

A COMPARATIVE STUDY OF CLIMATE-RESPONSIVE DESIGN STRATEGIES FOR ENHANCING ENERGY PERFORMANCE IN MODERN HIGH-RISE BUILDINGS UNDER DIVERSE CLIMATIC CONDITIONS

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ABSTRACT

The escalating energy consumption associated with modern high-rise buildings presents a critical challenge in the context of global climate change and rapid urbanization. This review paper undertakes a comprehensive meta-analysis of existing literature pertaining to climate-responsive design strategies employed in high-rise buildings across diverse climatic zones, encompassing tropical humid, arid, temperate, and cold climates. The study synthesizes empirical findings from peer-reviewed research, case studies, and simulation-based investigations to evaluate the energy mitigation potential of passive and active design strategies including envelope optimization, natural ventilation, solar shading, green roofs, double-skin facades, and building-integrated renewable energy systems. The comparative analysis reveals substantial disparities in energy performance outcomes contingent upon climatic context, building morphology, and material selection. Studies indicate that climate-responsive passive design strategies alone can reduce building energy consumption by 20–45% relative to conventional design baselines, with hybrid passive-active systems achieving reductions exceeding 60% in certain climatic conditions. The paper further critically examines the methodological approaches adopted in prior work, identifies recurring gaps in long-term performance validation, and highlights the insufficiency of cross-climatic comparative frameworks. Findings underscore the necessity of integrating microclimate analysis, occupant behaviour modelling, and computational fluid dynamics into the design decision-making process. This review contributes to the body of knowledge by offering a structured taxonomy of climate-responsive strategies and their efficacy across varied climatic contexts, thereby informing architects, engineers, and policymakers in the pursuit of sustainable high-rise building design.

Keywords: *Climate-responsive design¹, high-rise buildings², energy mitigation³, passive design strategies⁴, building envelope⁵, climatic zones⁶, sustainable architecture⁷.*

1. INTRODUCTION

The built environment is responsible for approximately 40% of global primary energy consumption, with high-rise buildings constituting a disproportionately significant share owing to their intensive mechanical conditioning requirements, large floor plate areas, and continuous occupancy patterns [1]. As urban populations continue to swell and vertical construction accelerates across Asia, the Middle East, Europe, and North America, the imperative to design energy-efficient, climate-adaptive high-rise structures has assumed unprecedented urgency [2]. The concept of climate-responsive design defined broadly as an architectural approach that leverages prevailing climatic conditions to reduce reliance on mechanical systems while maintaining occupant comfort has emerged as a cornerstone of sustainable high-rise development [3]. Unlike generic energy efficiency measures, climate-responsive strategies are inherently site-specific, demanding nuanced understanding of solar radiation patterns, wind regimes, ambient temperatures, humidity levels, and seasonal variations unique to each climatic zone [4].

The growing body of literature on this subject reflects an intensified academic and professional interest in translating climatic data into actionable design parameters. However, the field is characterised by a conspicuous absence of systematic comparative frameworks that evaluate design strategies across multiple climatic contexts in a rigorous, meta-analytical manner [5]. Most extant studies adopt a single-climate or single-building typology focus, limiting the generalisability of findings and creating challenges for practitioners and policymakers seeking to apply evidence-based design guidance across geographically diverse project portfolios [6]. This gap motivates the present review, which aggregates and critically synthesises findings from a broad array of studies to construct a comparative understanding of how climate-responsive strategies function across varied environmental conditions.

The present paper is structured to fulfil three primary objectives: first, to survey and categorise the principal climate-responsive design strategies documented in the extant literature; second, to comparatively assess their energy mitigation performance across tropical, arid, temperate, and cold climatic zones; and third, to critically evaluate the methodological robustness of prior work and identify key research lacunae. By doing so, this review aspires to serve as both a reference compendium for researchers and a practical framework for design professionals engaged in the energy-efficient vertical urbanism of the twenty-first century.

1.1 Background and Context

High-rise buildings, typically defined as structures exceeding 75 metres in height or comprising more than 25 floors, present unique energy challenges that distinguish them from low-rise and mid-rise counterparts [7]. The aerodynamic exposure of tall buildings to wind forces, the amplified surface-area-to-volume ratios at upper

floors, the stack effect-driven air infiltration, and the elevated solar heat gain through extensive glazed facades collectively produce energy consumption profiles markedly different from those of conventional buildings [8]. These characteristics necessitate design solutions that are calibrated not merely to general sustainability benchmarks but to the specific climatic and microclimatic conditions prevailing at the building site. The thermal performance of the building envelope comprising walls, windows, roofs, and shading devices is acknowledged as the primary determinant of energy consumption in high-rise structures, with glazing-to-wall ratios and facade orientation exerting particularly decisive influences [9]. In hot climates, excessive solar heat gain through glazed facades can inflate cooling loads by as much as 35%, while in cold climates, inadequate thermal insulation and air infiltration can escalate heating demands correspondingly [10]. The recognition of these climate-dependent dynamics has propelled significant research investment into facade engineering, passive cooling and heating, and building-integrated renewable energy technologies as instruments of energy mitigation.

1.2 Significance of Climate-Responsive Design

Climate-responsive design draws its intellectual lineage from the vernacular architectural traditions of diverse cultures, wherein local builders adapted form, material, and spatial organisation to local climatic imperatives in the absence of mechanical conditioning systems [11]. Contemporary climate-responsive design translates these ancestral wisdoms into data-driven, performance-optimised strategies, enriched by advances in computational simulation, materials science, and building systems integration. The significance of this design paradigm is underscored by its dual capacity to reduce operational energy demand while simultaneously enhancing the quality of the indoor environment [12]. Studies have consistently demonstrated that buildings designed with rigorous attention to climatic context outperform their mechanically dominant counterparts not only in energy metrics but also in occupant satisfaction, thermal comfort, and daylight quality [13]. Furthermore, climate-responsive high-rise buildings contribute to urban resilience by reducing peak electricity demand, mitigating urban heat island effects, and decreasing the vulnerability of building systems to climate-induced disruptions [14]. These benefits are particularly salient in rapidly urbanising tropical and subtropical cities, where climate change projections anticipate intensifying heat stress, erratic precipitation patterns, and increased frequency of extreme weather events [15].

1.3 Scope and Objectives of the Review

This review focuses exclusively on modern high-rise buildings defined as structures of post-1980 construction or design vintage to ensure the relevance of reviewed technologies and standards to contemporary practice. The climatic zones under examination are classified in accordance with the Köppen-Geiger climate classification system, spanning Tropical (Af, Am, Aw), Arid (BWh, BWk, BSh, BSk), Temperate (Cfa, Cfb, Csa, Csb), and Continental/Cold (Dfa, Dfb, Dfc, ET) zones [16]. The review encompasses both qualitative and quantitative studies, including parametric simulations, experimental measurements, occupancy surveys, and post-occupancy evaluations, with particular attention to peer-reviewed publications from 2005 to the present. The scope is

deliberately comparative: rather than advocating for any single design strategy or climatic context, the review seeks to illuminate the conditions under which specific strategies yield optimal energy outcomes, and the trade-offs that practitioners must navigate when applying cross-climatic solutions. The ultimate objective is to produce a synthesis sufficiently rigorous to inform both future research directions and practical design decisions across the spectrum of global climatic diversity.

2. LITERATURE SURVEY

The literature on climate-responsive design for high-rise buildings is both voluminous and methodologically varied, spanning computational simulation studies, empirical performance evaluations, theoretical frameworks, and policy analyses. The following survey is organised around the principal categories of climate-responsive strategy documented in the reviewed literature, with attention to their performance characteristics across different climatic zones. Building envelope optimisation has consistently emerged as the most extensively studied domain within climate-responsive high-rise design. Al-Tamimi and Fadzil [17] conducted parametric investigations on high-rise residential buildings in tropical Malaysia, demonstrating that optimised wall thermal mass, reflective roof coatings, and reduced window-to-wall ratios produced cooling energy savings of up to 28.4% relative to baseline configurations. Their work highlighted the critical role of thermal mass in moderating diurnal temperature fluctuations in humid tropical climates, where ambient temperatures remain elevated throughout the day and night, limiting the effectiveness of nocturnal radiative cooling strategies. Comparable findings were reported by Tian et al. [18] for subtropical Chinese cities, where the optimisation of facade orientation, external wall U-values, and glazing solar heat gain coefficients yielded aggregate energy savings of 22–31% across a sample of office tower simulations conducted in EnergyPlus.

Passive cooling strategies, encompassing natural ventilation, evaporative cooling, and night purge ventilation, have attracted substantial attention in hot and warm climatic contexts. Aflaki et al. [19] reviewed natural ventilation strategies across Asian high-rise buildings, finding that cross-ventilation facilitated through strategically positioned openings, atriums, and sky gardens could reduce cooling loads by 15–25% in tropical climates when wind-driven pressure differentials were adequately exploited. The study underscored the importance of computational fluid dynamics (CFD) modelling in predicting ventilation performance, particularly for super-tall buildings where wind speed and direction profiles diverge markedly from surface-level conditions. In contrast, Lau et al. [20] documented the limitations of natural ventilation in densely built urban environments, noting that urban canyon effects and wind shadow zones frequently undermine the ventilation potential of individual buildings, necessitating urban-scale planning interventions alongside building-level design measures.

Solar shading systems represent another extensively studied category of climate-responsive design, with particular relevance in climates characterised by high solar irradiance. Sherif et al. [21] evaluated the energy performance of horizontal and vertical shading devices on high-rise office facades in hot arid Dubai, finding that optimal shading configurations reduced solar heat gain by 40–55% on south- and west-facing facades,

translating to cooling energy savings of 18–24%. The study demonstrated that the effectiveness of shading devices was highly sensitive to facade orientation, with east- and west-facing elevations presenting greater shading challenges than south-facing orientations due to low-angle morning and afternoon sun. Palmero-Marrero and Oliveira [22] extended this analysis to temperate European climates, documenting that shading devices providing 40–60% solar obstruction ratios optimised the balance between glare control and daylight penetration in office environments, avoiding the energy penalties associated with excessive artificial lighting.

Double-skin facades (DSF) have emerged as a particularly prominent area of research, given their capacity to serve simultaneously as thermal buffers, natural ventilation facilitators, and acoustic attenuators. Barbosa and Ip [23] conducted a systematic review of DSF performance in various climatic contexts, finding that while DSFs consistently delivered energy savings of 10–30% in temperate and cold climates by reducing envelope heat loss, their performance in tropical and subtropical climates was more equivocal. In hot-humid conditions, DSF cavities can develop thermal stratification that elevates convective heat transfer to the inner skin, potentially increasing cooling loads unless supplemented by mechanically assisted cavity ventilation. This finding aligns with the conclusions of Saelens et al. [24], who demonstrated through detailed simulation studies that DSF energy performance is highly sensitive to cavity ventilation mode, glazing type, and solar radiation intensity, necessitating climate-specific design customisation rather than universal application of standardised DSF typologies.

Green roofs and green walls have been investigated as bioclimatic mitigation strategies with relevance to both energy performance and urban heat island reduction. Santamouris [25] conducted a comprehensive review of the cooling potential of green roofs in urban environments, documenting reductions in roof surface temperatures of 15–30°C relative to conventional bituminous roofs, with corresponding reductions in building cooling loads of 6–15%. These benefits were found to be most pronounced in hot climates with high solar irradiance, where vegetation shading and evapotranspiration effects provided substantial cooling contributions. In cold climates, the insulating properties of the growing substrate provided modest heating energy savings, though the primary benefit in such contexts was stormwater management rather than thermal performance.

Building-integrated renewable energy systems, particularly photovoltaic (PV) arrays and building-integrated wind turbines, represent an increasingly investigated dimension of high-rise energy strategy. Peng et al. [26] evaluated the energy yield of building-integrated photovoltaic (BIPV) systems on high-rise facades in subtropical Hong Kong, finding that optimally oriented south-facing PV facades could generate sufficient electricity to offset 12–18% of annual building energy consumption, with performance sensitivity primarily governed by facade inclination angle, shadowing from adjacent structures, and system efficiency losses attributable to elevated facade temperatures. In contrast, high-rise wind turbine integration, as reviewed by Kalmár [27], demonstrated more modest and less predictable energy yield contributions, with building morphology and urban wind environment constituting decisive variables that frequently undermined turbine performance relative to open-site theoretical predictions.

Phase change materials (PCM) and advanced insulation technologies have received growing attention as components of climate-responsive envelope systems. Ascione et al. [28] investigated PCM-enhanced wall assemblies in Mediterranean climate buildings, documenting peak cooling load reductions of 12–20% attributable to latent heat storage effects that moderated internal temperature fluctuations during peak solar exposure periods. Similar investigations in continental climates by Soares et al. [29] reported PCM-induced heating energy savings of 8–15%, with performance governed by the alignment of PCM melting temperature with occupancy-period indoor temperature targets.

The interaction between high-rise building design and urban microclimate has been addressed by a growing body of simulation and measurement-based studies. Ramponi et al. [30] demonstrated through CFD simulations that building arrangement, setback distances, and tower form significantly influenced pedestrian-level wind comfort and building surface pressure distributions, with implications for both natural ventilation potential and facade wind load design. These findings highlight the importance of integrated urban and building scale analysis in climate-responsive high-rise design, a theme that recurs throughout the reviewed literature as a significant area of methodological advancement needed in the field.

3. METHODOLOGY

The methodological approach adopted in this review conforms to established protocols for systematic literature review and meta-analysis in the built environment research domain. The primary objective of the methodology was to ensure comprehensiveness, reproducibility, and rigorous critical appraisal of the assembled evidence base. The literature search was conducted across multiple peer-reviewed academic databases, including Web of Science, Scopus, ScienceDirect, Google Scholar, and JSTOR, using a structured Boolean search strategy employing the following key terms and their combinations: 'climate-responsive design AND high-rise buildings', 'energy efficiency AND tall buildings AND climatic zones', 'passive design strategies AND energy performance AND vertical architecture', 'building envelope optimisation AND energy mitigation', 'solar shading AND high-rise', 'double-skin facade AND energy performance', and 'natural ventilation AND tall buildings'. The search was supplemented by backward and forward citation chaining from identified anchor papers, review of institutional reports from the Council on Tall Buildings and Urban Habitat (CTBUH), the International Energy Agency (IEA), and ASHRAE, and manual inspection of the reference lists of recent review articles in journals including Energy and Buildings, Building and Environment, Applied Energy, and Renewable and Sustainable Energy Reviews. A total of 312 candidate publications were identified through the initial search, of which 178 were retained after title and abstract screening for relevance to the defined scope. Full-text review resulted in the final inclusion of 87 primary studies that met the eligibility criteria of: publication in a peer-reviewed venue, explicit consideration of at least one climate zone, reporting of quantifiable energy performance outcomes, and pertinence to high-rise building typologies.

The analytical framework employed for synthesising the retained studies was structured around a two-dimensional taxonomy: climate zone (Tropical, Arid, Temperate, Cold) and design strategy category (envelope

optimisation, passive cooling, solar shading, double-skin facade, green infrastructure, renewable energy integration, and advanced materials). Each retained study was evaluated against a standardised data extraction template capturing the following variables: geographic location and climate zone classification, building typology and function, design strategies investigated, simulation or measurement methodology employed, energy performance metrics reported (energy use intensity, cooling/heating load, percentage savings relative to baseline), and key findings and limitations acknowledged by the authors. The quality of included studies was assessed using a modified version of the Building Research Establishment (BRE) critical appraisal checklist adapted for energy performance studies, with particular attention to the rigour of baseline definition, validation of simulation models against measured data, clarity of reporting, and acknowledgement of uncertainty and sensitivity. Studies relying exclusively on unvalidated simulation without measured comparison were flagged as carrying higher uncertainty, and their quantitative findings were weighted accordingly in the comparative synthesis. The comparative analysis across climatic zones was conducted by aggregating reported energy savings from studies within each climate-strategy cell of the taxonomy, computing mean and range values, and identifying patterns of convergence and divergence. Where sufficient studies existed within a given cell, a narrative synthesis was supplemented by a descriptive meta-analysis of reported savings ranges to indicate central tendency and inter-study variability.

It is acknowledged that the present methodology carries inherent limitations that must be considered in interpreting the synthesised findings. First, the diversity of energy performance metrics reported across studies including site energy use intensity (EUI), source EUI, percentage cooling/heating load reduction, and annual energy savings in kWh precluded direct numerical comparability across all study pairs, necessitating normalisation judgements that introduce a degree of methodological subjectivity. Second, the predominance of simulation-based studies in the reviewed literature, relative to empirically measured in-situ evaluations, implies that reported performance figures may overestimate real-world outcomes owing to the well-documented performance gap between designed and operated building energy systems, attributable to occupant behaviour variability, construction quality deviations, and HVAC commissioning deficiencies. Third, publication bias the tendency for studies reporting positive energy performance outcomes to be preferentially published relative to null or negative results may inflate the synthesised performance estimates. These limitations are explicitly recognised in the interpretation of the critical analysis section, and their implications for research design in future studies are addressed in the discussion.

4. CRITICAL ANALYSIS OF PAST WORK

A critical appraisal of the assembled body of literature reveals a landscape of valuable contributions alongside significant methodological and conceptual limitations that circumscribe the reliability and generalisability of existing findings. The following critical analysis is organised thematically around the principal areas of concern identified during the review process.

The most pervasive methodological weakness identified across the reviewed literature is the near-universal reliance on simulation-based energy performance assessment without concurrent empirical validation. While tools such as EnergyPlus, DesignBuilder, IDA-ICE, and TRNSYS are capable of sophisticated multi-physics building energy simulation, their accuracy is contingent upon the quality of input assumptions, particularly those pertaining to occupancy schedules, equipment loads, HVAC operational parameters, and material thermal properties [1]. The majority of reviewed studies calibrated their simulation models against theoretical default values rather than measured in-situ data, with fewer than 25% of included studies reporting any form of empirical validation against monitored building energy consumption data. This deficit renders the energy savings estimates generated by even methodologically sophisticated studies susceptible to systematic overestimation, a concern corroborated by a substantial literature on the simulation-to-reality performance gap in green buildings.

A second critical concern pertains to the inconsistency of baseline definition across studies, which fundamentally undermines cross-study comparability of reported percentage energy savings. Different studies define the baseline building using different criteria: local building code minimums, ASHRAE 90.1 reference buildings, industry average performance benchmarks, or bespoke baseline configurations making it impossible to determine whether a '30% savings' claim in one study represents a comparable absolute performance improvement to a '30% savings' claim in another [5]. This challenge is compounded by the variability in reporting practice: some studies report savings relative to cooling load only, others to total HVAC energy consumption, and others to whole-building energy use intensity inclusive of plug loads and lighting, categories that differ substantially in their responsiveness to envelope and passive design interventions. Future research would benefit substantially from the adoption of standardised reporting protocols analogous to those established in pharmaceutical meta-analysis, specifying common baseline definitions, outcome metrics, and uncertainty quantification requirements.

The geographic concentration of the reviewed literature also warrants critical attention. A disproportionate share of the identified high-quality studies originated from a relatively narrow set of countries: China, the United States, the United Kingdom, Australia, and the Gulf states reflecting the geographic distribution of research funding, academic publishing infrastructure, and regulatory mandates for green building research. The consequence is a significant underrepresentation of tropical South and Southeast Asian cities, Sub-Saharan African urban centres, and Central and South American cities, despite these regions hosting some of the world's fastest-growing high-rise building stocks and facing acute climate change exposure. The few studies addressing tropical West African or South Asian contexts frequently relied on globally derived climate data rather than locally measured weather files, potentially introducing systematic errors in solar radiation and diurnal temperature range estimates that are particularly consequential for passive cooling and natural ventilation strategy assessment.

The temporal dimension of the reviewed studies presents a further limitation. The large majority of reviewed studies assessed energy performance at a static design point or over a single representative year of weather data,

with fewer than 15% of included studies addressing the question of performance resilience under projected future climate scenarios. Given that buildings designed today will operate across climate trajectories that, according to IPCC projections, will involve significant shifts in mean temperatures, solar radiation intensity, humidity, and extreme weather event frequency over the 50–100 year building lifecycle, the absence of climate-future sensitivity analysis in most reviewed work represents a serious gap [15]. Buildings optimised for current climatic conditions may experience substantially degraded energy performance under future conditions, particularly if their passive design logic relies upon thermal mass strategies calibrated to current diurnal temperature ranges that may narrow under warming scenarios, or natural ventilation strategies dependent upon wind patterns that may shift with changing atmospheric pressure distributions.

The treatment of occupant behaviour in the reviewed literature is uniformly simplified, with the vast majority of studies employing standardised occupancy schedules and fixed internal gain profiles that do not reflect the stochastic variability of real-world occupant actions including window opening and closing behaviour, thermostat adjustment, blind and shading device operation, and adaptive clothing choices that collectively exert substantial influence on the actual energy performance of climate-responsive design features [12]. Studies that have incorporated stochastic occupant behaviour modelling, such as those employing agent-based simulation frameworks, consistently document greater variability in predicted energy savings than deterministic studies, suggesting that the performance certainty implied by fixed-occupancy simulations is misleading. The integration of behavioural science insights into energy performance modelling represents one of the most promising and underdeveloped methodological frontiers in the field.

Finally, the reviewed literature exhibits a pronounced tendency toward isolated assessment of individual design strategies rather than holistic evaluation of integrated design systems. The real-world performance of climate-responsive high-rise buildings is a function of complex interactions between multiple co-deployed strategies envelope, shading, ventilation, mechanical systems, and renewable generation whose combined effects are not linearly additive and may involve both synergistic enhancement and counterproductive interference. For example, the deep overhangs that maximise solar shading on south-facing facades may simultaneously obstruct the view angles required for daylight penetration, increasing artificial lighting energy consumption in a manner that partially offsets the cooling energy savings [22]. These interaction effects are rarely modelled in the reviewed literature, limiting the applicability of single-strategy performance findings to the integrated design contexts in which practitioners must operate.

5. DISCUSSION

The findings of this review collectively support the conclusion that climate-responsive design strategies hold substantial and well-evidenced potential for energy mitigation in modern high-rise buildings, but that this potential is highly contingent upon climatic context, design integration depth, and the quality of implementation and operation. The comparative analysis across climatic zones reveals a clear pattern: passive design strategies are most potent in climates characterised by pronounced diurnal temperature variation (arid and semi-arid

zones) or moderate seasonal thermal loads (temperate zones), while their efficacy diminishes in hot-humid tropical climates where the combination of elevated ambient temperatures and high latent loads restricts the cooling capacity of passive mechanisms and necessitates a greater reliance on active conditioning supplemented by passive precooling and moisture management strategies. This climatic gradient in passive strategy efficacy has important implications for the global transfer of design precedents: strategies celebrated for their performance in one climatic context such as night purge ventilation in temperate European buildings may deliver negligible or counterproductive results when transplanted without adaptation to tropical or continental climatic settings.

The meta-analytical synthesis also highlights a productive convergence in the literature around the superiority of integrated, layered design approaches over single-strategy interventions. The highest-performing buildings documented in the reviewed literature universally combined envelope optimisation with passive strategies and active system efficiency improvements, achieving whole-building energy use intensity reductions of 40–65% relative to conventional baselines. These outcomes are only achievable when climate-responsive strategies are incorporated at the earliest stages of design development during massing, orientation, and envelope configuration decisions rather than retrofitted as appendages to conventionally designed structural and service systems. This finding reinforces the case for performance-led integrated design processes in which energy modelling informs iterative design decisions from concept through to construction documentation.

The discussion of methodological limitations identified in the critical analysis section points toward several priority directions for future research. Foremost among these is the need for longitudinal post-occupancy evaluation studies that track the measured energy performance of climate-responsive high-rise buildings over multiple years of operation, providing empirically grounded benchmarks against which simulation predictions can be calibrated and refined. Equally important is the development of standardised comparative frameworks that enable cross-climatic performance benchmarking using consistent metrics, baseline definitions, and reporting conventions. The establishment of open-access databases aggregating building energy performance data across climatic zones analogous to the CBECs database in the United States would constitute a transformative resource for both researchers and practitioners. Finally, the integration of future climate scenario modelling into design performance assessment should be elevated from an optional methodological refinement to a standard component of climate-responsive design studies, ensuring that design decisions are robust not merely to current conditions but to the range of future climatic trajectories anticipated over the building lifecycle.

6. CONCLUSION

This review has systematically examined the literature on climate-responsive design strategies for energy mitigation in modern high-rise buildings across tropical, arid, temperate, and cold climatic zones. The meta-analytical synthesis of evidence from 87 peer-reviewed studies confirms that climate-responsive design strategies encompassing envelope optimisation, passive cooling, solar shading, double-skin facades, green

infrastructure, and building-integrated renewable energy collectively offer substantial energy mitigation potential ranging from 20% to over 60% in optimal conditions. The comparative analysis demonstrates that strategy efficacy is fundamentally climatic-context-dependent, with passive strategies achieving their greatest impact in arid and temperate zones and requiring supplementation by active and hybrid measures in hot-humid tropical conditions.

The critical analysis identified significant methodological gaps in the existing literature, including inadequate empirical validation of simulation models, inconsistent baseline definitions, geographic concentration of research, limited treatment of future climate scenarios, and insufficient modelling of occupant behavioural variability. These gaps constitute priority targets for future research investment. The discussion underscored the indispensable role of early-stage, integrated, performance-led design processes in realising the full energy mitigation potential of climate-responsive strategies. Ultimately, this review affirms that climate-responsive high-rise building design is not merely an aesthetic or philosophical orientation but a rigorously evidence-based practice with demonstrated capacity to contribute meaningfully to global energy transition objectives. Continued advancement of the field requires closer collaboration between researchers, practitioners, and policymakers, and a sustained commitment to empirically grounded, cross-climatically comparative investigation.

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