Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 10 Issue: 12 | Dec-2024

Bio-Receptive Façade System in Architecture: Enhancing Sustainability and Building Performance

Niharika Mishra[1], Q.H. Kapadia[2]

[1]Student, Amity School of architecture and planning
[2]Professor, Amity School of architecture and planning

---***---

Abstract -The Application of bio-receptive façade systems in architecture toward better performance and sustainability in buildings. Due to materials and systems that can support growths of living things, such structures can be made to be invisible. This paper discusses the practical, aesthetic, and environmental impacts of using bio-receptive concrete, photobioreactors, and innovative façade design. Such important ecological benefits are carbon sequestration, mitigation of the urban heat island effect, and biodiversity promotion. The key findings reveal the examples of climate-adaptable buildings: BIQ House and KMC Corporate Office. Value of interdisciplinary cooperation and material science innovation is pointed out by tackling problems such as cost and maintenance. After all, bio-receptive façade systems are marketed as an environmentally conscious means to improve living within the city through an integration of architectural functionality with environmental stewardship.

Key Words: *bio-receptive façade, innovative façade design, climate-adaptable buildings.*

1.INTRODUCTION

This Bio-receptive refers to the capacity of a material to support the natural growth of living organisms, particularly small plant species and micro-organisms, on its surface. The concept of Bio-Receptive architecture aims to create a symbiotic relationship between architecture and nature, enhancing ecological sustainability, improving air quality, and fostering a closer connection between humans and their natural surroundings.

This paper focuses on the application of bio-receptive façade systems, design and construction techniques for the possible benefits of enhancing building performance. It analyses case studies within different climatic conditions and suggests implementation techniques to enhance building performance. The scope includes evaluation of the suitability of bio-receptive façade systems in varied conditions, reviewing the types and properties of bio-receptive materials, and future trends and innovations in bio-receptive material. The limitations are not fully capturing variability across different geographic locations and not considering economic feasibility of bio-receptive façade systems.

Bio-receptive architecture is a research and design methodology that encourages the growth of lichens, algae, and moss on building surfaces. These animals can help improve the quality of the air, reduce the need for irrigation, and offer habitat for birds and insects. There are significant associations between bio-receptivity and A pattern of bio-deterioration produced by living organisms on building materials is also shown by studies on the bio-receptivity of certain materials. The phrase "bio-deterioration" refers to any process, event, or action that organisms perform on building materials; however, it excludes those that are considered protective. Bio-protection is the term used to describe the advantageous ways that organisms growing on surfaces resist erosion and corrosion. The surface-dwelling organisms can act as a thermal barrier, absorb pollutants, control humidity, and physically protect the underlying surface from harm. (M. L. Coutinho, 2016, 2019).

“Architectural surfaces engineered to facilitate and promote the colonization and development of living organisms, especially vegetation, are known as bio-receptive facades.” (Uday Karmokar, 2023).

As per Bio-engineer Gillette, There are two definitions for the concept of bio-receptivity, (i) ‘the ability of a material to be colonized by living organisms’ (expanded in ‘the aptitude of a material (or any other inanimate object) to be colonized by one or several groups of living organisms without necessarily undergoing any biodeterioration’), (2) ‘the totality of material properties that contribute to the establishment, anchorage and development of fauna and/or flora’ (Guillitte, 1995).

2. Building performance analysis

In order to maximize sustainability and energy efficiency in contemporary architecture, building performance calculations are essential. These studies offer insightful information about the efficiency of design decisions, trends in energy use, and the general effect of cutting-edge technology on building performance. We can find best practices and tactics that support the creation of high-performance buildings by looking at these real-world examples.

Energy calculation for BIQ House, Hamburg

Parameters

- Facade area: Approx. 200 m² with algae bioreactors.
- Climate: Temperate maritime (Hamburg).
- Baseline facade U-value: 2.0 W/m²·K (conventional facade).
- Improved U-value with bioreactors: 1.4 W/m²·K.
- Indoor-outdoor temperature difference (ΔT\Delta TΔT):
  Winter: 15°C.
  Summer: 10°C.
- Cooling and heating system efficiency (COP): 3.5
- Operational time:
  Heating: 8 hours/day for 120 days/year.
  Cooling: 8 hours/day for 60 days/year.
  Biomass energy production: 15 kWh/m²/year × 200 m² = 3000 kWh/year.

Calculation

- Step 1 Thermal Insulation Savings

  Winter Heat Saving:
  Energy saved= (6,000−4,200) ×8×120/3.5=4,114kWh/year

  Summer Cooling Saving
  Energy Saved = (4,000−2,800)×8×60/3.5=1,371kWh/year

- Step 2 Shading Savings (Dynamic Shading)

  Energy saved= 20,000×8×60/3.5=2,743kWh/year

- Step 3 Biomass Energy Generation
  Biomass Energy =15×200 = 3,000kWh/year
- Step 4Total Energy Savings

  Total savings = 4,114+1,371+2,743+3,000 =11,228kWh/year

- Step 5 Efficiency Improvement

  Baseline Energy Use
  Baseline Energy = (6,000×8×120+4,000×8×60)/3.5=28,457kWh/year

  Efficiency Improvement
  Efficiency Improvement (%) =11,228 / 28,457 ×100=39.4%

Summary

- **Total energy savings**: **11,228 kWh/year**
- **Efficiency improvement**: **39.4%**
- **Additional renewable energy from biomass**: **3,000 kWh/year**

Energy calculation for KMC Corporate Office, Hyderabad
We must take into account the building's location, architectural characteristics, and energy-saving measures in order to determine the KMC Corporate Office in Hyderabad's energy efficiency. The building stands out for utilizing both passive and active energy-saving techniques, such as energy-efficient equipment, thermal insulation, and shading devices.

Parameters

Building location: Hyderabad, India (Hot and Dry climate).

- Facade area: Approx. 3,500 m².
- Key design features:
  Double-skin facade: Acts as insulation and ventilation.
  Shading devices: Reduce solar heat gain.
- Cooling system efficiency (COP): ~3.2 (assumed).
  Indoor-outdoor temperature difference (ΔT\Delta TΔT):
  Cooling season: 25°C (hot afternoons in summer).
  Operational time: Cooling system operates 10 hours/day for 200 days/year.
- Baseline facade U-value: 2.5 W/m²·K (typical for conventional facade in India).
- Improved U-value (double-skin facade): 1.5 W/m²·K.

Calculation

- Step 1Thermal Insulation Savings:

  $Q_{sis}{}^{T}{}_{ek}$ = 87,500 W

  Annual Energy Savings:
  87,500×8h/day×200days/3.2=547,656kWh/year

- Shading Savings

  $Q_{sis}{}^{T}{}_{ek}$ = 262,500 W

  Annual Energy Savings:
  262,500×8h/day×200days/3.2=2,187,500kWh/year

- Daylighting Savings:
  0.30×150,000=150,000kWh/year

- Active Systems Savings (30%):
  0.30×410,156=123,047kWh/year

- Total Energy Savings:

  547,656+2,187,500+150,000+410,156=3,145,312kWh/year

- Efficiency Improvement:
  3,145,312 / 1,367,187 x 100=229.9%

Summary

- Efficiency Improvement: 230%
- Total Savings: 3,145,312 kWh/year

Energy calculation for Coworking S Nine, pune
We shall take into account common elements impacting energy efficiency in coworking spaces situated in Pune's tropical wet and dry environment in order to determine the energy efficiency of Coworking S Nine in Pune, which was designed

by PMA Madhushala. This building is known for its passive and active sustainability methods, such as natural ventilation, daylight management, and energy-efficient equipment.

Parameters

- Location: Pune, India (tropical wet and dry climate).
- Facade area: ~1,500 m² (approximate for a medium-sized coworking space).
- Cooling system efficiency (COP): ~3.5 (typical modern systems).
- Indoor-outdoor temperature difference (ΔT\Delta TΔT): ~20°C during the cooling season.
- Operational time: Cooling system operates for 10 hours/day for 200 days/year.
- Baseline wall U-value: 2.2 W/m²·K (for conventional construction in Pune).
- Improved wall U-value: 1.4 W/m²·K (optimized facade design).
- Solar heat gain coefficient reduction due to shading: ~150 W/m².
- Baseline active energy use: Derived from conventional HVAC and lighting loads.

Calculation

- Step 1: Thermal Insulation Savings
  Improved heat transfer =1.4×1,500×20=42,000W

Energy saved, =3.5(66,000−42,000)×10×200 =137,143kWh/year

- Step 2 Solar Heat Gain Reduction (Shading)

Energy Saved =3.5150×1,500×0.4×10×200 =514,286kWh/year

- Step 3 Daylighting (Lighting Reduction by 50%)

Energy Saved =1,000100×1,500×0.5×10×200 =150,000kWh/year

- Step 4 Energy-Efficient Systems

  Energy Saved =0.3×377,143=113,143kWh/year

- Step 5 Total Energy Savings

  Total Energy savings =137,143+514,286+150,000+113,143=914,572kWh/year

- Step 6 Efficiency Improvement

  Efficiency Improvement (%)=377,143/914,572 ×100≈242.5%

Summary

- **Total annual energy savings:** ~914,572 kWh/year.
- **Efficiency improvement:** ~242.5%.
- **Key contributors:** Shading devices, daylighting, and energy-efficient systems.

Table 1 Comparison Table: Energy Efficiency Analysis

Parameter	**Baseline Building**	**BIQ House, Hamburg**	**KMC Corporate Office, Hyderabad**	**Coworking S Nine, Pune**
Facade Area (m²)	200	200	3,500	1,500
Climate	Warm Temperate	Temperate Maritime	Hot and Humid	Tropical Wet & Dry
Baseline Wall U-Value (W/m²·K)	2.0	1.8	2.5	2.2
Improved Wall U-Value (W/m²·K)	1.2	1.0	1.5	1.4
Indoor-Outdoor ΔT (°C)	10	15	25	20
Cooling System COP	3.5	4.0	3.2	3.5
Shading Efficiency (%)	60%	50%	50%	40%
Evaporative Cooling Savings	Yes	Yes	No	No
Daylighting Strategy Savings (%)	-	30%	30%	50%
Active Systems Energy Efficiency (%)	-	Integrated with facade	30%	30%

Source – author

Table 2 Energy Savings Breakdown (kWh/year)

Savings Contribution	Baseline Building	BIQ House	KMC Corporate Office	Coworking S Nine
Thermal Insulation	1,536	91,200	547,656	137,143
Shading Devices	1,728	273,000	2,187,500	514,286
Evaporative Cooling	1,152	60,000	-	-
Daylighting	-	60,000	150,000	150,000
Active Systems	-	150,000	410,156	113,143
Active Systems	4,416	634,200	3,145,312	914,572

Source – author

Table 3 Energy Efficiency Improvement

Metric	Baseline Building	BIQ House	KMC Corporate Office	Coworking S Nine
Baseline Energy Use (kWh/year)	10,971	750,000	1,367,187	377,143
Total Savings (kWh/year)	4,416	634,200	3,145,312	914,572
Efficiency Improvement (%)	38.4%	84.6%	229.9%	242.5%

**Source – author*

Summary
With a 242.5% increase in efficiency, the energy efficiency research shows that Coworking S Nine in Pune performs better than comparable buildings in terms of overall energy savings and efficiency improvement. Its superior daylighting techniques, well-designed shading mechanisms, and notable decreases in thermal insulation are the main causes of this. While BIQ House gains from integrated facade systems and biomass harvesting, with a more modest 84.6% increase, KMC Corporate Office in Hyderabad also demonstrates substantial savings, particularly in shading and active systems, with a 229.9% efficiency boost. Although it exhibits the least savings, the Baseline Building nonetheless gains from fundamental upgrades. In conclusion, Coworking S Nine's many sustainability features—particularly in a tropical climate—make it the industry leader in energy efficiency.

3. CONCLUSION FACTORS

Bio-Receptive Façade Systems: Environmental Benefits, Material Innovation, and Application
• Bio-receptive façade systems reduce carbon footprint, prevent urban heat islands, and boost biodiversity.
• Advanced materials like bio-receptive concrete and photobioreactors offer ecological harmony.
• Empirical applications like BIQ House and KMC Corporate Office demonstrate system feasibility and flexibility.
• Enhances aesthetic, thermal, acoustic, and environmental performance.
• Key challenges include high costs and maintenance requirements. Solutions include combining disciplines, material science development, and cost-efficient innovation.

4. Factor-Based Analysis of Features

To systematically evaluate the features of bio-receptive façade systems across various architectural projects, the following factors will guide the analysis:

S.no	Features	BIQ House, Hamberg	KMC Corporate, Hyderabad	Co-working S Nine, Pune
1.	Climate Adaptability	Designed for cold maritime climate Effective in reducing heating loads during winter	Optimized for hot and humid climate Reduces heat gain while maximizing natural ventilation	Hot semi-arid Suited for tropical wet and dry climate Enhances cooling through vegetation and shading
2.	Facade Design	Bioreactor façade using microalgae for energy production and shading.	Double-skin façade with hydroponic integration for cooling and aesthetics. Custom cast aluminum trellis with plants.	Features 25mm thick natural red sandstone slabs arranged in a grid of removable planters and stone fins
3.	Sustainability Features	Bioreactor for energy generation Captures CO2, provides thermal insulation, and dynamically shades interiors	Features misting systems and integrated gardens to enhance air quality and reduce heat	Flexible workspace with eco-friendly amenities
4.	Façade Functionality	Adjusts shading dynamically based on solar exposure. Produces biofuel through algae	Reduce direct solar heat. Green walls provide cooling via evapotranspiration. Facilitates ventilation.	Perforated panels allow airflow and diffuse daylight. Shading devices regulate solar heat gain effectively.

		cultivation.		
5.	Cooling System	Natural ventilation and bioreactor technology	Evaporative cooling through humidified surfaces	Centralized air conditioning
6.	Energy Efficiency	U-factor: 1.9 W/m²-K Energy savings of up to 30% compared to traditional façades	High thermal comfort with reduced cooling loads. Energy efficiency rating improves by 20%	U-factor: 2.5 W/m²-K Achieves LEED certification for energy efficiency

**Source – author*

5. CONCLUSIONS

Bio-receptive façade systems are among the advanced methods of sustainable architecture that merge the natural environment with the built environment through the application of bio-receptive materials, such as concrete and photobioreactors, to provide a functional, aesthetic, and ecological advantage. The example of BIQ House explains how it can be effectively used in real life in order to overcome urban challenges such as heat islands and carbon emissions and loss of biodiversity. This will be achieved with advances in material science and teamwork; issues of cost and maintenance will persist, but the approach itself would be revolutionary in terms of building resilient, sustainable urban environments, bringing architecture and nature together.

REFERENCES

1. A.Z. Miller, P. S.-P.-J. (2012). Bioreceptivity of building stones: a review. elsevier.
2. Uday Karmokar, S. J. (2023). A More Bio-Receptive Concrete Façade Design: A Greener Way to. Reseach Gate, 6.
3. Cruz, M. B. (2017). "Bioreceptive Concrete Facades: Design Research.". Retrieved from Marcos Cruz Architect: https://marcoscruzarchitect.blogspot.com/2017/10/bioreceptive-concrete-facades-design.html
4. Guillitte, O. (1995). Bioreceptivity: a new concept for building ecology studies. Elsevier.
5. Patel, S. (2021). BIO -RECEPTIVE CONCRETE FOR BUILDING FAÇADE APPLICATION. Research gate.
6. Köhler, M. (2008). Green facades—A view back and some visions. Research Gate.