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IMPACT OF ADAPTIVE BIOMIMETIC BUILDING SKINS ON INDOOR THERMAL COMFORT: A COMPUTATIONAL EVALUATION

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Abstract

Introduction. Recent advances in computational design have transformed architectural facades from static envelopes into dynamic systems capable of adapting to environmental conditions in order to enhance thermal comfort and energy efficiency. **Purpose of the study**. This study aims to evaluate the thermal performance of an adaptive biomimetic building skin (ABBS), inspired by plant thermoregulation mechanisms, applied to a typical residential building located in Guelma, Algeria, which is characterized by a hot Mediterranean climate. **Methods**. Following the thermal validation of a base model, the research integrated two complementary approaches: a problem-driven biomimetic strategy to define the morphology and kinetic behavior of facade modules, and a parametric simulation workflow developed in Rhino Grasshopper, coupled with the Ladybug and Honeybee plugins for environmental and energy analysis. The ABBS was tested under five aperture configurations (−30° to +30°) across east, south, and west orientations during representative summer and winter periods, based on the ASHRAE Standard 55 adaptive comfort model**. Results.** The results demonstrate that the best-performing scenarios achieved up to a 17.7 % reduction in overheating hours during summer and up to a 22 % improvement in thermal comfort during winter through enhanced passive solar gains**.** This study confirms the potential of bio-inspired responsive facades to optimize indoor thermal conditions and highlights the effectiveness of computational biomimicry as a pathway toward climate-adaptive and energy-efficient architectural envelopes contributing to sustainable building design.

Keywords: biomimicry; adaptive building skins; computational design; parametric simulation; thermal comfort.

Introduction

In the context of climate change and the urgency of energy transition, the building sector plays a pivotal role, accounting for approximately 30 % of global energy consumption and 26 % of greenhouse gas emissions (International Energy Agency, 2023). Nearly 60 % of this energy is allocated to heating and cooling systems (Al-Obaidi et al., 2017) to ensure adequate thermal comfort (Betman et al., 2024). Consequently, reducing this demand has become a strategic priority for achieving carbon neutrality by 2050 (Sommese et al., 2022). The building envelope, particularly glazed surfaces, offers significant potential for optimization (Öztürk et al., 2024), as it can account for up to 60 % of a building's total thermal gains and losses (Kheybari et al., 2025). In continuous interaction with dynamic environmental factors such as solar radiation and outdoor air temperature (Tabadkani et al., 2021), the envelope strongly influences heat transfer processes, thereby affecting occupants' thermal comfort (Abbaas et al., 2023). In response to these challenges, the capacity of the building envelope to adapt to fluctuating climatic conditions has become a key strategy for enhancing overall building performance. In this context, dynamic facades have emerged as innovative technological solutions capable of adjusting their thermal, optical, and morphological properties in real time in response to climatic conditions, solar exposure, or seasonal variations (Hosseini et al., 2021). These responsive systems offer an effective solution to the growing demands for sustainability and occupant comfort (Elhennawi and Sameh, 2025). Goharian et al. (2025) classify adaptive facades into several categories, ranging from passive systems based on orientation strategies or intrinsic material properties, to active, intelligent, and kinetic solutions that integrate movable elements and real-time control technologies. These approaches are further expanded by interactive or switchable facades capable of modifying their physical or optical behavior directly in response to environmental stimuli. Among these strategies, biomimetic facades are particularly noteworthy for their ability to emulate adaptive mechanisms found in nature. By translating biological responses into architectural systems, biomimetic design enables the development of responsive, autonomous, and energy-efficient building envelopes aligned with contemporary requirements for sustainability and thermal comfort. Nature, particularly plants, offers a wide range of adaptive strategies for responding to environmental fluctuations (Bijari et al., 2025). Despite their immobility, similar to buildings, plants have evolved mechanisms to react to external stimuli such as light, temperature, and humidity (Sheikh and Asghar, 2019). These responses often manifest as movements in specific organs, including leaves, stems, or petals. Plant movements are generally classified into two main types: tropisms, which are directional responses, and nastic movements, which are non-directional (Shahin et al., 2023). In particular, temperature variations can induce thermotropic and thermonastic behaviors, which serve as valuable natural models for dynamic adaptation in architectural applications.

These natural mechanisms have become a fundamental source of inspiration for the development of dynamic biomimetic envelopes capable of reconfiguring themselves in response to ambient thermal conditions, thereby improving both energy efficiency and occupant comfort (Saci Hadef et al., 2025). The advancement of computational design understood as the use of algorithmic and parametric tools to generate, simulate, and optimize architectural forms and behaviors has been instrumental in translating these biological strategies into architectural applications. In particular, parametric modeling environments such as Grasshopper enable the simulation and iterative refinement of complex adaptive behaviors with a high degree of precision (Maksoud et al., 2023). When coupled with the integration of smart materials responsive to environmental inputs, computational tools facilitate the design of low-energy systems that dynamically react to changing conditions (Brzezicki 2024a; Sommese et al., 2024). This synergy between biology, algorithmic design, and materials science has given rise to a new generation of responsive architectural skins that align energy performance with enhanced indoor comfort (Altameemi and Jabbar, 2025; Soliman and Bo, 2023).

Numerous studies, including those by Hadbaoui (2018), Khelil et al. (2020), Kuru et al. (2018), Mohamed Abd El-Rahman et al. (2020), and Soliman and Bo (2023), demonstrated the effectiveness of adaptive biomimetic envelopes in improving building thermal comfort. Drawing on plant-based thermoregulatory mechanisms and developed through computational design workflows particularly parametric platforms that enable the rapid generation, simulation, and optimization of multiple facade configurations these studies have produced responsive systems capable of modulating indoor conditions by reducing indoor temperatures and shortening periods of thermal discomfort across a wide range of climatic contexts.

These findings highlight the relevance of computational design in emulating the complex adaptive behaviors observed in the plant kingdom, thereby providing a robust foundation for the development of durable, high-performance, and responsive building envelopes. Nevertheless, two major gaps remain. First, most existing research focuses on office or commercial buildings, largely overlooking the residential sector, despite its significant share in global energy consumption. In Algeria, the residential sector is considered the most energy-intensive, accounting for 43 % of total national energy use (APRUE, 2019). Second, the majority of studies primarily address hot-arid climates, leaving warm Mediterranean climates (Csa) largely unexplored in biomimetic approaches to indoor thermal comfort.

The present study seeks to address these gaps by applying a computational biomimetic approach to residential buildings located within this climatic context. To this end, an adaptive biomimetic facade inspired by the morphological and behavioral adaptation mechanisms of the Heavenly Blue flower (*Ipomoea tricolor*) is proposed. The prototype is applied to a residential building situated in Guelma, Algeria, representative of a hot Mediterranean climate (Csa) (Fig. 1), a context that remains underexplored in current biomimetic research. Leveraging a parametric design workflow developed in Rhino Grasshopper, the proposed kinetic facade is designed and simulated to modulate its aperture in response to solar orientation and seasonal variations. Performance is evaluated through thermal simulations based on the adaptive comfort model defined by the ASHRAE Standard 55, with a particular focus on reducing thermal discomfort hours in order to lower heating and cooling energy demands. By extending biomimetic strategies to the residential sector, this work aims to deliver an architectural solution that integrates energy efficiency, indoor thermal comfort, and ecological innovation, thereby contributing to the broader objectives of energy transition and sustainable development.

Methods

To achieve the objectives of this research, a structured, multi-phase methodology was developed to assess the thermal performance of the proposed adaptive biomimetic facade system. The process begins with a climatic characterization of the

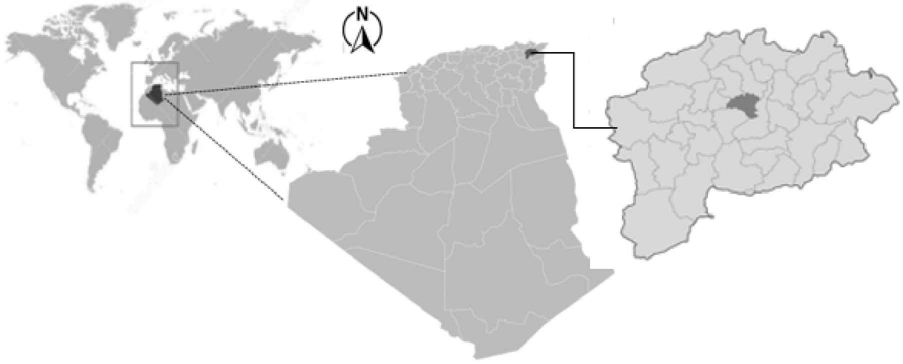

Fig. 1. Geographic location of the study area in Guelma, northeastern Algeria

study site, followed by a detailed description of the case study building. On-site measurements are then conducted to calibrate and validate a baseline thermal model. Subsequently, a biomimetic design approach is applied to develop the adaptive facade prototype. Finally, dynamic thermal simulations are performed to evaluate and compare the performance of the proposed solution with that of the existing envelope under both summer and winter conditions.

Climate Analysis

According to the Köppen Geiger climate classification, Guelma (northeastern Algeria) is characterized by a hot Mediterranean climate (Csa), defined by dry summers and cold, humid winters. Solar path diagrams (Figs. 2 and 3), generated for this location using the Climate Consultant software and based on the adaptive comfort model from the California Energy Code 2013, indicate that during the summer period, 1,385 hours per year require external shading, whereas 260 hours benefit from direct solar gains to maintain indoor comfort. In winter, this pattern is reversed: 1,096 hours require solar gains, while 566 hours demand shading when outdoor temperatures exceed 27°C. These results highlight the necessity of balancing effective solar protection during summer with optimal solar access in winter.

Case Study Description

The space under investigation is a room located on the third floor of a typical residential building in the “19 Juin” residential area, southeast of Guelma (36°45′18.67″ N, 7°42′74.09″ E). Positioned at an intermediate level, as shown in Fig. 4, in order to limit thermal gains from both the roof and the ground, the space measures 5.20 × 5.75 m with a ceiling height of 3.06 m. Oriented due east, it is fitted with a 3.00 × 1.60 m window, resulting in a window-to-wall ratio (WWR) of 30 %. Such a ratio is considered relatively high, increasing the risk of summer overheating as well as winter heat losses.

Validation Model

To validate the simulation model, a real residential living room was selected as the case study. On-site measurements were conducted on January 23 and July 25, representing extreme winter and summer conditions, respectively (Figs. 4 and 5).

Temperature data were collected at two-hour intervals from 8:00 a.m. to 6:00 p.m. using a Hanna HI991003 digital thermometer positioned 1 m above

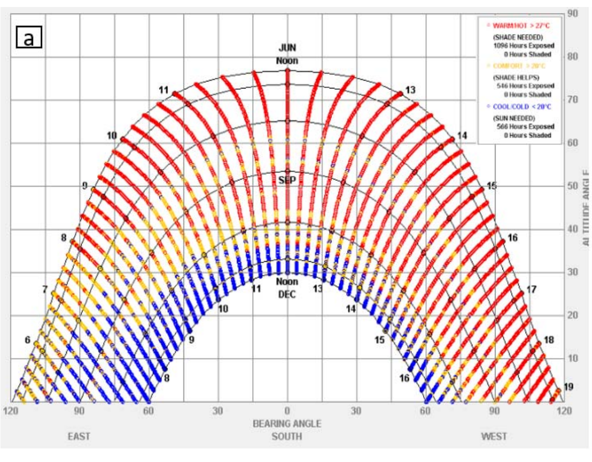

Fig. 2. Solar path diagrams for the city of Guelma, summer solstice

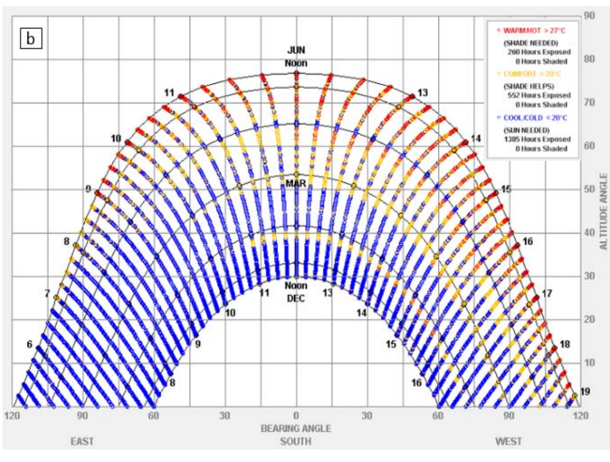

Fig. 3. Solar path diagrams for the city of Guelma, winter solstice

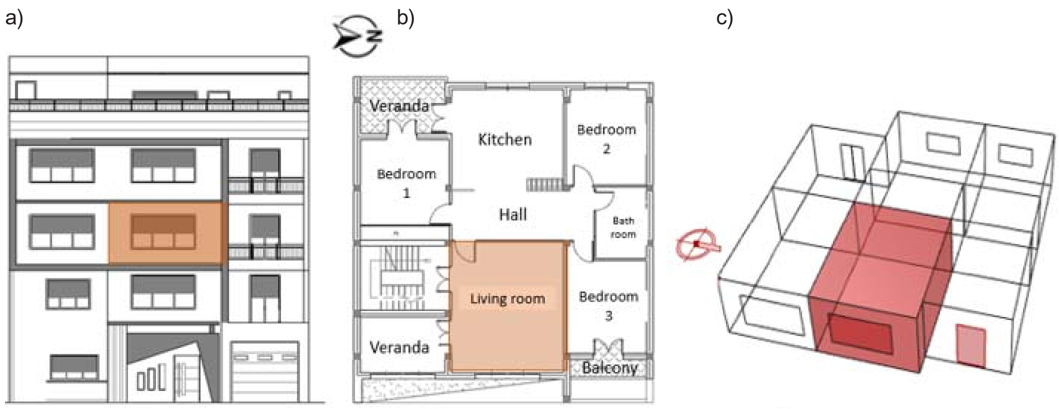

Fig. 4. Case study room: (a) facade view, (b) floor plan (scale 1:50), and (c) 3D perspective

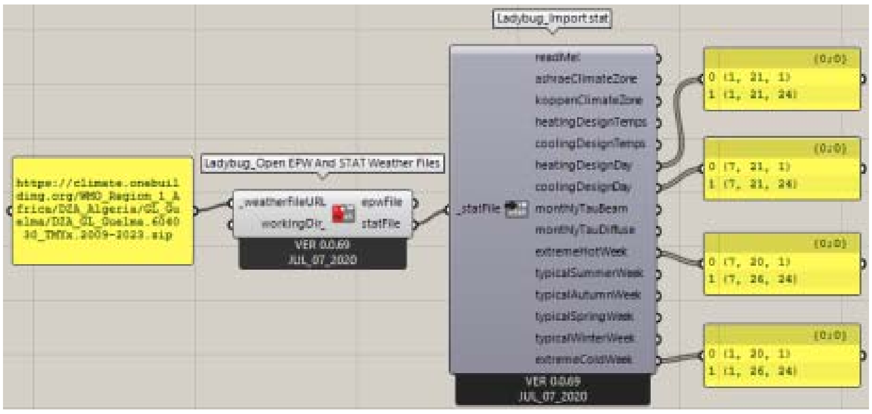

Fig. 5. Grasshopper parametric script used to identify representative days and extreme seasonal weeks for the climatic analysis of Guelma

the floor, in accordance with ASHRAE Guideline 14 (Chaturvedi et al., 2024). To ensure data reliability, indoor conditions were kept stable throughout the monitoring period: the HVAC system, lighting, and electrical appliances were turned off; the space remained unoccupied; and all doors, windows, and shading devices were controlled to eliminate internal and external heat gains. The resulting distribution of simulated operative temperatures is presented in Fig. 6.

To assess the accuracy of the simulation model, two statistical performance indicators were calculated: the mean bias error (MBE) and the coefficient of variation of the root mean square error (CV (RMSE)), using the following ASHRAE formulas:

$$MBE = \frac{\sum_{i=1}^{n}(Mi - Si)}{\sum_{i=1}^{n} Mi}; \quad (1)$$

$$CV(RMSE) = \frac{1}{\bar{y}}\sqrt{\frac{\sum_{i=1}^{n}(Mi - Si)^2}{n}}, \quad (2)$$

where *Mi* is the measured value, *Si* is the simulated value, *n* is the total number of values considered in the calculation ,and $\bar{y}$ is the mean of the measured values.

The results indicate excellent agreement between measured and simulated data, with an MBE of 0.1 % and a CV (RMSE) of 1.1 % during the summer period, and an MBE of −1.32 % and a CV (RMSE) of 2.92 % during the winter period. These values are well within the acceptable limits defined by ASHRAE Guideline 14-2014, which recommends an MBE within ±10 % and a CV (RMSE) below 30 %.

Adaptive Biomimetic Building Skin (ABBS) Design

The development of the adaptive facade system is based on a structured biomimetic design approach, articulated around the observation, abstraction, and transposition of principles derived from natural systems.

The biological inspiration is drawn from the Heavenly Blue Morning Glory (*Ipomoea tricolor*), a climbing plant characterized by phototropic and thermonastic movements of its petals. These petals unfold during daytime under the combined influence of light and temperature and close at night or under cooler conditions, following a helical kinetic motion driven by differential cell growth between the adaxial and abaxial surfaces. Fig.7 illustrates the open and closed states of the flower.

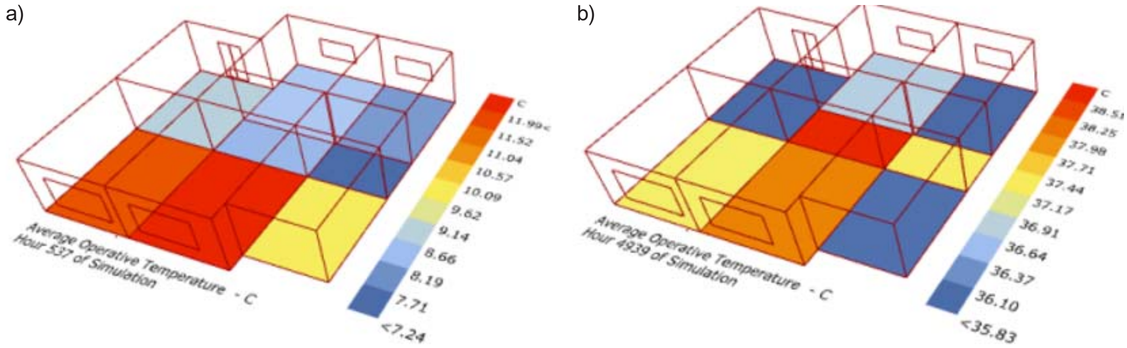

Fig. 6. Simulated distribution of operative temperature on the third floor, including the case study room: (a) hot summer day at 8:00 a.m.; (b) cold winter day at 4:00 p.m

Each facade module rotates around its longitudinal axis, reproducing this natural opening and closing mechanism within an angular range from −30° (closed state) to +30° (fully open state), with 15° increments, as illustrated in Fig. 8. Six modules are radially arranged around a fixed central axis, forming a kinetic cell capable of modulating the facade's solar permeability (Saci Hadef et al. 2025).

The functional transposition of this adaptive behavior led to the integration of shape memory polymers (SMPs), which are smart materials capable of altering their geometric configuration in response to thermal stimulation (Brzezicki 2024b). This material choice enables the system to adjust its morphology in real time according to climatic conditions: during summer, the elements expand to reduce solar gains, whereas in winter, they close to enhance passive solar heat gains (Chayaamor-Heil and Laracuente, 2020; Naeem et al., 2024). Consequently, the biomimetic process, rooted in an understanding of the thermal and photic interactions of *Ipomoea tricolor*, results in an autonomous kinetic facade system that integrates energy efficiency, seasonal adaptability, and a living-inspired architectural expression.

Fig. 7. Dynamic responses of Ipomoea tricolor (Heavenly Blue Morning Glory) to light and temperature variations

Building Thermal Performance Simulations

In this study, the thermal performance of the building was simulated using Rhinoceros 3D and Grasshopper, with the integration of the Ladybug and Honeybee plugins for energy analysis. Climate data in EPW format were imported via the One Climate Building platform, and simulations were carried out using the EnergyPlus engine. The 3D model was assigned the necessary physical properties to evaluate adaptive thermal comfort conditions.

The adaptive comfort chart, developed in accordance with ASHRAE Standard 55 and the EN 15251 Class I model (Amoruso et al., 2019), visualizes the comfort zone corresponding to an 80 % acceptability threshold, based on the relationship between indoor operative temperature and prevailing outdoor temperature (Lakhdari et al., 2021).

This diagram enables the identification of temperature combinations leading to thermal discomfort and provides a calculation of the total annual comfort hours within the analyzed zones (Lucarelli and Carlo, 2020).

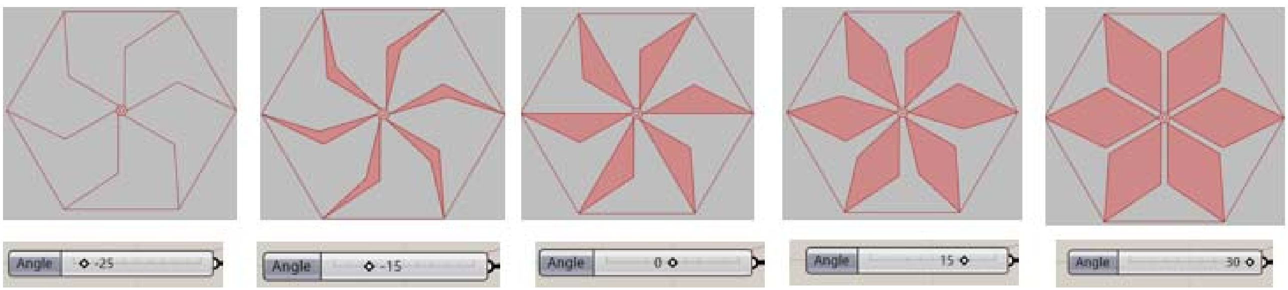

Fig. 8. Script of a single shading system unit under various configurations according to the orientation angle

Thermal Simulation Inputs

Within the Rhinoceros 3D environment and its Grasshopper plugin, the simulation parameters were classified as constant (fixed) and variable, according to their role in model construction and their influence on the simulation scenarios.

Constant parameters include the invariant characteristics of the simulation model, which were maintained identically across all investigated variants. These parameters relate to the following aspects.

Geometry (Modeling)

The test space (living room) (Fig. 9) was modeled in Rhinoceros 3D and integrated into Grasshopper for parametric simulation. This approach allows for the precise adjustment of shading system configurations in accordance with the defined scenarios.

Construction Materials

The building's structural system consists of reinforced concrete columns and beams. The materials composing each building element including the external and internal walls, intermediate floor, ground slab, roof, and windows were defined in Grasshopper, incorporating their thermo physical characteristics (Fig. 10). For opaque elements, the parameters considered include thermal conductivity, density, and specific heat capacity. For transparent elements, the selected indicators are thermal transmittance (U-value), solar heat gain coefficient (SHGC), and visible transmittance (VT). All thermophysical properties were defined in accordance with the Algerian Thermal Regulation (DTR, 1997).

Occupancy Profile

The living room, as the main space of the apartment, is primarily occupied during the afternoon and evening, from 12:00 p.m. to 12:00 a.m. (Lahmar et al., 2022), with a constant occupancy rate of 100 % (five occupants) after work or school hours. This occupancy profile accounts for recurrent domestic activities such as family gatherings and recreational activities (e.g., watching television, reading, and studying).

Temperature Setpoints and HVAC System

The indoor temperature setpoints were defined as 20°C during the winter heating period and 26°C during the summer cooling period.

The simulated HVAC system corresponds to an Ideal Loads Air System with a coefficient of performance (COP) of 2.7. This system does not represent a specific HVAC technology but instead calculates the ideal heating and cooling loads required to maintain the defined thermal comfort conditions.

Artificial Lighting

Artificial lighting levels were defined based on the installed fixtures and occupancy schedules, ensuring a lighting power density appropriate for the functional requirements of the living room. In accordance with ASHRAE recommendations, the minimum illuminance level was set to 300 lux to ensure adequate visual comfort during occupied periods (Fig. 11).

Equipment Loads

Internal electrical loads were estimated based on appliances commonly used in a residential living

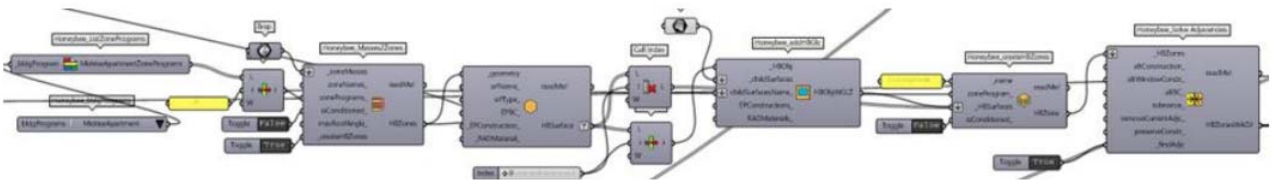

Fig. 9. Parametric definition of the test model generated in Grasshopper

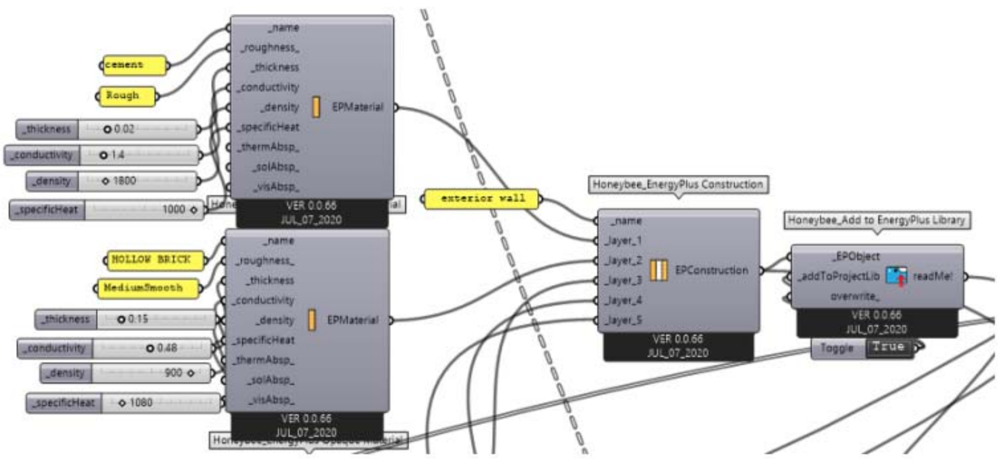

Fig. 10. Parametric definition of the external wall materials of the case study generated in Grasshopper

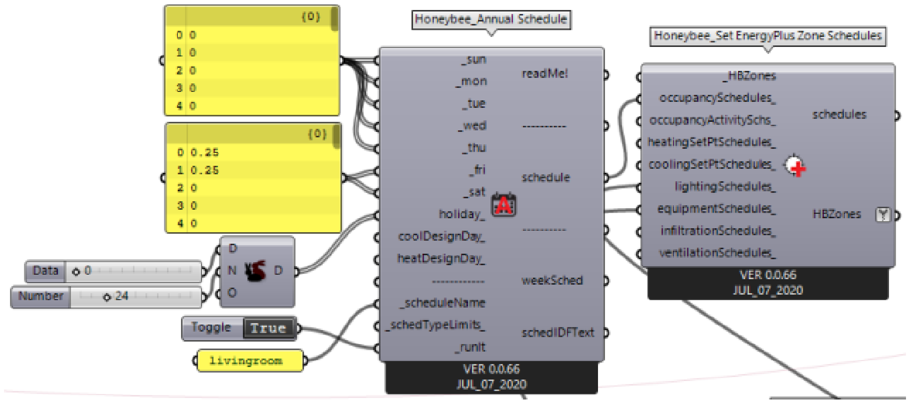

Fig. 11. Script defining the occupancy profile generated in Grasshopper

room, including a television, a set-top box or internet box, table or floor lamps, and chargers for electronic devices (e.g., phones and tablets). Based on these appliances, the total internal electrical load was set to 5 W/m², in accordance with reference values for residential living spaces (Fig. 12).

Shifting to the variable parameters, which represent the adjustable factors aimed at assessing their impact on the building's thermal and energy performance. This study focused on two main variables.

Orientation

Building orientation significantly influences solar exposure and heat gains, thereby affecting thermal and energy performance. Orientation was analyzed along three principal directions: 0° (south), 90° (west), and 270° (east), with 90° increments. The north orientation (180°) was excluded due to its limited exposure to direct solar radiation, which reduces its relevance for evaluating passive solar gains.

Rotation Angle of the Solar Control System

The behavior of the biomimetic shading device was analyzed through five louver opening configurations corresponding to the following rotation angles: −30° (fully open, 100 % opening), −15° (75 % opening), 0° (50 % opening), +15° (25 % opening), and +30° (fully closed, 0 % opening).

Results and Discussion

This section examines the impact of the adaptive biomimetic building skin (ABBS) on reducing thermal discomfort hours during both summer and winter periods. The analysis compares thermal performance before and after ABBS integration across three facade orientations (east, south, and west), each evaluated under five rotational configurations ranging from fully open (−30°) to fully closed (+30°), with a 15° interval between successive positions.

Thermal Performance before ABBS Integration

During the summer period, the analysis of the adaptive comfort chart indicates that, across all orientations. The results presented in Fig. 13 reveal that the majority of simulated hours fall outside the comfort zone defined by ASHRAE Standard 55 (outdoor temperatures between 18 °C and 28 °C, and indoor operative temperatures between 18 °C and 24 °C).

This reflects a high incidence of thermal discomfort caused by overheating, particularly when

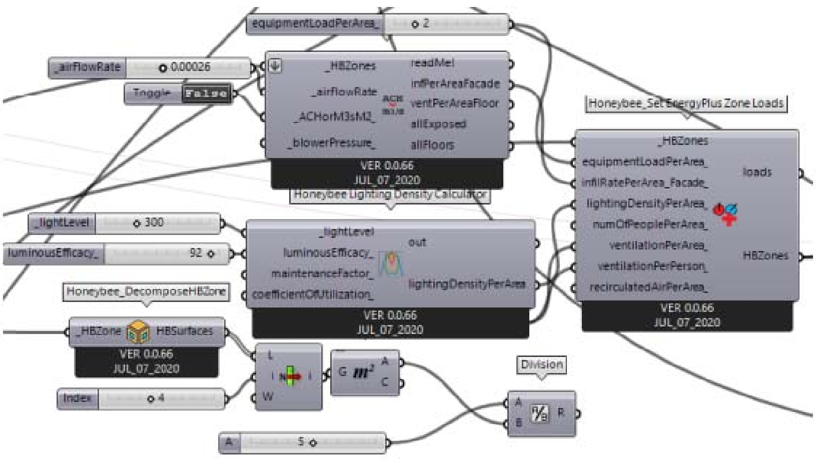

Fig. 12. Script defining the internal equipment loads generated in Grasshopper

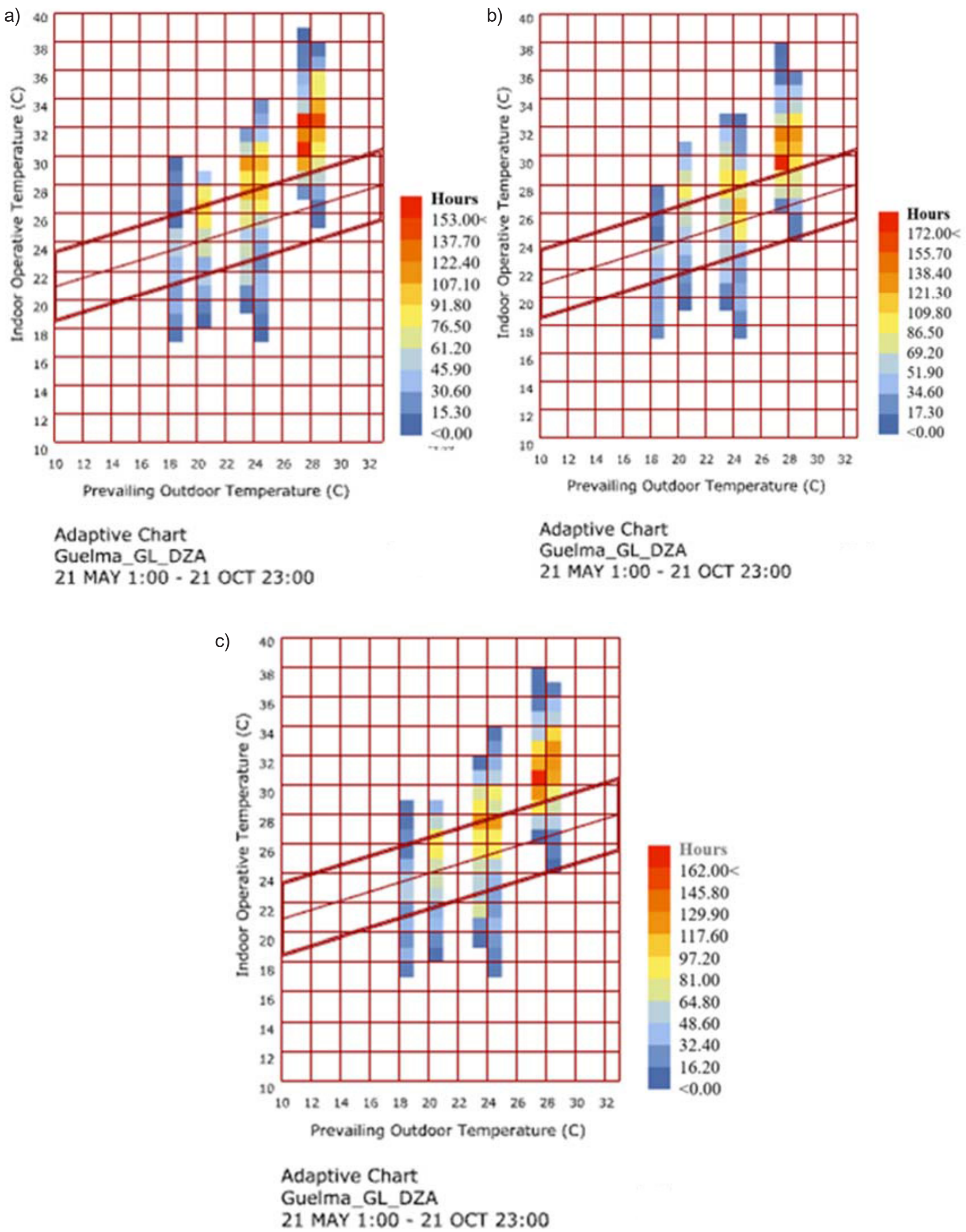

Fig. 13. Adaptive comfort model diagrams for the summer period before ABBS integration: (a) east facade, (b) south facade, and (c) west facade

outdoor temperatures exceed 28°C, resulting in indoor operative temperatures reaching up to 38°C, far above the recommended comfort thresholds. The progression of solar exposure throughout the day significantly affects indoor thermal conditions. For the east-facing facade, more than 153 hours of thermal discomfort were recorded, primarily due to direct solar radiation during the morning hours. This early exposure leads to a rapid increase in indoor operative temperatures. For the south-facing facade, discomfort levels are even higher, exceeding 172 hours, as a result of prolonged solar gains throughout the day, which cause continuous heat accumulation within the indoor space. The west-facing facade registers more than 162 hours of discomfort, predominantly during the late afternoon, when solar intensity peaks and exacerbates overheating during the final hours of the diurnal cycle.

In winter, the adaptive comfort charts reveal a pattern opposite to that observed during the summer period: thermal discomfort is primarily driven by low indoor temperatures, which frequently fall below the comfort range defined by ASHRAE Standard 55, particularly when outdoor temperatures drop below 18°C. In the case study, the east-facing room with single glazing records up to 203 hours of thermal discomfort, reflecting significant heat losses and insufficient morning solar gains to compensate for nighttime heat loss. By comparison, the south-facing facade registers 185 hours of discomfort (Fig. 14), likely benefiting from more favorable solar exposure during daytime hours. The west-facing facade records 196 hours of discomfort (Fig.15), as late-afternoon solar gains generally prove insufficient to offset morning cool conditions, resulting in extended periods of thermal discomfort.

Thermal Performance after ABBS Integration

During the summer period, the integration of the adaptive biomimetic building skin (ABBS) leads to a notable reduction in thermal discomfort hours, as shown in Fig. 16, with performance varying according to facade orientation and system rotation angle. On the east facade, a partial closure at −15° results in only a marginal improvement of 1 % (3 hours). The neutral position (0°) yields a more substantial reduction of 11.56 % (20 hours), while the +15° configuration ensures the optimal performance, with a 12.71 % decrease (22 hours). This improvement is likely attributable to effective morning solar shading combined with sufficient natural daylight penetration.

However, a greater closure at +30° slightly reduces this benefit, resulting in a 10.98 % reduction (19 hours), possibly due to diminished ventilation and increased heat accumulation within the space. For the south-facing facade, a −15° rotation provides a limited improvement of 2.85 % (5 hours), which appears insufficient to counteract intense midday solar gains. The most effective configuration is the neutral position (0°), achieving a 17.71 % reduction (31 hours), likely offering a balanced compromise between solar protection and daylight access. Further closure at +15° and +30° yields diminishing returns, with reductions of 10.85 % (19 hours) and 6.78 % (12 hours), respectively. These results suggest that excessive shading may hinder natural ventilation and contribute to thermal stagnation during peak heat periods. On the west facade, a −15° opening results in a modest improvement of 2.47 % (4 hours), primarily effective during the early afternoon.

Notably, the neutral position (0°) leads to an increase in discomfort by 6.79 % (+11 hours), indicating an inadequate response to late-afternoon solar exposure. In contrast, the +15° configuration demonstrates the best performance for this orientation, reducing discomfort by 6.79 % (11 hours), while the +30° setting yields a limited improvement of 3.09 % (5 hours).

During the winter period, the impact of the adaptive biomimetic building skin (ABBS) on indoor thermal comfort exhibits a clear trend of improvement with increasing device aperture, particularly for orientations with significant solar exposure (Fig. 17).

Under the fully closed condition (+30°), the case study initially records 196 hours of thermal discomfort. Progressive opening of the system leads to incremental reductions: at +15°, discomfort

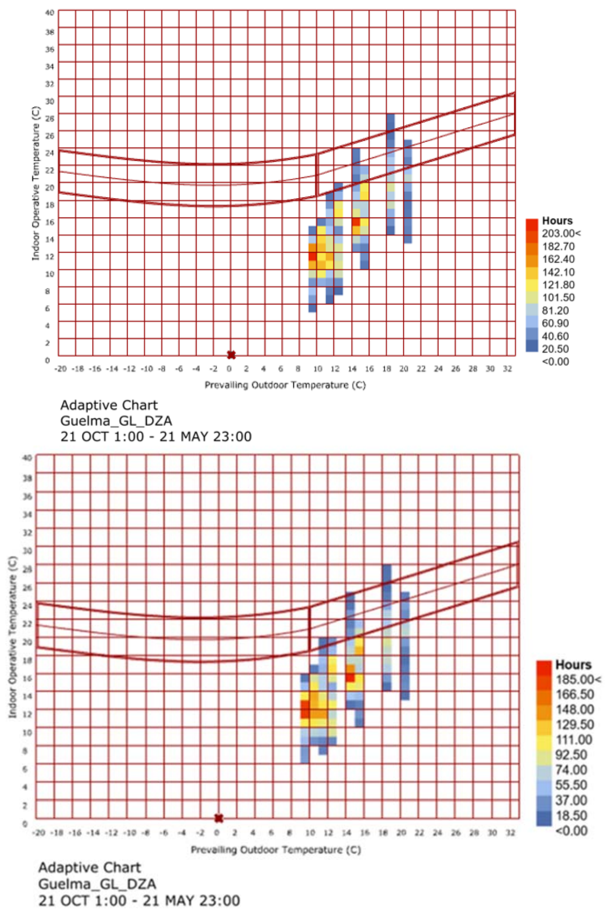

Fig. 14. Adaptive comfort model diagrams for the winter period without ABBS integration: east facade (top) and south facade (bottom)

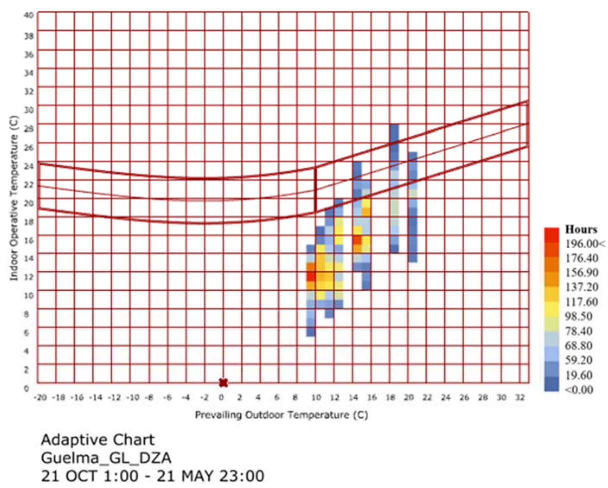

Fig. 15. Adaptive comfort model diagrams for the winter period without ABBS integration: west facade

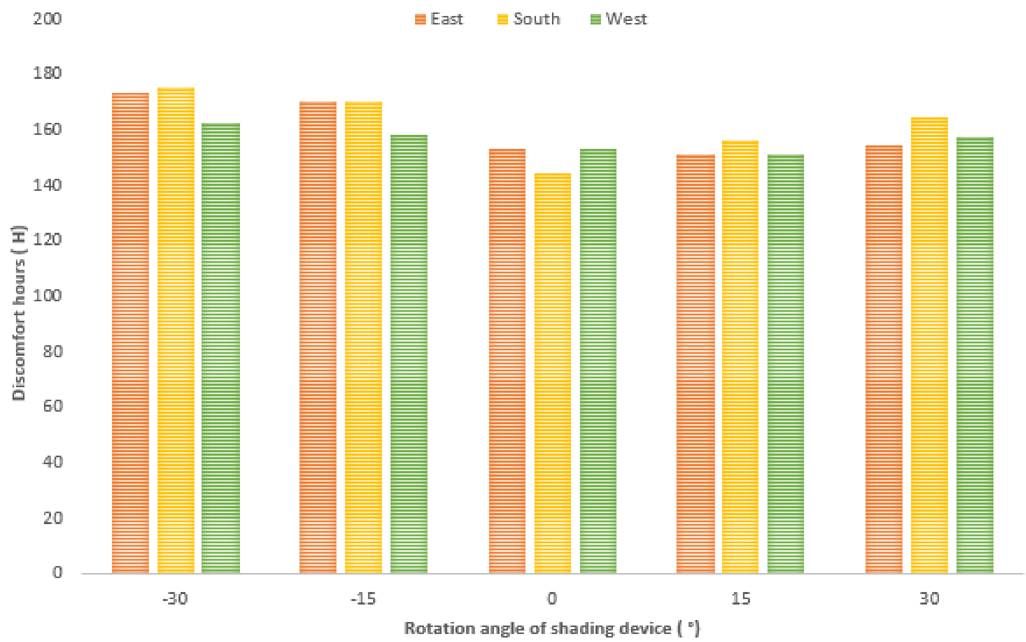

Fig. 16. Impact of ABBS integration on thermal discomfort hours during the summer period

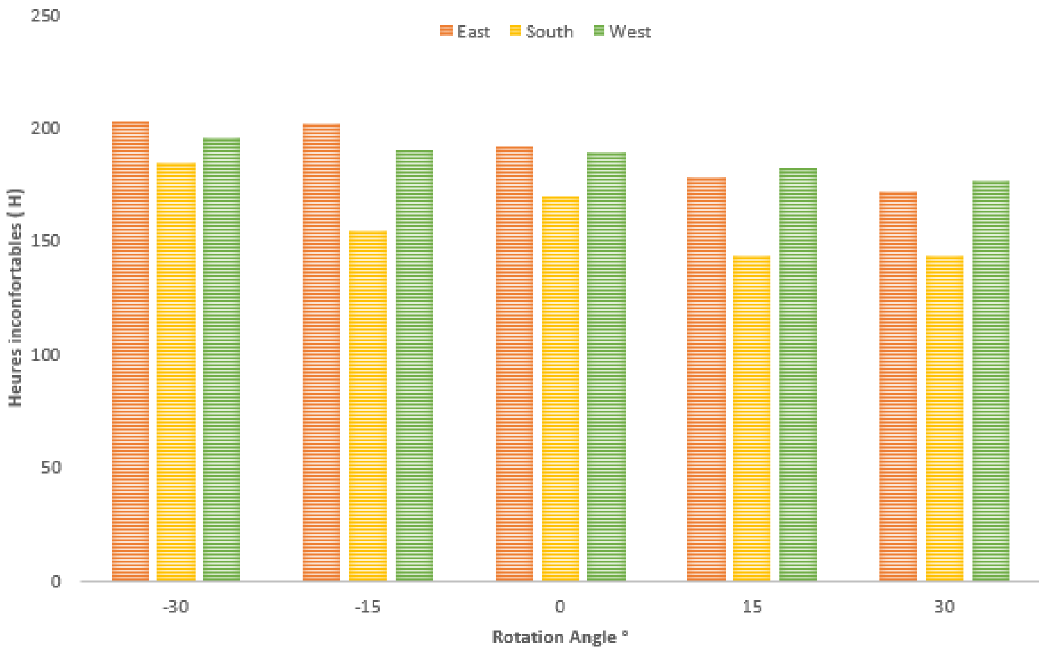

Fig. 17. Impact of ABBS integration on thermal discomfort hours during the winter period

decreases to 190 hours (2.95 %), and to 189 hours (3.44 %) at the neutral position. Larger openings at −15° and −30° further enhance comfort, reducing discomfort hours to 182 (6.89 %) and reaching a minimum of 177 hours (9.69 %), respectively.

On the east facade, where morning solar gains are critical during winter, a gradual opening of the ABBS leads to a significant reduction in thermal discomfort. A partial opening at +15° yields only a minor improvement of 0.49 % (1 hour), whereas the neutral configuration (0°) achieves a 5.41 % reduction (11 hours). Wider openings at −15° and −30° provide greater benefits, reducing discomfort hours to 178 (12.31 %) and 172 (15.27 %), respectively. These results indicate that increased exposure to early-day solar radiation enhances heat gains and helps compensate for nighttime heat losses for this orientation.

For the west-facing room, which these findings highlight the benefit of maximizing afternoon solar input in mitigating cold-related discomfort in winter. The south façade, which receives the highest solar exposure throughout the day, presents the greatest potential for thermal improvement. Under the fully closed configuration (+30°), thermal discomfort is estimated at 185 hours. Opening the system to +15° significantly reduces discomfort to 155 hours (16.21 %), while the neutral position (0°) results in 160 hours (13.51 %). Wider apertures at −15° and −30° deliver the most substantial improvements, reducing discomfort to 144 hours (22.16 %), underscoring the effectiveness of maximizing passive solar gains through increased facade openness during the winter months.

Overall, the simulation results confirm the thermal regulatory potential of the ABBS system across different orientations and seasonal conditions. During summer, the east and west facades benefit most from partial closure (+15°), which effectively moderates solar heat gains while preserving ventilation. In winter, wider openings (−15°) enhance passive solar heating and reduce thermal discomfort. For the south facade, the neutral configuration (0°) emerges as a consistent compromise, performing effectively in both seasons by balancing solar shading with adequate daylight access. These findings validate the contribution of orientation-adaptive facade mechanisms and demonstrate the applicability of biomimetic strategies in improving thermal performance while reducing heating and cooling energy demands.

Conclusion

The simulation results confirm the potential of computational approaches for the design of biomimetic adaptive envelopes capable of enhancing thermal comfort in residential buildings. Based on parametric modeling in Rhino Grasshopper and dynamic thermal simulations using the Ladybug and Honeybee plugins, the ABBS system evaluated across multiple orientations, facade configurations, and seasonal conditions demonstrates a significant capacity to reduce periods of thermal discomfort by dynamically modulating solar gains and indoor operative temperatures. This performance is achieved through rotational adjustments inspired by the thermonastic behavior of *Ipomoea tricolor*, which prove particularly effective for facades exposed to intense solar radiation in summer and low-angle sunlight during winter. The proposed computational biomimetic approach represents a notable advancement in architectural innovation, enabling the translation of complex biological mechanisms into adaptive, high-performance building envelope solutions. This study is distinguished by its methodological integration of biomimicry and algorithmic design, providing a robust framework for the development of responsive and resilient envelope systems that simultaneously optimize thermal comfort, energy performance, and daylight availability.

Although the findings are derived from numerical simulations, they establish a solid foundation for future experimental validation under real or controlled conditions. Furthermore, the proposed computational framework may be extended through multi-objective optimization incorporating thermal comfort, daylighting, and energy performance criteria, in order to assess the transferability of the system to other climatic contexts and building typologies. The application of this approach has the potential to support the design of scalable and adaptive building envelopes that enhance thermal comfort, improve energy efficiency, and promote environmental sustainability, in line with the principles of sustainable architecture.

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ВЛИЯНИЕ АДАПТИВНЫХ БИОМИМЕТИЧЕСКИХ ОБОЛОЧЕК ЗДАНИЙ НА ВНУТРЕННИЙ ТЕПЛОВОЙ КОМФОРТ: ВЫЧИСЛИТЕЛЬНЫЙ ОЦЕНКА

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Аннотация

Введение. Современные достижения в области вычислительного проектирования способствовали переходу архитектурных фасадов от статичных оболочек к динамическим системам, способным адаптироваться к условиям окружающей среды с целью повышения теплового комфорта и энергоэффективности. **Целью данной работы** является оценка тепловой эффективности адаптивной биомиметической оболочки здания, вдохновленной механизмами терморегуляции растений, на примере типового жилого здания в городе Гельма (Алжир), расположенного в условиях жаркого средиземноморского климата. **Методы**. После валидации базовой тепловой модели здания в исследовании были применены два взаимодополняющих подхода: проблемно-ориентированная биомиметическая стратегия, направленная на формирование морфологии и кинетического поведения фасадных модулей, а также параметрическое моделирование в среде Rhino Grasshopper с использованием плагинов Ladybug и Honeybee для климатического и энергетического анализа. Система адаптивной биомиметической оболочки здания была протестирована при пяти конфигурациях раскрытия (от −30° до +30°) для восточной, южной и западной ориентаций в репрезентативные летний и зимний периоды с использованием адаптивной модели теплового комфорта ASHRAE Standard 55**.** Полученные **результаты** показывают, что наиболее эффективные сценарии обеспечивают снижение часов перегрева до 17,7 % в летний период и повышение уровня теплового комфорта до 22 % в зимний период за счет усиления пассивных солнечных теплопоступлений**.** Исследование подтверждает потенциал биомиметических адаптивных фасадов в оптимизации внутренних тепловых условий и подчеркивает эффективность вычислительной биомиметики как перспективного направления в разработке климатически адаптивных и энергоэффективных архитектурных оболочек, способствующих устойчивому развитию зданий.

Ключевые слова: биомиметика; адаптивные оболочки зданий; вычислительное проектирование; параметрическое моделирование; тепловой комфорт.