries in the world, facing monsoon-related flooding, tropical cyclones, and increasingly severe extreme heat not as separate risks but as concurrent ones (Urbanet, 2025). Dhaka's urban flood hazard is classified as high, with damaging flood events expected at least once per decade under current conditions (ThinkHazard, n.d.), and city drainage infrastructure is already strained by unplanned urbanisation of low-lying floodplains (World Bank, 2015). Layered on top of that is a heat island that keeps intensifying. Research on Dhaka's UHI puts the trend at 0.21°C per decade over the past twenty-five years, an effect attributed largely to the built environment itself: concrete, asphalt, and glass absorb and slowly release solar heat, while high-rise buildings and narrow streets further obstruct air circulation in what researchers call the urban canyon effect (Tabassum *et al.*, 2024). The effect is also strongly seasonal, as Figure 1 shows. UHI intensity in Dhaka reaches 0.95°C in winter, against an annual average of 0.48°C and a monsoon-season low of 0.23°C. This matters because envelope and shading decisions calibrated only to the annual average will badly understate winter heat-retention effects (Tabassum *et al.*, 2024). Section 4.4 works through that seasonal pattern numerically and projects where it is likely headed by mid-century.

Heat-related productivity losses in Dhaka already account for a measurable share of city GDP and are projected to keep rising (The Business Standard, 2026a). This fits a broader regional pattern. A 29-year (1990–2019) analysis of heat stress across ten South Asian megacities found Dhaka and Chittagong already logging an elevated number of annual hours at "danger" levels on combined heat-index and environmental-stress measures, with those danger-level hours climbing noticeably since 2011. Projected annual work-hour losses for the vulnerable population across these megacities range from 0.25 to 860.6 hours for light work, 43 to 1,595.9 hours for moderate work, and 291 to 2,402 hours for heavy manual work, a category that includes a large share of Bangladesh's own construction workforce (Debnath *et al.*, 2023). Coastal and near-coastal Bangladesh also faces design wind speeds exceeding 260 km/h in some zones, (Government of Bangladesh, 2021; Building360, 2026) so building envelopes, cladding fixings, and rooftop structures need to be engineered with that in mind (Building360, 2026).

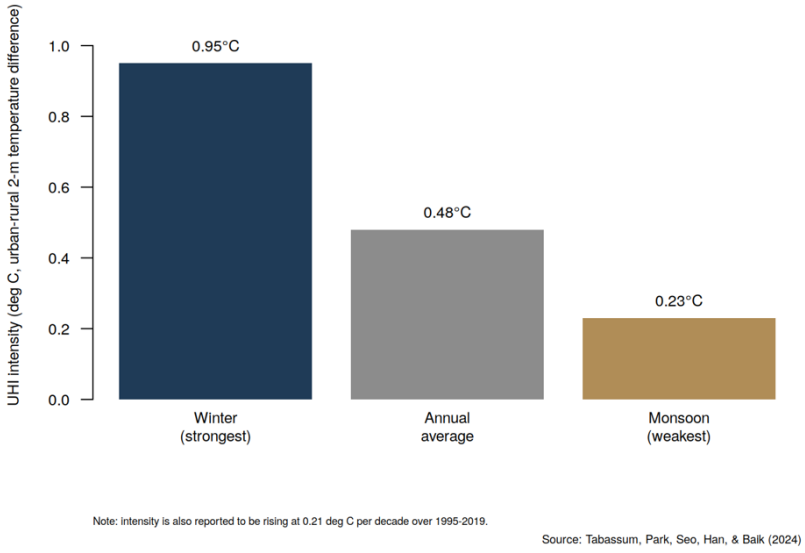

Figure 1: Seasonal Urban Heat Island Intensity in Dhaka.
Note: UHI intensity in Dhaka is roughly four times stronger in winter than in the monsoon season, against an annual average of 0.48°C. Data from Tabassum et al. (2024).

International Literature on Climate-Resilient and Passive High-Rise Design

A fairly consistent set of passive design strategies appears across the international literature on hot-humid climates: building orientation to limit solar exposure, external shading and overhangs, high-albedo or reflective envelope materials, and natural-ventilation strategies that reduce reliance on mechanical cooling (Chen *et*

al., 2017). Parametric studies of high-rise residential buildings in hot and humid climates find that envelope-related variables (solar heat gain coefficient, wall and roof absorptance, window-to-wall ratio) are among the most sensitive determinants of cooling energy demand and indoor thermal comfort, ahead of many active-system interventions. A holistic combination of these passive parameters can cut annual cooling load by up to 56.7% and peak cooling load by up to 64.5% relative to an unoptimised baseline (Chen *et al.*, 2017); Section 4.2 runs a comparable envelope-tiering exercise for a representative Dhaka apartment unit. A related simulation study of Hong Kong's hot-humid residential stock cautions that this effectiveness will not hold steady over time. Natural ventilation's cooling potential is projected to fall by up to 69% under future warming scenarios, even as the value of airtightness measures rises by up to 329%, with annual cooling-degree hours in the study's baseline city roughly doubling, from 2,058 to 4,106 hours, by century's end (Liu *et al.*, 2020). Passive-design guidance calibrated to today's climate baseline may therefore need revisiting as Dhaka's own UHI trend (Section 2.1) continues. More broadly, resilient building design is increasingly framed as a companion discipline to sustainable design rather than a subset of it, pairing climate-change mitigation (lower embodied and operational emissions) with adaptation to hazards the building will face regardless of how mitigation efforts turn out (Allplan, 2025). Reviews of internationally certified sustainable skyscrapers show that many of the envelope and structural strategies that earn certification credit also function as resilience measures in practice, even where they were originally justified on energy-efficiency or marketing grounds. Examples include asymmetric massing and tapering to shed typhoon-level wind loads, buffer-zone sky-gardens, and adaptive façade systems (Al-Kodmany, 2022).

A parallel, and considerably less integrated, literature addresses flood-resilient building and site design specifically. A comprehensive review of climate-induced urban flooding identifies three structural measures with the most consistent evidence of damage-avoidance benefit: elevating the building's lowest occupied or serviced level, permeable and controlled-entry foundation design, and site grading that directs floodwater away from the building perimeter. These sit alongside city-scale drainage and green-infrastructure measures that lie outside any individual project's control (Dharmarathne *et al.*, 2024). Section 4.3 applies the first of these measures numerically, as a plinth-elevation check referenced to Dhaka's own documented flood levels. At the individual-building and campus scale, a design-framework study built from a Chinese university campus case shows that flood-resilience measures work best when they are part of the architectural and urban design decisions from the concept stage, rather than bolted on once the architectural scheme is fixed. Examples include sunken courtyards doing double duty as detention volumes, elevated ground-floor programming, and permeable hardscape (Xu *et al.*, 2023). Neither of these literatures has been systematically connected to the passive thermal-design work reviewed above, even though both are ultimately about the same envelope and site-design decisions. The Tier 3 framework in Section 4.7 treats them as one sequenced design problem rather than two separate checklists.

Regulatory Context: The Bangladesh National Building Code

The Bangladesh National Building Code (BNBC), first issued in 1993, was substantially revised in its 2020 edition to update seismic zonation, wind-load provisions, and structural design methodologies (Urban Resilience Project, 2021). The wind-load provisions are now adapted from ASCE 7-05 (American Society of Civil Engineers [ASCE], 2006) rather than the older fastest-mile methodology (Lixon *et al.*, 2022). Comparing the 1993 and 2020 provisions, Lixon *et al.* (2022) find an average 26.58% increase in prescribed design wind pressures across Bangladesh's eight administrative divisions.

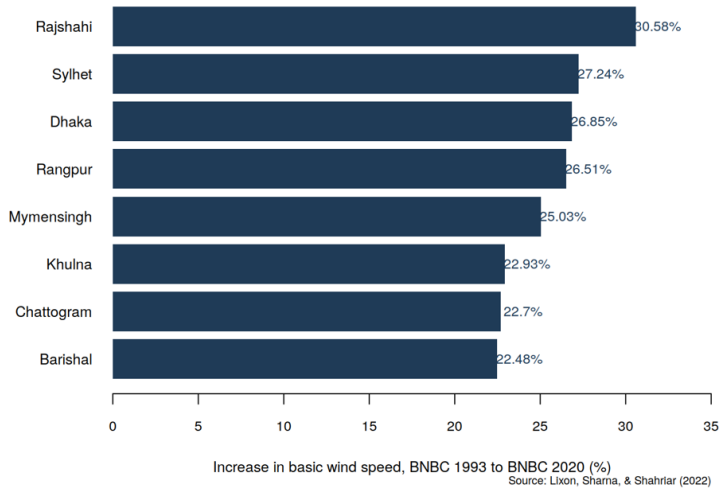

Figure 2: Percentage Increase in BNBC Basic Design Wind Speed by Division, 1993 to 2020.
Note: Data from Lixon et al. (2022).

A substantial share of the existing high-rise stock ... would require.' with: 'Much of the existing high-rise stock, designed under the earlier code, may therefore not meet the wind actions now prescribed by BNBC 2020. Whether this reduces actual safety depends on the governing load case (seismic action often governs in Dhaka), original design margins and overstrength; buildings approved under the earlier code remain lawfully compliant, as BNBC 2020 does not apply retrospectively against wind hazard than current practice would require. The increase is not uniform across divisions, as Figure 2 shows. Rajshahi (30.58%) and Sylhet (27.24%) saw the largest upward revisions, while the coastal Barishal and Chattogram divisions, already designed to higher baseline wind speeds under the 1993 code, saw comparatively smaller percentage increases (22.48% and 22.70%, respectively), even though their absolute design wind speeds remain the highest in the country. Dhaka's own divisional increase of 26.85% (basic wind speed rising from 58.33 m/s to 65.70 m/s) sits close to the national average, and Section 4.1 carries that figure through to a full pressure profile for a representative high-rise. Flood, drainage, and plinth-height provisions, waterproofing requirements, and fire-safety standards were also updated in the 2020 edition, and the Capital Development Authority (RAJUK) enforces these through the Dhaka Imarat Nirman Bidhimala building-construction rules (Building360, 2026)' with: '(Government of Bangladesh, 2021). In Dhaka, the Capital Development Authority (RAJUK) approves buildings under the Building Construction Act, 1952 and the Dhaka Mohanagar Imarat (Nirman, Unnayan, Sangrakshan O Apasaran) Bidhimala, 2008, which require compliance with BNBC. Bidhimala building-construction rules (Building360, 2026). Even so, code compliance functions more as a floor than as a resilience strategy in its own right. It sets minimum structural safety margins against codified hazard assumptions rather than driving a design process oriented toward minimising climate-related operational and damage risk over the building's service life.

Barriers to Climate-Resilient Design Adoption in the Bangladesh Context

Adoption of climate-resilient design in Bangladesh's construction sector is still held back by a mix of cost, awareness, and institutional factors. A 2025 sector study found that only 28% of surveyed engineers, builders, architects, and planners reported being highly aware of climate-resilient construction practices (Figure 3). The same study flagged the use of local, sustainable construction materials as the least-adopted practice in the sector, with weak institutional promotion of materials already developed by public research bodies making the gap worse (Mongabay,

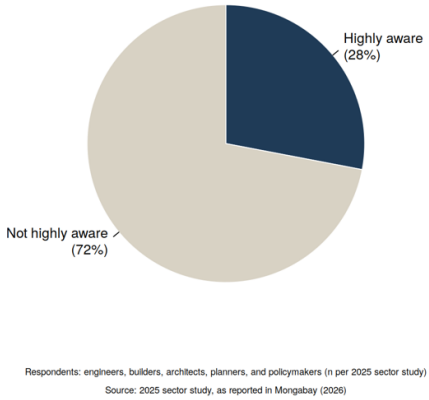

Figure 3: Reported Awareness of Climate-Resilient Construction Practices Among Bangladeshi Built-Environment Professionals.
Note. Only 28% of surveyed professionals reported high awareness. Data from a 2025 sector study, as reported in Mongabay (2026).

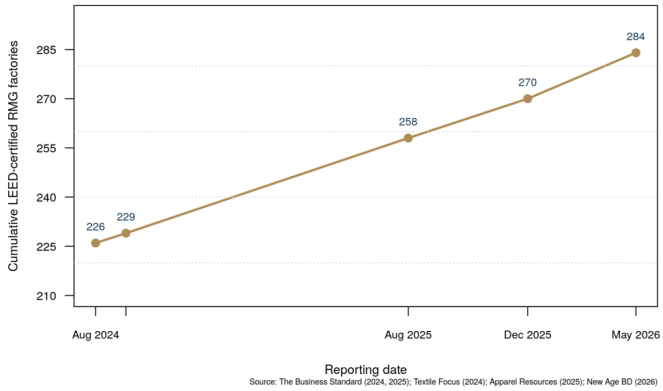

Figure 4: Cumulative LEED-Certified Ready-Made Garment Factories in Bangladesh, August 2024 to May 2026
Note: The figure shows export-sector uptake against which domestic awareness (Figure 3) can be benchmarked. Data compiled from industry reporting, including Apparel Resources (2026).

2026). Even where climate-resistant housing solutions have been developed and demonstrated, they have struggled to reach the millions of households at risk from natural disasters (EnviroLink Network, 2026). Government and development-partner initiatives are working to build sustainable-materials innovation and life-cycle assessment capacity into the sector, including a joint UNEP–UNOPS–UN-Habitat programme with the Ministry of Housing and Public Works, RAJUK, and the Housing and Building Research Institute. This work is explicitly framed as still in progress rather than mainstreamed (The Business Standard, 2026b).

Where climate-resilient and certified-green construction has taken hold at scale in Bangladesh, it has done so in one specific, externally incentivised segment. The country's ready-made garment manufacturing sector has added LEED-certified factories at a steady pace, reaching 270 certified facilities by December 2025 and 284 by May 2026, more than a hundred of them at the Platinum tier (Figure 4). This growth has been driven substantially by international buyer requirements rather than domestic regulatory push (Apparel Resources, 2025). Strong and steadily accelerating uptake where an external market incentive exists contrasts sharply with the 28% domestic awareness figure in Figure 3 for the broader, domestically financed residential high-rise stock. It also mirrors barriers already documented in the international literature on green-building adoption in developing and emerging economies, where cost, capacity, and a lack of localised standards are repeatedly identified as the main constraints (United Nations Environment Programme, 2021).

MATERIALS AND METHODS

Research Design

The study combines a structured literature synthesis with parametric numerical modelling. The synthesis (Section 2) followed the documented search and selection procedure in Section 3.2. It supplies the hazard context, code provisions, and literature benchmarks against which the numerical models are framed and checked. Four parametric models were then applied to one representative Dhaka high-rise (Section 3.3): wind-load structural analysis (Section 3.4), passive-design cooling-load analysis (Section 3.5), a flood/plinth-height freeboard check (Section 3.6), and UHI seasonal decomposition with trend projection (Section 3.7). Applying all four to the same building means the results can be read together as a single compound-hazard exercise rather than four unrelated calculations. Each model follows a governing code provision or standard engineering method rather than a black-box procedure. Every parameter is listed with its value and justification in Tables 2–4 and Appendix A, and the complete calculation, including the uncertainty and verification steps, is implemented in a short open script supplied as Supplementary Material S1, so that every value in Section 4 can be reproduced. Three steps were added to establish how far the deterministic results can be trusted: one-at-a-time sensitivity analysis, Monte Carlo uncertainty analysis (Section 3.8), and model verification against code tables, independent published values, and literature benchmarks (Section 3.9). A practitioner vignette (Section 3.10) provides a qualitative check on how the modelled issues appear in real design review.

Literature Search and Selection Procedure

The literature review followed a structured, purposive (semi-systematic) procedure suited to a problem that spans several disciplines and a thin local evidence base (Snyder, 2019). Table 1 summarises the protocol. Peer-reviewed sources were identified from Scopus, Web of Science, and Google Scholar using the search strings shown, restricted to English-language publications from 2015 to 2026. Earlier foundational code documents (ASCE 7-05; ASHRAE Handbook) were also included because the BNBC 2020 provisions are derived from them. Records were screened first on title and abstract and then on full text against the inclusion and exclusion criteria in Table 1, followed by one round of backward citation searching from the included papers. Because peer-reviewed, Bangladesh-specific empirical research on climate-resilient high-rise design is scarce, a second, targeted search covered institutional and grey sources: World Bank/GFDRR and UNEP reports, Government

Table 1: Literature Search and Selection Protocol.

Element	Specification
Databases	Scopus; Web of Science Core Collection; Google Scholar (first 100 results per string); backward citation search of included papers
Search strings (combined with AND/OR)	("high-rise" OR "tall building" OR "residential tower") AND ("passive design" OR "envelope" OR "cooling load" OR "shading"); ("wind load" AND ("BNBC" OR "ASCE 7" OR "building code")); ("flood resilien*" AND ("building" OR "plinth" OR "site design")); ("urban heat island" AND "Dhaka"); ("climate-resilient" OR "green building") AND ("Bangladesh" OR "developing countr*") AND ("barrier*" OR "cost")
Period / language	2015–2026 (foundational codes and handbooks exempt); English
Inclusion criteria	(i) Quantitative evidence on passive envelope or cooling performance in hot-humid climates; (ii) wind-load code provisions or comparisons relevant to BNBC; (iii) building- or site-scale flood-resilience measures; (iv) Dhaka heat or UHI characterisation; (v) adoption barriers, cost premia or regulation of climate-resilient or green buildings in Bangladesh or comparable economies

Exclusion criteria	Cold or temperate climates only; no quantitative, regulatory or design-guidance content; non-building scale (e.g., regional hydrology only); duplicates or superseded versions
Grey-literature search	Targeted: World Bank/GFDRR, UNEP, ThinkHazard, Government of Bangladesh/BNBC documentation, national news and industry sources (context only)
Source-role rule	Model parameters taken only from peer-reviewed, code/standard or institutional technical sources

of Bangladesh code documentation, hazard databases, and reputable national news and industry reporting for current sector statistics. A source-role rule was applied throughout. Only peer-reviewed literature, codes and standards, and institutional technical reports were used to set numerical model parameters. News and industry sources were used only to describe current market and adoption context (Sections 1 and 2.4) and never as model inputs. The final corpus comprises 37 sources: 17 peer-reviewed journal articles, one methodological text, four codes, standards and technical handbooks, five institutional or government reports and databases, and ten news, industry and web sources.

Selection and Justification of the Representative Building

No single instrumented Bangladeshi high-rise has published wind, thermal, and flood performance data together, so all four numerical models run on one representative building and site, specified from typical Dhaka high-rise practice and the code and climate figures set out in Section 2. Table 2 lists the shared parameters and the basis for each. The building was selected to meet five criteria. (1) Relevance: at 20 storeys (64 m) it is clearly a high-rise in Dhaka's regulatory sense (more than 10 storeys or 33 m; Government of Bangladesh, 2021) and representative of the residential towers that

Table 2: Representative Building and Site Parameters Used in the Numerical Models.

Parameter	Value	Basis and justification
Location	Dhaka, Bangladesh	Largest high-rise market; all hazard data available
Storeys / total height	20 storeys / 64.0 m	Above the 10-storey high-rise threshold; rigid-building limits satisfied (H <= 91 m, na = 1.03 Hz >= 1 Hz; ASCE, 2010)' with 'H <= 91 m; na = 0.35 Hz (flexible); rigid G used as a comparison simplification (Section 3.3)
Floor-to-floor height	3.2 m	Typical Dhaka residential floor height (tested 3.0–3.4 m in Section 3.8)
Plan footprint	20 m × 20 m (L/B = 1)	Consistent with the comparative methodology of Lixon *et al.* (2022); H/B = 3.2
Exposure category	ASCE 7-05 Exposure B (= BNBC 2020 Exposure A, urban/suburban)' and the basis to 'ASCE (2006); Government of Bangladesh (2021); ASCE Exposure C (= BNBC Exposure B) tested as a scenario	ASCE (2006) / BNBC 2020 definition for built-up urban terrain; Exposure C tested as a scenario
Basic wind speed, BNBC 1993 / BNBC 2020	58.33 m/s / 65.70 m/s	Dhaka division values (Lixon *et al.*, 2022)
Representative apartment unit	100 m² floor area; two exposed façades (S and W), each 10 m × 3.2 m	Mid-level corner unit; most solar-exposed common unit type
Outdoor design dry-bulb temperature	35.0°C	Representative Dhaka summer peak design condition (tested ±1°C, SD)
Indoor cooling set-point	24.0°C	Standard comfort cooling set-point (ASHRAE, 2021)
Design Flood Level (DFL)	7.84 m PWD	1988 historic peak flood level, Tongi gauge (World Bank, 2017)
Reference flood-protection standard	8.20 m PWD embankment crest (0.36 m freeboard)	Sayed and Haruyama (2017)

dominate the city's new vertical floor space. (2) Validity of a transparent method: with height H = 64 m ≤ 91 m, a height-to-least-width ratio of 3.2 (< 4), and an In ASCE 7-10 Eq. 26.9-3, H is in FEET. With H = 64 m (210 ft), na = 43.5/210^0.9 = 0.35 Hz, not 1.03 Hz (BNBC period T = 0.0466 H^0.9 = 2.0 s gives the same conclusion). The building is FLEXIBLE, not rigid. Replace '(2) Validity ... qualifies as rigid. The ASCE 7 directional procedure with a rigid-structure gust factor is therefore applicable, and no dynamic or wind-tunnel analysis is needed.' with: '(2) Transparency of method: with H = 64 m <= 91 m and a height-to-least-width ratio of 3.2 (< 4), the approximate frequency expression of ASCE (2010) applies and gives na = 0.35 Hz (H in ft), so the building is dynamically sensitive (flexible). A rigid-structure gust factor (G = 0.85) is retained here only as a simplification for the code-to-code comparison; project design must use the flexible-structure gust factor Gf of BNBC 2020. of na ≈ 43.5/H^0.9 ≈ 1.03 Hz for a reinforced-concrete moment frame (ASCE, 2010), the building qualifies as rigid. The

Table 3: Wind-Load Model Parameters and Justification

Parameter	Value	Justification
Kz (velocity-pressure exposure coefficient)	2.01 (z/zg)^(2/α), α = 7.0, zg = 365.76 m, z ≥ 9.14 m	ASCE 7-05 Exposure B power law; reproduces the code's tabulated values (Section 4.5)
Kzt (topographic factor)	1.0	Flat deltaic terrain; no hills, ridges or escarpments
Kd (directionality factor)	0.85	ASCE 7-05 value for buildings (MWFRS)
G (gust-effect factor)	0.85	'Rigid-structure value adopted as a simplification for the code-to-code comparison (building na = 0.35 Hz is flexible; Section 3.3); tested 0.80-0.90 ≈ 1.03 Hz ≥ 1 Hz; Section 3.3); tested 0.80–0.90
Cp, windward wall	0.8	ASCE 7-05 external pressure coefficient, all L/B
Cp, leeward wall	−0.5	ASCE 7-05 value for L/B = 0–1 (square plan); tested −0.3 to −0.5
GCpi (internal pressure)	±0.18	Enclosed building; cancels in net MWFRS load (not included in base shear)
V, BNBC 1993 / 2020	58.33 / 65.70 m/s	Dhaka division (Lixon *et al.*, 2022)

ASCE 7 directional procedure with a rigid-structure gust factor is therefore applicable, and no dynamic or wind-tunnel analysis is needed. (3) Comparability: the square 20 m × 20 m plan (L/B = 1) matches the comparative methodology of Lixon *et al.* (2022), so the computed code-to-code increase can be checked against their independent divisional result. (4) Conservative exposure for the thermal model: a 100 m² mid-level corner unit with south- and west-facing façades represents the most solar-exposed common unit type at Dhaka's latitude (about 23.8°N), where afternoon west-façade gains drive peak cooling. (5) Traceable flood reference: the site is referenced to the Tongi gauge in northern Dhaka, where both the 1988 design flood level and the embankment crest standard are documented in the literature. The results in Section 4 should therefore be read as illustrating the order of magnitude and design direction involved, not as a structural, energy, or flood-risk assessment of any particular building. Section 5.2 returns to this limitation.

Wind-Load Analysis Methodology

Design wind pressures were calculated with the directional procedure (Method 2) of ASCE 7-05 (ASCE, 2006), which BNBC 2020 adopts for the main wind-force-resisting system (MWFRS; Lixon *et al.*, 2022). The same procedure underlies commercial structural-analysis packages such as ETABS and STAAD.Pro. Velocity pressure at each storey height z was computed as qz =

Table 4: Envelope and Load Parameters by Tier for the Cooling-Load Model.

Parameter	Tier 1 – Baseline	Tier 2 – Passive	Tier 3 – Integrated	Justification
Window-to-wall ratio	40%	30%	25%	Typical Dhaka speculative façade; reduced glazing as a passive measure (Chen *et al.*, 2017)
Glazing U-value (W/m²K)	5.8	3.3	1.8	Clear single / tinted double / low-E double glazing (ASHRAE, 2021)
SHGC	0.75	0.50	0.28	Same glazing types as above

External shading factor	1.00	0.75	0.55	None / moderate overhangs and fins / deep shading with low-E
Wall U-value (W/m²K)	2.2	2.0	0.76	Uninsulated brick masonry / masonry with reflective finish / insulated wall
Wall solar absorptance	0.65	0.35	0.30	Medium-dark finish / light reflective coating / high-albedo finish
Roof U-value (W/m²K)	3.5	1.8	0.75	Bare RC slab / slab with reflective tiles / insulated cool roof
Roof solar absorptance	0.70	0.50	0.20	Weathered concrete / reflective tiles / cool-roof membrane
Air-change rate (ACH)	1.0	0.9	0.7	Leaky baseline / standard sealing / improved airtightness (Liu *et al.*, 2020)
Common: Tout / Tin / ho	35.0°C / 24.0°C / 17 W/m²K			Dhaka summer design; comfort set-point; ASHRAE (2021) summer exterior film coefficient
Common: I wall / I glass / I roof	550 / 650 / 550 W/m²			Mean S+W façade peak / west-façade afternoon peak / roof value on the amortised basis
Common: volume, ϱcp	320 m³; 1,200 J/m³K			100 m² × 3.2 m; air at standard conditions

0.613. The BNBC 2020 structure importance coefficient I = 1.0 for residential occupancy and is therefore omitted · Kz · Kzt · Kd · V² (qz in Pa, V in m/s). The net MWFRS design pressure at each storey combined the windward and leeward components: p = qz · G · Cp,windward − qh · G · Cp,leeward. For an enclosed building, internal pressure (±GCpi) acts equally on the windward and leeward walls and cancels in the net horizontal load. It is therefore excluded from the base-shear calculation and is relevant only to component and cladding checks. Total base shear was obtained by summing p × storey height × building width over all 20 storeys. The calculation was repeated for the BNBC 1993 and BNBC 2020 basic wind speeds. The BNBC 1993 case applies the 1993 basic wind speed within the BNBC 2020 (ASCE 7-05) procedure; it isolates the effect of the wind-speed revision and is not a reproduction of the full BNBC 1993 fastest-mile method for the BNBC 1993 and BNBC 2020 basic wind speeds. Table 3 lists each parameter with its justification.

Passive-Design Cooling-Load Methodology

Peak sensible cooling load for the representative apartment unit was estimated with a steady-state, single-zone sol-air heat-balance model. The model follows the method in the ASHRAE Handbook—Fundamentals (ASHRAE, 2021) and is structured similarly to the envelope-focused parametric approach of Chen *et al.* (2017). Wall and roof conduction gains were calculated from the sol-air temperature, Tsol-air = Tout + (α · I)/ho, with a 3.0°C longwave-radiation correction for the roof. This is slightly smaller than the commonly used value of about 3.9°C for horizontal surfaces and so errs on the conservative (higher-load) side. Window conduction was calculated from the outdoor–indoor dry-bulb difference, window solar gain as SHGC · Awindow · Isolar · (shading factor), and ventilation/infiltration load from the tier-specific air-change rate. Internal loads (eight occupants at 90 W and 12 W/m² for lighting and equipment) were held constant across tiers so that the comparison isolates the envelope. The roof gain was amortised over the stack: the 400 m² roof was divided equally among the 20 storeys, giving 20 m² per unit. A mid-level unit result therefore represents the building-average roof burden rather than a top-floor worst case. Three envelope configurations were tested, matching the three tiers of the framework in Section 4.7, and Table 4 lists every tier-specific value with its justification. Latent (moisture) loads were not modelled. This is a deliberate simplification, because the comparison concerns envelope-driven sensible gains, but it means absolute loads understate total plant capacity in Dhaka's humid climate (Section 5.2).

Flood/Plinth-Height Freeboard Methodology

The recommended finished plinth elevation was computed as Plinth level = DFL + Freeboard, with the Design Flood Level taken as Dhaka's documented 1988 historic peak, 7.84 m PWD at the Tongi gauge (World Bank, 2017). This is the same event the city's primary flood-protection embankment was calibrated against, to a crest level of 8.20 m PWD, a freeboard of roughly 0.36 m above the 1988 peak (Sayed & Haruyama, 2017). Three freeboard scenarios were tested, matching the three tiers of the framework. Tier 1 adopts the existing. This level is an author-defined benchmark, not a value prescribed by BNBC 2020; actual plinth levels must satisfy BNBC 2020, the Dhaka Mohanagar Imarat Bidhimala 2008

and RAJUK/DAP requirements. citywide embankment freeboard (0.36 m), so that an individual plinth is no lower than the city's own defence standard. Tier 2 adds 0.15 m as a site-drainage margin for plot-level ponding and drainage surcharge during intense rainfall, the condition targeted by the controlled-entry foundation and perimeter-grading measures reviewed in Section 2.2 (Dharmarathne *et al.*, 2024). Tier 3 adds a further 0.35 m climate-uncertainty allowance for intensifying monsoon flood frequency and stage over the building's design life. Because no downscaled flood-stage projection is available for the Tongi reach, the 0.35 m value was set within the plausible range of design-life stage increase adopted in the uncertainty analysis (0–0.60 m; Section 3.8). Its

Table 5: Input Distributions Used in the Monte Carlo Uncertainty Analysis

Model	Uncertain input	Distribution	Rationale
Wind	Gust-effect factor G	Uniform 0.80–0.90	Range of rigid-building values from the ASCE 7 calculated-G procedure
Wind	Leeward Cp	Uniform −0.5 to −0.3	Plan aspect ratio L/B from 1 to 2
Wind	Power-law exponent α	Uniform 6.5–7.5	Variability of urban terrain roughness within Exposure B
Wind	Floor-to-floor height	Uniform 3.0–3.4 m	Range of Dhaka residential practice (changes total height)
Cooling	Outdoor dry-bulb Tout	Normal, mean 35.0°C, SD 1.0°C	Year-to-year variation of peak design condition
Cooling	Solar irradiance (wall, glass, roof)	Uniform ±10%	Orientation, sky clarity and haze
Cooling	Exterior film coefficient ho	Uniform 15–20 W/m²K	Wind-speed dependence
Cooling	U-values, SHGC	Uniform ±10% of tier value	Product and workmanship variation
Cooling	Absorptance, shading factor	Uniform ±0.05 of tier value	Finish ageing and soiling; shading geometry
Cooling	Air-change rate	Uniform ±25% of tier value	Construction quality and occupant behaviour
Cooling	Internal loads	Uniform ±20%	Occupancy and appliance variation
Flood	DFL (gauge/datum)	Normal, mean 7.84 m, SD 0.10 m	Gauge reading and datum-transfer uncertainty
Flood	Design-life climate stage increase	Triangular (0, 0.20, 0.60 m)	Plausible intensification of monsoon peak stage (no downscaled projection available)
Flood	Local ponding depth	Uniform 0–0.15 m	Plot-level drainage surcharge
UHI	Decadal trend	Normal, mean 0.21°C, SD 0.05°C	Statistical uncertainty of reported trend (assumed; not reported in source)
UHI	Seasonal baseline	Normal, SD 0.05°C	Measurement and averaging uncertainty

adequacy is then tested probabilistically rather than assumed (Section 4.5). All levels are referred to the PWD datum used by the source data. Any project application should confirm the datum against the site survey, since PWD and mean-sea-level datums differ.

Urban Heat Island Seasonal Decomposition and Trend-Projection Methodology

Dhaka's monthly UHI profile was reconstructed from the three seasonal figures reported by Tabassum *et al.* (2024): a winter (December–February) intensity of 0.95°C, a monsoon (June–October) intensity of 0.23°C, and an annual mean of 0.48°C. Solving for the transitional-season (March–May and November) mean that reproduces the published annual figure gives a season-weighted decomposition. This is a simple breakdown of published summary statistics into an illustrative monthly profile, not an independent measurement or a fitted regression. The seasonal baselines were then projected to 2030, 2040, 2050, and 2060 by linear extrapolation of the reported trend of +0.21°C per decade (Tabassum *et al.*, 2024), applied evenly across seasons. This is a first-order illustration of where the currently reported trend leads if it simply continues. It is not a downscaled regional climate-model projection, and the possibility of non-linear acceleration under continued densification is examined as a scenario in Section 4.5.

Sensitivity and Uncertainty Analysis

Two complementary analyses were carried out for each model (Saltelli *et al.*, 2008). First, a one-at-a-time (OAT) sensitivity analysis perturbed each input by ±10% (±1°C for outdoor temperature) about its base value while holding all others fixed, to rank the inputs by influence. Second, a Monte Carlo uncertainty analysis propagated plausible ranges of all uncertain inputs simultaneously, using 10,000 random samples per model (fixed random seed for reproducibility). The input distributions, summarised in Table 5, reflect the ranges of professional judgement, code options, and data uncertainty discussed in Sections 3.3–3.7. Code-prescribed values (basic wind speeds, Kd, Kzt, and Cp,windward) were held fixed because the study compares code provisions rather than hazard probabilities. For the thermal model, climatic inputs were sampled once per realisation and shared across the three tiers, while envelope properties were sampled independently for each tier, so that the tier comparison reflects envelope differences under common weather. For the flood model, the sampled quantity is a design-life flood stage, defined as the documented DFL (with gauge and datum uncertainty) plus a climate-driven stage increase plus local ponding depth. Each tier is evaluated by its exceedance probability, the share of samples in which that stage exceeds the plinth level. Results are reported as the median and the 5th–95th percentile range (P5–P95).

Model Verification

In the absence of instrumented data for a single Dhaka high-rise, each model was verified against established benchmarks at three levels. Code verification checked that the implementation reproduces published code values: the Kz power law against the tabulated Exposure B coefficients of ASCE 7-05 (ASCE, 2006), and the closure of the cooling-load components and the UHI decomposition by direct recomputation. Independent-result verification compared model outputs with values derived independently by other researchers: the code-to-code pressure increase against the divisional result of Lixon *et al.* (2022), and the Tier 1 plinth level against the documented embankment crest of Sayed and Haruyama (2017). Benchmark plausibility compared model outputs with the ranges reported in the literature, namely the envelope-driven peak cooling reduction of Chen *et al.* (2017) and the dominance of glazing-related gains in hot-humid high-rise residences. The verification results are reported in Section 4.5. These checks establish that the models are correctly implemented and consistent with

Table 6: Design Wind Pressure at Selected Storeys, Representative 20-Storey Dhaka High-Rise

Storey	Height (m)	qz, BNBC 1993 (kPa)	qz, BNBC 2020 (kPa)	p, BNBC 1993 (kPa)	p, BNBC 2020 (kPa)	Increase (%)
1	3.2	1.242	1.576	1.765	2.239	26.87
5	16.0	1.457	1.849	1.911	2.425	26.87
10	32.0	1.776	2.254	2.128	2.700	26.87
15	48.0	1.995	2.531	2.277	2.888	26.87
20 (roof)	64.0	2.166	2.747	2.393	3.036	26.87

Note: p = net MWFRS pressure (windward plus leeward); internal pressure cancels in the net load (Section 3.4).

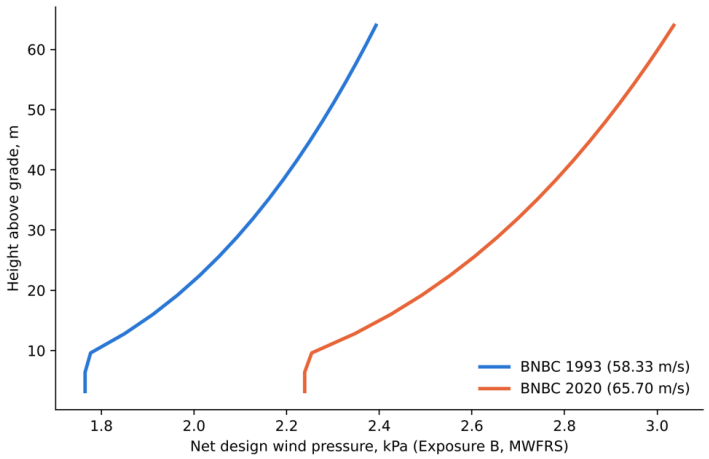

Figure 5: Design Wind Pressure Profile for a Representative 20-Storey Dhaka High-Rise: BNBC 1993 Versus BNBC 2020.

Note: Author's calculation using the ASCE 7 directional procedure; basic wind speeds from Lixon et al. (2022).

established benchmarks. They do not constitute empirical validation against measured building performance, which remains the main direction for future work (Section 5.2).

Practitioner Case Illustration

The four numerical analyses are supplemented, not replaced, by a practitioner vignette drawn from the author's structural design vetting and quality-control role on high-rise and industrial projects in the Dhaka region. structural design vetting and quality-control role' (previous line) with 'owner-side design review and quality-control role', so the text does not imply the author was the structural engineer of record. Add at the end of the paragraph: 'Permission to use the anonymised project documentation was obtained from the project owner. Against three criteria: (i) the author held a formal review role with full access to the design documentation; (ii) the review took place during the transition to BNBC 2020, so code-driven changes in wind actions were directly observable; and (iii) the project had to make plinth, drainage, and envelope decisions comparable to those modelled in Sections 3.4–3.6. The evidence consisted of the project's design-basis report, structural calculation package and drawings, and the review comment log maintained during vetting. As part of the review, the author independently re-computed the design wind pressures with the same ASCE 7 directional equations used in Section 3.4 and compared them with the consultant's frame-analysis output. Documentary findings were triangulated across these sources, and the project is anonymised for confidentiality. This documentation approach follows the author's earlier published structural condition-assessment case studies of Bangladeshi industrial buildings (Jany, Islam, & Shirin, 2026; Jany, Islam, Shirin, & Karim, 2026). The vignette serves the paper's hypothesis-generating aim. It is a qualitative check on how the modelled issues enter real design practice, not an empirical validation of the parametric models, and the need for instrumented, project-specific validation is addressed in Section 5.2 and the Conclusion.

Table 7: Peak Design Cooling-Load Breakdown by Envelope Tier (W)

Component	Tier 1 – Baseline	Tier 2 – Passive	Tier 3 – Integrated
Wall conduction	2,706	2,000	755
Roof conduction (amortised)	2,145	870	217
Window conduction	1,633	697	317
Window solar gain	12,480	4,680	1,602
Ventilation/infiltration	1,173	1,056	821
Internal (occupants + lighting/equipment)	1,920	1,920	1,920
Total peak cooling load	22,058 (22.1 kW)	11,224 (11.2 kW)	5,632 (5.6 kW)
Reduction vs. Tier 1	—	49.1%	74.5%

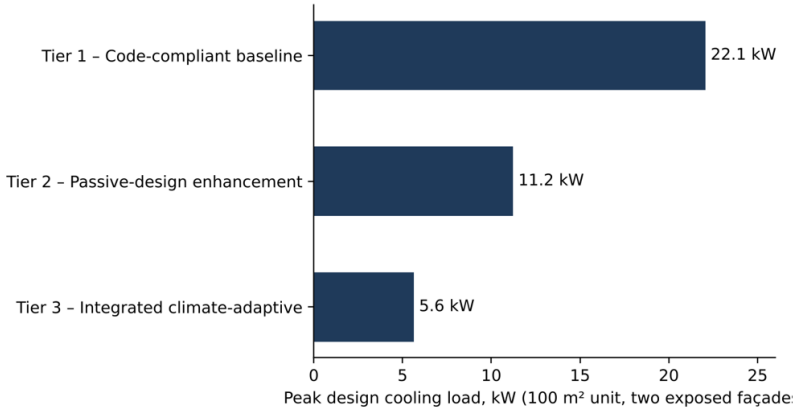

Figure 6: Peak Design Cooling Load by Envelope Tier, Representative Dhaka High-Rise Apartment Unit
Note: Author's sol-air heat-balance calculation (sensible load; parameters in Table 4).

RESULTS AND DISCUSSION

Wind-Load Structural Analysis Results

Table 6 gives the computed velocity pressure and net

Table 8: Recommended Plinth Elevation by Tier, Representative Dhaka High-Rise Site

Scenario	Freeboard above DFL (m)	Recommended plinth level (m PWD)	Basis
Design Flood Level (DFL)	—	7.84	1988 historic peak, Tongi gauge (World Bank, 2017)
Tier 1 - Embankment-referenced baseline	0.36	8.20	Matches existing Dhaka embankment freeboard standard (Sayed & Haruyama, 2017)
Tier 2 – Passive/site-design enhancement	0.51	8.35	Adds 0.15 m site-drainage margin
Tier 3 – Integrated climate-adaptive	0.86	8.70	Adds 0.35 m climate-uncertainty allowance

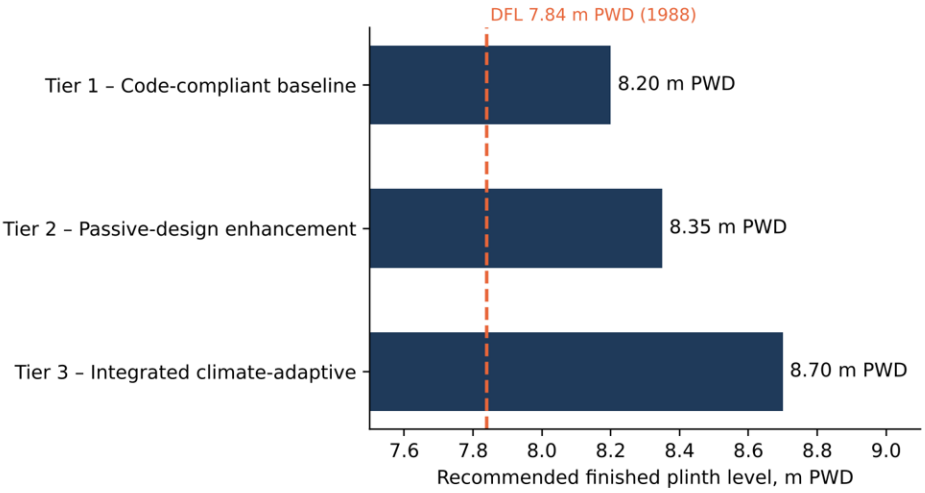

Figure 7: Recommended Plinth Elevation by Tier, Representative Dhaka High-Rise Site
Note: DFL = documented 1988 historic peak flood level (World Bank, 2017). Author's freeboard design check.

design wind pressure at five representative storeys, and Figure 5 plots the full profile across all 20 storeys. Because both codes share the same exposure profile and only the basic wind speed changes, the percentage increase in net design pressure is constant with height at 26.87%. This is within 0.02 percentage points of the 26.85% divisional figure that Lixon *et al.* (2022) report independently for Dhaka. Summed across all 20 storeys, total base shear rises from about 2,699 kN under BNBC 1993 to about 3,423 kN under BNBC 2020, an increase of about 725 kN. Because the ratio holds constant in relative terms, the percentage increase is the same at every storey, but the largest absolute increase in kPa occurs at the top. That is where cladding fixings, parapet detailing, and lateral-bracing connections tend to be most sensitive to wind-pressure margin, which is consistent with the upper-storey structural review discussed in the practitioner case in Section 4.6.

Passive-Design Cooling-Load Results

Table 7 breaks the computed peak cooling load down by component for each envelope tier, and Figure 6 plots the totals. Against the Tier 1 code-compliant baseline' to 'Tier 1 typical-practice baseline of 22.1 kW, the Tier 2 passive-design envelope cuts peak cooling load by 49%, to 11.2 kW, and the Tier 3 integrated climate-adaptive envelope cuts it by 74%, to 5.6 kW. Solar gain through glazing dominates the load at every tier, falling from 57% of the

Table 9: Derived Seasonal UHI Baseline and Trend Projection, Dhaka (°C)

Season	2024 (baseline)	2030	2040	2050	2060
Winter (Dec–Feb)	0.95	1.08	1.29	1.50	1.71
Annual mean	0.48	0.61	0.82	1.03	1.24
Transitional (Mar–May, Nov), derived	0.44	0.57	0.78	0.99	1.20
Monsoon (Jun–Oct)	0.23	0.36	0.57	0.78	0.99

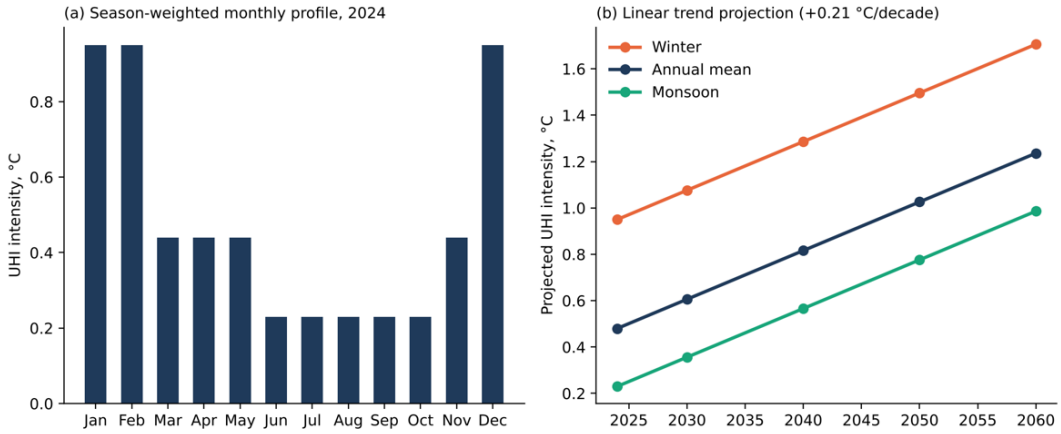

Figure 8: Seasonal Decomposition and Trend Projection of Dhaka's Urban Heat Island Intensity
Note: Author's season-weighted decomposition of seasonal statistics reported by Tabassum et al. (2024), with linear extrapolation of the reported trend. Non-linear urbanisation effects are not modelled.

total at Tier 1 to 42% at Tier 2 and 28% at Tier 3. For this representative Dhaka unit, this confirms the international parametric finding that glazing-related variables (window-to-wall ratio, SHGC, shading) are the most sensitive envelope lever in hot-humid climates (Chen *et al.*, 2017). The Tier 2 reduction lies in roughly the same range that Chen *et al.* (2017) report for envelope optimisation alone (up to 56.7% annual and 64.5% peak). The larger Tier 3 figure reflects the airtightness and cool-roof measures added to envelope optimisation, consistent with the airtightness sensitivity reported separately by Liu *et al.* (2020). These numbers describe a representative building, not a validated energy-simulation output for any specific project; Section 5.2 discusses that distinction further.

Flood/Plinth-Height Design-Check Results

Table 8 gives the recommended finished plinth elevation under each of the three freeboard scenarios, and Figure 7 plots the results against the documented 1988 Design Flood Level. The Tier 1 figure, 8.20 m PWD, coincides with the crest elevation of Dhaka's own flood-protection embankment. In other words, the code-compliant baseline for an individual building's plinth already matches the city's primary flood-defence standard, whether or not those designing to it realise it.' with: 'In other words, the Tier 1 benchmark places an individual building's plinth at the level of the city's primary flood-defence standard. This is an author-defined reference, not a BNBC 2020 requirement. baseline for an individual building's plinth already matches the city's primary flood-defence standard, whether or not those designing to it realise it. The Tier 2 site-drainage margin adds 0.15 m (8.35 m PWD), and the Tier 3 climate-uncertainty allowance adds a further 0.35 m (8.70 m PWD). This gives a total climate-adjusted freeboard of 0.86 m above the documented 1988 flood level, or 0.5 m above the existing embankment standard. In construction terms this is a modest increment (an extra half-metre of plinth fill and foundation extension), but it directly addresses the the flood frequency documented in Section 2.1 documented in Section 2.1, where damaging flood events are expected at least once per decade under current conditions (World Bank, 2015). Section 4.5 quantifies how much each increment reduces the probability of exceedance.

Table 10: Monte Carlo Uncertainty Results (10,000 Samples per Model)

Model output	Deterministic value	Median	P5–P95 range
Base shear, BNBC 1993 (kN)	2,699	2,456	2,132–2,810
Base shear, BNBC 2020 (kN)	3,423	3,116	2,705–3,565
Increase in base shear, 2020 vs. 1993 (%)	26.87	26.87	26.87–26.87
Peak cooling load, Tier 1 / 2 / 3 (kW)	22.1 / 11.2 / 5.6	21.8 / 11.2 / 5.6	19.9–23.9 / 10.3–12.2 / 5.1–6.1
Cooling reduction, Tier 2 vs. Tier 1 (%)	49.1	48.7	44.2–52.9
Cooling reduction, Tier 3 vs. Tier 1 (%)	74.5	74.2	71.8–76.5
Flood exceedance probability, Tier 1 / 2 / 3 (%)	—	44.5 / 16.0 / 0.1	High-climate case: 68.0 / 41.8 / 4.5
UHI annual mean, 2060 (°C)	1.24	1.24	0.93–1.54
UHI winter, 2060 (°C)	1.71	1.71	1.40–2.02

Note: The deterministic base shear lies above the Monte Carlo median because the base case uses the code value Cp,leeward = −0.5, the upper end of the sampled range.

Table 11: One-at-a-Time Sensitivity: Change in Output for a ±10% Change in Each Input

Output	Input (ranked by influence)	Change in output (%)
Base shear, BNBC 2020	Basic wind speed V	−19.0 / +21.0
	Floor-to-floor height	−12.5 / +12.9
	Gust-effect factor G	±10.0
	Power-law exponent α	−6.5 / +5.7
	Leeward Cp	±4.4
Peak cooling load, Tier 1	SHGC; shading factor; glass irradiance; window-to-wall ratio	±5.6 to ±5.7 each
	Outdoor temperature (±1°C)	±1.9
	Wall U-value; roof U-value	±1.2; ±1.0
	Wall and roof absorptance; glazing U-value; ACH	±0.5 to ±0.8 each

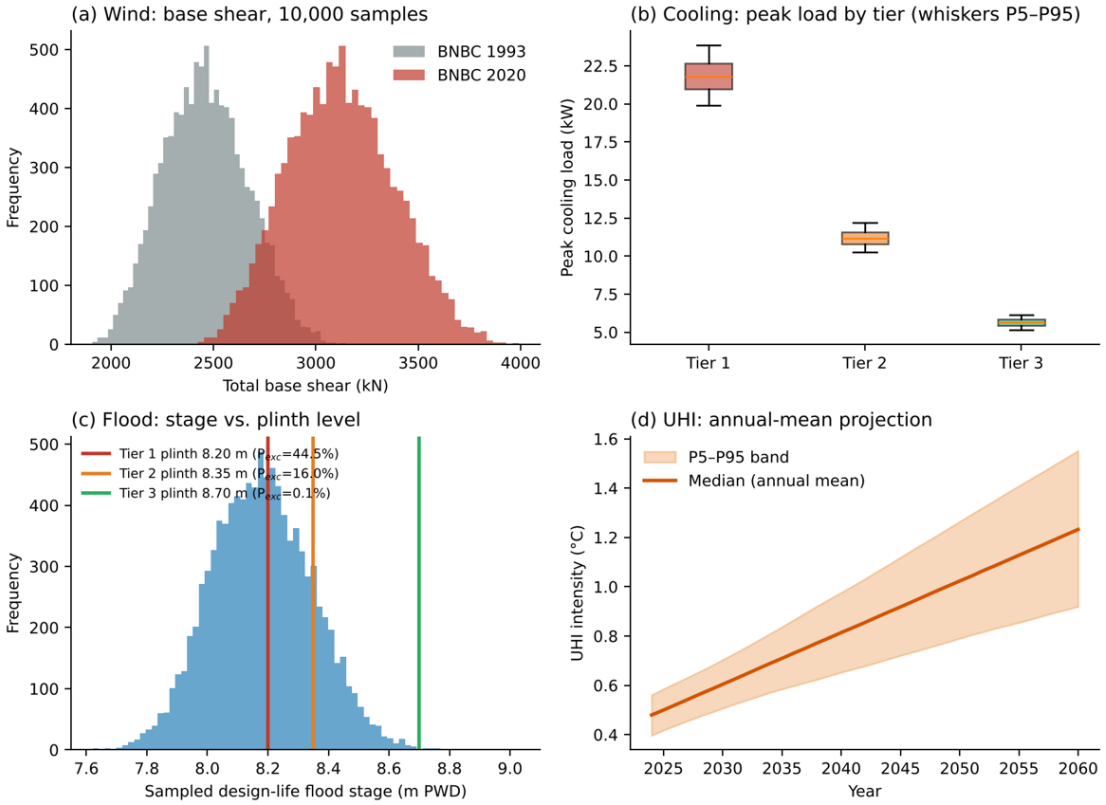

Figure 9: Monte Carlo Uncertainty Results for the Four Models

Note: (a) Base shear under BNBC 1993 and 2020; (b) peak cooling load by tier (box = interquartile range, whiskers = P5–P95); (c) sampled design-life flood stage against the three plinth levels, with exceedance probabilities; (d) annual-mean UHI projection band. Author's calculation.

Urban Heat Island Seasonal Profile and Trend Projection

Table 9 gives the derived seasonal UHI baseline and its projection to 2060, and Figure 8 plots both the seasonal profile and the trend. The season-weighted decomposition implies a transitional-season (March–May and November) mean intensity of about 0.44°C, consistent with the reported annual mean once winter and monsoon are weighted by the number of months each covers. Carrying the reported +0.21°C-per-decade trend forward, winter UHI intensity, already the most severe seasonal value, is projected to reach 1.29°C by 2040 and 1.71°C by 2060, while the annual mean rises from 0.48°C to about 1.24°C over the same period. Winter is already the seasonal peak (Section 2.1) and is likely to remain so. Envelope and shading decisions calibrated only to today's annual-average UHI therefore risk under-designing for a winter heat-retention effect that both the current data

and this projection show to be disproportionately large and, on this illustrative trajectory, growing. As noted in Section 3.7, this is a linear extrapolation of a reported trend rather than a downscaled climate-model projection,

Table 12: Model Verification Against Code Tables, Independent Results, and Literature Benchmarks

Model	Verification check	Benchmark	Result	Status
Wind	Kz power law vs. tabulated coefficients	ASCE 7-05 Table 6-3, Exposure B, 17 heights (ASCE, 2006)	Max. deviation 0.005 (0.8%)	Verified
Wind	code-to-code row: increase, Dhaka	26.87% = (65.70/58.33)^2 - 1 is an arithmetic identity with Lixon et al. (2022), not independent verification	26.87% (Δ = 0.02 pp)	Consistent
Cooling	Component closure	Sum of components = total	Exact	Verified
Cooling	Envelope-driven peak reduction	Up to 64.5% peak (Chen *et al.*, 2017)	Tier 2: 49% (within range)	Consistent
Cooling	Dominant load component	Glazing-related variables most sensitive (Chen *et al.*, 2017)	Glazing solar gain 57% of Tier 1; top-ranked in OAT	Consistent
Flood	Tier 1 plinth vs. city defence standard	Embankment crest 8.20 m PWD (Sayed & Haruyama, 2017)	8.20 m PWD	Verified
UHI	Decomposition closure	Annual mean 0.48°C (Tabassum *et al.*, 2024)	0.48°C	Verified
All	Comparison with instrumented building data	Not available for any single Dhaka high-rise	—	Future work (Section 5.2)

and it is best read as an illustrative trajectory rather than a forecast; Section 4.5 gives its uncertainty range.

Uncertainty, Sensitivity, and Verification Results

Table 10 and Figure 9 summarise the Monte Carlo results, and Table 11 ranks the most influential inputs from the OAT analysis. Three findings stand out.

First, the relative code-to-code comparison is robust, while the absolute values are not. Across all 10,000 wind samples, the BNBC 2020 increase in base shear remained exactly 26.87% (with the gust factor held constant). The same was true under an Exposure C scenario, because every non-wind-speed parameter scales both codes identically and the increase depends only on the ratio of the squared wind speeds. Absolute base shear, by contrast, varied by roughly ±15% (P5–P95 of 2,705–3,565 kN for BNBC 2020) and was most sensitive to storey height, the gust factor, and terrain roughness (Table 11). The headline finding of an approximately 27% increase is therefore insensitive to the representative-building assumptions, whereas absolute forces must be computed for each specific project.

Second, the tier ranking for cooling load is unaffected by input uncertainty. The Tier 2 reduction ranged from 44% to 53% (P5–P95) and the Tier 3 reduction from 72% to 77%. In no sample did Tier 2 achieve less than a 38% reduction or Tier 3 less than 69%. The OAT analysis confirms that glazing-related inputs (window-to-wall ratio, SHGC, shading factor, and glazing irradiance) dominate. Each changes Tier 1 load by about ±5.7% for a ±10% change, three to eight times more than any opaque-envelope or ventilation input. This supports the design priority set out in Section 4.7.

Third, the flood increments have a quantifiable value. Under the assumed distribution of design-life flood stage (median 8.18 m PWD; P5–P95 7.91–8.46 m PWD), the probability that the stage exceeds the plinth falls from 44.5% at Tier 1 to 16.0% at Tier 2 and 0.1% at Tier 3. Under a more severe climate assumption (stage increase up to 0.90 m), the corresponding values are 68.0%, 41.8%, and 4.5%. Tier 3 remains the only tier that keeps exceedance below 5% across both assumptions. For the UHI, the 2060 annual-mean intensity has a P5–P95 range of 0.93–1.54°C (winter 1.40–2.02°C). An accelerating scenario, in which the decadal increment grows by 25% per decade, gives 1.53°C, close to the upper end of that range. The linear projection in Table 9 is therefore best regarded as a central, not an upper-bound, estimate.

Table 12 reports the verification checks. The Kz implementation reproduces all 17 tabulated ASCE 7-05 Exposure B coefficients from 4.6 m to 76 m to within 0.005 (0.8%), a difference attributable to the rounding of the tabulated values to two decimals. The code-to-code pressure increase reproduces the independent divisional figure of Lixon *et al.* (2022) to within 0.02 percentage points. The cooling-load components close exactly to the reported totals, and the resulting Tier 1 intensity of about 221 W/m² of floor area and the share of solar gain through glazing (57%) are consistent with the literature finding that glazing dominates peak load in hot-humid high-rise residences (Chen *et al.*, 2017). The Tier 1 plinth level coincides with the independently documented

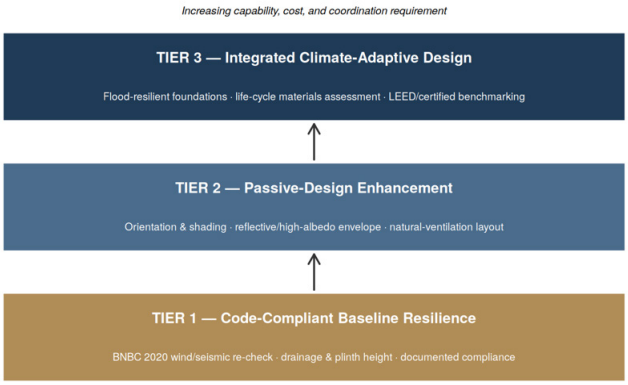

Figure 10: Proposed Three-Tier Progression From Code-Compliant Baseline Resilience to Fully Integrated Climate-Adaptive Design

embankment crest, and the UHI decomposition reproduces the published annual mean of 0.48°C exactly. During verification, one correction was made relative to the earlier version of the wind model ... leaves the percentage increase unchanged was made relative to the earlier version of the wind model: internal pressure, which cancels in the net MWFRS load, had been added to the net pressure. Removing it lowers the absolute pressures and base shears in Table 6 but leaves the percentage increase unchanged.

Illustrative Practitioner Case: Structural Design Vetting on an Industrial Administration Building in the Dhaka Region

Vetting structural designs and supporting quality-control processes' with 'carrying out owner-side design review and supporting quality-control processes. The author's role vetting structural designs and supporting quality-control processes for high-rise and industrial building projects in the Dhaka region, selected and documented as described in Section 3.10. It concerns an administration building for a manufacturing facility, where the revised BNBC wind and serviceability provisions directly affected column sizing, lateral-bracing selection, and roof-cladding fixing details during the structural review stage. The author's independent wind-load recalculation on that project, carried out with the same directional equations as Section 3.4, pointed in the same direction and was of roughly the same order of magnitude as the approximately 27% design-pressure increase quantified in Section 4.1. The project's calculation naturally used its own geometry and site exposure rather than the representative parameters adopted here, which Section 4.5 shows affects absolute forces but not the relative code-driven increase. As with the residential high-rise projects discussed in Section 2, climate-hazard considerations on this project entered the design process almost entirely through the code-mandated wind-load recalculation under BNBC 2020, triggered by the safety-margin gap documented in Section 2.3, rather than through any standalone resilience or passive-design brief. Plinth height and site drainage were set by reference to local waterlogging history rather than through the kind of formal flood-hazard check carried out in Section 4.3. Envelope-material and glazing decisions were fixed on cost and procurement-lead-time grounds well before any shading or solar-orientation analysis of the sort carried out in Section 4.2. That sequencing matches the pattern identified in Section 2.4. Code compliance operates as the de facto resilience standard in practice, and the passive-design and envelope-optimisation strategies that the international literature supports most strongly (Section 2.2), and that Section 4.2 quantifies, are rarely treated as a distinct design step, whether the building is residential or industrial. The vignette therefore points to both a gap and an opportunity. Structural vetting already provides a formal checkpoint at which wind, load, and serviceability

Table 13: Summary of the Three-Tier Framework: Measures, Cost, and Numerical Basis

Tier	Key measures	Marginal cost	Numerical basis / supporting literature
Tier 1 – Baseline	BNBC 2020 wind/seismic re-check; drainage and plinth height; documented compliance	~0% for wind/seismic re-check (code-mandated); plinth benchmark author-defined	+26.9% design wind pressure, robust to all model assumptions (Sections 4.1, 4.5); 8.20 m PWD plinth (Section 4.3); Lixon *et al.* (2022); Building360 (2026)
Tier 2 – Passive	Orientation and shading; reflective/high-albedo envelope; natural-ventilation layout	Low; design/specification changes, no certification fees	−49% peak cooling load (P5–P95 −44% to −53%) (Sections 4.2, 4.5); flood exceedance 44.5% → 16.0%; Chen *et al.* (2017); Liu *et al.* (2020); Tabassum *et al.* (2024); Allplan (2025)
Tier 3 – Integrated	Flood-resilient foundations; life-cycle materials assessment; LEED/certified benchmarking	~7% mean surcharge; 7.43–9.43% Gold/Platinum; 0.4–2.6 yr payback	−74% peak cooling load (P5–P95 −72% to −77%); +0.5 m climate freeboard, exceedance ≤ 4.5% (Sections 4.2, 4.3, 4.5); Xu *et al.* (2023); Dharmarathne *et al.* (2024); Hu & Skibniewski (2021); Uğur & Leblebici (2018)

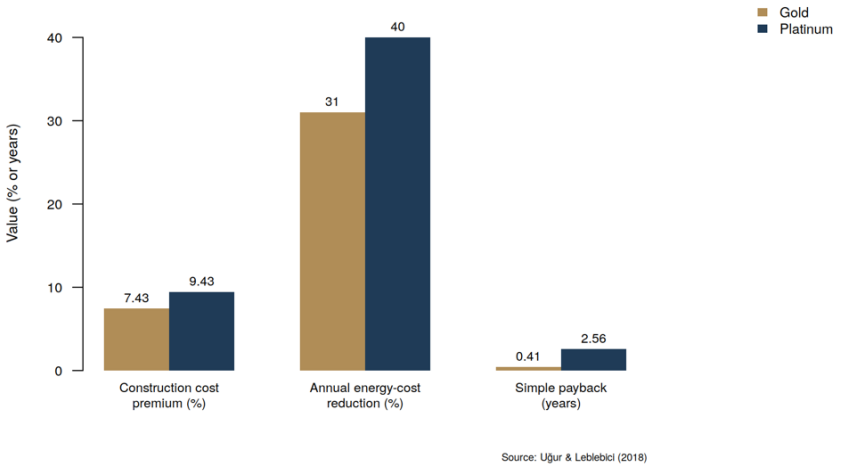

Figure 11: Cost Premium, Energy Savings, and Payback of LEED Gold and Platinum Certification
Note: The Tier 3 cost premium is bounded and offset by measurable energy savings: Gold and Platinum certification carried construction cost premiums of 7.43% and 9.43%, respectively, in a matched case study, against annual energy-cost reductions of 31% and 40%. Data from Uğur and Leblebici (2018).

assumptions are scrutinised, and that checkpoint could be extended, at fairly low marginal cost, into a structured review of passive-design and envelope decisions before those choices are fixed at the architectural design freeze. This is essentially the Tier 1-to-Tier 2 transition that the framework in Section 4.7 formalises.

A Three-Tier Framework for Climate-Resilient High-Rise Design, Numerically Grounded

Sections 4.1 to 4.5 put numbers, and uncertainty ranges, behind each tier of the framework that Section 2 introduced conceptually and Section 4.6 illustrated in practice (Figure 10). Tier 1 corresponds to the BNBC 2020 wind-load margin and flood freeboard quantified in Sections 4.1 and 4.3. Tier 2 corresponds to the roughly 49% peak cooling-load reduction quantified in Section 4.2, together with the added site-drainage freeboard from Section 4.3. Tier 3 corresponds to the fully integrated cooling-load reduction of roughly 74% and the additional 0.5 m of climate-adjusted flood freeboard from Sections 4.2 and 4.3. The framework is designed to be adopted incrementally, not as a package requiring a fully certified green-design process from the outset.

Tier 1 — Code-Compliant Baseline Resilience. This tier formalises what BNBC 2020 compliance already requires (updated wind-load design, seismic zonation, plinth height, and drainage provisions) as an explicit, documented resilience baseline rather than a background regulatory formality. For projects designed under earlier code assumptions, it includes a wind and serviceability re-check against BNBC 2020 provisions Seismic actions (BNBC 2020, Dhaka in Seismic Zone 2) were not analysed in this study and may govern lateral design of high-rise buildings in Dhaka (quantified for a representative building in Section 4.1), given the documented margin increase between the 1993 and 2020 wind-load requirements. Earlier condition-assessment work on existing Bangladeshi industrial buildings shows that such re-checks of the existing stock are practicable within normal consulting workflows (Jany, Islam, Shirin, & Karim, 2026).

Tier 2 — Passive-Design Enhancement. Building on Tier 1, this tier brings in the passive strategies that the international literature supports most strongly for hot-humid climates and that Section 4.2 quantifies: façade orientation and shading to limit direct solar exposure, reflective or high-albedo envelope materials, and layouts that support natural ventilation, evaluated at the architectural design-freeze stage rather than retrofitted afterwards. The sensitivity results in Section 4.5 indicate that glazing ratio, glazing SHGC, and shading deserve first priority within this tier. Tier 2 needs no certification process and fits within conventional design and construction budgets, which makes it the most immediately actionable tier for most domestically financed high-rise projects.

Tier 3 — Integrated Climate-Adaptive Design. The most capability- and cost-intensive tier brings together, in one coordinated design process, the flood-resilient site and foundation detailing quantified in Section 4.3, life-cycle materials assessment, and internationally benchmarked certification such as LEED. For any structural materials programme feeding into the life-cycle assessment, durability and strength performance under sustained loading are the first-order concern For any structural materials programme ... (Ridoy et al., 2026). LEED uptake in Bangladesh has so far concentrated in externally financed and export-oriented facilities. The cost of this tier is better described as a bounded, quantifiable premium than an open-ended one. A global survey of more than 1,300 certified projects across 11 countries found a mean and median green construction cost surcharge of 7% across all building types (Hu & Skibniewski, 2021). A matched case study of Gold- and Platinum-certified buildings found additional construction costs of 7.43% and 9.43%, respectively, offset by annual energy-cost reductions of 31% and 40% and simple payback periods

of 0.41 and 2.56 years (Uğur & Leblebici, 2018). This tier makes most sense for projects with access to green financing, international buyer or investor requirements, or an organisational sustainability mandate, and the payback evidence suggests that the case strengthens once a project's holding period exceeds about two to three years.

The framework is intended less as a rigid sequence than as a practical maturity model. A project team can adopt Tier 1 immediately at effectively no marginal cost. Tier 2 can be treated as a near-term target that fits within current design workflows and, as Section 4.2 shows, roughly halves peak cooling load. Tier 3 can be treated as a capability investment, phased in once project scale, financing structure, or client requirements justify the additional cost and coordination effort.

Insulation

Cladding and roof membranes must meet the BNBC 2020 Part 4 fire-protection requirements for high-rise buildings, external shading must not obstruct fire-fighting access openings, and reduced air-change rates must still satisfy the Part 8 ventilation minimums and the habitable-room window-opening requirements.

Discussion

Theoretical and Practical Implications

Theoretically, the study's contribution is to connect three literatures (passive thermal design, structural wind engineering, and flood-resilient site design) that are normally reviewed, and quantified, separately, even though they govern the same envelope, foundation, and massing decisions on a single building. Treating them as one compound-hazard design problem is offered as a transferable approach for other South Asian deltaic and monsoon-climate markets facing a similarly compound hazard profile, not as a claim specific to Bangladesh. The approach is calibrated numerically to Bangladesh's seasonal UHI profile (Section 4.4), divisional wind-code revision (Section 4.1), and documented flood level (Section 4.3), and its uncertainty is bounded explicitly (Section 4.5). The uncertainty analysis adds a methodological point of its own. Code-to-code and tier-to-tier comparisons are far more robust to representative-building assumptions than absolute values are, so a representative-building approach is well suited to policy and sequencing questions even where it cannot replace project-specific design.

Practically, the three-tier structure in Section 4.7 is built deliberately around the adoption pattern documented in Section 2.4. Rather than presenting climate-resilient design as a single certification threshold that only externally financed or export-linked projects clear (Figures 3 and 4), it breaks resilience into a graduated, numerically bounded sequence that a domestically financed developer can enter at Tier 1 and progress through as capability and financing allow. For structural engineers and design reviewers specifically, Section 4.6 points to a concrete, low-cost procedural change. The wind-load and serviceability re-check already mandated by BNBC 2020 could be extended into a documented Tier 1/Tier 2 screening checklist, informed by the cooling-load reduction quantified in Section 4.2 and the glazing-first priority identified in Section 4.5, rather than establishing an entirely new review stage.

Limitations and Directions for Future Research

The numerical analyses in Sections 4.1–4.5 go well beyond the conceptual synthesis in Section 2, but they remain parametric and illustrative rather than site-measured or empirically validated. This is both the paper's contribution and its main limitation. Five limitations follow. First, all results relate to a single representative building and site, not to any instrumented Bangladeshi high-rise. Section 4.5 shows that the relative, code-driven comparisons (BNBC 1993 versus 2020; Tier 1 versus Tiers 2 and 3) are robust, but project-specific geometry, exposure, orientation, and construction quality will shift the absolute values. Second, the cooling-load model is a steady-state, single-zone calculation of sensible load. It omits latent load, thermal mass, and dynamic effects, so it does not substitute for a dynamic whole-building simulation tested to the ASHRAE Standard 140 method of test (ASHRAE, 2017). Similarly, the UHI projection is a linear extrapolation of a reported trend rather than a downscaled climate model. Third, the uncertainty analysis relies on assumed input distributions (Table 5), several of which (notably the flood-stage increase and the UHI trend uncertainty) could not be derived from published statistics; the reported ranges are therefore conditional on those assumptions. Fourth, the practitioner vignette in Section 4.6 is a single case, not a systematic empirical dataset. Verification (Section 4.5) confirms correct implementation and consistency with established benchmarks, but not agreement with measured performance.

These limitations point to three priorities for future research. The first is empirical, project-level studies that instrument specific Dhaka high-rise buildings against the parametric assumptions in Sections 3.4–3.5. Such studies would extend both the international parametric findings (Chen *et al.*, 2017) and the representative-building results reported here (Section 4.2) into a locally validated, project-specific evidence base. Two strands of digital-construction practice in Bangladesh point to how this instrumentation gap might be closed without waiting for a dedicated research programme. Building Information Modelling workflows already being adopted to coordinate multidisciplinary design data on Bangladeshi urban construction projects offer a natural home for the project-specific parameter sets this limitation calls for (Jany, Karim, *et al.*, 2026). Drone-based monitoring of high-rise construction progress offers a comparatively low-cost route to the site-specific geometry and construction-quality records that the representative-building approach in Section 3.3 cannot supply (Jany, 2026). The second priority concerns the existing building stock. Research is needed on how BNBC 2020's updated wind and flood provisions interact

with the large stock of high-rise buildings designed under the 1993 code, using full structural-analysis software on real as-built geometries rather than the representative parametric model in Section 4.1. Such work would establish what proportion of Dhaka's existing high-rise stock now carries a may not meet the wind actions now prescribed by BNBC 2020 and where retrofit priority should go, building on condition-assessment methods already applied to existing Bangladeshi buildings (Jany, Islam, & Shirin, 2026; Jany, Islam, Shirin, & Karim, 2026). Third, given the documented gap between low domestic awareness of climate-resilient practices and comparatively strong uptake in externally incentivised segments such as LEED-certified garment factories, research into financing and incentive mechanisms may do more to close the adoption gap in domestically financed residential high-rise construction than further technical refinement of the numerical models presented here. Reproduce the full equations, parameters, assumptions, and code underlying Sections 4.1–4.5, both for transparency and so that researchers can substitute measured, project-specific data for the representative parameters used here.

For practitioners, the framework in Section 4.7 offers a practical entry point. Extending the structural design-vetting checkpoint already standard on Bangladeshi high-rise projects to document Tier 1 compliance formally, and to screen for the Tier 2 passive-design opportunities quantified in Section 4.2, is achievable within current organisational and regulatory constraints. It also lays the operational groundwork on which Tier 3 capability can later be built, once project economics and client requirements justify it.

CONCLUSION

High-rise design in Bangladesh sits at the intersection of rapid vertical densification and a compound, worsening climate hazard profile: urban flooding, an intensifying urban heat island, and cyclonic wind loading that reaches well beyond the coastal belt. This paper has put numbers on each element of that compound hazard for a representative 20-storey Dhaka high-rise and has bounded each estimate with sensitivity and uncertainty analysis. BNBC 2020's wind-load provisions 'impose design pressures and storey shears about 26.9% higher than the BNBC 1993 basic wind speed at every storey (with the gust factor held constant). This figure reproduces the divisional finding for Dhaka by Lixon *et al.* (2022) to within 0.02 percentage points and is unaffected by the representative-building assumptions. A passive-design envelope package removes roughly half of the representative unit's peak sensible cooling load, and a fully integrated climate-adaptive package removes roughly three-quarters, a ranking that holds across all sampled input combinations. A flood-freeboard check tied to Dhaka's documented 1988 flood level and embankment standard indicates that an embankment-referenced plinth level matches the city's primary flood defence. A modest additional 0.5 m of climate-adjusted freeboard reduces the estimated probability of design-life flood exceedance from about 45% to well under 5%. Dhaka's urban heat island, already about four times more intense in winter than in the monsoon season, is projected on current trends to see its annual-mean intensity more than double (to about 1.2°C, with a 5–95% range of 0.9–1.5°C) by 2060.

Drawing on an illustrative case from structural vetting practice on Dhaka-region projects (Section 4.6), the paper has argued that the practical path for most Bangladeshi developers is not immediate pursuit of fully certified climate-adaptive design. It is a staged, numerically bounded progression: formalised code-compliance documentation and low-cost passive-design screening first, followed by integrated, certified climate-adaptive design as project economics, financing access, and organisational capability allow. The parametric models presented here indicate the order of magnitude of that investment and its likely payoff at each tier. Checking those models against instrumented, project-specific structural, energy, and hydrological data, as set out in Section 5.2, is the necessary next step.

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