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COMPARISON OF TRADITIONAL AND CONTEMPORARY WINDBREAKERS IN HOT-DRY AND HOT-HUMID CLIMATE ZONES

COMPARACIÓN DE LOS CORTAVIENTOS TRADICIONALES Y CONTEMPORÁNEOS EN ZONAS CLIMÁTICAS CÁLIDAS Y SECAS Y CÁLIDAS Y HÚMEDAS

COMPARAÇÃO ENTRE QUEBRA-VENTOS TRADICIONAIS E CONTEMPORÂNEOS EM ZONAS CLIMÁTICAS QUENTES E SECAS E QUENTES E ÚMIDAS

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ABSTRACT

This study aims to comparatively evaluate traditional and contemporary windbreaker systems used in hot–arid and hot–humid climate regions in terms of structural effectiveness, energy efficiency, and visual harmony with the landscape. The research adopts a simplified Multi-Criteria Decision Analysis (MCDA) framework integrated with a Likert-scale rating system, applied across a case study of eight different settlements. The findings reveal that traditional systems exhibit high efficiency in passive ventilation and climate-responsive morphology. In contrast, contemporary systems demonstrate advantages in energy efficiency through the use of sustainable materials and advanced technological solutions. However, contemporary applications tend to show limited visual integration with the local context and an increased dependence on mechanical systems. By integrating traditional environmental knowledge with contemporary climate-responsive design approaches, this study provides a comprehensive, multi-scalar perspective and an innovative contribution to sustainable architectural design strategies.

Keywords
windbreaker systems, climate-responsive architecture, energy efficiency, passive cooling, visual harmony, traditional architecture, sustainable facade design

RESUMEN

El objetivo de este estudio es evaluar comparativamente los sistemas de cortavientos tradicionales y contemporáneos utilizados en regiones climáticas cálidas y áridas, y cálidas y húmedas, en términos de eficacia estructural, eficiencia energética y armonía visual con el paisaje. La investigación adopta un marco simplificado de análisis de decisiones multicriterio (MCDA) integrado con un sistema de calificación de escala Likert, aplicado a ocho casos de asentamientos distintos. Los resultados revelan que los sistemas tradicionales presentan una alta eficiencia en la ventilación pasiva y una morfología que responde al clima. Por el contrario, los sistemas contemporáneos demuestran ventajas en cuanto a eficiencia energética gracias al uso de materiales sostenibles y soluciones tecnológicas avanzadas. Sin embargo, las aplicaciones contemporáneas tienden a mostrar una integración visual limitada con el contexto local y una mayor dependencia de los sistemas mecánicos. Al integrar los conocimientos medioambientales tradicionales con enfoques de diseño contemporáneos orientados al clima, este estudio ofrece una perspectiva global y multiescalar, lo que constituye una contribución innovadora a las estrategias de diseño arquitectónico sostenible.

Palabras clave
sistemas cortavientos, arquitectura sensible al clima, eficiencia energética, refrigeración pasiva, armonía visual, arquitectura tradicional, diseño sostenible de fachadas

RESUMO

Este estudo tem como objetivo avaliar, comparativamente, os sistemas tradicionais e contemporâneos de quebra-ventos utilizados em regiões climáticas quentes e áridas e quentes e úmidas, em termos de eficácia estrutural, eficiência energética e harmonia visual com a paisagem. A pesquisa adota uma estrutura simplificada de Análise de Decisão Multicritério (MCDA), integrada a um sistema de classificação em escala Likert, aplicada a oito casos distintos de assentamentos. Os resultados revelam que os sistemas tradicionais apresentam alta eficiência em ventilação passiva e morfologia responsiva ao clima. Em contrapartida, os sistemas contemporâneos demonstram vantagens em termos de eficiência energética graças ao uso de materiais sustentáveis e soluções tecnológicas avançadas. No entanto, as aplicações contemporâneas tendem a apresentar uma integração visual limitada com o contexto local e uma maior dependência de sistemas mecânicos. Ao integrar o conhecimento ambiental tradicional com abordagens contemporâneas de design responsivas ao clima, este estudo oferece uma perspectiva abrangente e multiescalar, contribuindo de forma inovadora para estratégias de design arquitetônico sustentável.

Palavras-chave
sistemas de proteção contra o vento, arquitetura sensível ao clima, eficiência energética, refrigeração passiva, harmonia visual, arquitetura tradicional, design sustentável de fachadas

INTRODUCTION

Climate-sensitive design is a fundamental principle of sustainable architecture. In hot-dry and hot-humid regions, wind direction and intensity significantly influence indoor comfort and energy consumption (Hemmatzadeh & Akgüç, 2023). Traditional architecture has long integrated passive windbreak systems—such as badgir, mashrabiya, and wooden or stone shading elements—to regulate airflow, provide shade, and maintain thermal comfort (Bagasi et al., 2021; Lotfabadi & Hançer, 2019). These systems not only improve climatic performance but also preserve visual and cultural harmony with the environment (Chohan et al., 2024). However, rapid urbanization and standardized construction processes have led to these traditional strategies being neglected, replacing them with mechanical and energy-intensive solutions (Zahrawi & Aly, 2024; Kitsopoulou et al., 2024).

Previous studies have highlighted the thermal and environmental advantages of traditional designs—such as finding up to 47% energy savings in hot-dry regions and significant microclimatic improvements through landscape-based windbreaks (Dewalle & Heisler, 1988; Weninger et al., 2021). Despite this evidence, existing studies still lack an integrative quantitative framework to evaluate the structural, energetic, and visual dimensions of windbreak systems across diverse climatic contexts. To address this gap, this study develops a comparative MCDA-based framework combined with a Likert-scale rating system to systematically assess the performance of traditional and contemporary designs. Unlike previous descriptive reviews, the proposed model introduces replicable, multi-criteria metrics that bridge vernacular passive strategies and modern technological solutions, contributing to the advancement of climate-responsive and sustainable architectural design.

This study comparatively evaluates traditional and contemporary windbreak systems in hot-dry and hot-humid climates, focusing on their structural effectiveness, energy efficiency, and visual harmony with the surrounding landscape. Eight settlements from two climatic zones and different historical periods have been analyzed. The results provide a multi-scale framework for reinterpreting climate-sensitive design in contemporary architecture, discussing the potential of integrated approaches that combine traditional knowledge with modern innovation.

LITERATURE REVIEW

The concept of climate-compatible design has emerged in different forms, especially in regions with extremely hot and harsh climatic conditions. Windbreaks, which support natural ventilation and provide passive air conditioning, have been used in traditional and contemporary architectural applications as an important strategy to increase indoor comfort and contribute to sustainability goals by reducing energy consumption (Givoni, 1998; Bahadori, 2018).

TRADITIONAL WINDBREAKER SYSTEMS

Traditional windbreak systems, a significant component of sustainable architecture in hot climates, effectively use natural ventilation to improve indoor comfort while minimizing energy consumption. Among them, badgir (windcatcher) structures are widely used in Iran and the Arabian Peninsula to direct airflow indoors and regulate temperature. Studies from Yazd show that such systems can maintain indoor conditions below 20 °C in winter and 35 °C in summer, achieving thermal comfort with zero energy use (Hemmatzadeh & Akgüç, 2023). Similarly, Al-Ajmi et al. (2006) demonstrated that the cooling performance of their system varies according to geometric parameters, such as height and cross-section.

The role of traditional windbreaks in energy efficiency has been repeatedly confirmed. Soflaee and Shokouhian (2005) emphasized their contribution to natural cooling, while El-Shorbagy (2010) underlined their cultural and architectural significance. More recent work integrates computational simulations to enhance traditional performance through hybrid or CFD-based analyses (Sirror, 2024; Ghoulem et al., 2020). These systems reduce cooling loads, improve indoor air quality, and remain key references for low-energy building design (Ma et al., 2024; Jassim, 2018).

Although the literature confirms the effectiveness and cultural importance of traditional windbreak systems, most studies are case-specific and descriptive, focusing on isolated climatic contexts without standardized evaluation criteria. Comparative and quantitative assessments across regions remain limited, and few studies examine how these passive systems can be adapted to contemporary energy standards. This study addresses these gaps by introducing a replicable, multi-criteria MCDA framework that objectively compares traditional and modern windbreak strategies, thereby bridging empirical observations with systematic performance analysis.

CONTEMPORARY WINDBREAKER SYSTEMS

Contemporary windbreaker systems have evolved from traditional passive approaches into dynamic, adaptive designs supported by computational modeling and advanced materials (Kabošová et al., 2019; Akgün, 2021). The integration of carbon fiber composites and nanomaterials improves both mechanical strength and energy conversion efficiency, allowing for higher performance under variable climatic conditions (Tolasa & Furi, 2025). By combining vernacular principles with modern technologies, recent hybrid windbreak models have both enhanced natural ventilation and improved energy efficiency in buildings (Sirror, 2024).

Beyond architecture, windbreak systems have gained importance in agriculture and landscape design as tools for climate adaptation and mitigation. In agroforestry, they mitigate climate impacts and increase crop productivity (Mume & Workalemahu, 2021), while bio-integrated and material-based designs support environmental resilience in urban and rural contexts (Margolis & Robinson, 2007). Engineering-oriented strategies, such as combined protection systems for wind turbines, boost operational efficiency and extend lifespans (Kaverin et al., 2024), illustrating a shift toward data-driven, performance-optimized design thinking (Radha & Kistelegdi, 2016).

Examples such as Masdar City in the United Arab Emirates demonstrate how traditional airflow principles can be reinterpreted through hybrid systems to achieve substantial cooling and energy savings (Reiche, 2010). Similarly, agrivoltaic systems that integrate agriculture with solar generation have improved wind-load management and land-use efficiency (Zahrawi & Aly, 2024).

Although contemporary systems successfully integrate advanced materials and computational tools, current research often focuses on technological optimization rather than a holistic evaluation of sustainability. The literature still lacks comparative frameworks linking structural, energetic, and visual performance across diverse applications—from architecture to agroforestry. This study addresses the gap by offering a quantitative, multi-criteria evaluation framework that positions contemporary windbreaks within a broader sustainable design paradigm, bridging environmental performance with cultural and contextual awareness.

ENERGY EFFICIENCY AND BUILDING ENVELOPE

Building envelope design plays a crucial role in improving thermal comfort and reducing energy losses. Proper insulation, orientation, and material selection can significantly improve building performance (Al-Homoud, 2004). For instance, high-performance façades integrate optimal insulation thickness, thermal resistance, and radiation control that vary across climates (Ascione et al., 2015). However, differences in building codes across countries have led to inconsistent energy performance in similar climates. (Bienvenido-Huertas et al., 2019).

Recent technological advances have allowed adaptive envelope systems, such as dynamic insulation elements, smart windows, and green façades, to provide accurate energy control and improved comfort (Kumar et al., 2022; Kitsopoulou et al., 2024). While traditional windbreaks were primarily designed to reduce wind loads, contemporary solutions integrate ventilation and façade optimization, thereby reducing dependence on mechanical cooling in hot climates. On the other hand, emerging dynamic façades and smart materials—such as kinetic panels, phase-change materials, and aerogels—can cut cooling demands by up to 20–25% (Perino & Serra, 2015; Narbuts & Vanaga, 2023). However, despite their promise, these technologies face challenges, including high cost and limited long-term performance data (Almesbah & Wang, 2025).

Although advances in envelope technology have expanded the potential for energy savings, most studies still focus on technical optimization rather than comprehensive environmental performance. Comparative frameworks that connect traditional passive elements (mashrabiya, jali, overhangs) with modern adaptive systems remain scarce, and few works quantify their combined climatic and aesthetic impacts. This study addresses these limitations by developing a multi-criteria evaluation model that assesses the structural, energetic, and visual dimensions of windbreak-based façade systems, thereby contributing to a holistic understanding of sustainable envelope design.

METHODOLOGY

To investigate windbreak systems from various angles, this study employs a mixed-techniques research strategy, combining comparative case analysis with mixed methods. The research compares and assesses windbreak solutions, including their structural efficacy, energy efficiency, and aesthetic coherence with the surrounding environment. A systematic and comprehensive assessment was conducted using qualitative and quantitative data analysis techniques. The scope of the research includes countries with traditional and modern examples in different geographical and cultural contexts located in hot-dry and hot-humid climate zones. There are eight settlements included in the study: Yazd (Iran), Shibam (Yemen), Masdar City (UAE), Doha (Qatar), Bali (Indonesia), Kerala (India), Raffles Place (Singapore), and Nanjing (China) (Figure 2). Traditional and modern windbreak systems sensitive to the climate in these settlements have been examined from a broad perspective. In this context, it has been revealed how windbreak system applications have evolved in the context of climate, region, technology, and modernization.

Three main criteria were used in the analysis process: structural efficiency, energy efficiency, and visual harmony with the landscape. The structural efficiency criterion was evaluated based on the design approach, material type, material durability, system life, and maintenance requirements. The energy efficiency of the systems was examined in terms of energy efficiency, passive ventilation capacity, cooling load, CO_2 emissions, and potential for overall energy consumption reduction. Visual harmony with the landscape was considered regarding local material use, environmental integration, aesthetic continuity, and cultural references.

All three criteria were assigned equal weight in the overall evaluation. This decision is based on the premise that structural performance, energy efficiency, and

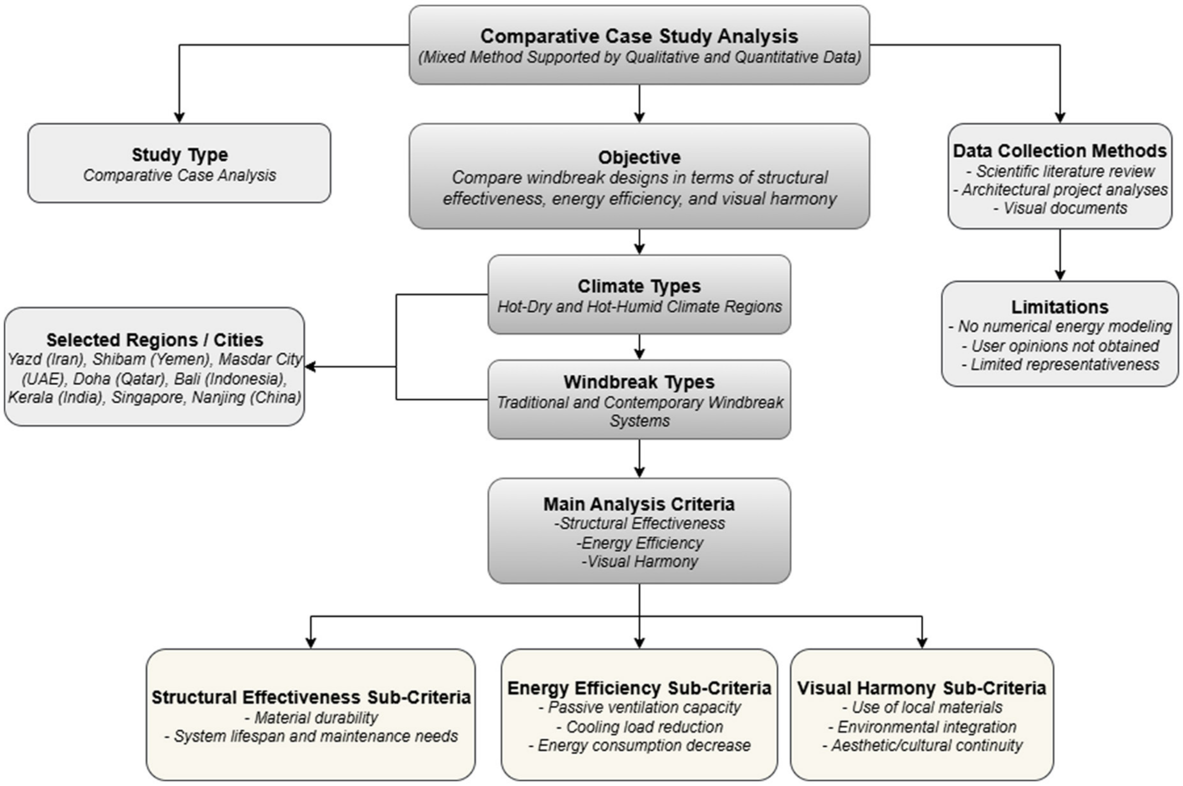


Figure 1. Flowchart of study. Source: Prepared by the authors.

visual-cultural integration represent complementary and interdependent dimensions of sustainability in architectural design. Treating them equally prevents bias toward a single dimension and supports a balanced comparison between traditional and contemporary systems. Similar equal-weight approaches are frequently applied in early-stage architectural MCDA studies where data normalization across diverse sources is required (Saaty, 2008; Mardani et al., 2015).

Among the data collection methods employed were a scientific literature review, analyses of architectural projects, analyses of drawings and visuals, and qualitative content analysis of various scientific publications. The simplified Multi-Criteria Decision Analysis (MCDA) used in the study provides an analytical framework that enables the systematic evaluation of multiple criteria in decision-making processes and is particularly effective for managing complex decisions, such as those in architecture and environmental design. Likert-type scoring is a preferred measurement method for quantifying subjective assessments and facilitating comparative analysis (Triantaphyllou, 2000; Belton & Stewart, 2012; Boone & Boone, 2012; Joshi et al., 2015). The data obtained in the study were integrated into an evaluation system developed based on three main criteria and examined within the framework of a simplified Multi-Criteria Decision Analysis (MCDA). In this context, the systems' compliance with the specified criteria was analyzed comparatively using a Likert-type scoring method that combined qualitative and quantitative data. A rating scale ranging from 1 to 5 was used to determine the performance level of each example; this scale was defined as "very low (1)", "low (2)", "medium (3)", "high (4)", and "very high (5)". The authors used the Likert-scale scoring based on a comparative analysis of published data, architectural documentation, and visual evidence. The scoring was based on expert judgment, following a structured Likert-scale evaluation framework commonly applied in environmental and architectural assessment research (Malewczyk et al., 2024; Arslan & Yildirim, 2023). To minimize subjectivity, a cross-checking process was applied: each case study was independently rated and then re-evaluated to reach consensus. This expert-based assessment method aligns with common practices in architectural and environmental evaluation studies, where qualitative interpretation is quantified through structured rating systems (Boone & Boone, 2012; Joshi et al., 2015; Triantaphyllou, 2000). Such an approach enables reproducibility and comparability across case studies when numerical data are limited or heterogeneous. The ratings were based on the explanations provided in the table, considering sub-criteria such as the type of material used, formal structure, climatic adaptation, and architectural integrity. This approach has allowed a comprehensive evaluation of qualitative and quantitative data, thereby revealing differences in performance both within and between systems.

This methodological approach aims to develop a holistic

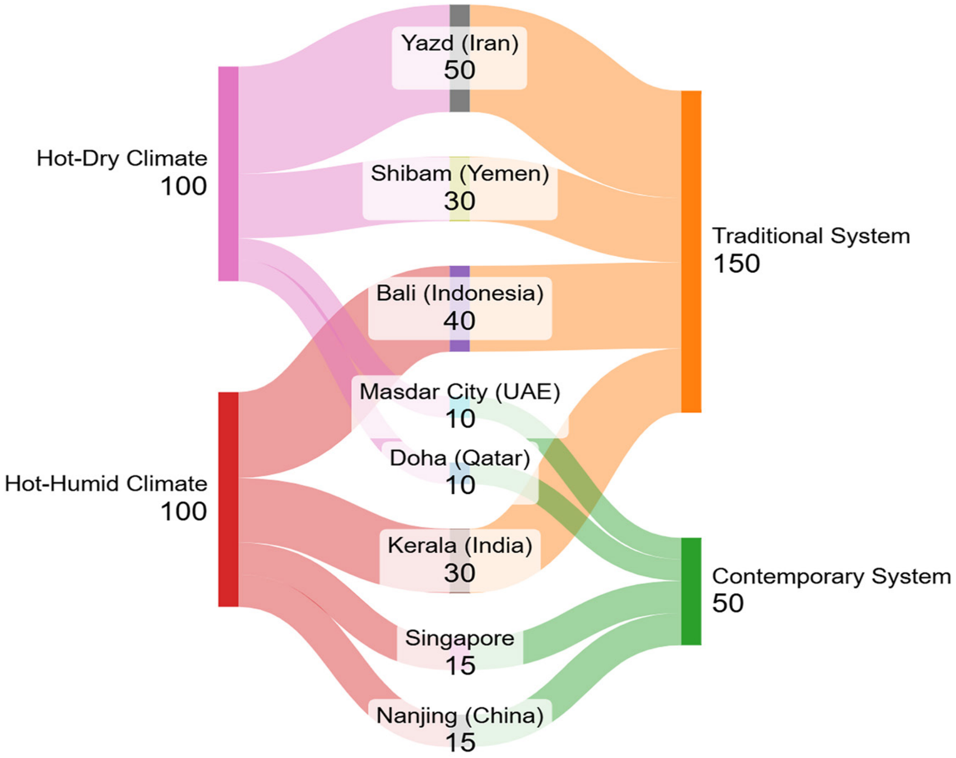


Figure 2. Sankey diagram of the study. Source: Prepared by the authors.

understanding of the performance and contextual effects of windbreak designs. However, the study's limitations include the lack of numerical energy modeling, the lack of user feedback, and the limited representativeness to certain areas (e.g., traditional and contemporary windbreak application systems in hot-dry and hot-humid climate zones) (Figure 1).

The Sankey diagram in Figure 2 shows the flow relationships among climate types, selected case cities, and windbreak system types. The numerical values in the diagram are not absolute quantitative data but rather proportional indicators, reflecting representation frequency and typological importance in the literature. For example, higher values were assigned to the cities of Yazd and Shibam, which are well known for their Badgir applications in hot-dry climates, given their comprehensive representation in the literature. In contrast, examples in settlements such as Masdar City and Nanjing, where contemporary systems are applied, were defined as more limited but innovative applications with high sampling power. The visibility, frequency of repetition, and depth of analysis of case studies in the literature were considered in determining their inclusion in the diagram.

FINDINGS AND DISCUSSION

In this study, eight different windbreak systems found in hot climate regions were evaluated considering climate type (hot-dry and hot-humid), period (traditional or contemporary), and three basic performance criteria (structural effectiveness, energy efficiency, and visual harmony). Furthermore, the findings are supported by comparative graphical analyses. The sample areas were selected from hot-dry (Yazd, Masdar, Shibam, Doha) and hot-humid (Bali, Singapore, Kerala, Nanjing) climate zones, which made it possible to compare the differences (Table 1).

The Badgir system in Yazd is a well-known example of a traditional way to deal with hot-dry weather. This method works well for passive cooling because it uses vertical air towers woven into the limited roadway fabric to direct natural airflow. Reports that the system can lower indoor temperatures by up to 6°C show how powerful its passive cooling effect is. Thanks to earth-based materials and their integrated visual appeal with local architecture, they exhibit a high level of harmony with the landscape (Al-Ajmi et al, 2006; Hejazi & Hejazi, 2014; Hemmatzadeh & Akgüç, 2023; Naghipour & Bakirova, 2024). The traditional building fabric in Shibam creates passive airflow corridors with dense settlements and mud towers in a hot-dry climate. Temperature balance is maintained thanks to its heat storage properties. Visually, it fits harmoniously with its surroundings thanks to the unity of its materials and colors (Table 1).

Masdar City uses modular structures and responsive facade systems as a model for a contemporary and sustainable city. However, its structural efficiency is mainly dependent on mechanical systems. Although it is supported by solar shading and renewable energy sources, its energy efficiency remains moderate. Visually, its high-tech design struggles to establish a strong aesthetic connection with the desert environment (Reiche, 2010).

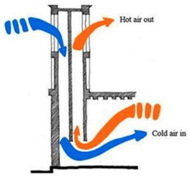
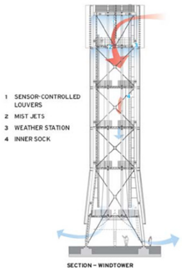
Contemporary panel systems in Doha offer limited structural contribution with their flat facade elements. Air circulation is mainly dependent on air-conditioning systems. Energy efficiency is limited because they rely heavily on active cooling methods rather than passive solutions. Moreover, the flat, modern facade language visually stands out from its surroundings (Table 1).

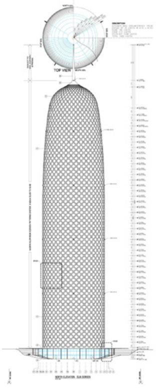
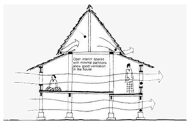
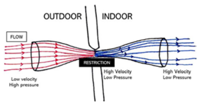
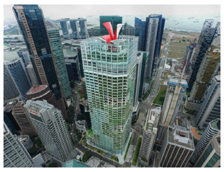
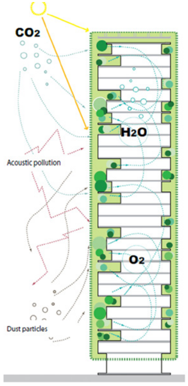
Wooden windbreak systems in Bali aim to make people more comfortable by providing natural shade and only partially open areas in a hot, humid environment. These systems do not change the structure much and are low-density, spreading horizontally. They do not do a good job of controlling airflow or providing thermal insulation, making them less energy-efficient. On the other hand, the use of local materials and vegetation supports visual integrity. The jali (latticework) windbreak systems used in traditional architecture in Kerala, combined with high eaves and columnar planning, adapt to hot and humid climatic conditions. This system, which offers low maintenance requirements using local materials such as stone and wood, balances indoor temperatures through passive ventilation while providing energy efficiency by allowing daylight to enter in a controlled manner. Jali elements regulate visual permeability to provide privacy while harmonizing with the local fabric in an aesthetically cohesive manner (Table 1).

Green facade systems in Singapore aim to improve facade performance through vertical greening as a contemporary approach. Their modular and layered structure makes them structurally robust. Vegetation reduces solar gain while lowering internal temperatures, thereby improving energy efficiency. The biophilic (nature-friendly) design approach supports the system's visual integration with the city (Safikhani & Baharvand, 2017; Kitsopoulou et al., 2024). In particular, the Vertical Forest in Nanjing incorporates dense vertical vegetation as a contemporary high-rise solution. Layered green facades provide structural integrity and regulate indoor temperatures by creating a microclimate. This system has been reported to provide up to 25% energy savings. The dense plant structure also gives the facade a dynamic visual character and creates a symbolic aesthetic (Table 1).

A comprehensive case study table below reveals the multidimensional relationships between the climatic context, structural analysis, and architectural aesthetics, and comparatively evaluates windbreak systems' physical

Table 1. Case Study Analysis. Source: Prepared by the authors.

Settlement / Application	Image	Diagram	Climate / Era	Structural Efficiency	Energy Efficiency	Visual Harmony
Yazd, Iran / Badgir (wind tower)			Hot Dry / Traditional	-Badgir (wind towers) -Narrow streets -Adobe and brick materials -High durability -Low maintenance	-Climate resilience -Ventilation with zero energy -Indoor temperature below 35°C in summer -Indoor temperature drop of ~6°C -40-50% energy savings	-Urban integrity -Harmony with the traditional urban fabric
Shibam, Yemen / Urban Fabric			Hot Dry / Traditional	-Dense settlement structure -Multi-story adobe towers -Vertical stability -Low resistance -Low maintenance	-Vertical natural air flow	-Visual integrity -Monotonous urbanization -Integration with the urban fabric
Masdar City, UAE / The Wind Tower			Hot Dry / Contemporary	-Wind tower -Lightweight steel, glass, recyclable, and high-tech materials -High resistance -High maintenance	-Passive + evaporative systems -~50% cooling savings -Temperature drop of 5-10°C on the street -60% energy savings	-Far from local aesthetics -A modern approach, -Structural reference to the traditional fabric

Doha, Qatar / Doha Tower			Hot Dry / Contemporary	-Modernized Mashrabiya -Double-skinned facades -Composite panel systems -Modules that direct wind flow -High maintenance	Improved HVAC efficiency	Low landscape integration
Bali, Indonesia / Wide eaves and wooden canopies			Hot Humid / Traditional	-Open plans, -Wide eaves -Wooden shading -Wood and bamboo structures -Low resistance	-High natural ventilation -Low humidity control	-Integrated with the natural landscape -Natural materials, traditional forms, and environmentally friendly
Kerala, India / Jali			Hot Humid / Traditional	-Jali (latticework) -High eaves, -Columned plans -Stone and wood materials -Low maintenance	-Passive ventilation, -Controlled use of natural light	-Harmony with the tissue -Aesthetic integrity -Harmony with the traditional architecture
Raffles Place, Singapore / CapitaGreen			Hot Humid / Contemporary	-Green facade modules, -Steel and glass structure systems -Biomimicry approach -High maintenance with semi-automatic systems	-Hybrid systems - 30% energy savings with sensor-controlled ventilation on facades -Reduction of the UHI effect -15-25% reduction in energy consumption	-A sense of extension of the urban green fabric -High integration with nature
Nanjing, China / Vertical Forest			Hot Humid / Contemporary	-Green wind shields, -Vertical landscaping -Green facade -Biomimicry approach -Concrete material -High maintenance	-CO_2 emission reduction (~25 tons/year); -Shading and windbreak effect	High integration with nature The pursuit of aesthetic form

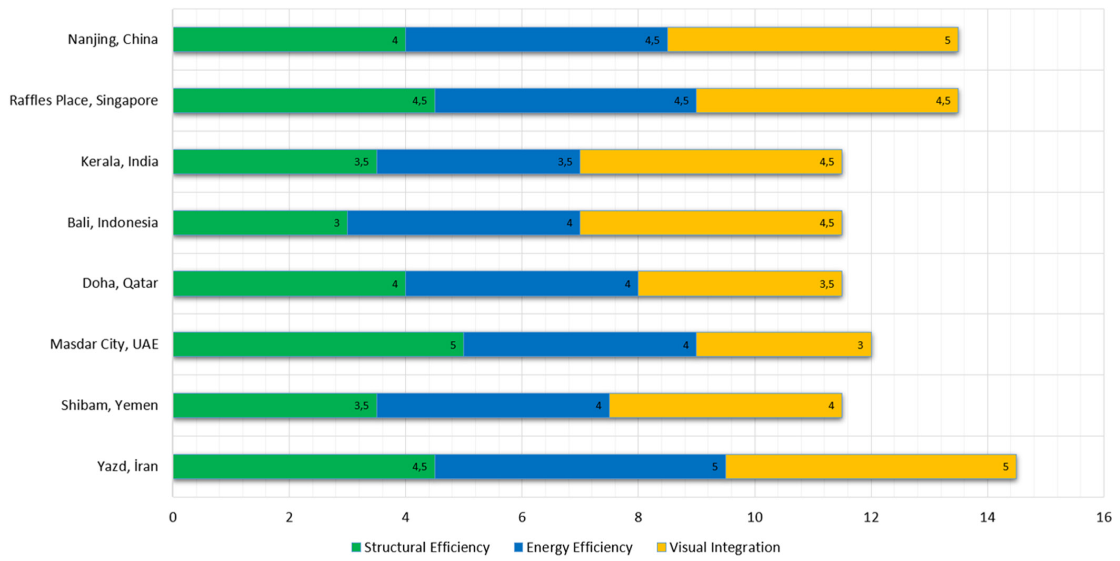


Figure 3. Performance comparison of windbreaker systems. Source: Prepared by the authors.

and visual performance (Table 1).

This comparative analysis examined windbreak systems based on three main criteria using a simplified Multi-Criteria Decision Analysis (MCDA) approach: Structural Efficiency, Energy Efficiency, and Visual Harmony with the Landscape. The compliance levels of the analyzed systems with the criteria have been determined. To determine the level of compliance for each example, a Likert-type 1–5 rating scale covering both qualitative and quantitative parameters was used, with 1 indicating very low, 2 indicating low, 3 indicating medium, 4 indicating high, and 5 indicating very high. Based on the explanations in the table, each example has been given a score between 1 and 5, considering the materials used, formal structure, climatic suitability, and architectural integrity (Figure 3).

The Structural Efficiency criterion evaluates the system's capacity to passively direct airflow and ventilation, and its level of integration with the structure's overall form. For example, the Badgir windbreak system in Yazd received the highest score (5) thanks to its compatibility with the narrow street network and its effective guiding of passive airflow. However, contemporary systems, such as the modular panels in Doha, were given a more moderate score (4) due to their reliance on modern HVAC systems. Traditional systems such as those in Bali, which have a weak vertical organization and expand horizontally, received lower scores due to their low aerodynamic efficiency (Figure 3).

The energy efficiency criterion is related to the system's ability to provide passive cooling, lower indoor temperatures, and reduce total energy consumption. The Yazd and Vertical Forest examples received the highest score (5) because they achieved a reduction in indoor temperature of up to 6°C and energy savings of 40–50% (Hemmatzadeh & Akgül, 2023; Kitsopoulou et al., 2024). However, despite the benefits of natural ventilation, systems such as Shibam and Kerala scored only moderately because they require frequent maintenance or have limited thermal insulation (Figure 3).

The Visual Harmony with Landscape criterion was evaluated based on the aesthetic relationship established by the system with the urban environment, local materials, and cultural context. Traditional systems compatible with local textures and which have become cultural icons (e.g., Yazd, Kerala) received high scores. In contrast, systems with abstract and modernist forms, disconnected from their surroundings (e.g., Masdar City), received lower visual harmony scores, despite their functionality. This scoring method evaluated windbreak strategies in different climate zones using a holistic approach, considering quantitative performance indicators (e.g., cooling effect, energy savings) and qualitative assessments (e.g., material compatibility, cultural continuity) (Figure 3).

The eight samples examined in the study were evaluated separately based on three main criteria: Structural Efficiency, Energy Efficiency, and Visual Harmony with the Landscape. Each sample was scored on a 5-point Likert scale. The sum of the scores obtained for each criterion was used as a combined performance indicator to assess the system's overall success. This total score is an indicator of the system's overall success.

Although hot and dry, Yazd, Iran, has the best overall score (14.5), mainly due to its structural elements, energy efficiency, and aesthetic harmony. This shows how well Yazd's traditional Badgir windbreak system works, how it adapts to the weather, and how it fits into the culture. The systems in Raffles Place, Singapore, and Nanning, China, with humid climates, scored 13.5 points, making them the next-highest-rated after Yazd. These modern systems have scored high marks, particularly regarding visual harmony and energy efficiency. This demonstrates the importance of technological integration and harmony with nature in the design of windbreak systems. Masdar City, UAE, has high energy-efficiency performance but scores an average mark (12) due to poor visual harmony with the urban fabric and poor landscape integration. Shibam, Yemen, Doha, Qatar, Bali, Indonesia, and Kerala, India, have the lowest scores among the settlements evaluated, with 11.5 points. The examples show that structural energy and visual harmony are not achieved. This evaluation criterion reveals that the examples must not only meet technical or formal requirements, but also require a holistic approach to their climatic and cultural context (Figure 3).

The comparatively low scores of Shibam, Doha, Bali, and Kerala (11.5) indicate that structural efficiency, energy performance, and visual harmony were not achieved simultaneously. In Shibam, the dense urban texture provides thermal stability but limits natural ventilation and adaptability, leading to reduced structural and energy efficiency. In Doha, despite technological façade improvements, dependence on mechanical HVAC systems decreases overall sustainability and increases maintenance demands. Bali's open and horizontally oriented wooden structures provide shading but lack aerodynamic efficiency and thermal insulation, resulting in lower energy performance. In Kerala, although the jali windbreak system ensures cultural and aesthetic harmony, its limited insulation and frequent maintenance requirements reduce structural resilience. These findings suggest that design-material mismatches, insufficient integration of passive and active systems, and challenges in contextual adaptation are the primary causes of the low combined scores. The comparison highlights that achieving high holistic performance requires striking a balance between technological innovation, climatic suitability, and cultural continuity.

CONCLUSIONS

This study compares traditional and contemporary windbreak systems in eight different settlements in different climate zones, using a multi-criteria evaluation framework based on three main criteria (structural effectiveness, energy efficiency, and visual harmony with the landscape). The evaluations have shown the need to evaluate technological adequacy and sustainable design principles, including cultural continuity, contextual harmony, and passive climate management. The findings reveal that traditional systems still offer high performance, particularly their potential to direct natural airflow and reduce energy consumption. At the same time, contemporary applications interpret this potential in different ways through innovative materials, automation, and modular systems.

In hot-dry climates, traditional solutions like the Badgir are especially beneficial regarding structural efficiency. On the other hand, modern examples like Nanjing and Raffles Place, which make use of plants, achieve remarkable energy efficiency. Examples that successfully create aesthetic unity with regional materials, customary forms, and the surrounding environment are more effective in terms of visual harmony. Meanwhile, technology intrusions in specific modern systems have adversely affected visual continuity, producing designs that are disjointed from the surrounding environment.

In conclusion, this study highlights the significance of integrating architectural strategies into the design of windbreak systems for sustainable architecture, informed by past local and climatic experiences but reinterpreted through contemporary engineering and material technologies. This study provided a comparative assessment of traditional and contemporary windbreaker systems across hot-dry and hot-humid climates through a simplified MCDA–Likert framework. The findings highlight that traditional systems, such as badgir and jali, demonstrate superior climatic responsiveness and cultural integration, whereas contemporary systems—although technologically advanced—often lack contextual harmony.

For architects and urban planners, the results underscore the need to design façades and outdoor systems that strike a balance between technological performance and climatic and cultural adaptation. The study suggests that reinterpreting traditional passive strategies through contemporary materials and digital fabrication could lead to more sustainable and place-sensitive designs. The outcomes may inform local design guidelines and sustainability certification systems by emphasizing passive ventilation, shading, and cultural compatibility as integral performance indicators in hot regions. Urban climate adaptation policies could benefit from incorporating simplified multi-criteria evaluation frameworks, such as the one proposed in this research, to assess and rank façade and ventilation solutions in the early design stages. Further studies should integrate dynamic simulations and on-site measurements to validate the performance of windbreaker systems under evolving climate scenarios. Quantitative modeling of airflow and energy savings under future CMIP6 projections could expand the applicability of this framework. Additionally, extending the evaluation to mixed or temperate climates would provide a broader understanding of the cultural and environmental adaptability of such systems. Overall, this research bridges traditional environmental knowledge and modern sustainable technologies, providing a replicable, interdisciplinary evaluation framework for designing climate-sensitive, culturally resilient architectures.

AUTHOR CONTRIBUTION CRediT

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