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Original Research Article

Daylight Control in Greenhouse Environments Using Kinetic Skin and Annual Energy Consumption Optimization*

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Problem statement: Shade-loving plants are sensitive to high-light intensity and grow in low-light environments. These plants, which constitute a significant component of indoor green landscapes, require an illuminance range of 300 to 1000 lux for optimal growth. Conversely, greenhouses rely on energy-intensive mechanical and electronic equipment to maintain ideal growth conditions, leading to increased energy consumption. Consequently, controlling daylight and reducing energy use in these production units are of great importance. Kinetic skins, as a sustainable architectural solution, have been employed in this study and play a crucial role in daylight control and energy consumption reduction.

Research objective: This study aims to propose an adaptive envelope for controlling daylight in greenhouses designed for shade-loving plants while reducing energy consumption in Babolsar.

Research method: This research employed a quasi-experimental approach. Initially, theoretical studies were examined through a literature review, then a software-based model was developed in Rhino and Grasshopper. The proposed envelope design was inspired by the traditional Orosi windows of Mazandaran and consisted of three geometric patterns: square, circle, and Dodecagon. Energy and daylight simulations were performed using Honeybee and Ladybug, where the energy analysis was conducted with the OpenStudio engine and daylight analysis with Radiance.

Conclusion: Among the three geometric patterns, the square pattern demonstrated the best performance in terms of daylighting and energy efficiency. Based on the Useful Daylight Illuminance (UDI) index, this envelope provided optimal daylight conditions for 63.2% to 91.4% of the time while transmitting excessive illuminance above 1000 lux less frequently than the other patterns. Regarding the annual Energy Use Intensity (EUI) index, the square pattern recorded the lowest energy consumption at 154. 19 kWh/m², reducing energy consumption by 13.75% compared to the base model. The findings indicate that the square geometry outperforms circular and Dodecagon geometries in the design of adaptive greenhouse panels.

Keywords: *Daylight Control, Kinetic Skin, Greenhouse Environment, Shade-Loving Plants, Energy Consumption Reduction, UDI and EUI Indicators.*

Introduction and problem statement

Greenhouses play a crucial role in preserving plant species diversity worldwide. Among these species, shade-loving plants are particularly sensitive to high levels of sunlight intensity, as excessive light can disrupt their growth and lead to their deterioration. Therefore, controlling the amount of sunlight is essential for this category of plants (Heshmati, 2019). On the other hand, human progress throughout the twentieth century has led to environmental and energy crises, which have become fundamental issues in human

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societies today. In this regard, architecture cannot remain indifferent to these challenges, as energy consumption in buildings significantly impacts the environment (Syam et al., 2023; Saleh et al.,2022; Huang et al., 2025). Greenhouses, as production units, are among the major energy consumers. These spaces require high energy consumption due to their off-season production and the provision of specific environmental conditions for plant species. Additionally, the nature and function of greenhouses make them highly sensitive to their surrounding environment. Among various climatic factors, daylight is one of the most critical elements affecting greenhouses, and its control during different hours of the day can enhance greenhouse performance and efficiency (Shokri, 2015; Fathi Pirkashani, 2020; Momeni et al., 2012; Heshmati, 2019). Movable facades have evolved beyond mere decorative elements and significantly contribute to creating optimal indoor conditions and reducing energy consumption in architecture. These facades enable control over the amount of light entering the indoor environment (Zhang et al., 2022; Mengmeng et al., 2024; Gonçalves et al., 2024; Brzezicki, 2024; Goharian et al., 2025; Yunitsyna & Sulaj, 2025). A fundamental component of a greenhouse is its facade. While sunlight and heat are essential for plant growth and development, certain plant species require less light and are, in fact, shade-tolerant. Adjusting the amount of incoming light through movable facades can enhance the growth of these plants. The primary objective of this research is to "control daylight in greenhouse environments for shade-loving plants and reduce energy consumption." In this context, the study seeks to answer the question: "Which pattern is suitable for designing a movable facade to control daylight in greenhouses designed for shade-loving plants?" To this end, the research aims to propose an appropriate geometric pattern for greenhouse movable facades. To achieve this goal, the geometry of traditional Iranian Orosi windows, a historical method of light control in Iranian architecture, has been utilized. Specifically, the geometric pattern of orosi windows from traditional houses in Mazandaran Province has been adopted and modeled using a quasi-experimental method in the Rhino software with the Grasshopper plugin. Additionally, light and energy simulations were conducted using the Honeybee and Ladybug software. Finally, the obtained results were validated by comparing them with a base (conventional) model. Among the three examined patterns, the third pattern (square geometry) was identified as the most suitable for controlling light and reducing energy consumption in greenhouses. The following sections provide a review of the relevant literature and the theoretical framework of the study.

Literature Review

Previous studies on the design of movable facades and daylight control indicate that the use of such facades in architecture significantly impacts energy optimization and light management. The following section reviews some relevant research: Abedini et al. (2025, 48) conducted a study aimed at multi-objective optimization of window and shading systems in office buildings, examining the role of fixed shading devices as a passive strategy to enhance energy efficiency, thermal comfort, and daylight performance. Conducted in the hot and dry climate of Qom, this study utilized Rhino, Grasshopper, Honeybee, and Ladybug simulation tools to evaluate shading strategies. The results demonstrated that fixed external shading devices could reduce Energy Use Intensity (EUI) by up to 14.95%. Additionally, the use of side fins and horizontal louvers reduced Annual Sunlight Exposure (ASE) by 36.25% and 9.38%, respectively. Moreover, the Spatial Daylight Autonomy (SDA) index reached 100% in some shading systems, indicating their positive impact on daylight quality. Yunitsyna & Sulaj (2025, 73) investigated daylight optimization in architectural classrooms using a biomimetic-based movable shading system, focusing on its effects on glare control and visual comfort enhancement. The study employed ClimateStudio and Grasshopper for Rhino to evaluate various scenarios for achieving a balance between natural daylight and glare control. The findings showed that adaptive systems could reduce glare and regulate incoming light effectively. Goharian et al. (2025, 90) focused on the design and evaluation of an adaptive kinetic facade to optimize daylight performance in office buildings. The study introduced a movable facade equipped with photovoltaic panels and plexiglass, which improved daylighting and visibility while optimizing energy consumption. Using Radiance and post-processing methods, the study evaluated daylight performance. Three strategies were tested: blocking direct sunlight, tracking the sun's path, and minimizing facade movement. The results indicated that the direct sunlight-blocking strategy increased the Useful Daylight Illuminance (UDI, 300–3000 lux) from 49% to 90%.Yarmohammadi et al., (2023, 56) in a study titled "Algorithmic Design of Smart Building Facades for Daylight Control Inspired by the Movement Pattern of Iris Flowers" found that the movement of iris flower petals could inspire the design of smart shading systems for building facades. These systems, by adjusting incoming light, reduced solar radiation and heat absorption, contributing to energy optimization.Mahyari et al., (2022, 82) in a study titled "Proposing an Adaptive Smart Facade with a Biomimetic Approach to Reduce Energy Consumption" demonstrated that smart facades could reduce total thermal load by 28%, cooling load by 56%, and the likelihood of daylight glare by 23%. These results highlight the importance of adaptive and dynamic designs in controlling environmental conditions. Sheikhi Nashalji (2022, 63) in a study titled "Design of Smart Shading for Office Buildings to Control Direct Sunlight Entry Based on Reducing Cooling Load, Inspired by Iranian-Islamic Geometric Patterns" found that using Iranian-Islamic geometric patterns in movable shading systems could provide better control over incoming light and reduce energy consumption in office buildings. Khatibi et al., (2022, 75) in a study titled "Investigation of Thermal Behavior of Facades to Determine the Optimal Option for Energy Consumption" compared the performance of single-skin facades with fixed shading, double-skin glass facades, double-skin facades with movable shading, and movable facades. The results showed that facades with movable shading reduced energy consumption more effectively than other options. Nasr et al., (2020, 48) in a study titled "Impact of Movable Facade Geometry on Energy Optimization Inspired by the Movement Algorithm of the Sensitive Plant" found that smart facades could automatically adjust incoming light and, in the hot climate of Shiraz, to prevent excessive sunlight entry during summer. Maden & Kızılorenli (2023, 66) in a study titled "Modular Responsive Facade Designs for Daylight Control and Visual Comfort" demonstrated that responsive facades could reduce energy consumption and improve daylighting in buildings. Ozdemir and Cakmak (2022, 38) in a study titled "Evaluation of Daylight Quality and Illuminance in Office Spaces with Flat Facades and Dynamic Shading Systems in Hot and Dry Climates" showed that dynamic (movable) shading systems could adjust based on the sun's position and provide outputs compliant with LEED standards. This study by Mirmomtaz et al. (2023) was conducted with the aim of evaluating the role of movable shading devices in the simultaneous optimization of natural daylight and energy consumption in office buildings. In this research, three design scenarios—including no shading, peripheral shading, and adaptive movable shading—were simulated using Ladybug Tools. The results indicate that employing adaptive movable shading systems in the hot and dry climate of Isfahan can enhance the effective daylight area by more than 20% and reduce annual energy consumption by over 48%.(Zabihi et al., in-press) investigated the significant role of the traditional Iranian architectural element, Sabak, in enhancing the quality of natural daylight and reducing glare in office spaces. In this study, an optimized geometric pattern for the Sabak element was developed using advanced simulation tools such as Grasshopper, Ladybug, Honeybee, and the genetic algorithm-based Galapagos plugin. The results indicated that the optimized design increased

Useful Daylight Illuminance (UDI) by up to 54% and reduced annual glare index by 15.6%. This research highlights how indigenous architectural components, when integrated with contemporary design approaches, can effectively improve the daylight performance of modern buildings.

Theoretical Framework

- **Daylight and its control**

Daylight refers to the light that reaches the Earth's surface from the sun, encompassing both direct sunlight and diffused skylight. A fundamental aspect of architecture and interior space design is the control of daylight to optimize illumination and reduce energy consumption. This control is achieved through two methods: fixed and movable systems. Unlike fixed systems, movable systems can adjust the amount of incoming light based on weather changes and the sun's position (Edwards & Torcellini, 2002; Atamewan, 2022; Lee et al., 2022; Reinhart, 2014; Lee et al., 2022; Li, 2024). In the present study, the use of movable facades as a strategy for controlling light in greenhouse environments is investigated.

- **Movable facades and their role in light control**

Movable facades are structures capable of changing their configuration in response to environmental conditions, allowing control over light, heat, and airflow (Barozzi et al., 2016). In contemporary architecture, these facades are recognized as a solution for optimizing energy consumption and enhancing environmental quality. One of the key applications of movable facades is regulating daylight in indoor spaces and greenhouses, ensuring sufficient light for plant growth while preventing excessive harmful light (Bahri et al., 2025; Takhmasib et al., 2023; Sharaidin, 2014; Nashaat & Waseef, 2017; Hosseini et al., 2019; Mahmoud & Elghazi, 2016). In this research, the design of a movable facade is inspired by traditional Mazandaran orosi windows. Orosi windows, a type of traditional Iranian window, are considered a suitable model for designing Orosi modern light control systems due to their ability to regulate light and provide natural ventilation.

- **Importance of light in greenhouses and shade-loving plants**

A greenhouse is a controlled environment that enables the provision of suitable conditions for plant growth. Sunlight is one of the most critical factors affecting the growth of greenhouse plants. Each plant species requires a specific amount of light for photosynthesis, varying in intensity, quality, and duration. Among plant species, shade-loving plants (Fig. 1) require a limited light intensity and are sensitive to direct sunlight. The optimal light range for these plants is defined as 300 to 1000 lux, and exposure to light intensities beyond this range can lead to reduced growth and damage to their leaves (Yano, 2001; Yeang, 2013). Therefore, precise control of daylight in greenhouses designed for shade-loving plants (Table 1) is essential for optimizing plant growth and preventing light-induced damage.

Research Gap and Basis of the Present Study

The present research aims to address the research gap in the field of daylight control in greenhouses designed for shade-loving plants. A review of the literature indicates that, to date, no specific standard has been established for the optimal light level in greenhouses for shade-loving plants. Most previous studies have focused on daylight control in residential, office, and educational buildings (Maden & Kızılorenli, 2023; Cakmak & Ozdemir, 2022), while light control metrics in non-residential environments, such as greenhouses, have received less attention. In this study, by defining the Useful Daylight Illuminance (UDI) index in three light ranges—less than 300 lux, 300 to 1000 lux, and more than 1000 lux—the optimal light level for shade-loving plants has been determined. This index serves as the basis for designing a movable greenhouse facade capable of optimizing incoming light based on the plants' needs and environmental conditions. The primary goal of this design is to optimize daylight in the greenhouse and reduce energy consumption through an adaptive system that can adjust light

Fig. 1. From right to left: Guzmania, Aspidistra, Dieffenbachia, Sansevieria. Source: www.pinteres.com.

Table 1. Shade-Loving Plants Based on the Theoretical Foundations of the Research. Source: Auther.

Shade-Loving Plants			
Row	**Name**	**Row**	**Name**
1	Peperomia	13	Guzmania
2	Philodendron	14	Aglaonema
3	Epipremnum aureum	15	Aspidistra elatior
4	Maranta leuconeura	16	Zamiifolia
5	Sansevieria	17	Dieffenbachia
6	Platycerium	18	Hedera helix
7	Dracaena	19	Adiantum capillus-veneris
8	Dracaena sanderiana	20	Chamaedorea elegans
9	Kalanchoe	21	Spathiphyllum
10	Tradescantia	22	Calathea makoyana
11	Ficus Pumila	23	Aspidistra elatior
12	Bambusoideae	24	Bromeliad

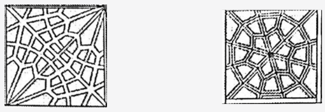
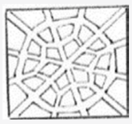
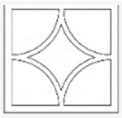
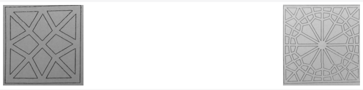
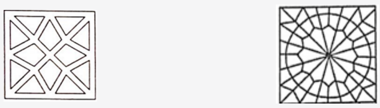
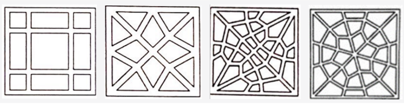
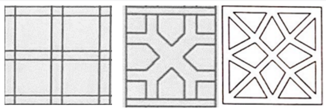
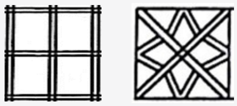
according to environmental changes. This research not only provides a solution for light control and energy management in greenhouses but also, for the first time, introduces a specific light metric for greenhouse environments designed for shade-loving plants—an aspect that has received limited attention in previous studies.

Research Methodology

The objective of this research is to control daylight in greenhouse environments to protect shade-loving plants and optimize energy consumption through the design of movable facades. To achieve this goal, the present study adopted a mixed-method approach, incorporating documentary analysis, comparative analysis, and computational simulation. In the first stage, using the documentary method, theoretical foundations related to daylight control and the design of movable facades were reviewed. These studies served as the analytical basis for the design of movable facades in this research. In the second stage, to design the movable facade pattern, inspiration was drawn from the geometry used in historical Iranian architecture, particularly traditional Orosi windows. Given that the study area is the city of Babolsar in Mazandaran Province, which has a temperate and humid climate, historical houses registered with the cultural heritage organization of this region were examined. The results of this investigation revealed that similar to the architecture of central Iran, passive strategies for light control and energy optimization were employed in these houses. Since greenhouses feature extensive transparent surfaces, this research utilized the pattern of traditional Orosi windows in designing the greenhouse's movable panels. In the third stage, to identify and extract suitable Orosi patterns, architectural documents related to 11 historical houses in Mazandaran were collected through the Mazandaran Province Cultural Heritage Organization. These patterns were subjected to comparative geometric analysis, and the results of this analysis are presented in Table 2.

Following the analysis of the geometry of Orosi windows in traditional houses of Mazandaran Province, three primary patterns (Fig. 2), which exhibited the

Table 2. Geometric patterns used in the traditional orsi windows of Mazandaran province houses. Source: Authors.

No	The Name of the House	Patterns in the Orosi window	Geometry
1	Afghan-Nejad, Behshahr		Dodecagon + Circle
2	Ghareshi, Amol		Circle
3	Ramadani, Sari		Dodecagon
4	Nima Yushij, Nour		Dodecagon
5	Fazel, Sari		circle
6	Garna Nadri, Larijan		circle
7	Hezarjeribi, Behshahr		circle
8	Kalbadi, Sari		Dodecagon + Square
9	Monochehri, Amol		Dodecagon + circle + Square
10	Aghajansab, Babol		Dodecagon + Circle
11	Najafi, Babol		Circle + Square

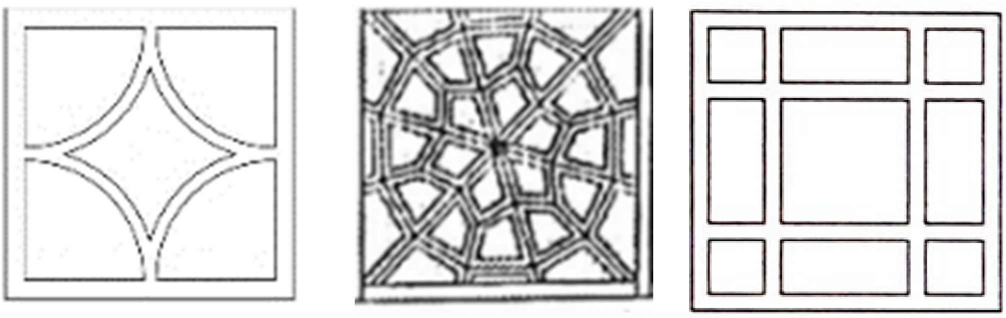


Fig. 2. Geometry of the three final patterns in the shell panel. Source: Authors.

highest frequency and commonality among the studied samples, were selected as the basis for designing the movable greenhouse facade. These three patterns are rooted in traditional Iranian geometry and their adaptability to the lighting and environmental conditions of greenhouses.

By determining the light-passing section (the diaphragm for light entry when the facade is open), the movable section, and the fixed section (non-light-passing), the final pattern of the movable facade panel is presented in Fig. 3.

The proposed movable facades were parametrically designed using Grasshopper software to optimize daylight for shade-loving plants within the 300–1000 lux range. The facade adjustment algorithm was defined based on two main parameters: illuminance and solar incidence angle. In this algorithm, illuminance data were extracted from Radiance simulations (based on Babolsar's climatic conditions) and used as input in Grasshopper. The angle of the facade panels (ranging from 0 to 45 degrees) is dynamically adjusted to reduce incoming light by closing the panels when illuminance exceeds 1000 lux. Additionally, the solar incidence angle (calculated from Ladybug data) was utilized to optimize the panel positions throughout different hours of the day. This dynamic process, integrated with energy simulations using the Honeybee plugin, ensured simultaneous light control and reduction in cooling and heating energy consumption. This approach enabled real-time adaptation of the facades to changes in light and climate, demonstrating superior performance compared to fixed or semi-dynamic systems. In the next step, simulations were conducted using Rhino (Version 7) and Grasshopper (Version 3) and are presented in Table 3.

Specifications of the base Model and Simulation Process

In this research, a base greenhouse model was designed to enable comparison between the performance of the proposed movable facade and conventional light control methods. This model was developed based on the regulations, standards, and principles of greenhouse design in Iran, with the following specifications:

- Double-pitched roof with a slope angle of 25 to 65 degrees.
- Greenhouse height: 4 meters to the eaves, 7 meters to the ridge, and 3 meters for the entrance door height.

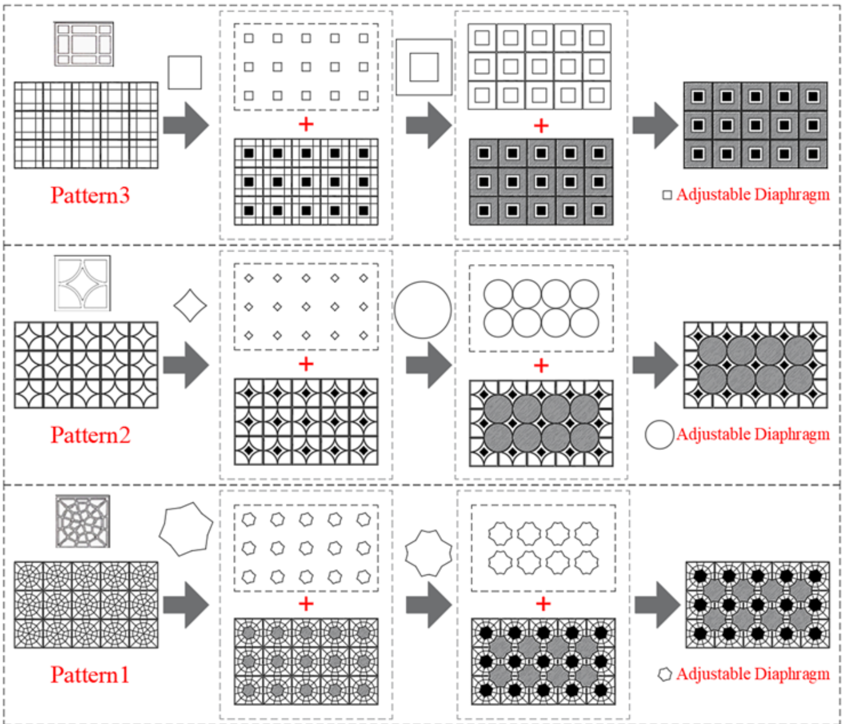
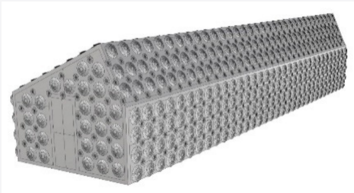
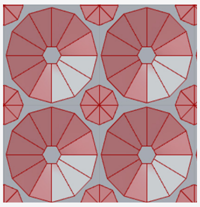
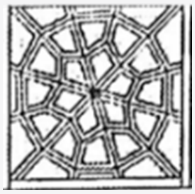
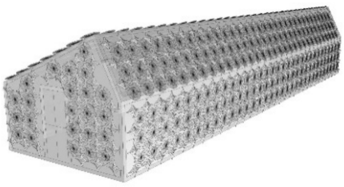
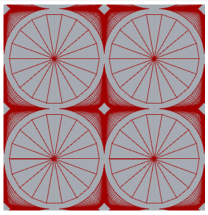
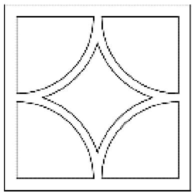
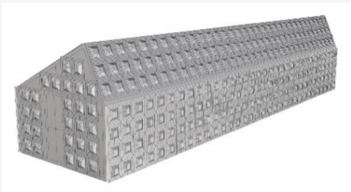
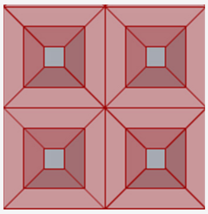
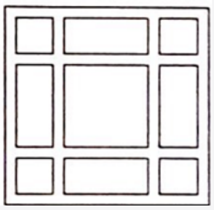
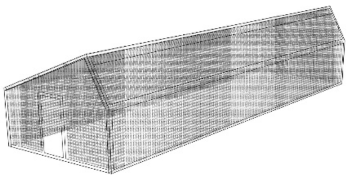
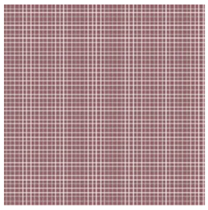


Fig. 3. The design process of the three final patterns for the shell panel design. Source: Authors.

Table 3. Process of shell modeling for light control in the greenhouse. Source: Authors.

Pattern	Light control pattern in the greenhouse	Modeling (Rhino + Grasshopper)	Final model	Panel dimensions
Pattern 1				50 cm * 50 cm
Pattern 2				50 cm * 5 0cm
Pattern 3				50 cm * 5 0cm
Base Model				2 cm * 2 cm

- Overall dimensions: 8 meters in width and 32.2 meters in length (Fig. 4, greenhouse elevation).
- Model orientation: elongated along the north-south axis with the entrance on the southern side.

For daylight control in this model, greenhouse protective netting (Fig. 4, light control netting in the greenhouse), commonly used as movable curtains in conventional systems, was employed. These nets, made of polypropylene and polyethylene fibers, are used to regulate the intensity of incoming light in the greenhouse. In this study, the performance of the traditional light control method was compared with the proposed movable facade to evaluate its effectiveness in controlling daylight and reducing energy consumption.

Simulation process

This research was conducted to compare the results of the base model with three different light control patterns in the greenhouse. To achieve optimal lighting conditions for shade-loving plants, the movable facade was installed on all sides of the greenhouse, and its performance was evaluated for each of the proposed patterns. Subsequently, the simulation results were compared, and the most optimal pattern for designing the movable facade panels for daylight control was selected. The simulations related to energy and daylight were performed using specialized software. In this regard, the Honeybee (Version 7.1) and Ladybug (Version 7.1) plugins were utilized for data analysis and processing. Additionally, the OpenStudio engine (Version 6.3) was employed for energy simulation, and Radiance (Version 4.5) was used for daylight analysis. The primary variable in this study is the degree of openness of the movable facade, which is dynamically adjusted based on the intensity of

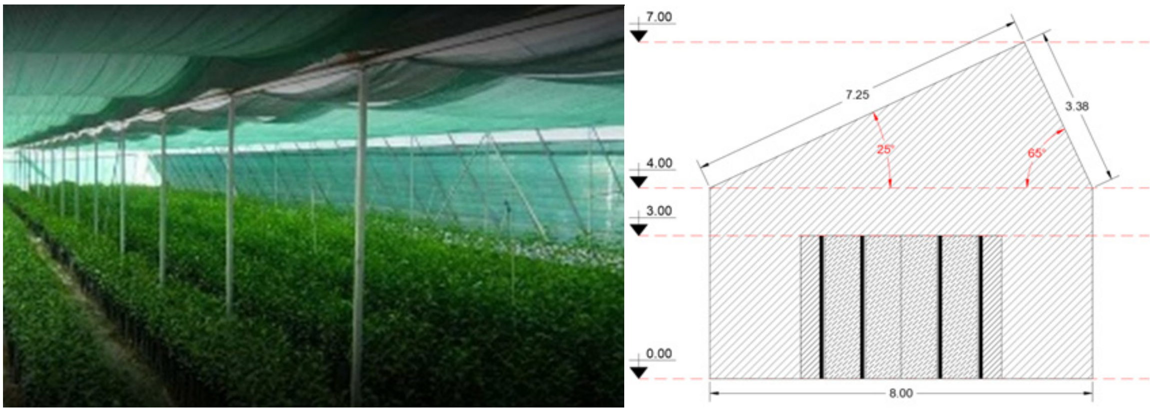


Fig. 4. From right to left: Base model facade, shading screen for greenhouse light regulation. Source: Authors.

incoming light. The algorithm for light and energy simulation is presented in Fig. 5.

Data Analysis

• Useful daylight illuminance (UDI) index

The UDI index is calculated based on absolute daylight illuminance values over a year and is defined as the percentage of occupied hours in a space where the indoor horizontal illuminance falls within the visual comfort range (Mardaljevic et al., 2009; Nabil & Mardaljevic, 2005). This index not only evaluates the frequency of useful daylight illuminance levels at a specific point but also indicates the occurrence of excessive daylight levels that may lead to glare and discomfort. The UDI index identifies an illuminance range that is neither excessively bright (above 1000 lux) nor too dim (below 300 lux). In this study, which focuses on daylight control in greenhouses designed for shade-loving plants, UDI values have been defined based on the specific light requirements of these plants. The considered ranges are as follows:

- Below 300 lux (insufficient light for the growth of shade-loving plants)
- 300 to 1000 lux (optimal and desirable range)
- Above 1000 lux (excessive light that may impair plant growth)

The objective of this research is to provide optimal lighting conditions within the 300 to 1000 lux range for shade-loving plants, as illuminance levels exceeding 1000 lux may disrupt their growth.

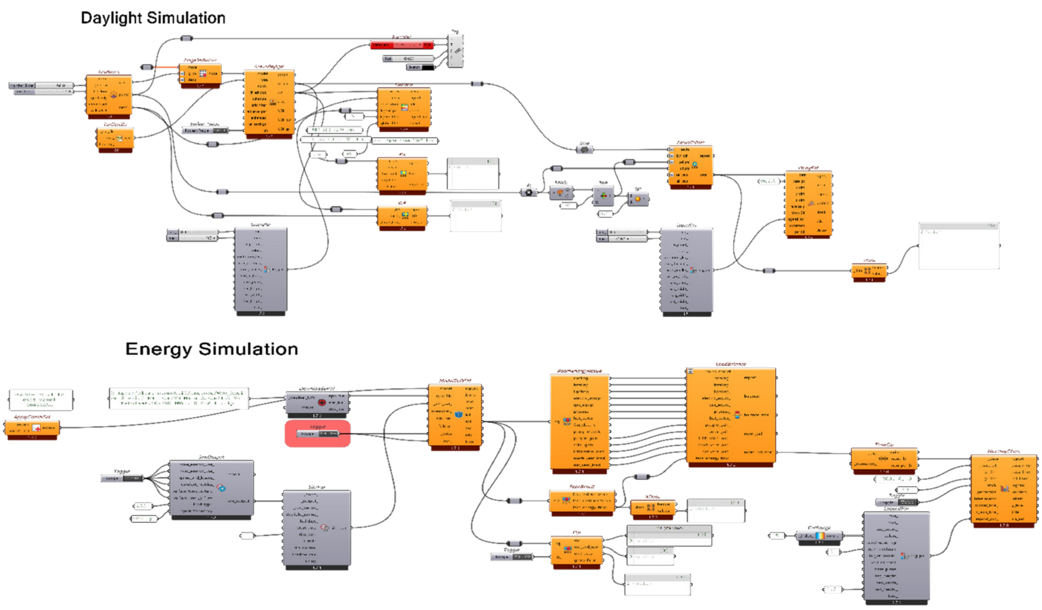


Fig. 5. Algorithm for light and energy simulations. Source: Authors.

Therefore, precise daylight control in greenhouses dedicated to these plant species is deemed essential.

- **UDI indices in pattern 1 (Dodecagon)**

Simulation results indicate that the proportion of useful daylight received, as measured by the UDI index, in the range above 1000 lux varies between 26.6% and 87.8% of annual hours. In the 300 to 1000 lux range, which is the optimal and primary target of this study, the daylight received in the space ranges from 10.2% to 57.6%. Additionally, in the range below 300 lux, the received daylight is calculated at 3.6% (Fig. 6).

- **UDI indices in pattern 2 (circle)**

Simulation results indicate that, according to the UDI index, the proportion of daylight received in the range above 1000 lux, which exceeds the requirements of shade-loving plants, varies between 23.8% and 79.2% of annual hours. The UDI value in the 300 to 1000 lux range, considered optimal for plant growth, ranges from 22.6% to 73.8%. Additionally, the UDI value below 300 lux in this pattern is recorded between 3.6% and 7.6% (Fig. 7).

- **UDI indices in pattern 3 (square)**

The simulation results indicate that the amount of light received in the range above 1000 lux in this pattern is minimized, with only 1% to 10% of the greenhouse space exposed to excessive light. Conversely, the range of 300 to 1000 lux, which is considered optimal for the growth of shade-loving plants, covers 63.2%

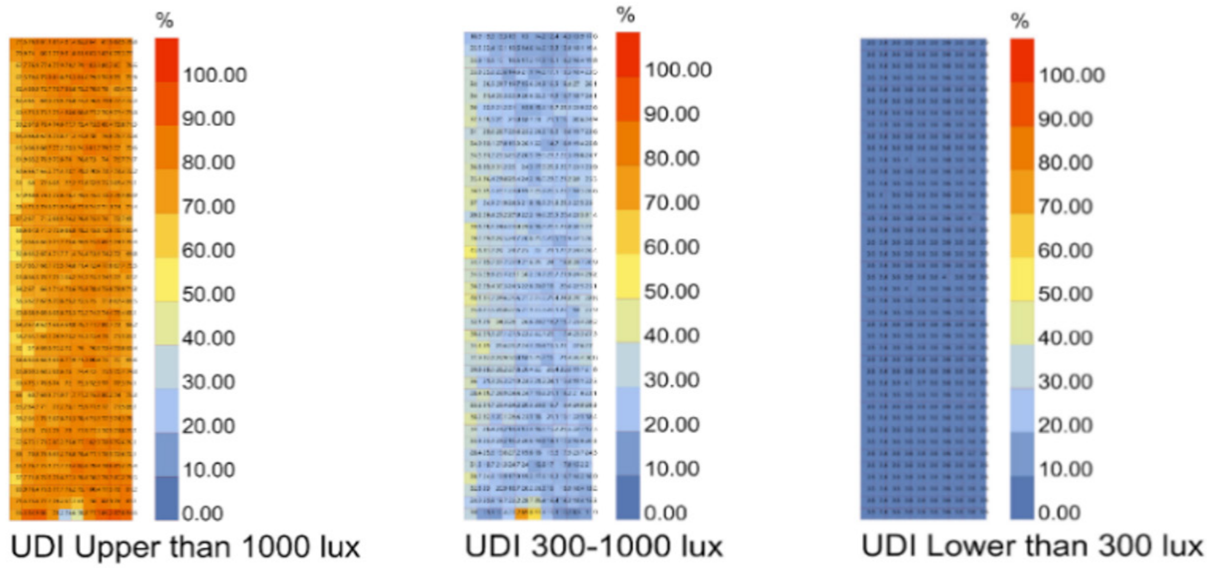


Fig. 6. Charts of the UDI index in the greenhouse with Pattern 1. Source: Authors.

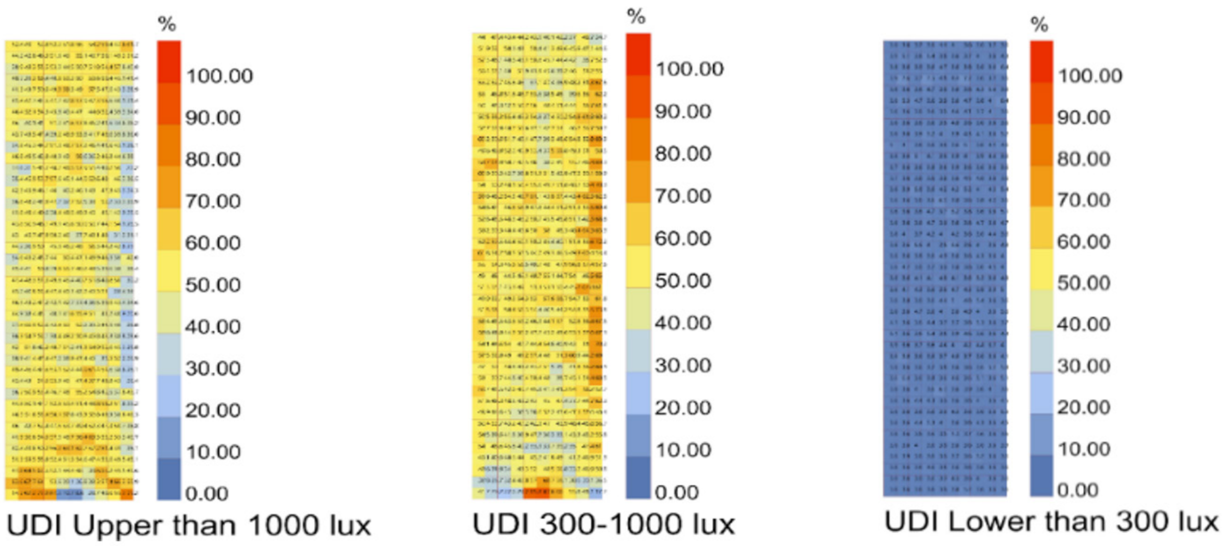


Fig. 7. Charts of the UDI index in the greenhouse with Pattern 2. Source: Authors.

to 91.4% of the greenhouse space. This value provides the highest amount of optimal light compared to the other two patterns. However, in the range below 300 lux, the received light varies between 3.6% and 31.6%, indicating that during certain hours, a portion of the greenhouse cultivation environment does not receive sufficient light (Fig. 8).

- **UDI inidces in the base model**

The simulation results indicate that the amount of useful light received, as per the UDI index, in the range above 1000 lux accounts for 47.2% to 89.3% of the annual hours. In the range of 300 to 1000 lux, which is considered the optimal range and the primary focus of the research, the light input to the space varies between 7.2% and 28.9%. Additionally, in the range below 300 lux, the amount of received light is calculated to be between 3.6% and 5% (Fig. 9).

A Comparison Between the Base Model and Three Movable Shell Patterns Based on the Udi Indices

- **Excessive light (Above 1000 Lux)**

- **Pattern 1:** 26.6% to 87.8% of annual hours are exposed to light above 1000 lux.
- **Pattern 2:** 23.8% to 79.2%, showing a reduction compared to Pattern 1.
- **Pattern 3:** 1% to 10%, the lowest among the three patterns.

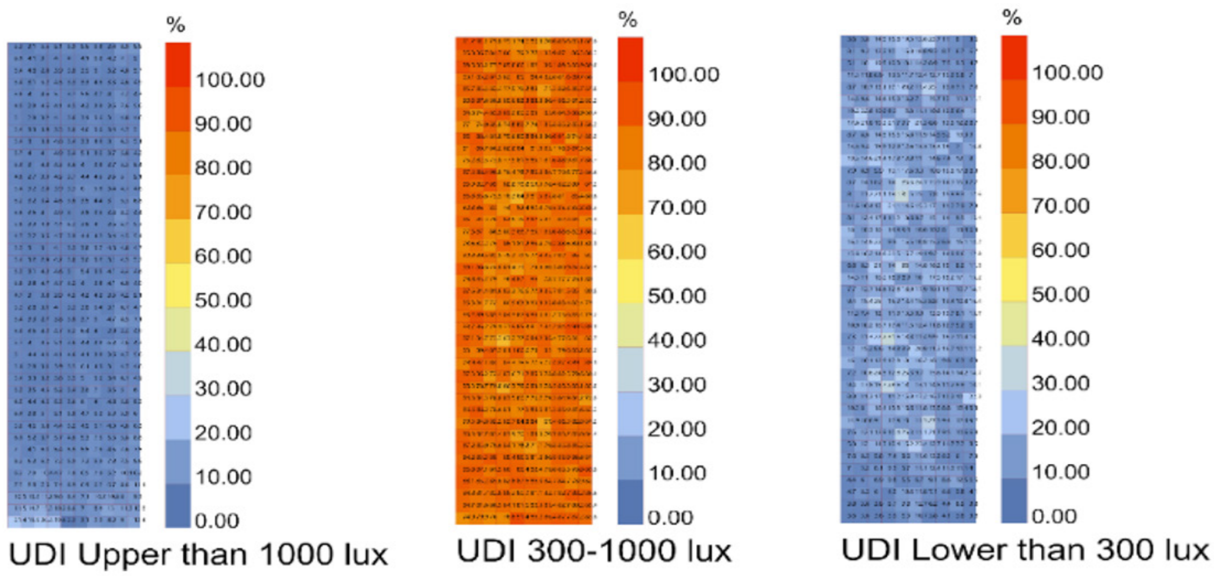


Fig. 8. Charts of the UDI index in the greenhouse with Pattern 3. Sources: Authors.

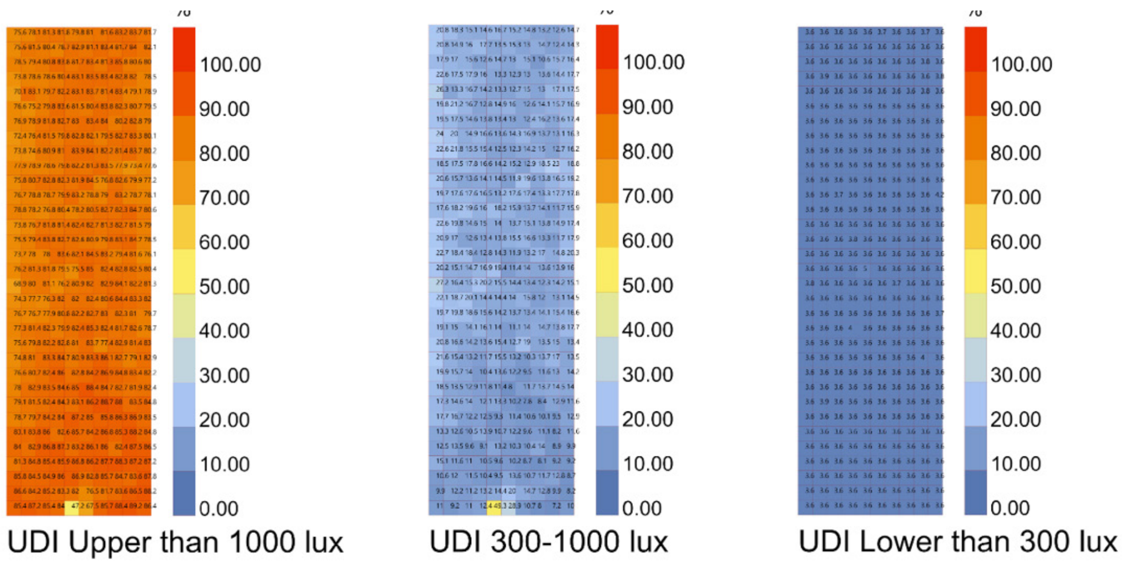


Fig. 9. Charts of the UDI index in the greenhouse with the light-transmitting net condition. Source: Authors.

- **Base model** (light-transmitting net): 47.2% to 89.3% of annual hours are exposed to excessive light.

Conclusion: Pattern 3 demonstrates the best performance in reducing excessive light, while Pattern 1 receives the highest amount of excessive light.

- **Optimal light (300 to 1000 Lux)**

- **Pattern 1**: Optimal light ranges from 10.2% to 57.6%.

- **Pattern 2:** UDI in this range varies from 22.6% to 73.8%.

- **Pattern 3:** Achieves the highest range, covering 63.2% to 91.4% of the greenhouse space.

- **Base Model:** Only 7.2% to 28.9% of the greenhouse space falls within this range.

Conclusion: Pattern 3 provides the highest amount of optimal light, while Pattern 1 exhibits the lowest efficiency in this range.

- **Insufficient light (below 300 Lux)**

- **Pattern 1:** 3.6% of annual hours fall within this range.

- **Pattern 2:** 3.6% to 7.6% of the greenhouse space experiences insufficient light.

- **Pattern 3:** 3.6% to 31.6%, the highest in this range.

- **Base model:** Insufficient light is recorded between 3.6% and 5%.

Conclusion: Although Pattern 3 provides the most optimal light, some parts of the greenhouse experience insufficient light during certain hours. Pattern 1 has the least insufficient light.

Discussion

Base model (light-transmitting net): Exhibits the highest excessive light, the lowest optimal light, but the least insufficient light.

Pattern 1: Shows a slight reduction in excessive light, a relative increase in optimal light, and minimal change in insufficient light.

Pattern 2: Demonstrates a significant improvement in increasing optimal light and reducing excessive light, but with a slight increase in insufficient light.

Pattern 3: Offers the best performance in reducing excessive light and increasing optimal light, but has the highest insufficient light during certain hours.

Overall conclusion: Pattern 3 is the most optimal design for providing suitable light for shade-loving plants in greenhouses, though it requires additional adjustments to address insufficient light during certain hours. The base model (light-transmitting net) performs the poorest in providing optimal light and results in the highest excessive light.

- **Received light environment based on annual hourly charts**

The presented charts illustrate the amount of daylight received (in lux) in the greenhouse across different hours of the day and months of the year. These charts consist of three main axes: the horizontal axis (bottom of the chart) represents the months of the year (January to December), indicating light variations across seasons; the left vertical axis represents the hours of the day (00: 00 to 24:00), showing the trend of light intensity changes throughout the day; and the right vertical axis represents the received light intensity (in lux), indicating the amount of light entering the greenhouse.

- **Base model (greenhouse light-transmitting net)**

Analysis of monthly variations shows that during the summer months (June, July, and August), the amount of received light significantly increases, while in winter months (December, January, and February), light intensity decreases but remains considerable during midday hours. The highest light intensity occurs between 12: 00 and 14:00, reaching 35,000 to 45,000 lux, which greatly exceeds the optimal range for shade-loving plants. The lowest light levels are observed between 06: 00 to 08: 00 and 18: 00 to 20:00, ranging from 200 to 500 lux, falling below the optimal range. Regarding light intensity, the received light exceeds 1000 lux for many hours of the day, surpassing the optimal range for shade-loving plants. In the morning and evening hours, light levels occasionally approach the 300 to 1000 lux range but constitute only a small percentage of the day. Consequently, the base model lacks effective control over incoming light, with light intensity exceeding the permissible limit for shade-loving plants during most midday hours (Fig. 10).

- **Pattern 1 (Dodecagon)**

Analysis of monthly variations indicates that during warmer months, excessive light has been reduced; however, high light levels are still received during some midday hours. Hourly variation analysis shows that the highest light intensity occurs between 11: 00 and 14:00, ranging from 25,000 to 35,000 lux, which is lower than the base model but still exceeds the permissible limit during certain hours. The lowest light levels are observed between 06: 00 to 08: 00 and 17: 00 to 19:00, ranging from 400 to 700 lux, representing an increase compared to the base model. Regarding received light intensity, the light level during some midday hours remains above 1000 lux, though reduced compared to the base model. The proportion of light within the 300 to 1000 lux range has increased but remains insufficient during certain hours of the day. Consequently, Pattern 1 partially reduces excessive light and increases the percentage of optimal light; however, light intensity during some midday hours remains excessive (Fig. 11).

- **Pattern 2 (circular geometry)**

Analysis of monthly variations reveals that excessive light during summer months is reduced compared to Pattern 1, with optimal light levels better maintained throughout all months of the year. Hourly variation analysis indicates that the highest light intensity occurs between 11: 00 and 14:00, ranging from 1,500 to 2,500 lux, reflecting a greater reduction compared to the previous two models. The lowest light levels are observed between 06: 00 to 08:00 and 18:00 to 20:00, ranging from 5,000 to 9,000 lux, which is closer to the optimal range. Regarding received light intensity, the amount of light exceeding 1,000 lux is lower than in the previous two models, and the hours within the 300 to 1,000 lux range have increased. During some morning and evening hours, light levels fall below 300 lux. Consequently, Pattern 2 provides better control over light levels compared to the base

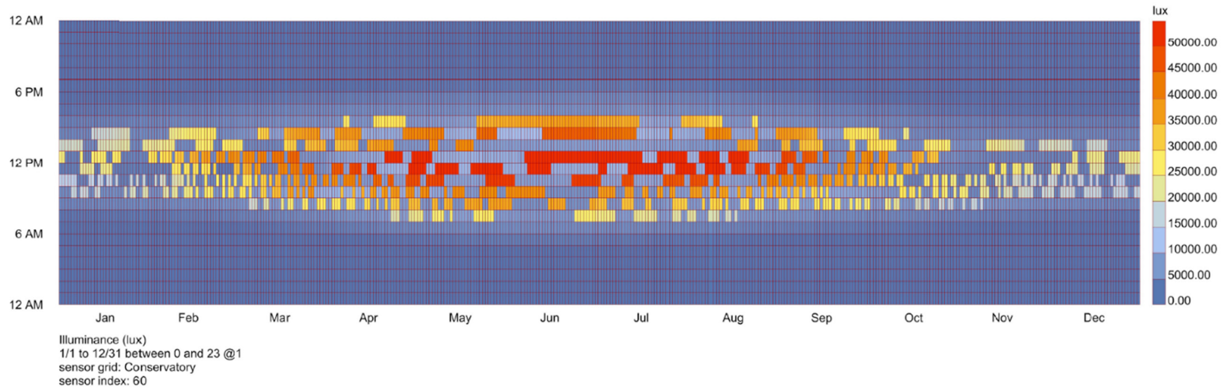


Fig. 10. Annual hourly chart of light received in the greenhouse in lux for the base model. Source: Authors.

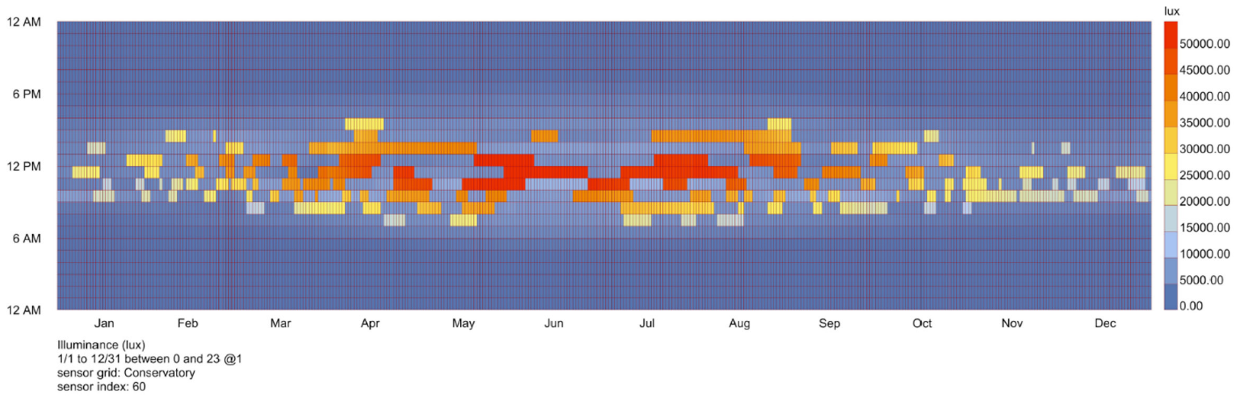


Fig. 11. Annual hourly chart of light received in the greenhouse in lux for Pattern 1. Source: Authors.

model and Pattern 1, achieving a more balanced reduction of excessive light and an increase in optimal light (Fig. 12).

- **Pattern 3 (circle)**

Analysis of monthly variations shows that this pattern optimally regulates the light entering the greenhouse across all months of the year. Hourly variation analysis indicates that the highest light intensity occurs between 12: 00 and 14:00, ranging from 10,000 to 18,000 lux, which represents the lowest amount of excessive light among all patterns. The lowest light levels are observed between 06: 00 to 08: 00 and 18: 00 to 20:00, ranging from 600 to 1,100 lux, which falls entirely within the optimal range. Regarding received light intensity, the amount of light exceeding 1,000 lux is minimized, with the majority of received light falling within the 300 to 1,000 lux range. Consequently, Pattern 3 demonstrates the best performance in light control, maintaining received light within the optimal range across all hours (Fig. 13).

Final Comparison of the Base Model and Movable Shell Patterns

Based on Table 3, Pattern 3 is the most optimal option for greenhouses cultivating shade-loving plants, as it effectively regulates light intensity across all months of the year, increases the hours of optimal light, and prevents excessive light exposure.

Energy Consumption Based on the Annual Energy use Intensity (EUI) Index

The EUI index, a key metric for assessing energy consumption in buildings, quantifies energy use in kilowatt-hours per square meter (kWh/m²). It is calculated by dividing the total energy load by the studied area's floor space, reflecting the energy consumed over a specific period (Mardaljevic et al., 2009؛Gonçalves, 2024؛ Nabil et al., 2009؛ Ma & Cheng, 2016؛ Abedini et al.,2025). Table 4 presents the energy consumption for the base model and the three proposed patterns. The data indicate that Pattern 3 is the most energy-efficient option, while the base

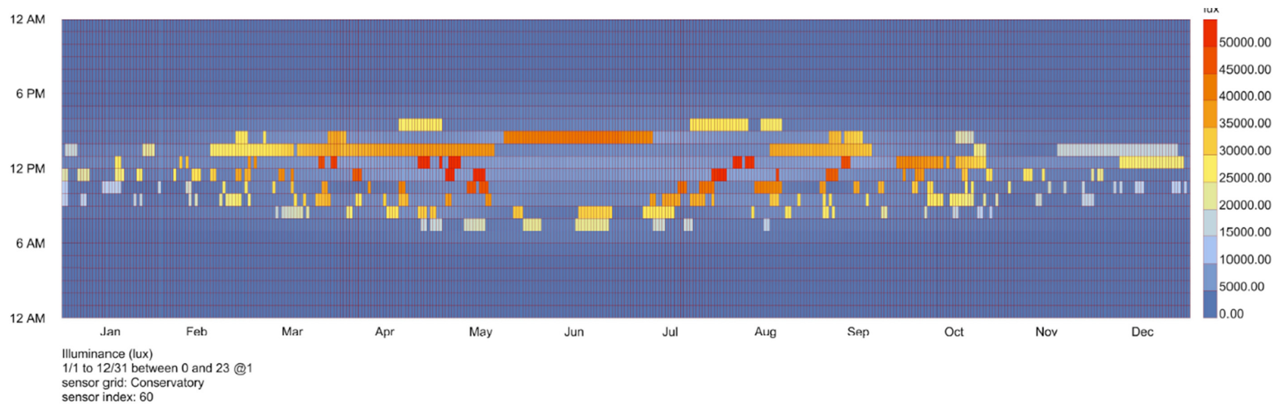


Fig. 12. Annual hourly chart of light received in the greenhouse in lux for Pattern 2. Source: Authors.

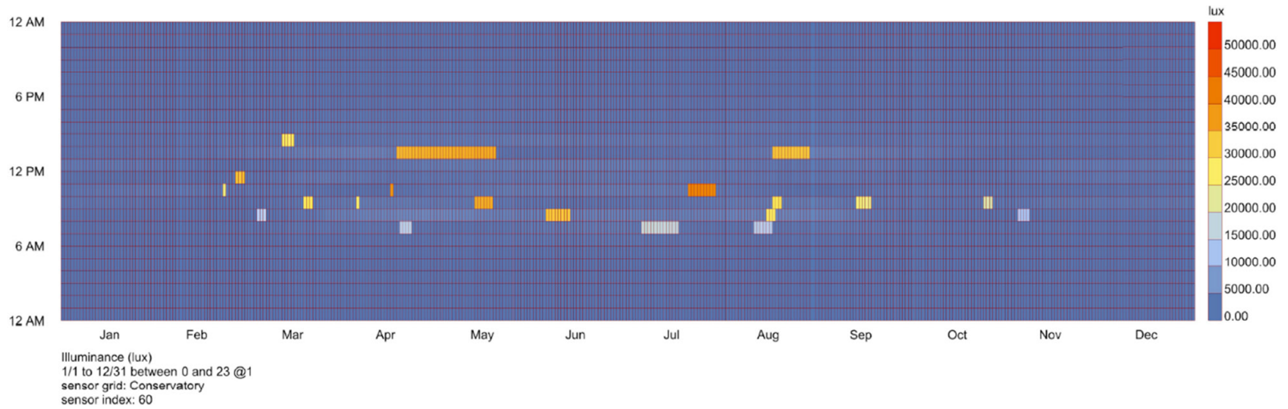


Fig. 13. Annual hourly chart of light received in the greenhouse in lux for Pattern 3. Source: Authors.

Table 3. A comparison between the base model and moving shell patterns using annual light reception. Source: Authors.

Model/ Pattern	Monthly Variations (January–December)	Hourly Variations (00:00–24:00)	Received Light Intensity (Lux)	Overall Outcome
Base Model	Highest daylight in summer, lowest in winter	Peak illumination from 10:00 to 16:00, reduced levels in morning/ evening	Over 1000 lux during most hours, limited optimal daylight	Poor control, excessive light levels, insufficient optimal daylight
Pattern 1	Improved summer control, but over-illumination persists in some months	Moderate reduction from 10:00 to 16:00, but excessive light still occurs	Decrease in excessive light, but the optimal range still needs tuning	Moderate improvement, midday over-illumination remains.
Pattern 2	Better summer control, daylight preserved in winter	Optimized daylight from 10:00 to 16:00	Increased optimal daylight, reduced excessive illumination	Enhanced control, more optimal daylight, reduced excessive lighting
Pattern 3	Best light control throughout the year	Ideal adjustment between 10:00 and 16:00	Maximum optimal range (300–1000 lux), minimal over-illumination	Best performance, highest optimal daylight, lowest excessive light

Table 4. Energy consumption in the greenhouse. Source: Authors.

Energy Consumer	Equipment Type	Pattern One	Pattern Two	Pattern Three	Base Model	Highest	Lowest
Heating	Radiant Heating System	22.22	27.61	34.05	21.82	Pattern Three	Base Model
Cooling	Environmental Cooling Fan	51.09	40.81	32.17	53.39	Base Model	Pattern Three
Interior Lighting	Plant Growth Wall Washer Lamp	6.05	5.85	5.15	7.23	Base Model	Pattern Three
Electrical Equipment	Includes Various Appliances	75.17	73.29	68.33	81.06	Base Model	Pattern Three
Ventilation System	Exhaust Fan	2.93	3.80	4.52	2.91	Pattern Three	Base Model
Pumps	Industrial Water Pumps	7.87	7.53	6.97	10.52	Base Model	Pattern Three
	Total Index (EUI) (kWh/m²)	165.33	158.89	154.19	176.93	Base Model	Pattern Three

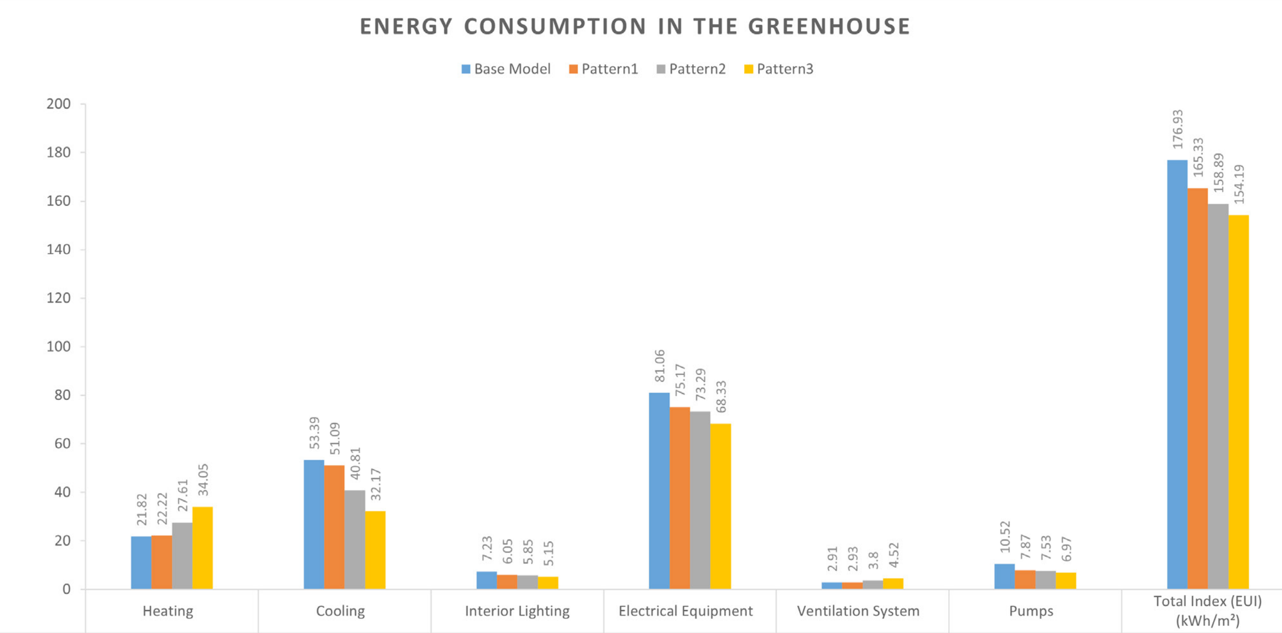
model exhibits the highest energy consumption. Analysis of different energy consumption components reveals that the radiant heating system in Pattern 3 has the highest consumption at 34. 05 kWh/m², compared to the base model's 21. 82 kWh/m², the lowest among the models. This increase in Pattern 3 is likely due to the need to maintain more optimal temperature conditions for plant growth. Conversely, the cooling system's energy consumption in Pattern 3 is reduced to a minimum of 32. 17 kWh/m², potentially resulting from optimized ventilation, reduced reliance on mechanical cooling, and the use of natural ventilation. Energy consumption for internal lighting in Pattern 3 is 5. 15 kWh/m², a significant reduction compared to the base model's 7. 23 kWh/m². This decrease reflects optimized lighting design, the use of energy-efficient LED lamps, and the effective utilization of natural light. For electrical equipment, the base model shows the highest consumption at 81. 06 kWh/m², while Pattern 3 records the lowest at 68. 33 kWh/m², likely due to better management of electrical loads and optimization of equipment. The energy consumption of ventilation fans in Pattern 3 reaches 4. 52 kWh/m², the highest among the models, compared to the base model. This increase may stem from more consistent use of mechanical ventilation systems or reduced reliance on active cooling. Meanwhile, the energy consumption of water pumps in Pattern 3 is 6. 97 kWh/m², a notable reduction from the base model's 10. 52 kWh/m², indicating optimization in irrigation and water recirculation systems. Overall, the total EUI for the base model is 176. 93 kWh/m², while in Pattern 3, it is reduced to 154. 19 kWh/m², representing a 12.85% decrease in total energy consumption. This reduction highlights Pattern 3 as the most efficient option for energy management in greenhouses. However, the increased energy use in heating and ventilation in some patterns suggests that reducing consumption in one sector may lead to increased consumption in others. Therefore, integrating and balancing energy management systems is essential to achieve maximum efficiency.

Given that the primary objective of this research is to control light in the greenhouse environment for shade-loving plants, with the required light range for these plants being 300 to 1,000 lux, a comparison was conducted between Pattern1, Pattern2, Pattern3, and the base model (conventional approach) based on the UDI index within this range. According to Table 5, Pattern 3 is the most effective pattern for achieving this objective.

Furthermore, the analysis of energy simulation results indicates that among the three patterns, Pattern 3 exhibits the lowest annual energy consumption, while Pattern 1 has the highest. However, compared to the base model, the base model records the highest energy consumption overall. According to Fig. 14, Pattern 3 is the most energy-efficient, demonstrating the lowest energy consumption among all patterns. The research findings confirm that Pattern 3 consistently outperforms the other patterns. Given that Pattern 3 features a square geometry without curves, this characteristic contributes to its superior performance in terms of both light and energy efficiency compared to the other two patterns.

Table 5. A comparison of UDI indices in the greenhouse. Source: Authors.

Greenhouse Model	UDI (300–1000 lux) in %	Average
Pattern One	10.02% to 57.06%	33.09%
Pattern Two	22.06% to 73.085	48.02%
Pattern Three	63.02% to 91.04%	7.03%
Base Model	7.02% to 28.09%	18.05%



	Heating	Cooling	Interior Lighting	Electrical Equipment	Ventilation System	Pumps	Total Index (EUI) (kWh/m²)
Base Model	21.82	53.39	7.23	81.06	2.91	10.52	176.93
Pattern1	22.22	51.09	6.05	75.17	2.93	7.87	165.33
Pattern2	27.61	40.81	5.85	73.29	3.8	7.53	158.89
Pattern3	34.05	32.17	5.15	68.33	4.52	6.97	154.19

Fig. 14. Energy consumption diagram in a greenhouse. Source: Authors.

Conclusion

This research aimed to control daylight in greenhouse environments for shade-loving plants, and its findings demonstrate that the use of movable shells can effectively achieve this goal. To accomplish this, traditional Iranian architectural methods were employed, with the design of movable shell panels inspired by the traditional Orosi windows of old houses in Mazandaran province. In the simulations conducted, two geometries—square and Dodecagon—were evaluated, with results indicating that the square geometry offers superior performance in regulating greenhouse light and reducing energy consumption. The innovation of this research lies in defining a light index for non-human environments and controlling light in greenhouses. To this end, the UDI index was tailored to the light requirements of shade-loving plants in greenhouse settings. A comparison of this research with previous studies shows that movable shells, similar to their applications in other architectural contexts (residential, office, educational, etc.), can effectively control daylight and reduce energy consumption. In terms of daylight control, Abedini et al. (2025) demonstrated that fixed shading devices reduce excessive light (ASE) and improve daylight quality. Yunitsyna & Sulaj (2025) utilized a biomimetic-inspired movable shading system and found that adaptive systems can reduce glare and optimize light distribution. Goharian et al. (2025) achieved an increase in the UDI index from 49% to 90% through adaptive movable facades, confirming the positive impact of movable systems on daylight regulation. The present research similarly demonstrates that movable shells, akin to smart shading systems and adaptive facades in prior studies, can effectively control daylight. Notably, compared to fixed shading systems (Abedini et al., 2025), movable shells offer greater adaptability to changing sunlight conditions, providing an optimal light range for shade-loving plants. Furthermore, aligning with Goharian et al. (2025), this research confirms the positive impact of adaptive designs in increasing optimal light levels, with Pattern 3 (square geometry) providing the highest amount of useful light for shade-loving plants. Regarding energy consumption, Mahyari et al. (2022) showed that adaptive shells reduced cooling loads by up to 56%. Kızılorenli & Maden (2023) found that responsive modular facades significantly reduced energy consumption. Khatibi et al. (2021) demonstrated that facades equipped with movable shading systems reduced energy consumption more effectively than other alternatives. The findings of this research align with these studies, showing that Pattern 3 (square geometry) achieves the lowest energy consumption compared to the base model and other patterns. Consistent with Mahyari et al. (2022), this study indicates that movable shells, particularly in greenhouse design, can significantly reduce energy consumption. Additionally, it aligns with Kızılorenli & Maden (2023), emphasizing that responsive and adaptive systems, even in greenhouse environments, can positively reduce reliance on artificial energy. However, in terms of innovation, previous studies have primarily focused on human-centric environments such as residential, office, and educational buildings, addressing light control for human comfort, with no specific index defined for controlling light in greenhouses for shade-loving plants. This research introduces a novel application by defining the UDI index for greenhouse environments and establishing a specific metric for light control tailored to shade-loving plants. While past studies focused on optimal light for humans, this research demonstrates that similar principles can be applied to greenhouses. Furthermore, the design of movable shells inspired by traditional Orosi windows represents an innovative use of vernacular elements in sustainable architecture. The primary distinction of this research lies in its focus on non-human environments (greenhouses) and the development of a light index specifically for shade-loving plants, an area underexplored in prior studies. Despite these significant findings, this research has limitations that should be considered when interpreting the results. First, the study was conducted in the temperate and humid climate of Babolsar, so the generalizability of the results to other climates, such as hot and dry or cold regions, requires further investigation under varying climatic conditions. Second, the plants studied were primarily shade-loving indoor plants, and the results may not apply to other plant species with different light requirements. Additionally, the research focused on light and energy indices, without a comprehensive analysis of economic or biological factors, such as maintenance costs or humidity and temperature conditions. These aspects could be explored in greater detail in future studies to provide a more comprehensive evaluation of the performance of movable shells in greenhouse environments.

References list

- Abedini, M. H., Gholami, H., & Sangin, H. (2025). Multi-objective optimization of window and shading systems for enhanced office Building performance: A case study in Qom, Iran. *Journal of Daylighting, 12*(1), 91-110. https://dx.doi.org/10.15627/jd.2025.6
- Atamewan, E. E. (2022). Appraisal of Day-lighting in Sustainable Housing Development in Developing Countries. *Journal of Studies in Science and Engineering, 2*(2), 59-75. https://doi.org/10.53898/josse2022225
- Bahri, S. Y., Forment, M. A., Riera, A. S., Heiranipour, M., & Hosseini, S. N. (2025). Kinetic facades as a solution for educational buildings: A multi-objective optimization simulation-based study. *Energy Reports, 13,* 3915-3928. https://doi.org/10.1016/j.egyr.2025.03.021
- Brzezicki, M. (2024). Enhancing Daylight Comfort with Climate-Responsive Kinetic Shading: A Simulation and Experimental Study of a Horizontal Fin System. *Sustainability, 16*(18), 8156. https://doi.org/10.3390/su16188156
- Edwards, L., & Torcellini, P. (2002). *Literature review of the effects of natural light on building occupants*. https://www.nrel.gov/docs/fy02osti/30769.pdf
- Fathi Pir-Kashani, S. (2020). *Tarahi-e sakhteman-e boland-martabeh ba hadaf-e behineh-sazi-ye masraf-e enerji az tariq-e posteh-ha-ye hoshmand* [Design of a high-rise building with the aim of optimizing energy consumption through smart skins] [Master's Thesis, Razi University]. https://ganj.irandoc.ac.ir/#/articles/fed338a3b701873cc34f6c868d4d67e8
- Goharian, A., Mahdavinejad, M. J., Ghazazani, S., Hosseini, S. M., Zamani, Z., Yavari, Y., Ghafarpoor, F., & Shoghid, F. (2025). Designing Adaptability Strategy to a Novel Kinetic Adaptive Façade (NKAF); Toward a Pioneering Method in Dynamic-objects Daylight Simulation (Post-Processing). *Journal of Daylighting 12*(1), 69-90. https://dx.doi.org/10.15627/jd.2025.5
- Gonçalves, M., Figueiredo, A., Almeida, R. M. S. F., & Vicente, R. (2024). Dynamic façades in buildings: A systematic review across thermal comfort, energy efficiency and daylight performance. *Renewable and Sustainable Energy Reviews, 199*, 114474. https://doi.org/10.1016/j.rser.2024.114474
- Heshmati, P. (2019). *Tarahi-e posteh-e taghyir-pazir-e hoshmand ba elham az giyahan baraye tanzim-e sharayet-e mohiti-e dakheli-ye faza, tarahi-e bagh va markaz-e tahghighat-e giyah-shenasi dar Tehran* [Design of an intelligent adaptive envelope inspired by plants to regulate indoor environmental conditions; designing a botanical garden and research center in Tehran] [Master's Thesis, Pars Institute of Architecture and Art]. https://ganj.irandoc.ac.ir/#/articles/fed338a3b701873cc34f6c868d4d67e8
- Hosseini, S. M., Mohammadi, M., & Guerra-Santin, O. (2019). Interactive kinetic façade: Improving visual comfort based on dynamic daylight and occupant's positions by 2D and 3D shape changes. *Building and Environment, 165,* 106396. https://doi.org/10.1016/j.buildenv.2019.106396
- Huang, T., Huang, W., Zhang, B., Chen, W., & Pan, X. (2025). Optimizing energy consumption in centralized and distributed cloud architectures with a comparative study to increase stability and efficiency. *Energy and Buildings, 333,* 115454. https://doi.org/10.1016/j.enbuild.2025.115454
- Khatibi, A., Shahbazi, M., & Torabi, Z. (2022). Analyzing the thermal behavior of facades in order to determine the optimal performance of energy consumption (Case study: An office building in Tehran). *Journal of Renewable and New Energy, 9*(2), 121-129. https://doi.org/20.1001.1.24234931.1401.9.2.13.6
- Kızılörenli, E., & Maden, F. (2023). Modular responsive facade proposals based on semi-regular and demi-regular tessellation: Daylighting and visual comfort. *Frontiers of Architectural Research, 12*(4), 601-612. https://doi.org/10.1016/j.foar.2023.02.005
- Lee, E. S., Matusiak, B. S., Geisler-Moroder, D., Selkowitz, S. E., & Heschong, L. (2022). Advocating for view and daylight in buildings: Next steps. *Energy and Buildings, 265*, 112079. https://doi.org/10.1016/j.enbuild.2022.112079
- Li, L. (2024). Research on daylighting optimization of building space layout based on parametric design. *Sustainable Buildings, 7*(3). https://doi.org/10.1051/sbuild/2024003
- Ma, J., & Cheng, J. C. (2016). Estimation of the building

energy use intensity in the urban scale by integrating GIS and big data technology. *Applied energy, 183*, 182-192. https://doi.org/10.1016/j.apenergy.2016.08.079

• Mahmoud, A. H. A., & Elghazi, Y. (2016). Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns. *Solar Energy, 126*, 111-127. https://doi.org/10.1016/j.solener.2015.12.039

• Mardaljevic, J., Heschong, L., & Lee, E. (2009). Daylight metrics and energy savings. *Lighting Research & Technology, 41*(3), 261-283. https://doi.org/10.1177/1477153509339703

• Mehyari, H., Zarkesh, A., & Mahdavi-Nezhad, M. J. (2022). Era'e-ye yek posteh-ye tatbiq-pazir-e hoshmand ba roykard-e biomimetic baraye kahesh-e masraf-e enerji [A biomimetic-based adaptive smart envelope for reducing energy consumption]. *Hoviat-e Shahr, 16*(52), 23–38. . https://doi.org/10.30495/hoviatshahr.2022.64865.12140

• Mengmeng, W. A. N. G., Zhuoying, J. I. A., & Lulu, T. A. O. (2024). Review of dynamic façade typologies, physical performance and control methods: Towards smarter and cleaner zero-energy buildings. *Journal of Building Engineering, 98*, 111310. https://doi.org/10.1016/j.jobe.2024.111310

• Mirmomtaz, S. M. M., Baharvand, M., Dehghan, N., & Safikhani, T. (2025). Multi-objective Optimization of Two Types of Kinetic Shading Devices to Enhance Energy Efficiency and Daylighting. Sustainable *Development of Geographical Enviroment, 6*(11), 41-58. https://doi.org/10.48308/sdge.2024.234834.1187

• Nabil, A., & Mardaljevic, J. (2005). Useful daylight illuminance: a new paradigm for assessing daylight in buildings. *Lighting Research & Technology, 37*(1), 41-57. https://doi.org/10.1191/1365782805li128oa

• Nashaat, B., & Waseef, A. (2017). *Responsive kinetic façades: an effective solution for enhancing indoor environmental quality in buildings*. In The First Memaryat International Conference (MIC 2017) Architecture of the Future: Challenges and Visions. Saudi Arabia. https://www.researchgate.net/publication/330347504_Responsive_Kinetic_Facades_An_Effective_Solution_for_Enhancing_Indoor_Environmental_Quality_in_Buildings?utm_source=chatgpt.com

• Nasr, T., Yarmahmoodi, Z., & Ahmadi, S. (2020). The Effect of Kinetic Shell's Geometry on Energy Efficiency Optimization Inspired by Kinetic Algorithm of Mimosa pudic. *Naqshejahan, 10*(3), 219-230. https://doi.org/20.1001.1.23224991.1399.10.3.3.3

• Özdemir, H., & Çakmak, B. Y. (2022). Evaluation of daylight and glare quality of office spaces with flat and dynamic shading system facades in hot arid climate. *Journal of Daylighting, 9*(2), 197-208. https://dx.doi.org/10.15627/jd.2022.15

• Reinhart, C. F. (2014). *Daylighting handbook I: Fundamentals, designing with the sun*. https://www.researchgate.net/publication/309661177_Daylighting_Handbook_I

• Saleh, M. T., Mansour, Y., Kamel, S., Dewidar, K., & Farid, A. A. (2022, August). Towards a Taxonomy of The 21st century Architectural Practices in the age of Sustainability and Technology. *In IOP Conference Series: Earth and Environmental Science* (Vol. 1056, No. 1, p. 012011). IOP Publishing. https://doi.org/10.1088/1755-1315/1056/1/012011

• Sharaidin, K. (2014). *Kinetic facades: towards design for environmental performance* (Doctoral dissertation, RMIT University). https://core.ac.uk/outputs/32229184/

• Sheikhi Nashlaji, M., & Mahdizadeh Seraj, F. (2022). Tarahi-e sayeban-e hoshmand baraye sakhteman-e edari baraye kontrol-e vorood-e noor-e mostaghim-e khorshid bar asas-e kahesh-e bar-e sarmayeshi ba algo-bardari az gereh-haye Eslami-Irani [Design of a smart shading system for administrative buildings to control direct sunlight using Islamic-Iranian patterns]. *Modern Architectural Research Journal, 2*(1), 7–26. https://dorl.net/dor/20.1001.1.28209818.1401.2.1.1.6

• Shokri, A. (2015). *Tarahi-e nama-ye motaharek dar raste-ye kontrol-e noor-e khorshid dar sakhteman-e edari* [Design of a kinetic facade to control sunlight in an office building] [Master's Thesis, University of Mazandaran]. https://ganj.irandoc.ac.ir/#/articles/d0403163635c20c454aa8e3671d28b79

• Syam, F. H., Wisdianti, D., Sajar, S., & Bahri, S. (2023). Study of sustainable architecture concepts. *International Journal of Research and Review, 10*(4), 419-424. https://doi.org/10.52403/ijrr.20230450

• Takhmasib, M., Lee, H. J., & Yi, H. (2023). Machine-learned kinetic Façade: Construction and artificial intelligence enabled predictive control for visual comfort. *Automation in Construction, 156*, 105093. https://doi.org/10.1016/j.autcon.2023.105093

• Yano, M., Kojima, S., Takahashi, Y., Lin, H., & Sasaki, T. (2001). Genetic control of flowering time in rice, a short-day plant. *Plant Physiology, 127*(4), 1425-1429. https://doi.org/10.1104/pp.010710

• Yarmahmoodi, Z., Nasr, T., Moztarzadeh, H. (2023). Algorithmic Design of Building Intelligent Facade to Control the Daylight Inspired by the Rafflesia Flower Kinetic Pattern. *Naqshejahan, 13*(2), 1-24.

• Yeang, H. Y. (2013). Solar rhythm in the regulation of photoperiodic flowering of long-day and short-day plants.

Journal of Experimental Botany, 64(10), 2643-2652. https://doi.org/10.1093/jxb/ert130

- Yunitsyna, A., & Sulaj, E. (2025). Daylight Optimization of the South-Faced Architecture Classrooms Using Biomimicry-Based Kinetic Facade Shading System. *Journal of Daylighting, 12*(1), 1-20. https://dx.doi.org/10.15627/jd.2025.1
- Zabihi, A., Mirzaei, R., Yazhari Kermani, A., & Heidari, A. (In-press). Optimizing the geometric pattern of light reception in the Sabak element to enhance the Optimal daylight level and use in the office building of Kerman. *Journal of Urban Ecology Researches*. https://doi.org/10.30473/grup.2025.70487.2833
- Zhang, Y., Zhang, Y., & Li, Z. (2022). A novel productive double skin façades for residential buildings: Concept, design and daylighting performance investigation. *Building and Environment, 212*, 108817. https://doi.org/10.1016/j.buildenv.2022.108817

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