

Exploring Envelope Design Through a Biomimetic Approach for Enhanced Thermal Comfort

Sameer Mohamed^{1*}, S.V. Lakshmi Priya², Priya Sasidharan³, Arevu Chelvi Sundarom⁴

Abstract

This research explores how biomimicry can transform building envelopes to create comfortable indoor climates, particularly in India's hot, dry regions. With rising temperatures and dense urbanization, conventional buildings heavily reliant on air conditioning are unsustainable. Biomimicry, inspired by nature's designs, offers an alternative to enhance adaptability, resilience, and energy efficiency in climate-responsive buildings. The study bridges the gap between conventional envelope design and climate adaptability by examining biomimetic principles for indoor temperature regulation. The methodology categorizes case studies based on biomimicry type, envelope design, and climate zones. Case studies, both international and Indian, are assessed using three parameters: biomimicry (biomimicry form/process), envelope design (materials, construction techniques, technologies, and design strategies), and thermal comfort (comfort strategies and thermal performance). Findings reveal that nature-inspired designs, such as adaptive shading and passive cooling, improve thermal comfort while reducing dependence on artificial climate control. Static biomimetic envelopes rely on envelope design (25–40%), thermal strategies (20%), and biomimicry (10%) for performance. In dynamic biomimetic envelopes, envelope design remains dominant (37–40%), while thermal strategies (25%) and biomimicry (12%) further enhance efficiency (vide my dissertation findings). Despite challenges like limited resources and awareness, biomimicry presents a promising path for sustainable architecture in India. This research concludes that integrating biomimetic principles into building envelopes fosters sustainable, adaptable, and comfortable spaces. By learning from nature, architects can design buildings that harmonize with the environment, promoting human comfort and environmental well-being while reducing reliance on energy-intensive cooling systems.

Keywords: Biomimicry, thermal comfort, static and dynamic envelope design, thermal performance

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INTRODUCTION

As the urban population and environmental challenges are rising, architectural exterior design has shifted toward sustainable and energy-efficient solutions [1]. Traditional passive systems struggle to respond to changeable weather patterns and severe climatic conditions, especially in hot climates. Natural forms, processes, and ecosystems inspire inventive designs by emulating their adaptable and responsive qualities. Understanding how flora, fauna, and natural structures manage temperature, moisture, and airflow helps in designing energy-efficient building envelopes that improve thermal comfort. This study bridges the gap between aesthetic, functional, and environmental performance in building façades, making biomimetic design a viable field for human comfort and sustainable architecture [2].

Significance of the Study

How can biomimetic ideas improve the building envelope design for thermal comfort? Biomimicry is used to examine how nature-inspired strategies, such as adaptive shading, moisture regulation, and temperature control in plants, animals, and natural ecosystems, can solve energy efficiency and indoor climate management problems [3]. By mimicking natural mechanisms, building envelopes can dynamically adjust to external climatic conditions, thereby eliminating the need for artificial heating and cooling. This study provides architects and designers with practical tips for building eco-friendly façades that fluidly adjust to temperature changes, optimize ventilation, and limit solar gain. By applying these adaptive solutions to architectural practice, research can set new norms for sustainable building design, creating robust, thermally comfortable places that promote human and environmental well-being [4].

Context

How can biomimetic concepts improve thermal comfort in the commercial building exterior designs in Indian metropolitan areas, offering novel alternatives to energy-intensive mechanical systems?

Research Gap Identified

Previous research has focused on discrete biomimetic features or envelope design principles, neglecting the ability of biomimicry to construct dynamic, responsive façades that improve building performance [1, 2]. This study fills the gap in previous research by studying how biomimetic concepts might be used to create dynamic, responsive façades that improve thermal comfort in Indian urban commercial projects [5].

Aim

The aim was to explore and develop biomimetic approaches to envelope design that specifically focus on thermal comfort solutions.

Objectives

- Examine biomimetic techniques, materials, and technologies for dynamic heat regulation.
- Categorize envelope designs for thermal comfort in seven climate zones: Temperate, Mediterranean, Tropical Savanna, Semi-Arid, Tropical, Hot and Dry, and Warm and Humid.
- International case studies are analyzed to identify essential factors in biomimetic envelope designs for thermal comfort.
- Develop a compendium of critical parameters to guide the future implementation of dynamic and static envelope systems for building thermal comfort, with climate-specific strategies for Temperate, Mediterranean, Tropical Savanna, Semi-Arid, Tropical, Hot and Dry, and Warm and Humid zones.

Scope

This study examined a biomimetic envelope design to improve thermal comfort in different climates. Envelope designs are categorized by climate zones to determine the best biomimetic methodologies, and worldwide case studies are examined to determine the implementation parameters. This study focuses on dynamic, responsive materials and technology to produce flexible building façades for crowded urban Indian contexts to support sustainability and thermal comfort [6].

Limitations

This study is limited to the hot and dry climate and the Indian urban context, which may limit the generalizability of the findings to other regions with distinct cultural or environmental conditions. Climate zone categorization is also broad and may not fully account for local microclimates that can impact a building's thermal performance.

Research Question

How can biomimetic principles be integrated into the building envelope design to optimize thermal comfort?

Research Sub-Questions

1. How can biomimetic principles guide the design of adaptive building envelopes specifically tailored to improve the thermal comfort in Indian urban commercial buildings?
2. What are the distinct ways in which biomimetic façades impact the thermal regulation of interior spaces, and how can these impacts be measured against conventional façade systems?
3. How do biomimetic façades influence the surrounding urban microclimate, and what strategies can be employed to maximize their positive environmental effects?
4. What specific design and sociocultural factors must be considered when implementing biomimetic thermal comfort solutions in diverse urban settings across India?

Hypothesis

Biomimetic envelope designs that mimic natural adaptive strategies can enhance thermal comfort and reduce energy consumption in buildings across hot and dry areas in India [7].

METHODOLOGY

This methodology uses exploratory research to examine how biomimetic concepts can improve thermal comfort in building envelope designs. It begins with a comprehensive literature review on biomimicry, envelope design, and thermal comfort to lay the groundwork. Subsequently, a detailed review categorized investigations by biomimetic techniques, envelope types, and climate zones. This classification identifies biomimicry levels, envelope systems (kinetic, dynamic, static), and thermal comfort criteria, such as heat dispersion and retention, for evaluation [8]. These criteria are used to assess worldwide and national case studies, including the Doha Tower, Eastgate Building, and Lotus Temple, to compare biomimetic solutions for thermal comfort in different regions. This analysis identifies effective tactics, trends, and obstacles, providing biomimetic envelope design guidance. In conclusion, generic parameters for various climatic zones and specialized factors for hot and dry regions of India were discussed, with a focus on biomimetic organism envelope design and problems (Figure 1).

LITERATURE STUDY

Biomimetic Architecture

Biomimetics comes from the Greek words “bios,” meaning life, and “mimesis,” meaning imitation. The late 20th and early 21st centuries saw major advances in architectural biomimicry. The word was introduced in the 1960s by the biophysicist Otto Schmitt, but Janine Benyus’s 1997 book “Biomimicry: Innovation Inspired by Nature” popularized the idea of using nature to solve human issues, particularly in architecture [7].

Envelope Design

Exterior walls, roofs, windows, and doors make up the envelope of a building. The building envelope has been part of the architectural design for millennia, but new construction technology and energy efficiency have made this phrase increasingly popular in the mid-20th century.

Thermal Comfort

Thermal comfort is a term used to describe a state in which a person feels neither too hot nor too cold, but “just right.” This concept has been studied since the early 20th century, with research focusing on the thermal balance of the human body. The term became more scientifically defined with the development of thermal comfort standards such as ASHRAE 55, which was first published in the 1960s.

Parameters for Analysis

The case study analysis is structured into three main categories: biomimicry, envelope design, and thermal comfort. This approach provides a clear view of how nature-inspired design principles, materials, and strategies work together to create energy-efficient adaptive façades (Table 1).

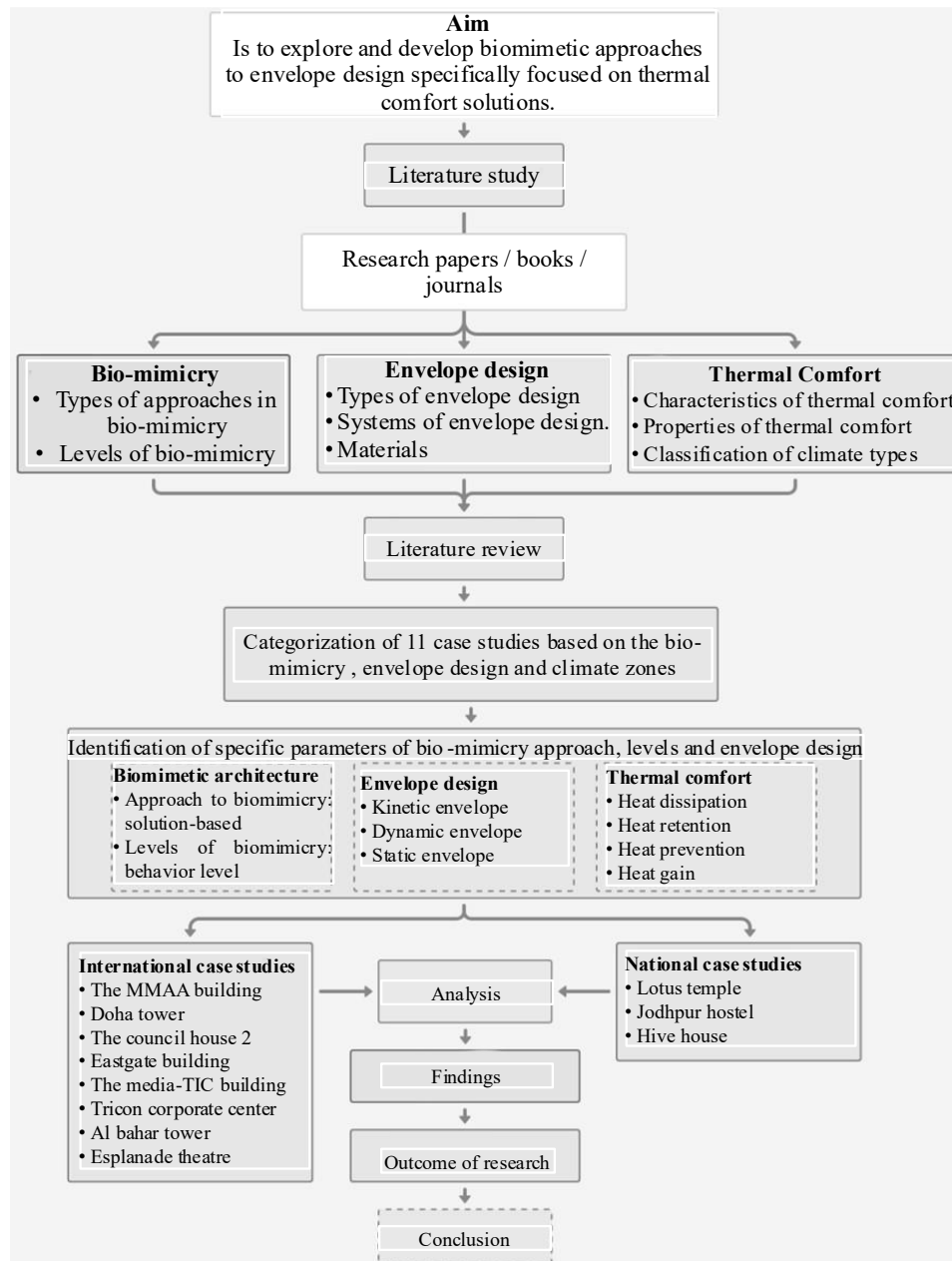


Figure 1. Methodology.

Table 1. Parameters for analysis.

Parameters	Biomimicry	Envelope design			Thermal comfort	
	<i>Biomimicry form/process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>	<i>Design strategies</i>	<i>Comfort strategies</i>	<i>Thermal performance</i>
Analysis						
Optimal comfort achieved						

Biomimicry

This category considers natural forms and processes as design inspiration for managing heat and light. By studying patterns and adaptive traits found in nature, such as natural cooling in termite mounds or shading by desert plants, this research explores ways to bring these adaptive qualities into building façades.

Envelope Design

This section focuses on the materials, technologies, and strategies that make up a building’s exterior.

Material and Construction

Evaluating materials that help with insulation, reflect sunlight, and adapt to changing conditions.

Technology

Smart solutions, such as shading, adjusting to the sun, and glass that control heat and light.

Design Strategies

Elements such as façade orientation, shading devices, and ventilation work together to enhance comfort.

Thermal Comfort

Thermal comfort refers to the effectiveness of the envelope in creating a stable, pleasant indoor environment.

Comfort Strategies

Understanding techniques like passive cooling and strategic insulation to keep the space comfortable naturally.

Thermal Performance

Assessing how well the envelope reduces heat gain, maintains coolness, and lowers energy needs.

Through this analysis, this study aims to develop practical biomimetic guidelines for adaptive façades that can be tailored to different climates, particularly in urban areas across India, where comfort and sustainability are key [9].

GRADING OF THERMAL COMFORT LEVEL

A simple grading system was created to measure the extent to which different case studies achieved thermal comfort. This system provides a clear and consistent method to evaluate the effectiveness of each design (Table 2).

Table 2. Grading of thermal comfort level.

Thermal comfort level					
Thermal comfort level	Color code				Points
Unsatisfactory					1
Basic comfort					2
Comfortable					3
Enhanced comfort					4

Thermal Comfort Levels

The grading scale uses four levels, each with a color code and a score from 1 to 4.

1. *Unsatisfactory (Red, Score: 1):* poor thermal comfort, requiring high energy for heating or cooling.
2. *Basic comfort (Yellow, Score: 2):* Meets basic comfort but relies on more energy for adjustments.
3. *Comfortable (Green, Score: 3):* Provides stable indoor temperatures with reduced reliance on mechanical systems.

4. *Enhanced comfort (Blue, Score: 4):* Achieves optimal comfort through advanced biomimetic strategies, dynamically adjusting to external changes with minimal energy.

The analysis was based on the identified parameters and their grading of thermal comfort.

CASE STUDY ANALYSIS

International Case Studies

Case Study 1: Council House 2 (CH2) Building Melbourne (Static Envelope)

Table 3. Council House 2 (CH₂) building, Melbourne analysis.

Parameters	Biomimicry	Envelope design	
	<i>Biomimicry Form/Process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>
Analysis	Mimics the form of the termite mounds by creating a series of wind chimneys in the west (Figure 2) and a double wall façade with a cavity in the north [6].	<p><i>North and south façade:</i> A double wall façade integrated with a wind chimney and green terrace helps in reducing heat gain.</p> <p><i>Materials used: concrete:</i> high thermal mass, heat retention.</p> <p><i>West façade:</i> Plain façade without any fenestrations, clad with steel perforated panels – heat dissipation.</p> <p><i>Materials used: steel:</i> High thermal conductivity and thermal mass.</p> <p><i>East façade:</i> Double wall system <i>Outer layer:</i> Timber slats <i>Middle layer:</i> Cavity <i>Inner layer:</i> Concrete wall (Figure 3).</p> <p><i>Materials used: Timber:</i> Low thermal conductivity and Moisture regulation [7].</p>	<p><i>Advanced Systems:</i> Incorporates phase-change materials for heat storage.</p> <p><i>Chilled Ceilings and Underfloor Heating:</i> Circulates water for adaptive, efficient temperature control. (Figure 4)</p> <p><i>Radiant Cooling:</i> Cools surfaces, not air, for energy-efficient comfort [14].</p>
<i>Optimal comfort achieved</i>			

Analysis based on identified parameters and their grading for thermal comfort (analysis by author, citation given for relevant sources).

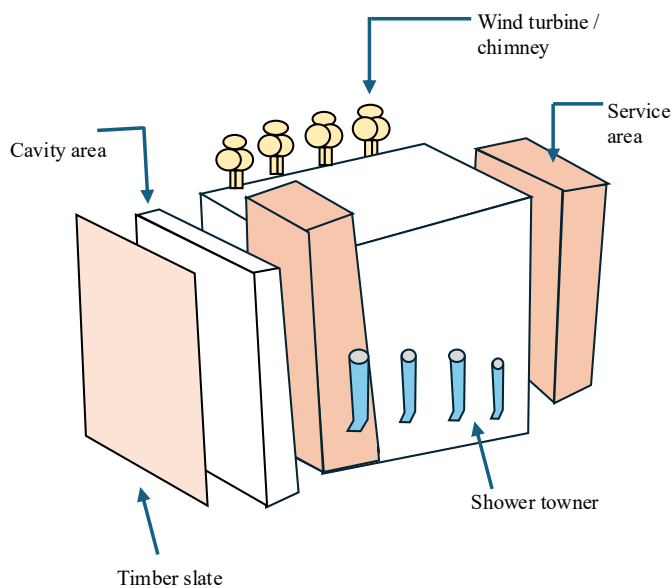


Figure 2. Biomimetic components in building form analysis.

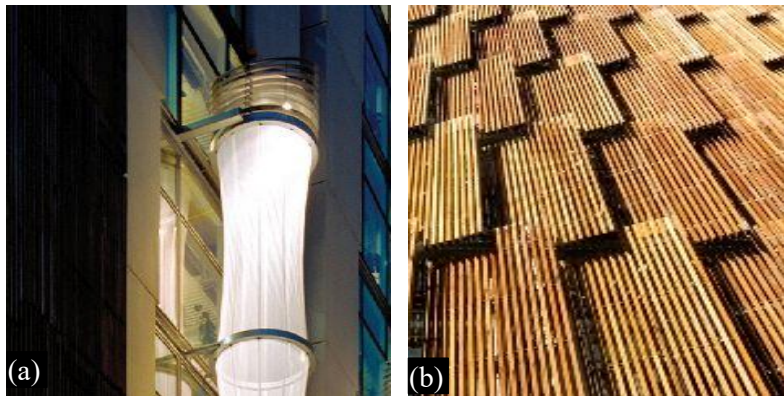


Figure 3. Shower tower (a) and timber slate (b) of the CH2 building.

Source: Nancy Yen-Wen Cheng, 2017 [7].

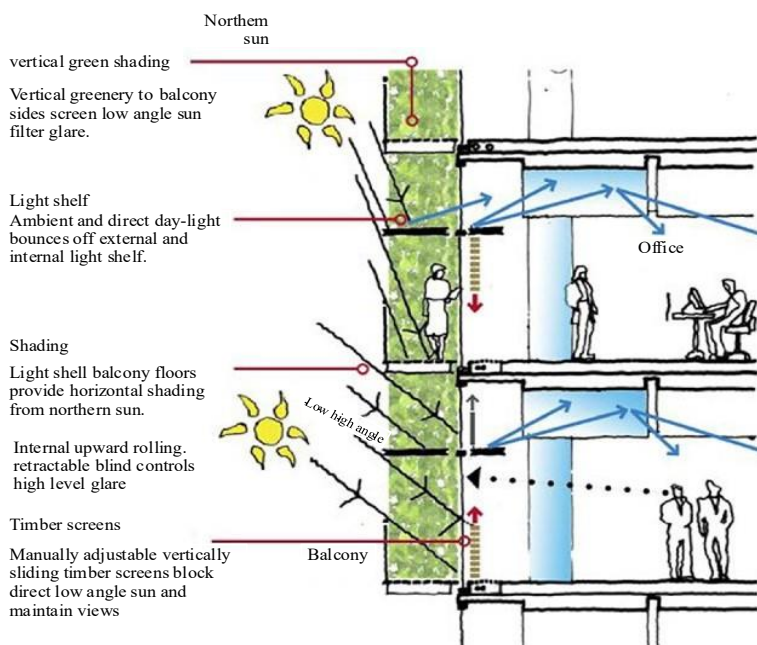


Figure 4. North façade of the CH2 building.

Source: Nadeen Nour ElDin, 2023 [14].

Table 4. Council House 2 (CH2) building, Melbourne analysis.

Parameters	Envelope design	Thermal comfort	
	Design strategies	Comfort strategies	Thermal performance
Analysis	Maximization of Passive Strategies Large windows for natural light, external shading devices, and a green façade enhance ventilation and temperature control. (Figure 5) [7].	Night Purge Opens windows for natural night cooling, cutting cooling loads by 20%. Optimized heat gain prevention and dissipation, maintaining comfortable indoor temperatures with minimized energy use. (Figure 6).	The CH2 building in Melbourne achieves high thermal performance through features like thermal mass, a double skin façade, and radiant cooling, reducing its energy consumption by up to 80% compared to conventional buildings [14] (Figure 7).
Optimal comfort achieved			

Analysis based on identified parameters and their grading for thermal comfort. (Analysis by author, citation given for relevant sources).



Figure 5. Curved ceiling and columns with high thermal mass.
Source: Nancy Yen-Wen Cheng. 2017 [7].



Figure 6. Chimney with wind turbines at the top for air circulation.
Source: Nancy Yen-Wen Cheng. 2017 [7].

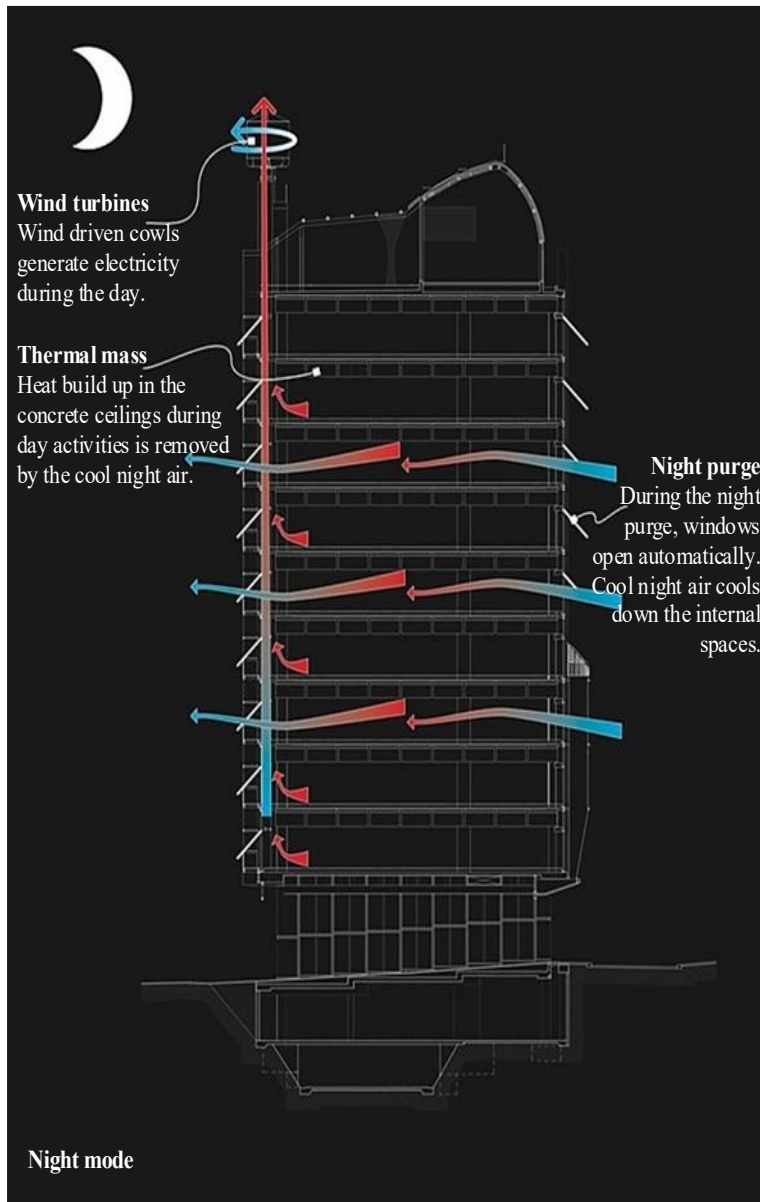


Figure 7. Night purge section.
Source: Nadeen Nour ElDin, 2023 [14].

Council House 2 (CH2) Building Melbourne Analysis Inference




The CH2 building mimics the behavior and construction techniques of the termite mound by addressing passive cooling techniques with four unique static façade designs tailored to the solar direction and wind direction, a north façade designed with a double wall system incorporating a wind chimney, and a green terrace with concrete (high thermal mass) material [10]. The west façade is also designed in a double wall system with operable timber slate with moisture regulation material properties, which helps in regulating optimum thermal comfort (Tables 3 and 4).

Case Study 2: Eastgate Centre, Zimbabwe (Static Envelope)

Eastgate Centre Zimbabwe Analysis Inference

The Eastgate Centre mimics the passive cooling techniques of the termite mound using a static façade with a double wall system, prickly concrete bodies (high thermal mass), and wind chimneys to regulate thermal comfort (Tables 5 and 6).

Table 5. Eastgate Centre, Zimbabwe analysis.

Parameters	Biomimicry	Envelope design	
	<i>Biomimicry Form/Process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>
<i>Analysis</i>	Mimics the form of the termite mounds by creating a series of wind chimneys and a double wall façade [6] (Figure 8)	<p><i>Façade design:</i> Double wall façade structure incorporates thick walls and internal voids to absorb and dissipate heat, working with a system of ventilation shafts to facilitate passive temperature regulation.</p> <p>a. <i>Outer layer:</i> Concrete prickly bodies</p> <p>b. <i>Middle layer:</i> Cavity</p> <p>c. <i>Inner layer:</i> Glass window</p> <p>d. <i>Materials used:</i></p> <p>e. <i>Concrete:</i> High thermal mass, heat retention</p> <p>f. <i>Steel:</i> High thermal mass</p> <p>g. <i>Clay:</i> Thermal mass and low conductivity (Figure 9)</p>	<p><i>Automated Vents:</i> Open and close to regulate airflow, reducing the need for mechanical cooling.</p> <p><i>Fan Assist:</i> Used minimally to enhance airflow only when needed, supporting the passive systems. (Figure 10)</p>
<i>Optimal comfort achieved</i>			

Analysis based on identified parameters and their grading for thermal comfort. (Analysis by author, citation given for relevant sources)

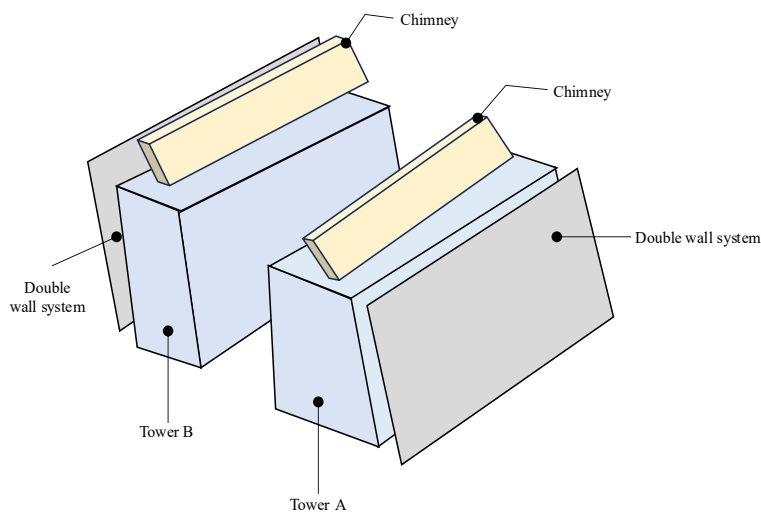


Figure 8. Biomimetic components in building form analysis.



Figure 9. Concrete prickly bodies with high thermal mass.

Source: Stefan Novakovic, *How Architects Are Getting Innovative and Addressing the Climate Crisis*, www.threemagazine.com [13].



Figure 10. Air circulation inside the office through the chimney
 Source: *Termite inspiration for a self-cooling building*, www.btp-cours.com [14].

Table 6. Eastgate Centre, Zimbabwe analysis.

Parameters	Envelope design	Thermal comfort	
	Design strategies	Comfort strategies	Thermal performance
Analysis	<i>Maximization of Passive Strategies:</i> Large windows for natural light, external shading devices, and a green façade enhance ventilation and temperature control. (Figure 11) [7].	<i>Chimneys and Air Stacks:</i> Mimic termite mound ventilation, circulating air naturally throughout the building.	The Eastgate Centre in Zimbabwe achieves thermal performance through passive cooling inspired by termite mounds, using vents, chimneys, and high thermal mass concrete walls to regulate indoor temperatures without air conditioning. This design reduces the building's energy consumption for cooling by up to 90%. (Figure 12).
Optimal comfort achieved			

Analysis based on identified parameters and their grading for thermal comfort. (analysis by author, citation given for relevant sources).



Figure 11. Concrete prickly bodies that act as a sunshade.
 Source: *Stefan Novakovic, How Architects Are Getting Innovative and Addressing the Climate Crisis*, www.threemagazine.com [13].



Figure 12. Eastgate Centre regulates thermal comfort using passive cooling techniques.

Source: Termite inspiration for a self-cooling building, www.btp-cours.com [14].

Case Study 3: Media TIC Building Barcelona (Dynamic Envelope)

Media TIC Building Barcelona Analysis Inference

The Media TIC mimics stomatal behavior by addressing ventilation capabilities in response to external conditions through a dynamic façade with double-walled Ethylene Tetrafluoroethylene (ETFE) cushions (UV resistance, self-cleaning, and low thermal mass) operated by a pneumatic system to regulate thermal comfort (Tables 7 and 8).

Table 7. Media TIC building Barcelona analysis.

Parameters	Biomimicry	Envelope design	
	Biomimicry form/process	Envelope material and construction technique	Technology
Analysis	<p>Mimics the process of stomata in the envelope design, rather than in form.</p> <p>Irregular concave and convex triangular shapes enhance airflow and reduce wind pressure, inspired by atomic structures for visual distinctiveness and energy efficiency (Figure 13) [6]</p>	<p><i>Northeast façade: Static façade:</i> Glass curtain wall system allows sunlight.</p> <p><i>Northwest façade: Static façade:</i> Structural diagrid support– heat dissipation.</p> <p><i>Southeast façade: dynamic façade:</i> Double-layer cladding with a 3-layer ETFE with pneumatic system heat prevention.</p> <p><i>Southwest façade: Dynamic façade:</i> Lenticular system with two nitrogen-filled ETFE layers to filter solar heat (Figure 14).</p> <p><i>Materials used:</i> ETFE: UV resistance, self-cleaning, and low thermal mass.</p> <p><i>Steel:</i> high thermal mass and light weight</p>	<p><i>Pneumatic and sensor system:</i> Smart sensors and a pneumatic system adjust cushion inflation based on real-time light and temperature, optimizing solar shading.</p> <p><i>Energy management:</i> Central control coordinates solar shading, temperature, and energy storage (Figure 15) [6].</p>
Optimal comfort achieved			

Analysis based on identified parameters and their grading for thermal comfort (Analysis by author, citation given for relevant sources)

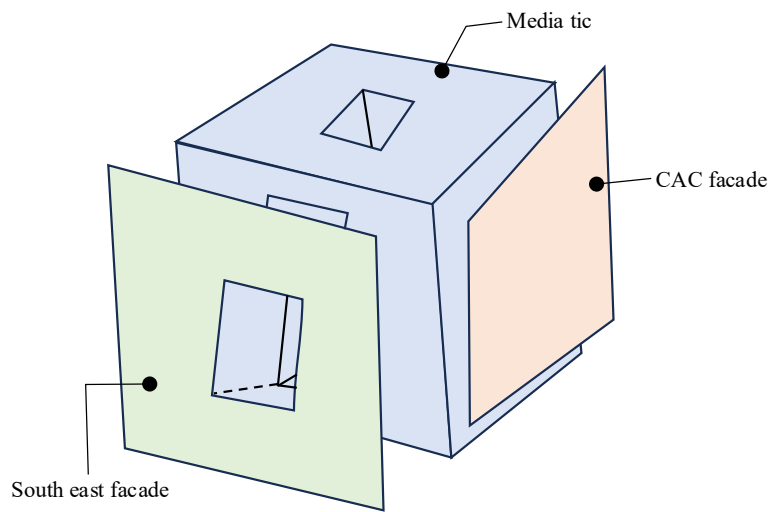


Figure 13. Biomimetic components in building form analysis.

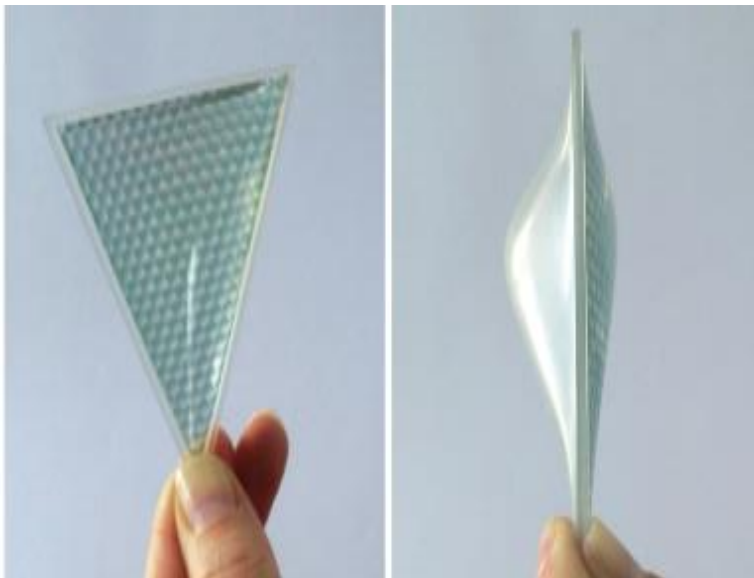


Figure 14. Ethylene tetrafluoroethylene (ETFE) prototype.
Source: Abdulmajid Karanouha and Ethan Kerberb. 2015 [6].

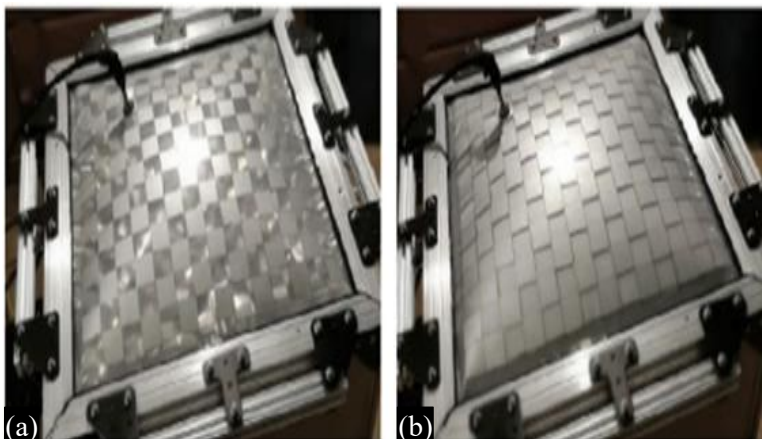


Figure 15. ETFE cushion: geometry and frit pattern design.
Source: Abdulmajid Karanouha and Ethan Kerberb. 2015 [6].

Table 8. Media TIC Building Barcelona analysis.

Parameters	Envelope design	Thermal comfort	
	Design strategies	Comfort strategies	Thermal performance
Analysis	<ul style="list-style-type: none"> Designed with CAD/CAM technology The open layout maximizes adaptability to environmental conditions, with each façade tailored for sunlight and wind exposure. (Figure 16) [6]. 	<i>ETFE Cushions:</i> Adjustable solar factor cushions for dynamic heat gain management, ensuring comfortable indoor temperatures year-round. (Figure 17) [14]	Media TIC building achieves thermal comfort by climate-responsive façade systems by using a mix of fixed and inflatable ETFE (ethylene tetrafluoroethylene) cushions; the building’s façades effectively regulate interior temperatures based on solar exposure [6].
Optimal comfort achieved			

Analysis based on identified parameters and their grading for thermal comfort (analysis by author, citation given for relevant sources).

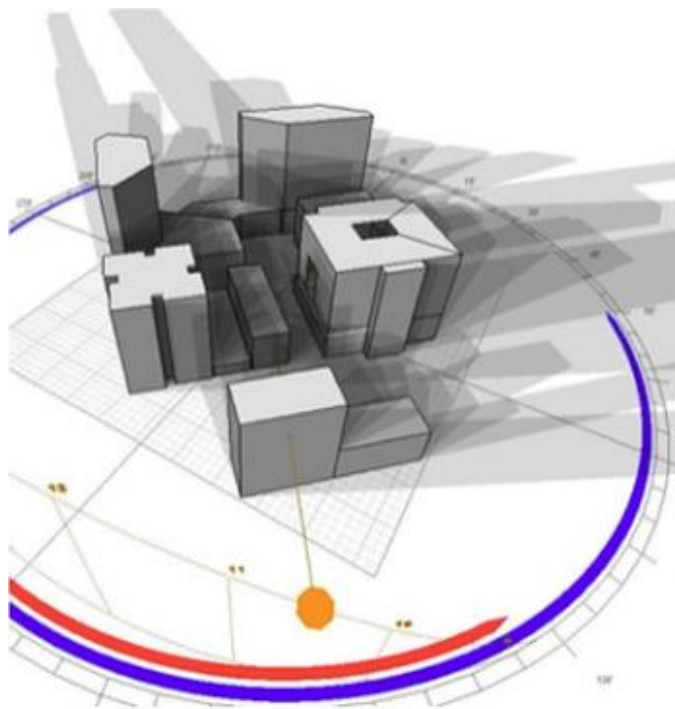


Figure 16. Building oriented as per the sun’s movement.

Source: Abdulmajid Karanouha and Ethan Kerberb. 2015 [6].

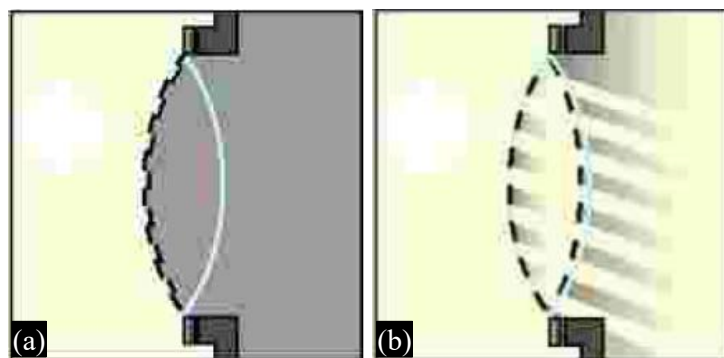


Figure 17. (a, b) Switching mechanism of the ETFE dynamic façade.




Source: Nadeen Nour ElDin,2023 [14].

Case Study 4: Al-Bahr Towers Abu Dhabi (Dynamic Envelope)

Al-Bahr Towers Abu Dhabi Analysis Inference

The Al Bahar Tower mimics floral activity by addressing the capacity of the butterfly to reflect sunlight and adaptability. A dynamic façade with double-walled polytetrafluoroethylene (PTFE) cushions (UV resistance, light weight, and low thermal mass) and an automated sun sensor system regulates thermal comfort (Tables 9 and 10).

Table 9. Al-Bahr Towers Abu Dhabi analysis.

Parameters	Biomimicry	Envelope design	
	<i>Biomimicry form/process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>
Analysis	Mimics the form of a flower in the envelope design rather than the form. (Figure 18) [7].	<p><i>Façade design:</i> Double wall façade system known as Mashrabiya made up of PTFE material (Figure 19)</p> <ol style="list-style-type: none"> <i>Outer layer:</i> PTFE dynamic unit <i>Middle layer:</i> cavity <i>Inner layer:</i> Double-glazed window <p><i>Materials used:</i></p> <ol style="list-style-type: none"> <i>PTFE:</i> Lightweight and UV-resistant, low thermal mass <i>Steel:</i> High thermal mass <i>Glass:</i> Double-glazed glazed naturally tinted glass [6]. 	<p>The tower incorporates an advanced automated shading system controlled by sun-tracking software, which adjusts the position of the Mashrabiya panels based on real-time solar angles (Figure 20).</p> <p>This technology can be overridden manually, providing flexibility in response to varying environmental conditions [7].</p>
Optimal comfort achieved			

Analysis based on identified parameters and their grading for thermal comfort. (Analysis by author, citation given for relevant sources).

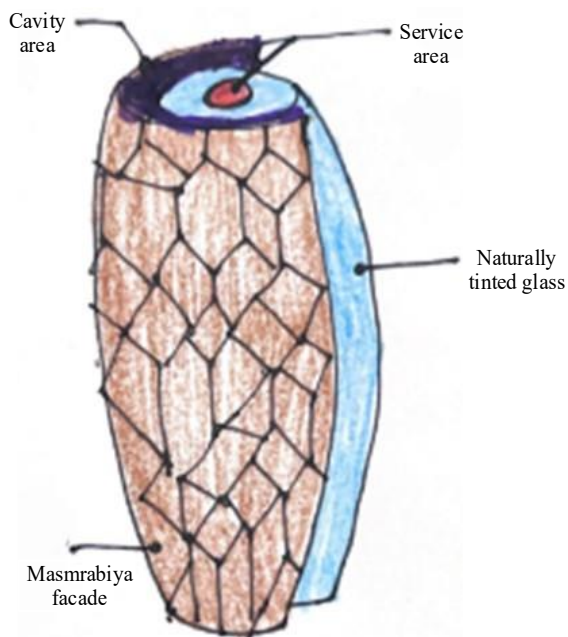


Figure 18. Biomimetic components in building form analysis.

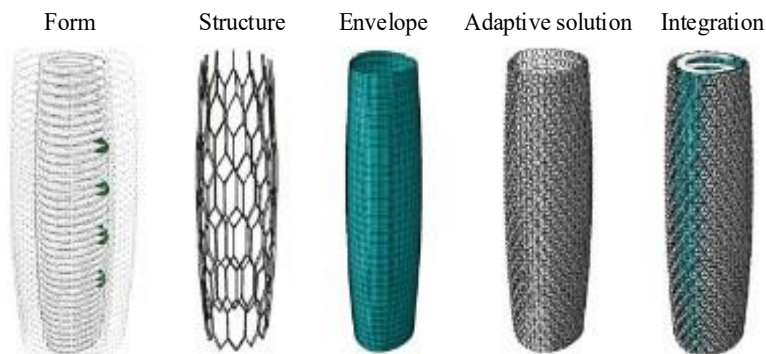


Figure 19. Components of the dynamic envelope in Al Bahar tower.
 Source: Abdulmajid Karanouha and Ethan Kerberb. 2015) [6].

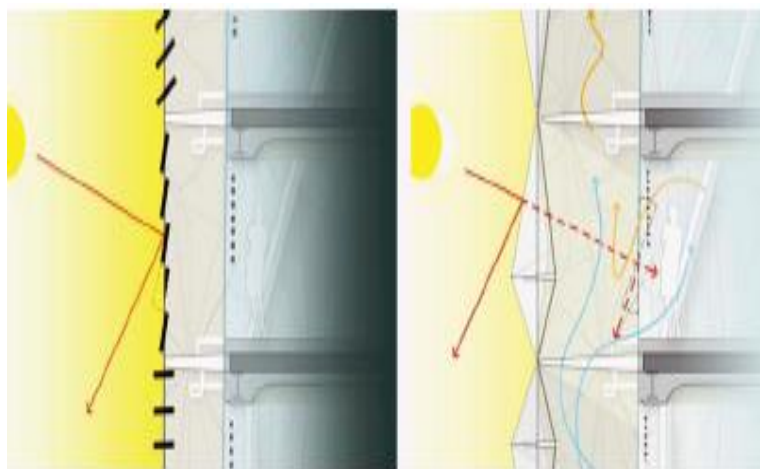


Figure 20. Comparisons between a regular envelope and a dynamic Mashrabiya.
 Source: Adapted from Mine Koyaz. Adaptability level of facade systems regarding facade performances. Interdisciplinary Perspectives for Future Building Envelopes; May 15–18, Istanbul, Turkey: ICBEST Istanbul; 2017.

Table 10. Al-Bahr Towers Abu Dhabi analysis.

Parameters	Envelope design	Thermal comfort	
	Design strategies	Comfort strategies	Thermal performance
Analysis	The tower exhibits an irregular and dynamic form characterized by a series of movable Mashrabiya panels, which draw inspiration from traditional Islamic architecture (Figure 21) [13]	<p><i>Building Orientation:</i> The towers are oriented to reduce exposure to intense sunlight, especially on the east and west façades, lowering solar gain and cooling loads passively.</p> <p><i>Mashrabiya:</i> The shading system itself acts as a passive solar control strategy by minimizing direct solar heat gain, reducing reliance on air conditioning without active cooling (Figure 22) [13].</p>	The Al Bahar tower in Abu Dhabi achieves thermal performance through the dynamic implementation of flower opening and closing with the physical characteristics of a butterfly. This design reduces the building’s energy consumption for cooling by up to 90% [13].
Optimal comfort achieved			

Analysis based on identified parameters and their grading for thermal comfort. (Analysis by author, citation given for relevant sources).



Figure 21. Dynamic Mashrabiya envelope.

Source: Ayça Tokuç, Fatma Feyzal Özkaban and Özge Andıç Çakır.,2018 [13].

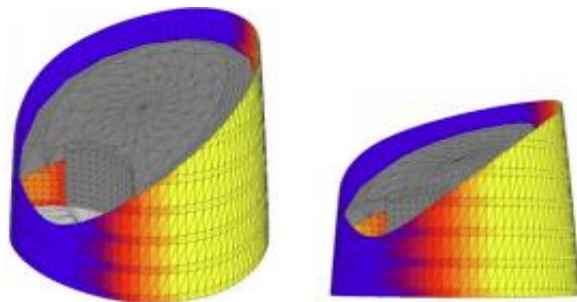


Figure 22. Optimized the Mashrabiya envelope and solar exposure level.

Source: Ayça Tokuç, Fatma Feyzal Özkaban and Özge Andıç Çakır., 2018 [13].




National Case Studies

Case Study 1: Lotus Temple, New Delhi (Static Envelope)

Lotus Temple, New Delhi Analysis Inference

The Lotus Temple mimics the ability of the flower to reflect sunlight through a static façade made of thick concrete (high thermal mass, heat retention) and Grecian marble (heat prevention) to regulate thermal comfort [11] (Tables 11 and 12).

Table 11. Lotus Temple, New Delhi analysis.

Parameters	Biomimicry	Envelope design	
	<i>Biomimicry form/process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>
Analysis	Literally mimics the form of a lotus flower in the form making it the envelope design (Figure 23) [7].	<p><i>Envelope design:</i> Petals are free-standing slabs that ensure structural stability and open interior spaces.</p> <p>Precast ribbed roofs support both structure and acoustics in the central hall (Figure 24)</p> <p>Materials used:</p> <ol style="list-style-type: none"> <i>Grecian marble:</i> Durability and reflection, reducing solar absorption. <i>Galvanized Reinforcement:</i> Prevents rust. <i>Concrete:</i> high thermal mass, heat retention [6] 	<p><i>Engineering and CAD:</i> Advanced computer programs, including Finite Element Analysis and wind tunnel tests, optimized structural stability.</p> <p><i>Construction techniques:</i> In situ concrete casting and innovative formwork catered to the temple's complex geometry.</p>
Optimal comfort achieved			

Analysis based on identified parameters and their grading for thermal comfort. (Analysis by author, citation given for relevant sources).

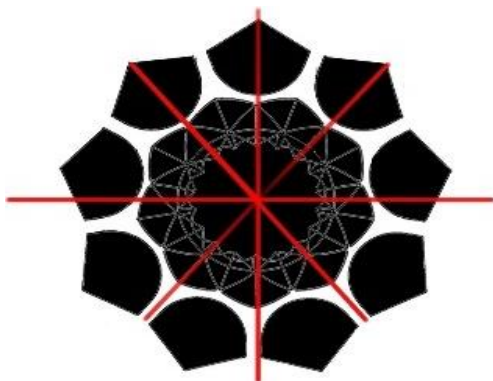


Figure 23. Biomimetic components in building form analysis.
 Source: Adapted from Sidra Sabahat, Alok Omar, 2022.



Figure 24. Roof with high thermal mass material.
 Source: Er. Mohammed Sahil, Er. Prafull Kothari, 2020.

Table 12. Lotus Temple, New Delhi analysis.




Parameters	Envelope design	Thermal comfort	
	Design strategies	Comfort strategies	Thermal performance
Analysis	<p>Biomimetic lotus-inspired design fosters passive cooling, cross-ventilation, and natural lighting.</p> <p>Surrounding pools assist with passive cooling and add to the spiritual ambiance.</p> <p>The skylight at the top allows natural light to penetrate, minimizing artificial lighting needs.</p>	<p><i>Ventilation:</i> Cross-ventilation and stack effect regulate indoor climate, while the skylight provides natural illumination and passive solar gain in cooler seasons.</p> <p><i>Energy efficiency:</i> Passive cooling through reflective materials and strategic openings reduces dependency on Heating, Ventilation, and Air Conditioning (HVAC) systems, highlighting biomimetic adaptation for thermal comfort.</p>	<p>Lotus Temple achieves thermal comfort through passive strategies like natural ventilation, reflective white marble cladding, and surrounding water pools that help cool the structure. The building’s concrete structure also provides thermal mass, regulating indoor temperatures by absorbing heat during the day and releasing it gradually at night.</p>
Optimal comfort achieved			

Analysis based on identified parameters and their grading for thermal comfort. (Analysis by author, citation given for relevant sources).

Case Study 2: Jodhpur Hostel Jodhpur (Static Envelope)
Jodhpur Hostel Jodhpur Analysis Inference




The Jodhpur Hostel replicates termite mound behavior and building by using passive cooling techniques through a static façade with a wind tower and high thermal mass material properties to regulate thermal comfort (Tables 13 and 14), respectively.

Table 13. Jodhpur Hostel Jodhpur analysis.

Parameters	Biomimicry	Envelope design	
	<i>Biomimicry form/process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>
<i>Analysis</i>	Mimics the form of the termite mounds by creating a wind tower and façade with high thermal mass	<i>Envelope design:</i> The wind tower structure incorporates air chambers and openings that support ventilation while allowing natural airflow, similar to the internal structure of termite mounds. This supports air movement without compromising structural stability. <i>Materials used: Concrete:</i> High thermal mass, heat retention	Traditional masonry techniques are employed for constructing the wind tower
<i>Optimal comfort achieved</i>			

Analysis based on identified parameters and their grading for thermal comfort.
 Analysis by the author, citation given for relevant sources.

Table 14. Jodhpur Hostel Jodhpur analysis.

Parameters	Envelope design	Thermal comfort	
	<i>Design strategies</i>	<i>Comfort strategies</i>	<i>Thermal performance</i>
<i>Analysis</i>	The wind tower is strategically designed to capture and channel prevailing winds, facilitating natural ventilation. Its height and shape are optimized to enhance airflow, and the overall layout incorporates cross-ventilation, shaded courtyards, and thermal mass elements. Shading elements like overhangs and Jaali screens minimize solar gain, while the building's orientation and openings maximize natural daylight.	The passive cooling elements, including cross-ventilation, thermal mass, and shading, ensure that internal temperatures remain stable without mechanical cooling. <i>Humidity control:</i> Continuous airflow facilitated by the wind tower helps manage humidity levels naturally, contributing to occupant comfort. <i>Air quality:</i> The design enables regular air exchange, maintaining high indoor air quality and occupant comfort while reducing reliance on air conditioning systems.	The Jodhpur Hostel's wind tower enhances thermal comfort through natural ventilation and evaporative cooling, effectively lowering indoor temperatures in the arid climate. Combined with the building's thermal mass, this passive system reduces the need for mechanical cooling, providing energy-efficient and sustainable temperature control.
<i>Optimal comfort achieved</i>			

Analysis based on identified parameters and their grading for thermal comfort. Analysis by the author, citation given for relevant sources.

Case Study 3: Hive House Surat (Dynamic Envelope)

Hive House Surat Analysis Inference

The Hive House reduces heat transfer and stabilizes the inside temperature by mimicking honeycomb behavior. The honeycomb shape directs airflow through its open cells, generating a passive cooling effect that optimizes the thermal comfort [12] (Tables 15 and 16).

Table 15. Hive House Surat analysis.

Parameters	Biomimicry	Envelope design	
	<i>Biomimicry form/process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>
<i>Analysis</i>	Mimics the form of a honeycomb structure in the elevation design	<i>Envelope design:</i> <i>Double wall façade system.</i> a. <i>Outer layer:</i> Stainless steel dynamic unit b. <i>Middle layer:</i> cavity	The solar sensor-based façade includes adaptive opening mechanisms informed by the sun's path

	rather than in the form.	c. <i>Inner layer</i> : Double-glazed window <i>Materials used</i> : a. Stainless steel (SS): high thermal mass, heat retention	and thermal comfort requirements, creating dynamic shadow patterns (sciography).
<i>Optimal comfort achieved</i>			

Analysis based on identified parameters and their grading for thermal comfort. Analysis by the author, citation given for relevant sources.

Table 16. Jodhpur Hostel Jodhpur analysis.

Parameters	Envelope design	Thermal comfort	
	<i>Design strategies</i>	<i>Comfort strategies</i>	<i>Thermal performance</i>
<i>Analysis</i>	The design is influenced by environmental analysis, incorporating unique mechanisms inspired by functional elements like airport bus doors and a hexagonal diagrid, enhancing airflow and light regulation.	The solar sensor-based façade optimizes thermal comfort and light exposure, while the green roof provides thermal insulation, effectively lowering interior temperatures. The façade minimizes solar heat gain, promoting cross-ventilation, and utilizing thermal mass for stabilizing indoor temperatures.	The thermal performance of a Hive House hinges on a holistic approach that integrates passive design strategies, efficient systems, and smart technologies. By emulating the natural efficiency of a beehive, such structures aim to create comfortable, energy-efficient living spaces with minimal environmental impact.
<i>Optimal comfort achieved</i>			

Analysis based on identified parameters and their grading for thermal comfort. Analysis by the author, citation given for relevant sources.

COMPARATIVE ANALYSIS

Static Façade Comparative Analysis

Key Comfort Contributions

- Biomimicry demonstrates a 10% comfort impact, perhaps improving performance, but it is restricted when applied alone.
- Thermal comfort tactics have a role in producing a more pleasant indoor environment, contributing 20% to total comfort levels, but have limitations in harsh climates.
- Envelope design plays a crucial role in passive and active climate moderation, contributing 25–40% to overall comfort (Figures 25–28).

Table 17. Static façade comparative analysis.

Parameters	Biomimicry	Envelope design			Thermal comfort		Total points
	<i>Biomimicry form/process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>	<i>Design strategies</i>	<i>Comfort strategies</i>	<i>Thermal performance</i>	
Council House 2 (CH2) Building, Melbourne	-Rectangular form	-Concrete -Timber -Steel	-Chilled Ceilings and Underfloor Heating -Radiant Cooling	-Passive ventilation strategies	-Night Purge	-Optimized heat gain -Heat Prevention -Heat dissipation	18

Eastgate Centre Zimbabwe	-Rectangular form -Central atrium	<ul style="list-style-type: none"> • Concrete • Glass 	-Automated Vents -Fan Assist	-Chimneys and Air Stacks	-Passive ventilation strategies -Prickly bodies -heat dissipation	-Optimized heat gain -Heat Prevention -Heat dissipation	16
Lotus Temple, New Delhi	-Semi-circle form -Central dome	-Concrete -Glass -Grecian marble -Galvanized reinforcement	-CAD systems used -Wind tunnel test -In situ concrete casting	-Passive ventilation strategies -Pools assist with passive cooling	-Cross-ventilation and stack effect -Passive cooling and strategic openings	-Optimized heat gain -Heat Prevention -Heat dissipation	12
Jodhpur Hostel, Jodhpur	-Rectangular form -Wind tower	-Concrete -Sandstone -Terracotta	-Traditional construction methods	-Wind tower catches prevailing winds -Cross-ventilation -Jaali minimizes heat gain	-Cross-ventilation -Continuous airflow	-Optimized heat gain -Heat prevention -Heat dissipation	15

Analysis based on identified parameters and their grading for thermal comfort (Table 17). Analysis by the author.

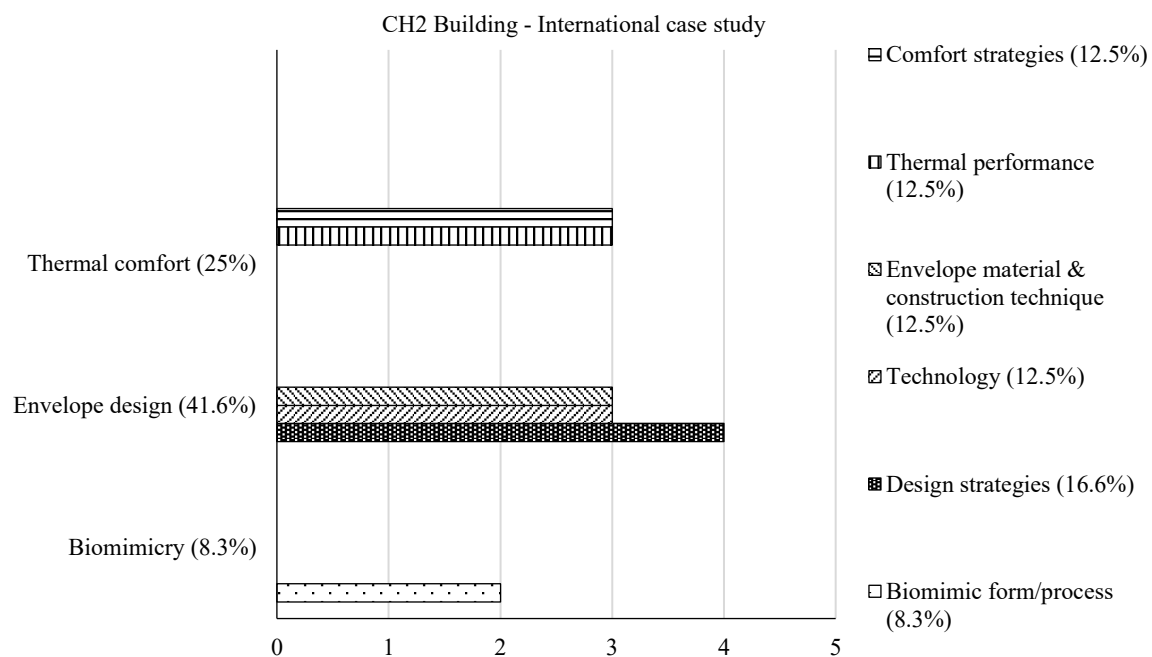


Figure 25. CH2 building—International case study comparative analysis.
 Overall thermal comfort achieved in the CH2 building =74.9%.

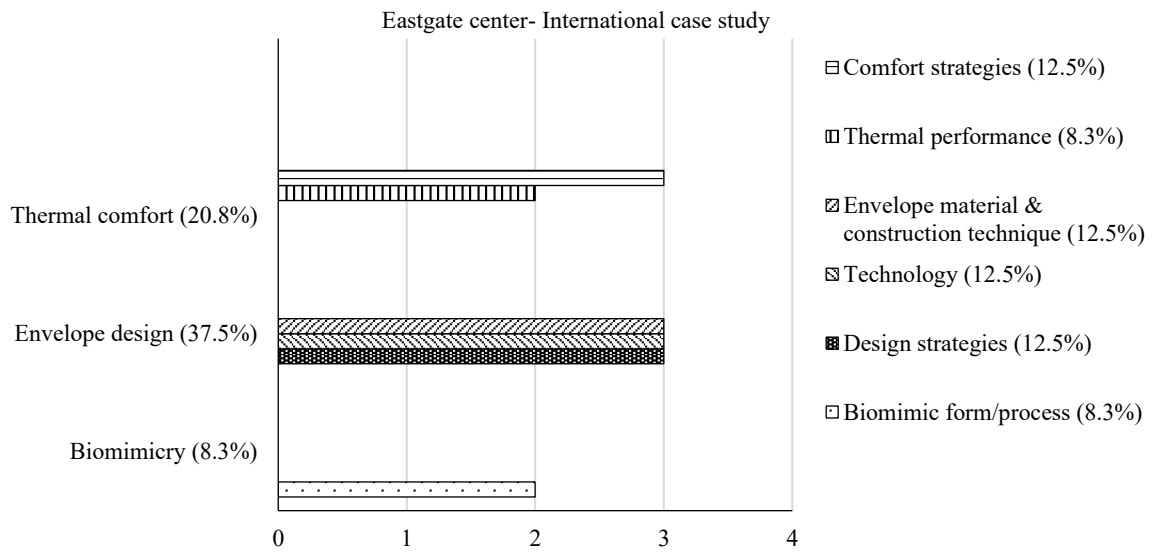


Figure 26. Eastgate Centre—International case study comparative analysis.

Overall thermal comfort achieved in Eastgate Centre = 66.6%

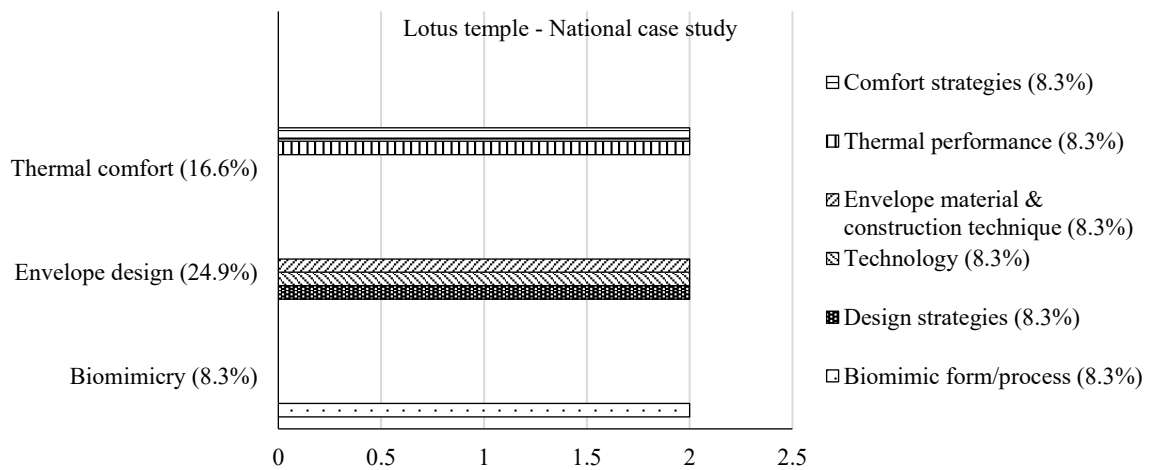


Figure 27. Lotus Temple—National case study comparative analysis.

Overall thermal comfort achieved in the Lotus Temple = 49.8%

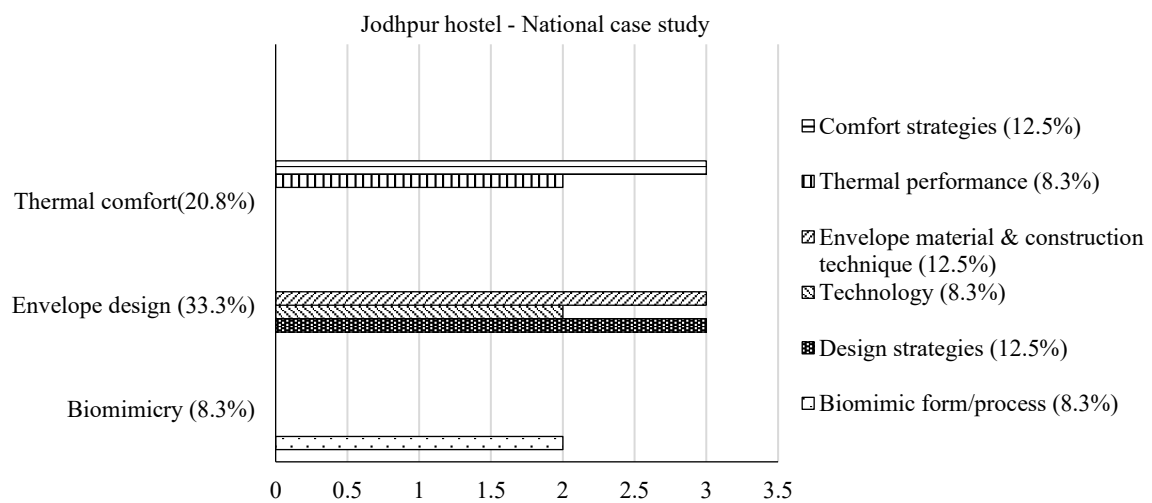


Figure 28. Jodhpur Hostel—National case study comparative analysis.

Overall thermal comfort achieved in Jodhpur Hostel = 62.4%.

Inference

Passive façades offer energy efficiency, cost-effectiveness, and ease of maintenance. In stable or moderate climates, façades with thermal mass, natural ventilation, and reflective or local materials are effective. They also incorporated cultural aesthetics and durable materials, making them suitable for specific environments with stable weather patterns. The inability of static façades to adapt to rapidly changing climates limits their performance under extreme weather conditions. While beneficial in moderate climates, they may require additional mechanical systems for occupant comfort under challenging conditions [13].

Dynamic Façade Comparative Analysis

Key Comfort Contributions

- Biomimicry adds 12% to comfort, somewhat higher than static systems.
- Thermal comfort solutions add 25%, emphasizing their value in dynamic systems.
- Envelope design plays a crucial role in overall comfort and versatility, contributing 37–40%.

Table 18. Dynamic façade comparative analysis.

Parameters	Biomimicry	Envelope design			Thermal comfort		Total points
	<i>Biomimicry form/process</i>	<i>Envelope material and construction technique</i>	<i>Technology</i>	<i>Design strategies</i>	<i>Comfort strategies</i>	<i>Thermal performance</i>	
Media TIC building Barcelona	-Rectangular form	-Steel -ETFE (<i>ethylene tetrafluoroethylene</i>)	-Smart sensors and pneumatic system	-Each façade is tailored for sunlight and wind exposure.	-Adjustable solar factor cushions for dynamic heat gain	-Optimized heat gain -Heat Prevention	17
Al-Bahr Towers, Abu Dhabi	-Rectangular form -Central atrium	-PTFE (<i>polytetrafluoroethylene</i>) -Steel -Glass	-Automated shading system controlled by sun-tracking software	-Movable façade -Self-shading façade	-Oriented to reduce exposure to intense sunlight -Passive solar control strategy	-Night Purge -Optimized heat gain -Heat Prevention -Heat dissipation	19
Hive House, Surat	-V shaper form -Designed considering environmental factors	-Concrete -Brick -Stainless steel	-Solar sensor-based façade -Sciography design	-Hexagonal diagrids -Automation systems	-Solar sensor-based façade optimizes thermal comfort and light exposure	-Optimized heat gain -Heat Prevention -Heat dissipation -Cross-ventilation	17

Analysis based on identified parameters and their grading for thermal comfort. Analysis by the author) (Table 18).

Inference

Dynamic façades offer real-time adaptability and comfort by adapting to weather and seasonal changes, according to comparative studies (Figures 29-31). Dynamic façades boost thermal comfort, minimize energy use, and add aesthetic value to buildings through responsive materials and automated

systems. The cost of flexibility is high. Dynamic façades require advanced technology and specialized materials, resulting in high initial prices, complexity, and continued upkeep. User interactions with automated systems can affect performance; hence, intuitive and user-friendly designs are required [14].

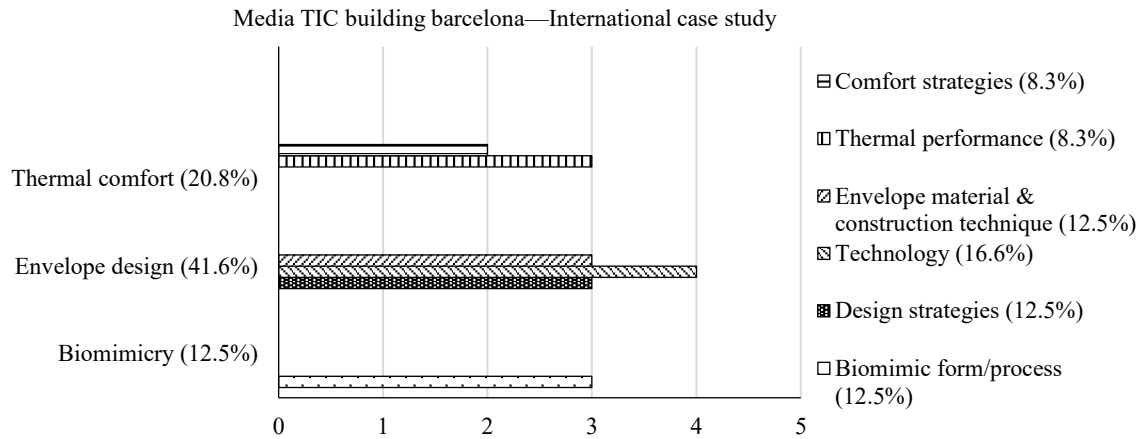


Figure 29. Media TIC building, Barcelona—International case study comparative analysis. Overall thermal comfort achieved in Media TIC building =74.9%.

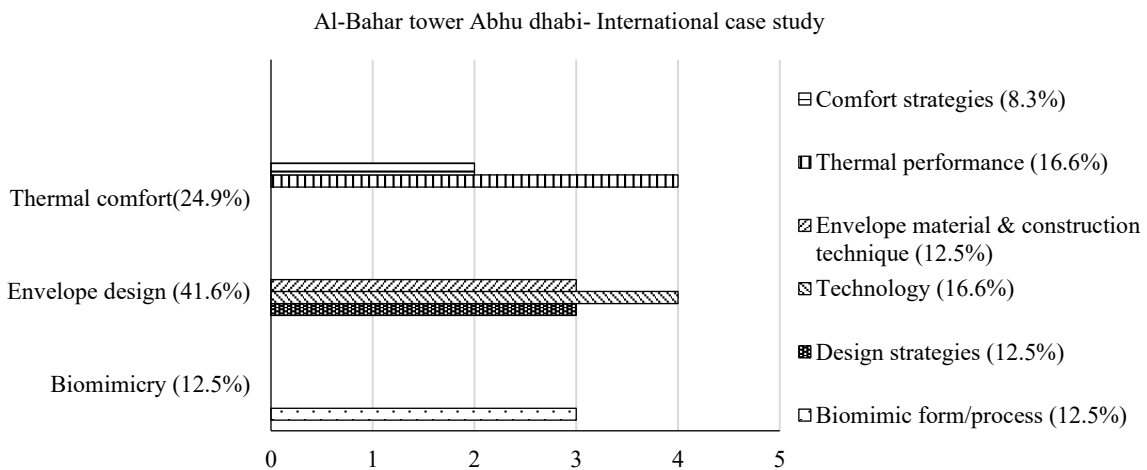


Figure 30. Al-Bahr Towers Abu Dhabi – International case study comparative analysis. Overall thermal comfort achieved in Al-Bahr Towers, Abu Dhabi = 79%.

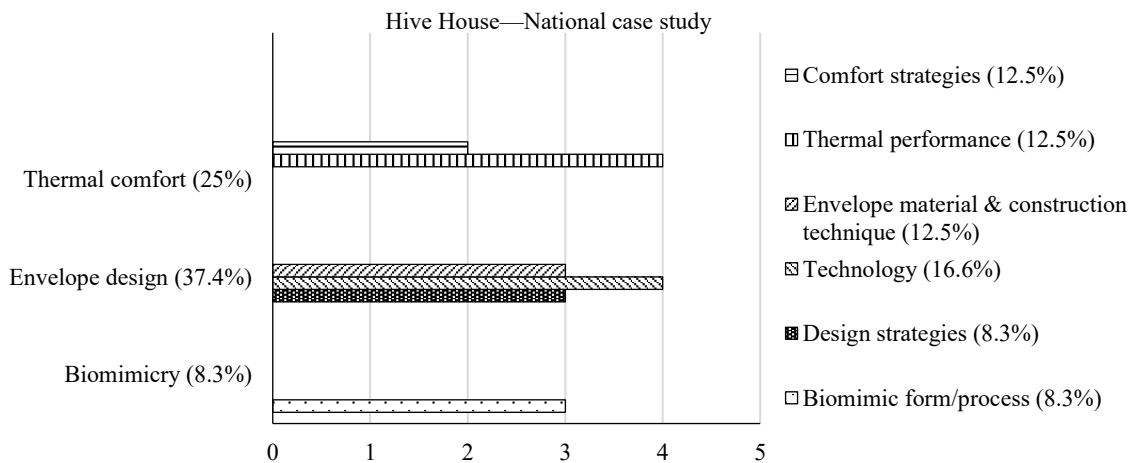


Figure 31. Hive House Surat—National case study comparative analysis. Overall thermal comfort achieved in Hive House = 70.7%.

FRAMEWORK GENERIC

Generic Framework

The generic framework (Table 19) was formulated based on an analysis of the identified parameters and their corresponding grading for thermal comfort, as established through the literature review and case study assessments. This represents a synthesized structure that connects climatic parameters, biomimetic principles, and architectural envelope strategies to achieve enhanced thermal comfort.

Table 19. Generic framework.

Parameters	Temperature range	Humidity	Biomimicry form/process (solution-based approach)	Envelope design	Ventilation strategies	Thermal regulation	Example
Climate							
Temperate Climate	5°C to 25°C	Moderate (50–60%)	<ul style="list-style-type: none"> • Behavior Level on Function • Behavior Level on Process • Organism Level on Construction 	• Retractable or adaptive shading devices	• Cross-ventilation	<ul style="list-style-type: none"> • Heat gain (winter) • Heat prevention (summer) 	CH2 building features operable timber slats.
Mediterranean Climate	10°C to 30°C	Low to moderate (40–60%)	• Behavior Level on Process	• A passive, high thermal mass envelope	• stack ventilation	<ul style="list-style-type: none"> • Heat retention (winter) • Heat prevention (summer) 	Media TIC building features dynamic ETFE cushions.
Tropical Savanna Climate	20°C to 35°C	Moderate to high (50–80%)	<ul style="list-style-type: none"> • Behavior Level on Function • Behavior Level on Process • Organism Level on Construction 	• Multi-layered façades	• Cross and stack ventilation	• Heat dissipation	Eastgate Centre features a double wall system. <i>Outer layer:</i> prickly bodies (high thermal mass layer) <i>Middle layer:</i> cavity with vegetation (air and heat circulation) <i>Inner layer:</i> wall (medium thermal mass) with openings.
Semi-Arid Climate	10°C to 35°C	Low to moderate (20–50%)	<ul style="list-style-type: none"> • Behavior Level on Form • Behavior Level on Process 	• Adaptive, reflective surfaces	• Natural ventilation with adjustable louvers	<ul style="list-style-type: none"> • Heat gain • Heat dissipation 	Tricon Corporate Centre features an adaptive envelope with respect to sun orientation.
Tropical Climate	20°C to 32°C	High (70–90%)	• Behavior Level on Form	• high-performance façades	• airflow-driven cooling strategies	<ul style="list-style-type: none"> • -Heat gain • -Heat dissipation 	Esplanade Theatre features a static envelope design.

							<i>Outer layer:</i> sunshade (triangular aluminium shades) <i>Inner layer:</i> glass (high-performance glass).
Hot and Dry Climate	15°C to 45°C	Very low (10-30%)	<ul style="list-style-type: none"> • Behavior Level on Function • Behavior Level on Process • Organism Level on Construction 	<ul style="list-style-type: none"> • Retractable or adaptive shading devices • Thick walls and thermal mass materials 	<ul style="list-style-type: none"> • Night ventilation and evaporative cooling methods 	<ul style="list-style-type: none"> • Prevent heat gain 	Al Bahar Tower features a dynamic façade with a double wall system. <i>Outer layer:</i> dynamic façade made up of six unit configurations (PTFE) <i>Inner layer:</i> glass (high performance).
Warm and Humid Climate	25°C to 35°C	Very high (80-100%)	<ul style="list-style-type: none"> • Behavior Level on Function • Organism Level on Construction 	<ul style="list-style-type: none"> • Breathable façades 	<ul style="list-style-type: none"> • Air circulation through large openings or perforated screens 	<ul style="list-style-type: none"> • Prevent heat retention 	

Analysis based on identified parameters and their grading for thermal comfort. (Developed by the author) (Table 19).

SPECIFIC PARAMETERS FOR HOT AND DRY CLIMATE IN INDIA

Biomimicry Parameters

The identified parameters and their corresponding biological analogies for hot and dry climatic contexts are summarized in Table 20. Table 20 presents the biomimicry parameters and organisms exhibiting adaptive principles relevant to thermal comfort, structured under the solution-based approach and different levels of biomimicry.

Table 20. Biomimicry parameters.

Biomimicry approach	Solution-based approach		
Levels of biomimicry	Behavior level (process)	Organism level (construction)	Behavior level (function)
	The passive temperature regulation properties of the organism	must mimic the physical properties of the organism, which help in temperature and comfort regulation.	Must mimic the ability to adapt to the environmental stimuli
	(e.g., Cactus' passive temperature regulation by its spores applied in Doha Tower)	(e.g., double wall system inspired by the termite mound's layered construction in Eastgate Centre).	(e.g., butterfly's ability to reflect sunlight and flower adaptiveness in Al Bahar Tower)

PARAMETERS FOR HIGH-RISE STRUCTURES

Envelope Design Parameters

The identified parameters and their corresponding configurations for high-rise structures are summarized in Table 21. Table 21 presents the key design considerations for high-rise building envelopes, emphasizing the spatial organization, façade typology, unit configuration, and integration of responsive technologies. These parameters were derived from simulation-based studies and case-specific analyses that evaluate the performance of dynamic façades in relation to solar exposure and thermal comfort.

Table 21. Envelope design parameters for high-rise structures.

Envelope design for high-rise structures	
The placement and orientation of the dynamic façade is decided by the simulation model; mostly, the Northern façade does not need one, as it receives less solar radiation.	
A. Façade type	Double skin system
	<i>Outer layer:</i> Retractable dynamic façade (adaptive to solar radiation)
	<i>Middle layer:</i> Cavity/buffer space
	<i>Inner layer:</i> Tinted glass curtain wall
B. Size of opening/units	<i>Curtain wall:</i> Floor to floor
	<i>Dynamic façade:</i> <ul style="list-style-type: none"> • Spaced 2 m from the curtain wall surface. • Dynamic façade size: 4m L×4m W
C. Unit configuration	Multiple units combined to work as a whole for better performance and to reduce operational costs.
D. Technology	Solar-based sensors to be used with an overridable system (e.g.: Al Bharas Mashrabiya façade)

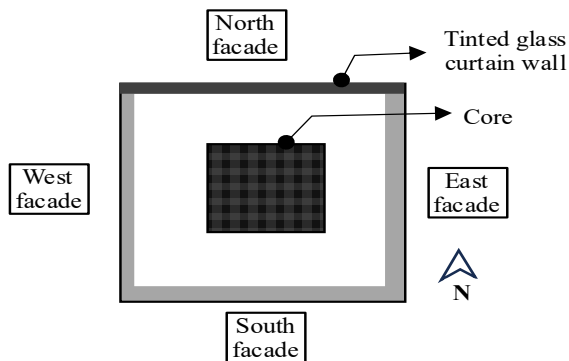


Figure 32. Planning strategies for envelope design for high-rise structures.

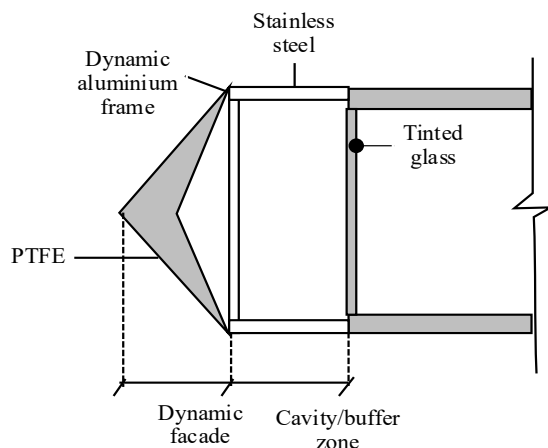


Figure 33. Envelope design for high-rise structures.

Ventilation Strategies for High-Rise Structures

The ventilation strategies identified for high-rise structures are summarized in Table 22. Table 22 outlines the biomimetic and passive approaches inspired by natural ventilation systems, integrating traditional methods with biological analogies to enhance airflow efficiency and thermal comfort in tall buildings (Figures 32 and 33).

Table 22. Ventilation strategies for high-rise structures.

Ventilation Strategies	Install wind towers or chimneys, mimicking termite mound ventilation systems, allowing air exchange through stack effects.
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Thermal Comfort Strategies for High-Rise Structures

The thermal comfort strategies identified for high-rise structures are summarized in Table 23. Table 23 highlights biomimetic approaches, such as night purging and the use of phase-change materials that mimic the termite mound's ability to absorb, store, and gradually release heat, thereby maintaining stable indoor temperatures and enhancing occupant comfort.

Table 23. Ventilation strategies for high-rise structures.

Thermal Comfort Strategies	Night purging and phase-change materials for heat absorption and slow release, similar to termite mound thermal regulation
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PARAMETERS FOR MID-RISE STRUCTURES

Envelope Design Parameters

The identified envelope design parameters for the mid-rise structures are summarized in Table 24. Table 24 presents the integration of both static and dynamic façade systems tailored to specific orientations to optimize thermal comfort and daylight performance. This approach combines adaptive shading with passive thermal control to achieve balanced energy efficiency across different façades.

Table 24. Envelope design parameters for mid-rise structures.

Envelope design for mid-rise structures	
It is a combination of static and dynamic façade systems tailored to specific orientations.	
A. Façade type	<p>North façade</p> <p>a. <i>Façade type</i>: Tinted glass curtain wall</p> <p>b. <i>Size of opening/units</i>: Curtain wall: floor to floor</p> <hr/> <p>East and south façade</p> <p>a. <i>Façade type</i>: Double skin system</p> <ul style="list-style-type: none"> • <i>Outer layer</i>: Adaptive dynamic façade (in response to sunlight and solar radiation) • <i>Middle layer</i>: Cavity/buffer space • <i>Inner layer</i>: Tinted glass curtain wall <p>b. <i>Size of opening/units</i></p> <ul style="list-style-type: none"> • <i>Glass Curtain wall</i>: Floor to floor • <i>Dynamic façade</i>: Spaced 2m from the curtain wall surface. • <i>Dynamic façade Size</i>: 3 m L × 2 m W <hr/> <p>West façade</p> <p>a. <i>Façade type</i>: Plain wall construction with high thermal mass material, and to plan the services and core on this side to act as a thermal buffer.</p> <p>(to note: for regions with west predominant wind directions, the parameters of the East and south façade are applicable)</p>
B. Unit configuration	An individual unit with an adaptive mechanism
C. Technology	Solar-based sensors to be used with an overridable system

Ventilation Strategies for Mid-Rise Structures

The ventilation strategies for the mid-rise structures are summarized in Table 25. Table 25 highlights the use of atrium spaces with adjustable louvers to enable cross-ventilation and enhance passive cooling (Figures 34–36).

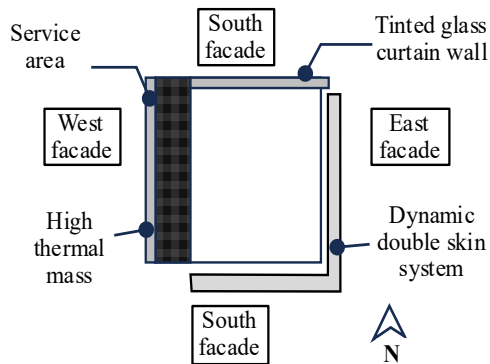


Figure 34. Planning strategies for envelope design for mid-rise structures.

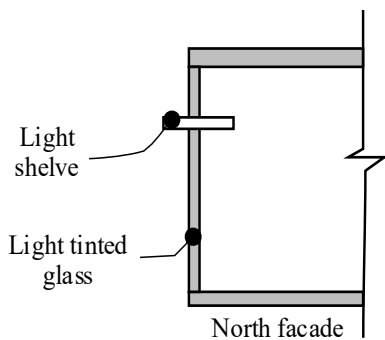


Figure 35. Envelope design for east and south for mid-rise structure.

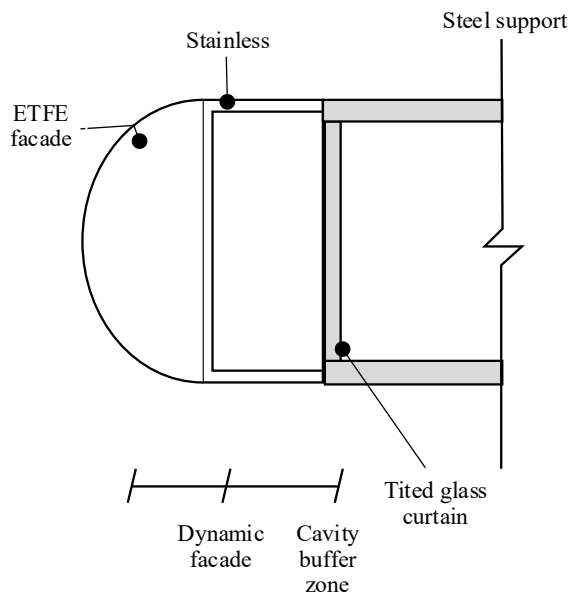


Figure 36. Envelope design for the north for a mid-rise structure.

Table 25. Ventilation strategies for mid-rise structures.

Ventilation Strategies	Implement cross-ventilation through atrium spaces with adjustable louvers to enhance passive cooling.
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Thermal Comfort Strategies for Mid-Rise Structures

The thermal comfort strategies for mid-rise structures are summarized in Table 26. Table 26 highlights the use of adaptive shading devices and self-cooling façades to regulate indoor temperatures and enhance occupant comfort.

Table 26. Ventilation strategies for mid-rise structures.

Thermal Comfort Strategies	Employ adaptive shading devices and self-cooling façades
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PARAMETERS FOR LOW-RISE STRUCTURES

Envelope Design Parameters

The identified envelope design parameters for the low-rise structures are summarized in Table 27. Table 27 presents a combination of static and dynamic façade systems tailored to specific orientations, optimizing thermal comfort, daylight, and energy performance in low-rise buildings.

Table 27. Envelope design parameters for low-rise structures.

Envelope design for low-rise structures It is a combination of static and dynamic façade systems tailored to specific orientations.	
A. Façade type	<p><i>North façade</i></p> <p>a. <i>Façade type:</i> normal window openings</p> <p>b. <i>Size of opening/units:</i> With context to local WWR</p> <hr/> <p><i>East and South Façade</i></p> <p>a. <i>Façade type:</i> double skin system</p> <ul style="list-style-type: none"> • <i>Outer layer:</i> adaptive dynamic façade (in response to sunlight and solar radiation) • <i>Middle layer:</i> cavity/buffer space • <i>Inner layer:</i> windows <p>b. <i>Size of opening/units</i></p> <ul style="list-style-type: none"> • <i>Glass Curtain wall:</i> floor to floor • <i>Dynamic façade:</i> Spaced 0.75 m from the windows • <i>Dynamic façade size:</i> 0.45m L × 0.45m W <hr/> <p><i>West façade</i></p> <p>a. <i>Façade type:</i> plain wall construction with high thermal mass material, and to plan the services and core on this side to act as a thermal buffer. <i>(To note: for regions with predominant west wind directions, the parameters of the East and south façade are applicable)</i></p>
B. Unit configuration	An individual unit with an adaptive mechanism
C. Technology	Solar-based sensors to be used with an overridable system

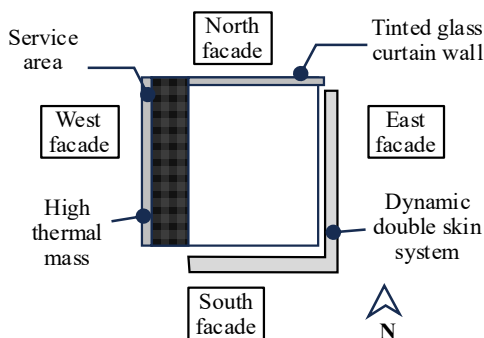


Figure 37. Planning strategies for envelope design for low-rise structures.

Ventilation Strategies for Low-Rise Structures

The ventilation strategies for low-rise structures are summarized in Table 28. Table 28 highlights the use of atrium spaces with adjustable louvers to facilitate cross-ventilation, enhance passive cooling, and reduce the reliance on mechanical systems.

Thermal Comfort Strategies for Low-Rise Structures

The thermal comfort strategies for low-rise structures are summarized in Table 29. Table 29 highlights the use of adaptive shading devices and self-cooling façades to regulate indoor temperatures and enhance occupant comfort.

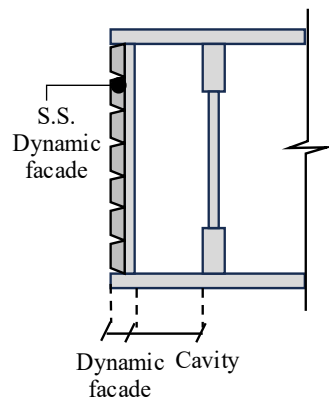


Figure 38. Envelope design for a low-rise structure.

Table 28. Ventilation strategies for low-rise structures.

Ventilation Strategies	Implement cross-ventilation through atrium spaces with adjustable louvers to enhance passive cooling.
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Table 29. Ventilation strategies for low-rise structures.

Thermal comfort strategies	Employ adaptive shading devices and self-cooling façades
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Materials

The materials used for the building envelope are summarized in Table 30. Table 30 highlights the structural, supporting, and façade materials along with their key properties, including strength, durability, thermal mass, transparency, and flexibility, enabling efficient thermal performance and low maintenance operation (Figures 37 and 38).

Table 30. Materials.

Envelope component	Materials	Properties
Structure	Concrete, brick	<ul style="list-style-type: none"> Compressive Strength Durability and Longevity High Thermal Mass
Supporting frames	Stainless steel	<ul style="list-style-type: none"> High strength and structural integrity Corrosion resistance Rigidity and stability Thermal resistance Longevity and low maintenance
Dynamic frames	Aluminium	<ul style="list-style-type: none"> Lightweight strength Corrosion resistance Ease of fabrication and maintenance
Façade material	PTFE (Polytetrafluoroethylene) is a synthetic fluoropolymer that's made up of carbon and fluorine	<ul style="list-style-type: none"> Non-stick Hydrophobic High density Resistant to high temperatures
	ETFE (Ethylene Tetrafluoroethylene) is a lightweight, durable, and highly versatile material	<ul style="list-style-type: none"> Lightweight High transparency and light transmission Thermal insulation Durability and resistance to weathering Self-cleaning surface Elasticity and flexibility High tensile strength

CONCLUSION

This research fills a gap by exploring how biomimetic design might develop building façades that organically adapt to their surroundings and improve thermal comfort in India's urban spaces. This study provides a realistic framework to help architects construct climate-responsive, nature-inspired building envelopes, unlike previous studies that have focused on individual biomimetic characteristics. It details the procedures, façade design, and materials for hot and dry locations to manage excessive heat and low humidity.

Declaration of Interest

Conflict of interest: The authors declare that they have no conflict of interest.

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