

BREATHING FAÇADES AS CLIMATE-RESPONSIVE STRATEGIES: CASE STUDIES ACROSS DIVERSE CLIMATIC CONTEXTS

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Abstract

Introduction. This study evaluates the effectiveness of breathable façades as an innovative architectural solution that contributes to ensuring continuous ventilation, improving indoor air quality, reducing pollutant accumulation, and decreasing energy consumption in diverse climatic and geographical contexts. **Purpose of the study.** The study aims to examine the use of these façades in different environments and determine their flexibility and effectiveness. **Methods.** A descriptive and comparative analytical approach was adopted, examining 42 global and regional models, spanning continents and diverse climates. The models were classified according to four principal criteria: geographical location, building materials, design systems, and ventilation patterns, with tables used to illustrate the most common patterns. **Results.** The findings indicate that global models emphasise diverse solutions that enhance ventilation and air quality, while the regional models are distinguished by the use of low-cost, environmentally sustainable materials, demonstrating flexibility and effectiveness. These results confirm the environmental and functional efficacy of breathable façades across varied climatic conditions.

Keywords: breathing façades, natural ventilation, climate adaptation, indoor air quality, comparative analysis, sustainable architecture.

Introduction

Natural ventilation is one of the most important architectural strategies aimed at improving the indoor environmental quality of buildings (Plazas and de Tejada, 2024). It contributes to air renewal and reduces the accumulation of pollutants and harmful substances within spaces, which directly impacts the health and comfort of users (Levie et al., 2014; Stabile, Dell'Isola, Russi, Massimo and Buonanno, 2017; Pesic, Calzada and Alcojor, 2018; Rodrigues, Santos, Gomes and Duarte, 2019). Research demonstrates that natural ventilation can significantly reduce energy consumption by reducing reliance on mechanical air conditioning systems, making it one of the essential solutions for achieving energy efficiency in buildings (Yang and Clements-Croome, 2020). From this perspective, breathing façades have emerged as an innovative architectural solution, allowing air to continuously circulate through their layers to provide effective natural ventilation (Shalaby, Abo El Enein, Saif, and El Gheznawy, 2020).

This approach is an extension of ancient architectural traditions, such as mashrabiya in Islamic architecture or wooden screens in Asian architecture, which were used to control light and air while maintaining privacy (Ashour, 2018). Breathing

façades are also directly linked to concepts of sustainability, not only through reduced energy consumption, but also through their ability to be manufactured from low-cost local materials such as stone, wood, and pottery, thus reducing the carbon footprint associated with transportation and production (Ulung, 2023). This opens the door to their application in a wide range of environments and climates (Farid, Ahmad, Raub and Shaari, 2016).

Despite the growing global interest in this type of façade, comparative studies examining the differences between global and regional models remain limited, particularly regarding their adaptability to diverse climatic conditions or the local materials used in their performance (Elghawaby, 2012).

Scope

This research examines breathing façades as a contemporary architectural strategy for improving the environmental performance of buildings by enhancing natural ventilation, reducing energy consumption, and minimising indoor pollutant accumulation, thereby improving air quality and user comfort. The scope of the study includes a comparative analysis of 42 global and regional models, categorised according to five main principal criteria: geographical location, climatic conditions,

climate adaptation, building materials, façade type, and building type. This diverse range of models was selected to provide a more comprehensive understanding of the flexibility of this technology and its adaptability to different environments. This approach enables the identification of similarities and differences in design and construction characteristics, as well as the evaluation of compatibility with sustainability requirements across diverse climatic contexts.

Objectives

This research aims to evaluate the effectiveness of breathing façades as a sustainable architectural solution through a comparative analysis of 42 global and regional case studies. The study focuses on evaluating the ability of these façades to improve natural ventilation and reduce energy consumption and pollutants as well as understanding how local materials and diverse design strategies can be employed according to different climatic conditions. Through this analysis, the study seeks to highlight similarities and differences between global and regional experiences, thereby clarifying the potential for broader application of this technology to achieve the principles of environmental and architectural sustainability.

Methodology

A set of integrated research methods was adopted to study breathing façades and analyse their impact on the environmental performance of buildings. The research began with a descriptive and analytical approach, collecting data from 42 global and regional models of breathable façades and categorising them according to five main criteria: geographical location, climate, building type, materials used, and architectural design. This categorisation enabled the

identification of architectural solution diversity and common patterns among the models, with a focus on the role of local materials in improving sustainability and optimising energy consumption.

Next, an inductive approach was applied to study each model individually, analysing how design elements and materials influence natural ventilation, pollutant accumulation, and energy efficiency. This detailed analysis contributed to drawing accurate conclusions about the effectiveness of each façade type in different environments.

Finally, a comparative approach was employed to evaluate the differences and similarities between global and regional models, focusing on design strategies, materials, and environmental characteristics. This analysis aimed to identify globally and locally applicable best practices and to understand how architectural solutions can be adapted to meet diverse climatic and functional needs, thereby enhancing the sustainability and efficiency of natural ventilation façades.

Historical Overview of Breathing Façades

Breathing façades are an extension of ancient architectural traditions that combine natural ventilation, climate mitigation, and privacy protection. They have evolved across different civilisations in various forms and materials. In the Islamic world, the mashrabiya (or roshan) is a prominent traditional example, where architects used perforated wood projecting from the façade to achieve natural ventilation, shade, and privacy (Ashour, 2018).

In India, the Jali system was used, consisting of stone screens (Fig. 1). These are perforated with intricate geometric patterns that allowed air to pass through and mitigated sunlight (Gupta et al., 2022). Similarly, in China, traditional buildings relied on



Fig. 1. Jali system In India

perforated wooden lattice screens, which served similar environmental and decorative functions (Yi, 2018)

In the 20th century, a modern model emerged in Brazil, based on the same traditional principles: Cobogó (Camacho et al., 2017; Miranda et al., 2019). Perforated or decorative concrete units were installed on façades to allow air to pass through (Fig. 2). This system represents an extension of mashrabiya structures (Vettorazzi et al., 2024) and uses modern materials suited to hot and humid climates (de Araújo and Bistafa, 2012).

Thus, Table 1 summarises the environmental characteristics of breathing façades across different civilisations. This historical sequence demonstrates that breathing façades are a universal concept that has evolved over the ages, relying on local materials and adapting to varying climatic conditions. This supports the primary objective of this research: to investigate effective and flexible solutions for natural ventilation, improving the environmental performance of buildings and reducing pollutants in modern architecture.

Case Studies of Breathing Façades

This section presents an analysis of selected breathing façade models, discussing the differences and similarities between their general information and façade key elements.

Selection Criteria for Case Studies

This research examines case studies that have employed breathing façades in buildings for several objectives, such as minimising pollution, enhancing indoor air quality, and optimising ventilation. The selected cases were categorised into global and regional models based on their geographical distribution to enable a systematic comparison of breathing façade application patterns across different regions.

Global models comprise projects selected from countries across multiple geographical regions worldwide, including Europe, Asia, North America, and Oceania. These models represent global trends in technological development, material use, and design strategies related to ventilated façades.

Regional models, in contrast, are limited to projects within a specific geographical area, such as the Middle East and North Africa (MENA) region. This allows for comparison of application

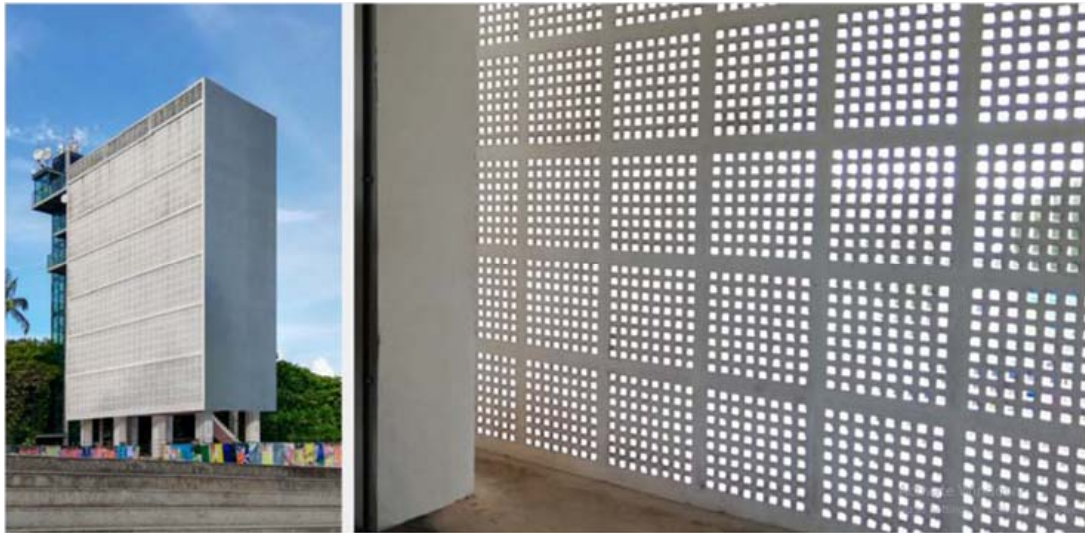


Fig. 2. Example of a cobogó building Caixa d'Água de Olinda, 1935

Table 1. Evolution of breathing façades across different civilisations

Culture/Country	Façade Type	Materials Used	Environmental Functions	Social/Additional Functions
Islamic World	Mashrabiya	Perforated Wood	Natural Ventilation, Climate Moderation, Shading	Privacy Protection, Decoration
India	Jali	Perforated Stone with Geometric Patterns	Ventilation, Sunlight Mitigation	Decoration, Privacy
China	Lattice Screens	Perforated Wood	Ventilation, Moderation	Moderation Decoration
Brazil	Cobogó	Perforated or Decorative Concrete	Ventilation, Natural Light, Heat Mitigation	Decoration, Privacy

patterns within a more homogeneous geographical context.

This comparative classification highlights the differences between global technological trends and regional application patterns. These differences can be explained by contextual characteristics of each region, such as prevailing construction practices, material availability, and local design and implementation considerations. To enhance the clarity of the case studies and increase the analytical value of the comparison, the buildings were first organised by architectural function, and then cases within each functional category were arranged by climatic group. The case studies are explored in two sections (Fig. 3).

Operational Definitions of Technical Parameters

To ensure consistent analysis and classification of technical characteristics, operational definitions for the technical variables used in the comparison tables were adopted.

Façade Types

The term single façade refers to façade systems consisting of a single outer layer that acts as the building's main envelope without an intervening air gap. Double façade refers to systems consisting of two layers separated by an air gap that allows for improved airflow and enhances the façade's environmental performance.

Control Systems

Control systems were classified according to the mechanism of operation of movable façade elements as follows:

- Manual Control relies on direct user intervention in operating façade elements, such as opening or closing movable parts.
- Manual Control — Rods and Pulleys System — relies on manual operation supported by a simple mechanical mechanism consisting of rods or pulleys to facilitate and control the movement of façade elements.
- Automatic Control (Automatic Device / Automated System) relies on mechanical or electronic systems that respond automatically to

environmental variables or predefined programs, without requiring direct user intervention.

These definitions were adopted to ensure standardised classification of operational and technical characteristics across all case studies under comparison.

Global Experiences

To illustrate the global prevalence of breathable façades and the diversity of their applications, global models from various regions were collected and analysed (Table 2). This analysis facilitates understanding of the differences and similarities between civilisations and the adaptation of environmental solutions to local conditions.

Regional Experiences

Regional models aim to demonstrate how traditional and modern principles of breathing façades can be adapted to local conditions. Table 3 presents these regional models with their basic analytical and comparative elements, facilitating understanding of their environmental and architectural characteristics.

Global Experiences: Selected Cases

This section focuses on analysing global models to explore the role of location, climate, climate adaptation, material selection, façade types, and building function in enhancing the effectiveness and resilience of breathing façades.

Site and Climate Analysis

The global distribution of models shows that most cases are concentrated in Southeast Asian countries, led by Vietnam, which alone accounts for 16 architectural models. This reflects the close connection between humid tropical climates and the need to develop breathable façades that respond to high temperatures, rainfall intensity, and humidity. Several models also appeared in India and Brazil, with four in each country — two nations with similar hot / humid tropical climates — reinforcing the idea that breathable façades were a direct response to challenging environmental conditions, aiming to achieve thermal comfort and provide natural ventilation (Table 4).

Conversely, individual cases in countries such as Canada, Germany, and Spain indicate that this

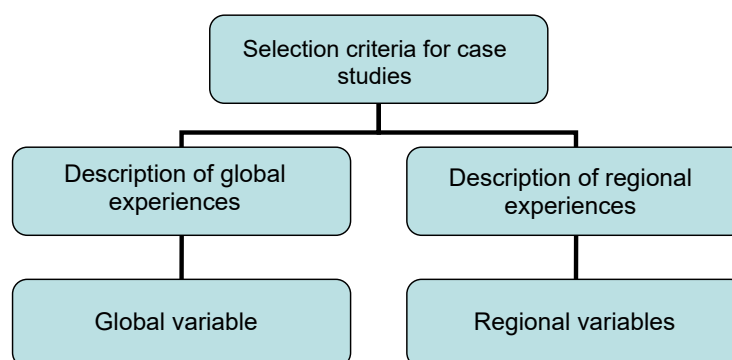


Fig. 3. Selection criteria for case studies

Table 2. Characteristics of Global Experiences (Part 1)

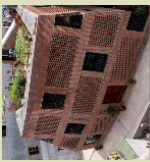
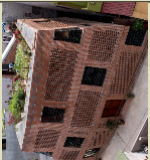
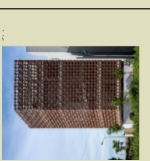
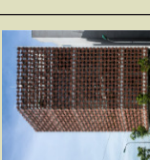
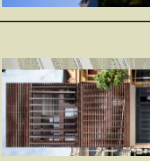
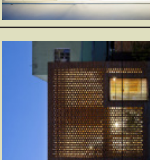
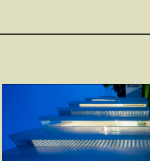
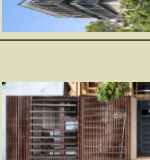
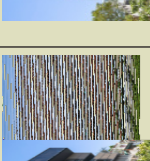
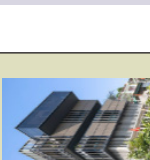
General Information		Key Elements of Breathing Façades				
Name	Picture	Location	Façade Type	Material	Control Mechanism	Function
Casa Nhà Bè		Vietnam	Double Static	Concrete – Glass	NA	Residential
Cueva de Ladrillos		Vietnam	Double Static	Brick	NA	
Cuckoo House		Vietnam	Double Static	Brick – Glass	NA	
Proper Breathing House		Vietnam	Double Static	Ceramic – Glass	NA	
NDC House		Vietnam	Double Static	Brick – Glass	NA	
Termitary House		Vietnam	Double Static	Brick – Glass	NA	
T House		Vietnam	Double Static	Brick – Glass	NA	
Tropical Cave		Vietnam	Double Kinetic	Wood – Glass	Manual control – system of robs and pulleys	
Tile Nest House		Vietnam	Double Static	Clay – Glass	NA	
The Light-house		Vietnam	Double Kinetic	Concrete – Glass	Manual control	

Table 2. Characteristics of Global Experiences (Part 2)

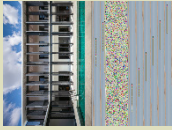
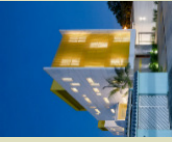
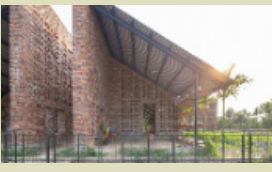
Name	Picture	Location	Façade Type	Material	Control Mechanism	Function
General Information			Key Elements of Breathing Façades			
Wall House		Vietnam	Single	Brick – Glass	NA	Residential
Brick Screen House		India	Double	Brick – Glass	NA	
HIVE House		India	Double	Metal – Glass	Automatic device – Automated system	
House of Shadow		Brazil	Single	Wood	Manual control	
MP Residence		Brazil	Double	Ceramic – Glass	NA	
The Manga		Brazil	Double	Metal – Glass	NA	
House BT		Thailand	Double	Steel – Glass	Manual control	
YPY 1731 Housing		Argentina	Double	Brick	NA	
'ARQ RIFA G'2010' House		Uruguay	Double	Brick – Glass	NA	
Stonewood House		Australia	Double	Stonewood – Glass	NA	

Table 2. Characteristics of Global Experiences (Part 3)

General Information		Key Elements of Breathing Façades				
Name	Picture	Location	Façade Type	Material	Control Mechanism	Function
Breathing Houses		Taiwan	Double Static	Metal – Glass	NA	Residential
Claudio Coello 121 Residential Building		Spain	Double Kinetic	Wood – Glass	Manual control	
Notre-Dame		Canada	Single Static	Brick	NA	
Premier Office		Vietnam	Double Static	Brick	NA	Office Buildings
Tropical Shed		Brazil	Single Static	Brick – Glass	NA	
Won & Won 63.5		South Korea	Double Static	Brick – Glass	NA	
Espacio Ngói		Vietnam	Double Static	Clay – Glass	NA	Educational
Wyndham Clubhouse		Vietnam	Single Static	Brick	NA	
Sharana Daycare Center		India	Double Static	Terracotta – Glass	NA	Hospitality
Aalen University Extension		Germany	Double Kinetic	Wood – Glass	Manual control	Cafe

Table 2. Characteristics of Global Experiences (Part 4)

General Information	Name	Terra Cotta Studio	Terra Cotta Workshop	M. A. C. Community Center
	Picture			
	Location	Vietnam	Vietnam	India
Key Elements of Breathing façades	Façade Type	Single	Single	Single
		Static	Static	Static
	Material	Brick	Brick	Concrete
	Control Mechanism	NA	NA	NA
	Function	Workshop	Factory	Community

Note: NA (Not Applicable) indicates that the control mechanism is a feature associated exclusively with kinetic façades and therefore does not apply to static façades.

architectural approach has also spread to regions with temperate or cold climates, often through contemporary techniques or reinterpretations of the traditional concept. Based on the numerical distribution, tropical / monsoon climates are most strongly associated with the spread of these models, followed by hot tropical climates in India and Brazil, while cases in temperate or cold regions remain relatively fewer. Nevertheless, these examples are important for demonstrating the universality of the concept and the diversity of its applications.

Climate Adaptation

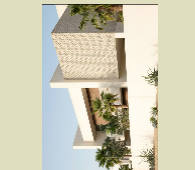
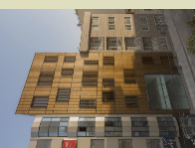
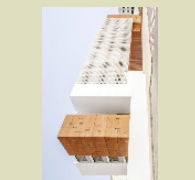
The analysis of the geographic and climatic distribution of the case studies reveals that breathable façades originally emerged in hot and humid climates, particularly in Southeast Asia and Latin America, where natural ventilation and heat-load reduction are critical concerns. This reflects a local adaptation, in which the architectural solution was directly driven by specific climatic conditions. However, the presence of similar models in Germany, Canada, and Spain demonstrates that the concept has not remained confined to its original context.

Instead, it has been reinterpreted and applied globally across diverse climatic environments. Consequently, breathable façades have evolved from a traditional local solution into a global architectural model capable of responding to a wide range of climatic and cultural conditions.

Building Materials

The analysis of global models reveals that brick was the most commonly used material, particularly in Vietnam, where it appeared in more than half of the cases, alongside clay and ceramics. This reflects the local availability of clay-based materials and their effectiveness in promoting ventilation and mitigating heat gain. Glass also featured prominently as a façade component, often used in combination with traditional materials. In contrast, India and Brazil employed a wider variety of materials, including metal, concrete, and terracotta, indicating a tendency to blend modern industrial products with conventional ones. European models (Spain and Germany) predominantly utilised wood and glass, aligning with regional sustainability priorities. In Canada, brick again emerged as the primary

Table 3. Characteristics of Regional Experiences

General Information		Key Elements of Breathing Façades				
Name	Picture	Location	Façade Type	Material	Control Mechanism	Function
Saadat Abad Residential Building		Iran	Double	Brick – Glass	NA	Residential
Ozgol Apartment		Iran	Single	Brick – Glass	Manual control	
Lima Villa		United Arab Emirates	Double	Concrete – Glass	NA	
Lantern House		Algeria	Double	Cement – Glass	NA	
Kohan Ceram Building		Iran	Double	Brick – Glass	Manual control	Office Buildings
Sharif Office Building		Iran	Double	Brick – Glass	Manual control	
Saadat Abad Commercial Office Building		Iran	Double	Wood – Glass	Manual control	
Concrete Phrontistery		Morocco	Double	Concrete – Glass	NA	
Cobogo House		Kuwait	Double	Tile – Glass	NA	Hospitality

Note: NA (Not Applicable) indicates that the control mechanism is a feature associated exclusively with kinetic façades and therefore does not apply to static façades.

Table 4. Distribution of locations and climates

Country	Number of Locations	Continent	Climate
Vietnam	16	Asia	Tropical Monsoon
India	4		Tropical Monsoon/ Subtropical
Brazil	4	South America	Tropical / Humid Subtropical
Argentina	1		Temperate
Uruguay	1		Temperate Oceanic
Australia	1	Oceania	Tropical / Arid
Thailand	1	Asia	Tropical Monsoon
South Korea	1		Temperate Continental
Taiwan	1		Subtropical / Tropical
Spain	1	Europe	Mediterranean
Germany	1		Temperate Oceanic
Canada	1	North america	Cold continental/ Subarctic

material, while Australia presented the only example of a stone-and-wood combination (Table 5). Overall, this diversity underscores the significant influence of both local resource availability and climatic conditions on material selection, alongside the growing impact of sustainability trends in contemporary architecture.

Façade Types

The analysis of façade types across the case studies reveals their role in simultaneously providing effective natural ventilation within buildings. Three main categories were identified:

- **Double-Skin Façades:** These were the most common type, particularly in Vietnam, where 10 out of 16 sites employed this system. Double-skin façades allow complete air circulation through a cavity between two layers: the inner layer can be opened or closed as needed, while the outer layer provides thermal protection against heat or cold. This system promotes natural airflow and enhances indoor environmental quality.

- **Single-Skin Façades:** These traditional façades feature limited openings and provide effective isolation from external climatic conditions. However, they are less effective than double-skin façades in regulating airflow and achieving natural ventilation.

- **Kinetic Façades:** These systems can be adjusted manually or automatically to modulate the intake of fresh air. While they offer flexibility, they may also increase the infiltration of outdoor pollutants if

not properly filtered, which can negatively impact indoor air quality.

Overall, double-skin façades were the most prevalent across the studied models, indicating a growing trend toward adaptable and environmentally responsive design strategies in diverse climatic regions (Table 6).

Building Types

The analysis of the case studies reveals that the majority of buildings were designated for residential use, alongside a range of other functions. In Vietnam, residential buildings dominated the 16 sites, with additional examples of office buildings, hospitals, cafes, workshops, and factories. This diversity reflects the broad applicability of breathable façades across various functional requirements. In India, most projects were residential, complemented by community and educational buildings. Similarly, Brazil's case studies consisted primarily of residential buildings, with some office buildings also present. In Argentina, Uruguay, Australia, Thailand, Taiwan, Spain, and Canada, residential buildings again constituted the majority. By contrast, South Korea focused exclusively on office buildings, while Germany's sole case study was an educational facility (Table 7).

Regional Experiences: Selected Cases

The regional models aim to demonstrate how traditional and modern principles of breathable

Table 5. Building Materials Used

Country	Material	Number of Buildings Used
Vietnam	Clay – Glass	2
	Brick	5
	Brick – Glass	5
	Ceramic – Glass	1
	Concrete – Glass	2
	Wood – Glass	1
India	Brick – Glass	1
	Terracotta – Glass	1
	Concrete	1
	Metal – Glass	1
Brazil	Brick – Glass	1
	Ceramic – Glass	1
	Wood	1
	Metal – Glass	1
Argentina	Brick	1
Uruguay	Brick – Glass	1
Australia	Stone – Wood – Glass	1
Thailand	Steel – Glass	1
South Korea	Brick – Glass	1
Taiwan	Metal – Glass	1
Spain	Wood – Glass	1
Germany	Wood – Glass	1
Canada	Brick	1

Table 6. Façade Types

Country	Façade Type				Control
	Double Façade	Single Façade	Static Façade	Kinetic Façade	
Vietnam	10		10		NA
	2			2	Manual control
		4	4		NA
India	1			1	Automatic device – Automated system
	2		2		NA
		1	1		NA
Brazi		1		1	Manual control
	2		2		NA
		1	1		NA
Argentina	1		1		NA
Uruguay	1		1		NA
Australia	1		1		NA
Thailand	1		1		Manual control
South Korea	1		1		NA
Taiwan	1		1		NA
Spain	1			1	Manual control
Germany	1			1	Manual control
Canada		1	1		NA

façades can be adapted to local conditions and available materials.

Site and Climate Analysis

The regional case studies were distributed across five countries: Iran (5 models), the United Arab Emirates, Kuwait, Algeria, and Morocco (one each). Iran accounted for the largest proportion of the studied models, reflecting the richness of its architectural heritage and the diversity of its climatic conditions — ranging from semi-arid climates in most areas to cold mountainous regions, which demand

distinct façade strategies. In the Arabian Gulf (the UAE and Kuwait), the models originated from hot, dry desert environments, highlighting the role of breathable façades in providing natural ventilation and shading. In contrast, the North African models (Algeria and Morocco) demonstrated adaptation to the Mediterranean climate, characterised by moderate coastal conditions and hot, dry interiors. In these cases, perforated façades were used to facilitate natural ventilation while simultaneously maintaining a decorative architectural character. Overall, semi-arid and hot, dry climates were the most prevalent among the regional models (Table 8).

Climate Adaptation

The regional case studies reveal how architecture in the Middle East and North Africa employs breathable façades as environmentally responsive solutions across diverse climatic contexts. In Iran, where the climate ranges from semi-arid to cold in mountainous areas, buildings incorporated façades that allow

Table 7. Distribution of Building Uses

Country	Residential	Office Buildings	Educational	Hospitality	Café	Workshop	Factory	Community
Vietnam	11	1	–	1	1	1	1	–
India	2	–	1	–	–	–	–	1
Brazil	3	1	–	–	–	–	–	–
Argentina	1	–	–	–	–	–	–	–
Uruguay	1	–	–	–	–	–	–	–
Australia	1	–	–	–	–	–	–	–
Thailand	1	–	–	–	–	–	–	–
South Korea	–	1	–	–	–	–	–	–
Taiwan	1	–	–	–	–	–	–	–
Spain	1	–	–	–	–	–	–	–
Germany	–	–	1	–	–	–	–	–
Canada	1	–	–	–	–	–	–	–

Table 8. Distribution of Locations and Climates

Country	Number of Locations	Continent	Climate
Iran	5	Asia	Hot and Dry Desert
United Arab Emirates	1		
Kuwait	1		
Algeria	1	Africa	Mediterranean Climate
Morocco	1		

summer ventilation while minimising winter heat loss, reflecting a dual adaptation to seasonal weather variations. In the Gulf countries (the UAE and Kuwait), characterised by hot, arid conditions, breathable façades prioritised the reduction of direct solar radiation while maintaining airflow, thereby improving thermal comfort despite extreme environmental conditions. Conversely, the North African models (Algeria and Morocco) offered solutions tailored to the mild Mediterranean climate along the coast and the drier conditions of the interior. Overall, these regional models exhibit a high degree of flexibility in adapting to diverse climatic patterns — ranging from hot and arid to semi-arid and temperate environments.

Building Materials

The analysis of materials used in the regional models reveals a clear preference for combining traditional and modern materials to suit local climatic conditions and functional requirements. In Iran, brick and glass dominate, reflecting the use of locally available materials. Wood combined with glass also appears in one Iranian site, indicating its application in smaller, more ventilated buildings. In the UAE and Morocco, concrete paired with glass reflects a modern, urban aesthetic well-suited to hot, arid climates. Glass facilitates the introduction of natural light while enabling controlled natural ventilation. Kuwait employs tiles combined with glass (Table 9), offering durability and reflective properties that help reduce heat gain. Algeria, meanwhile, uses cement with glass, likely for its thermal mass and structural resilience in the local climate.

Table 9. Building Materials Used

Country	Material	Number of Buildings Used
Iran	Brick – Glass	4
	Wood – Glass	1
United Arab Emirates	Concrete – Glass	1
Kuwait	Tile – Glass	1
Algeria	Cement – Glass	1
Morocco	Concrete – Glass	1

Façade Types

The analysis of façade types in the regional models reveals relatively limited diversity. Most buildings employ either double-skin or single-skin façades, with manual control systems implemented in certain cases. Double-skin façades facilitate natural ventilation and enhance indoor air quality, while the outer layer is typically constructed from materials that provide additional protection against harsh climatic conditions, such as extreme heat or strong winds. Iran exhibits a varied distribution of both double and single façades, with some models incorporating manual controls to regulate airflow as needed. In the UAE and Morocco, buildings utilise both façade types, though control mechanisms are simplified, as most structures do not require frequent adjustment. Kuwait and Algeria, however, rely primarily on manually controlled façades to enable ventilation in response to fluctuating climatic conditions (Table 10).

Building Types

The regional models reveal that residential and administrative buildings (offices) are the most common uses, reflecting the prevailing nature of urban activities in the region. Iran, for example, exhibits a mix of residential and administrative buildings, indicating the diversity of functional needs within its urban context (Table 11). This predominance of housing and administrative functions underscores the basic requirements of regional communities, while specialised uses — such as educational or hospitality facilities — remain limited in number and diversity.

Comparative Analysis of Global and Regional Models

The comparative analysis examines the similarities and differences between global and regional models across several key parameters. The evaluation begins with climate, location, and adaptation — identified as primary factors that shaped design responses — followed by an assessment of materials, façade patterns, and finally, building uses (Table 12).

As summarised in Table 12, global and regional models differ significantly across all analysed parameters:

Table 10. Façade Types

Country	Façade Type				Control
	Double Façade	Single Façade	Static Façade	Kinetic Façade	
Iran	1		1		NA
		1		1	Manual control
	3			3	Manual control
United Arab Emirates	1		1		NA
Kuwait	1		1		Manual control
Algeria	1		1		Manual control
Morocco	1		1		NA

Table 11. **Distribution of Building Uses**

Country	Residential	Office Buildings	Educational	Hospitality
Iran	2	3	–	–
United Arab Emirates	1	–	–	–
Kuwait	–	–	–	1
Algeria	1	–	–	–
Morocco	–	–	1	–

Table 12. **Comparative analysis between global and regional models**

Axis	Global Models	Regional Models
Location and Climate	Wide climatic diversity, dominated by humid tropical climates, with limited presence of temperate and hot, humid climates	Concentrated in hot, dry desert climates
Adaptation Strategies	Focused on combating high humidity	Focused on reducing heat gain in hot, dry conditions
Building Materials	Wide variety of materials (brick, concrete, wood, metal, glass)	Limited set of materials (brick, concrete, cement, and tile with glass)
Façade Systems	More diverse and flexible double-skin façades, combining movable glass with external protective layers, with manual and, in some cases, automatic controls	Simpler single or double-skin façades, with manual controls only
Building Uses	Predominantly residential, with diverse secondary uses including office buildings, educational facilities, and service activities (hospitals, cafes, factories)	Concentrated in residential and office buildings

- Location and climate reflect the different environmental challenges of controlling humidity in global contexts and confronting heat and solar radiation in regional ones.

- Adaptation strategies. In global models, adaptation focused on combating high humidity by promoting continuous natural ventilation to renew air and reduce indoor pollutants. In regional models, where the climate is hot and dry, the focus was on reducing heat gain and protecting interior spaces from direct solar radiation, while regulating ventilation to provide cooling without introducing hot or dusty air.

- Building Materials. This reflects a local trend toward simpler, more environmentally and resource-efficient solutions, compared to the greater flexibility observed in global models. This is also linked to the aesthetic and material expression of buildings, where locally available materials such as brick and wood are more sustainable than high-energy materials such as concrete and glass (Hammond and Jones, 2011; Dixit et al., 2010).

- Façade Systems. Global models relied on double-skin façades to enhance natural ventilation and improve indoor air quality (de Araújo and Bistafa, 2012; Stabile et al., 2017). Regional models, in contrast, reflected more practical but less flexible

solutions compared to their global counterparts (Gupta et al., 2022).

- Building Uses. Global models showed greater diversity in use patterns, while regional models tended to focus on primary uses — predominantly residential and administrative — with limited presence of other activities.

Conclusion

This study demonstrated that breathing façades — encompassing traditional architectural elements such as mashrabiya, jali screens, lattice screens, and cobogó — provide continuous natural ventilation. The results of the comparative analysis revealed that double-skin façades enhance ventilation by increasing the renewal of fresh air within buildings. This mechanism reduces pollutant accumulation in interior spaces and improves indoor air quality (IAQ). Furthermore, the use of locally sourced materials was found to contribute to a significant reduction in embodied energy. The findings also indicate that integrating double-skin façades with adaptive façade systems — which modulate openings to regulate ventilation as required — can improve both thermal performance and indoor comfort in hot-climate building designs. Collectively, these outcomes offer a viable framework that can be leveraged in the design of future buildings under similar climatic conditions.

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ДЫШАЩИЕ ФАСАДЫ КАК СТРАТЕГИИ РЕАГИРОВАНИЯ НА КЛИМАТИЧЕСКИЕ УСЛОВИЯ: ПРИМЕРЫ ИЗ РАЗЛИЧНЫХ КЛИМАТИЧЕСКИХ КОНТЕКСТОВ

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Аннотация

Введение. В данном исследовании оценивается эффективность дышащих фасадов как инновационного архитектурного решения, способствующего обеспечению непрерывной вентиляции, улучшению качества воздуха в помещении, снижению накопления загрязняющих веществ и уменьшению энергопотребления в различных климатических и географических условиях. **Цель исследования** — изучить использование этих фасадов в различных условиях и определить их гибкость и эффективность. **Методы.** Был применен описательный и сравнительный аналитический подход, в рамках которого были изучены 42 глобальные и региональные модели, охватывающие различные континенты и климатические условия. Модели были классифицированы по четырем основным критериям: географическое положение, строительные материалы, системы проектирования и схемы вентиляции, при этом для иллюстрации наиболее распространенных схем использовались таблицы. **Результаты** показывают, что глобальные модели делают акцент на разнообразных решениях, улучшающих вентиляцию и качество воздуха, в то время как региональные модели отличаются использованием недорогих, экологически устойчивых материалов, демонстрируя гибкость и эффективность. Эти результаты подтверждают экологическую и функциональную эффективность воздухопроницаемых фасадов в различных климатических условиях.

Ключевые слова: воздухопроницаемые фасады, естественная вентиляция, климатическая адаптация, качество воздуха в помещении, сравнительный анализ, устойчивая архитектура.