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Evaluating responsive façade shading for enhancing daylighting performance in university classrooms across Egyptian regions

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Abstract

Daylight quality and visual comfort are critical parameters in learning environments, particularly in climates with intense solar exposure. This study investigates responsive façade shading as a climate-adaptive strategy to improve indoor daylight performance in university classrooms across four Egyptian regions: West Cairo, Aswan, Alexandria, and Hurghada. A parametric simulation workflow was developed using Rhino, Grasshopper, Ladybug, Honeybee, Galapagos, and Wallacei-x to analyze annual daylight metrics (DA, UDI), visual comfort (DGP), and Quality of View (QV) under static and adaptive façade configurations. Findings demonstrate strong climatic dependence. Responsive shading consistently reduced over-lighting and lowered DGP, with the 50% opening ratio providing the most effective glare mitigation, while the 80% configuration improved daylight uniformity. Hurghada achieved the most balanced performance, combining stable DA and high QV with moderate glare levels. West Cairo maintained high DA but exhibited significant UDI instability, requiring finer modulation. Alexandria showed limited added benefit from responsiveness, and Aswan remained glare-dominated, indicating the need for additional control strategies. The study concludes that responsive shading should be deployed selectively and tailored to the climate, offering region-specific recommendations for future educational building design in Egypt.

Keywords Responsive facade, Visual comfort, Single and Multi-objective optimization, Educational buildings

1 Introduction

To regulate various climatic factors, such as temperature, solar radiation, humidity, and wind, an energy-efficient building envelope is required [1]. In this context, glazing and shading systems are essential elements, as they provide natural ventilation and daylighting while reducing undesirable solar heat gains. The proper design of these systems enhances overall building performance by ensuring indoor comfort, improving energy efficiency, reducing life cycle costs, and promoting occupants' productivity, well-being, and visual satisfaction [2]. In educational facilities, achieving optimal visual conditions, whether through natural or artificial lighting, is critical, as it directly influences



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students' performance and the overall quality of the learning environment [3]. Daylighting is the process of utilizing daylight to create desired lighting effects in buildings, such as highlighting objects and task areas. Despite its benefits, creating well-lit and visually comfortable spaces remains challenging due to functional requirements and users' subjective perception of light [4, 5]. However, an oversupply of daylight can lead to negative effects, such as glare risks, room overheating, and a lack of privacy [4]. Globally, over 40% of educational buildings exhibit inadequate indoor environmental quality, and 60–70% require additional heating, cooling, or ventilation interventions [6]. As the interface between indoor and outdoor environments, the façade acts as a thermal barrier and a critical shading element that controls solar exposure and influences visual comfort. However, shading systems often involve conflicting functionalities. Adequate daylighting is vital for maintaining occupants' physiological and psychological well-being, enhancing work efficiency, and supporting positive emotional states [5]. In production, work, and study spaces, a comfortable light environment can lift spirits and enhance work efficiency. Therefore, the design of the façade is essential for a well-designed building [7, 8]. Optimizing solar protection can decrease daylight penetration, which affects the visual comfort of occupants and raises the need for artificial lighting [9]. The effectiveness of shading devices depends on factors such as orientation, materiality, color, geometry, depth, and perforation percentage [10]. To address these interrelated variables and enhance building performance, parametric design and multi-objective optimization techniques are frequently employed to identify solutions that satisfy multiple performance criteria simultaneously [8, 9]. In Egypt, visual discomfort in educational spaces is exacerbated by inadequate lighting, particularly in the rear zones of classrooms. Challenges such as glare, insufficient daylight, and uneven light distribution contribute to increased energy consumption and reduced academic performance in hot climatic regions. Figure 1 illustrates examples of educational buildings in Egypt, highlighting common design conditions in hot arid contexts that negatively affect visual comfort and, consequently, students' learning outcomes.

Educational buildings in Egypt's hot and dry climate face substantial challenges in maintaining indoor comfort while minimizing energy demand. Traditional façade configurations frequently lead to overheating and insufficient daylight, thereby increasing reliance on artificial lighting and cooling systems. Although responsive façade systems have the potential to enhance energy efficiency and visual comfort, their application in educational buildings remains underexplored [12]. On one hand, Classrooms and Lecture halls in Egypt's hot, dry environment are frequently overexposed to sunlight, especially on south and south-west facing façades, which causes considerable glare and warmth even with air conditioning. As illustrated in Fig. 2, the transition from

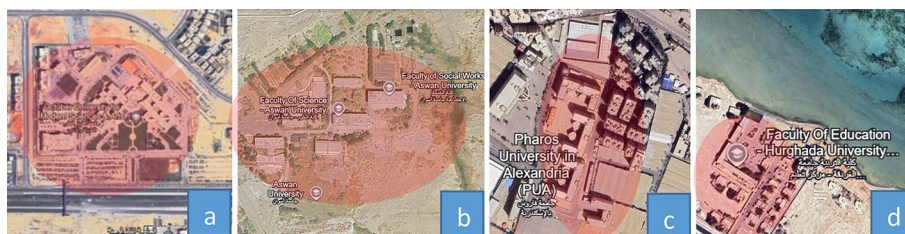


Fig. 1 a) University in 6 October city in Giza, b) Aswan University, c) Pharos University Alexandria, d) Hurgada University. Source: By the author using Google Earth Pro version 7.3.6.9

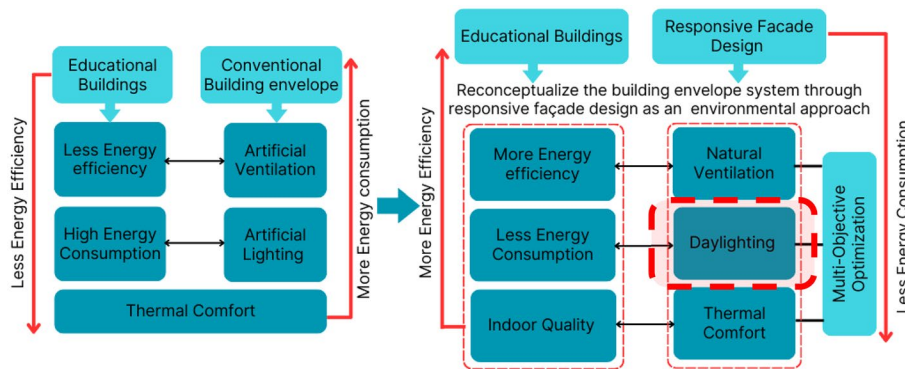


Fig. 2 Re-conceptualize the building envelope system through responsive façade design as an environmental approach. Source: Author

conventional building envelopes, which rely on artificial ventilation and lighting and result in high energy consumption, to responsive façade designs that enhance natural ventilation, daylighting, and thermal comfort, leading to improved energy efficiency and indoor quality. The approach supports multi-objective optimization to reduce overall energy consumption in educational buildings. This research will be on Daylighting.

Climatic variations across Egyptian regions, including the hot-desert conditions of Cairo, the hot-humid climate of Hurghada, the hot-arid environment of Aswan, and the humid Mediterranean climate of Alexandria, necessitate location-specific façade design strategies. This diversity underscores the importance of evaluating responsive façade performance across different environmental contexts. At the same time, university campuses serve as strategic platforms for sustainability due to their extensive and diverse building stock, including lecture halls, laboratories, research centers, administrative buildings, and conference facilities [12, 13]. This study examines the impact of intelligent responsive façade systems on visual comfort and daylight performance in university classrooms across four Egyptian regions. It addresses the challenges associated with visual comfort metrics, explores design trade-offs, and employs multi-objective optimization to improve façade performance in diverse climatic contexts.

2 Background and related studies

In recent years, educational buildings have received increasing attention in environmental design research, with particular emphasis on improving visual comfort in classrooms and lecture halls due to their direct impact on student performance and well-being [11, 14]. As a result, incorporating natural daylight instead of relying solely on artificial lighting has become a key strategy for reducing energy consumption and supporting sustainable campus development, especially in hot climates such as Egypt [15]. The existing literature addressing daylighting and comfort in educational buildings can be organized into three interconnected themes:

- (a) strategies for enhancing visual comfort in educational spaces, (b) the role of daylighting in improving indoor environments and its associated trade-offs, and (c) single- and multi-objective optimization approaches for selecting optimal façade and shading solutions.

2.1 Strategies for enhancing visual comfort in educational spaces

Visual comfort in educational spaces depends on achieving adequate daylight availability, uniform luminance distribution, glare control, and avoidance of excessive brightness and contrast [16]. Several studies have investigated architectural and façade-based strategies to enhance visual comfort in educational buildings, particularly in hot and arid climates. These strategies include optimizing shading geometry, window configuration, glazing ratios, façade orientation, and material properties. For example [1], applied multi-objective optimization to middle school classrooms in hot and dry regions, demonstrating that appropriate shading configurations can simultaneously improve daylighting conditions and thermal comfort. Similarly [17], evaluated different shading strategies, such as vertical and horizontal louvers and egg-crate systems, using visual comfort indicators, including sDA and ASE, to identify climate-responsive façade solutions.

Other studies have examined the influence of glazing ratios and window layouts on visual comfort and energy performance. In a Turkish school building [18], demonstrated that the window-to-wall ratio and window configuration significantly affect daylight distribution and indoor comfort. Likewise [19], optimized shading depth, angle, and position in office spaces to enhance UDI while reducing glare probability (DGP) and energy consumption. For primary educational facilities [20], employed genetic algorithms to optimize orientation, wall angles, and glazing types, achieving improvements in both visual and thermal comfort. Parametric investigations into responsive façade systems were also conducted in [21], which analyzed sun-responsive skins using metrics such as sDA, ASE, UDI, and DGP to enhance visual comfort. In the Egyptian context [22], evaluated right-angled triangular responsive façades under Cairo's climatic conditions, highlighting reductions in solar radiation and improvements in indoor comfort.

2.2 Daylighting as a key factor in visual comfort and indoor environmental performance

Several studies highlight the need to assess daylight metrics as integrated systems rather than isolated indicators. While research has examined shading depth, window geometry, and material properties, the interactions among metrics such as UDI, DA, DF, DGP, sDA, and EUDI remain underexplored. Studies such as [23] investigated thermochromic glazing systems using LINMAP decision-making to optimize daylighting and energy performance. Research on glazing ratios and window configurations further demonstrates that façade parameters strongly shape daylight quality [18]. These findings underscore the importance of climate-sensitive design, particularly in regions like Egypt, where façade performance varies significantly between hot-dry, hot-humid, and Mediterranean climates. Daylighting is widely recognized as a critical factor in enhancing indoor environmental quality, reducing reliance on artificial lighting, and improving energy efficiency in educational buildings [15]. Adequate daylight provision has been shown to positively influence student performance by improving visual comfort and reducing eye strain, especially in classrooms and lecture halls [11]. However, the literature also highlights that excessive daylight can lead to adverse effects such as glare, uneven luminance distribution, overheating, and loss of visual comfort [16]. Effective daylight control, therefore, requires balancing daylight availability with glare prevention and thermal performance. Study [24] proposed a data-driven, multi-objective optimization framework to improve daylighting, view quality, and energy efficiency in residential buildings under hot and dry conditions in Cairo, Egypt. The findings emphasized the

importance of balancing spatial daylight autonomy, outside views, and energy consumption. These studies emphasize the importance of daylighting as a crucial component of indoor environmental quality. Nevertheless, existing research often focuses on selected daylight metrics without providing a comprehensive evaluation of visual comfort indicators or a detailed comparison of their trade-offs. This limitation is particularly critical in regions such as Egypt, where high solar intensity and sky conditions demand carefully tailored daylighting strategies.

2.3 Single and multi-objective optimization approaches for visual comfort and energy performance

To address the complexity of balancing daylighting, visual comfort, and energy efficiency, numerous studies have adopted single and multi-objective optimization approaches using parametric modeling and genetic algorithms. Review study [25] analyzed 141 peer-reviewed articles published between 2014 and 2021, identifying shading devices, building orientation, façade geometry, window-to-wall ratio, and material properties as the most frequently optimized variables. Optimization tools such as Ladybug, Honeybee, EnergyPlus, TRNSYS, Galapagos, Octopus, and Wallacei were commonly employed. In an educational building [15], applied parametric optimization and genetic algorithms to enhance daylighting performance, achieving a 91% reduction in direct sunlight exposure while maintaining 83% daylight availability. Similarly [26], applied NSGA-II optimization using Wallacei to educational buildings across multiple climatic zones in China, demonstrating significant trade-offs between daylight sufficiency (UDI) and energy use intensity (EUI). In the Egyptian context [27], employed a multi-objective optimization methodology to enhance thermal energy efficiency and daylighting in office buildings across Cairo, Alexandria, and Aswan. The study reported significant reductions in thermal energy use intensity and improvements in UDI, demonstrating the influence of climatic location on optimal design parameters. Material-specific optimization approaches were explored in [23] through thermo-chromic glazing and LINMAP decision-making, while broader envelope and form optimization strategies were investigated in [28]. Other studies expanded optimization frameworks to include qualitative and aesthetic criteria. For instance [29], introduced a multi-objective façade design method that balances engineering performance with architectural expression, while [30] proposed modular responsive façade solutions based on tessellation patterns.

Based on the reviewed literature, a clear gap exists in the integrated evaluation of visual comfort metrics in educational buildings. While previous studies have addressed visual comfort strategies, daylighting performance, and optimization techniques independently, a comprehensive framework that systematically analyzes the trade-offs between multiple visual comfort indicators (UDI, DA, DE, DGP, sDA, and EUDI) remains lacking. Moreover, limited attention has been given to climate-specific façade optimization for educational buildings in hot regions such as Egypt. In the provided Table 1, the summary of some studies that utilized parametric modeling and responsive façades for shading systems optimization is provided based on the related studies.

Table 1 Overview of various research employing parametric modeling and responsive façades for the optimization of shading systems

Ref.	Loca-tion	Building Type	Façade Design Variables	Simulation Tools	Parameters Investigated	Main Findings
[30]	Izmir, Turkey	Office Building	Modular responsive façade using triangular and hexagonal tessellation	Rhinoceros / Grasshopper/ ClimateStudio	UDI, sDA, ASE, DGP	Enhance daylighting and visual comfort using tessellation-based adaptive shading
[24]	Cairo, Egypt	Standard residential apartment (Dar Misr Project)	Window-to-wall ratio (WWR), space proportions (SP), sun breakers	Rhino 6, GrasshopperLadybug Honeybee EnergyPlus, Radiance, Octopus	Space proportions (X/Y), WWR, space function, usage schedules, construction materials	Minimize EUI (kWh/m ²)Maximize VPO, Maximize sDA (300/50%), Minimize ASE (1000 lx/250 h); produce regression-based design logic
[16]	Cairo, Egypt	Governmental school classroom	Retrofit external shading units with slats (varied number, depth, angle)	Rhino, Grasshopper, Ladybug, Honeybee, Radiance, Daysim, Octopus (MOO using GA)	Number of slats, slat depth, slat inclination angle	Optimize daylight availability (sDA, UDI > 2000), reduce glare (aSE, DGP), enhance visual comfort
[27]	Cairo, Alexandria, Aswan (Egypt)	3-floor open-plan office building	Skylights, variable WWR, horizontal shading	Rhino, Grasshopper, Ladybug, Honeybee, Radiance, EnergyPlus, Octopus (GA)	Building expansion (EW), floor expansion (NS), orientation, skylight %, WWR, shading depth	Reduce thermal energy use (EUI); increase daylight sufficiency (UDI 100–2000 lx); compare climate variation
[29]	Unspecified real project	Existing building façade	Parametric skin with morphable NURBS surfaces and user-defined patterns	Rhino, Grasshopper, Human UI, Ladybug, Honeybee, Radiance, Octopus	Wave amplitude, wave frequency, block size (a–d), user preference, sDA, ASE	Minimize ASE (1000 lx/250 h), Maximize sDA (300 lx/50%), Match the user's aesthetic preference through expert system conversion

3 Methods

The study examined climate data specific to the study regions to understand the environmental setting. It then evaluated regional relevance using an optimization approach for a university classroom in Cairo, Alexandria, Aswan, and Hurghada. The performance criteria were divided into three parts: an analytical study on the theoretical model of the selected regions, a single and multi-objective optimization framework using Galapagos and Wallacei-x to assess trade-offs, and a comparative analysis to identify the most effective façade designs for balancing visual comfort and energy efficiency in hot, dry, and humid climates in different climatic zones. A preliminary single-objective optimization using Galapagos was performed to identify the base case for daylight availability and glare. These limits were then used as performance boundaries to guide the evolutionary population in Wallacei-x during multi-objective Pareto optimization.

3.1 Classroom case study model in Egyptian universities

Based on the previous analysis, a standardized theoretical classroom model was developed to represent a typical university classroom evaluated under four Egyptian climatic regions (Giza, Alexandria, Hurghada, and Aswan). The classroom geometry was not associated with a specific region; rather, it was derived from averaged dimensions reported in prior empirical studies conducted in Egyptian university buildings,

specifically at Sohag University and October Modern University for Sciences and Arts in West Cairo (6 October City) [14, 31]. These dimensions are consistent with the classroom specifications established by the Egyptian Educational Buildings Authority and are illustrated in Fig. 3. The resulting theoretical classroom has average dimensions of $10 \times 7 \times 3.5$ m, with an 80% WWR and a large south-facing window measuring 8.75×3.2 m.

The baseline classroom configuration employs clear single glazing with a visible transmittance of 0.67, reflecting the most common construction practice in Egyptian educational buildings. Although the south façade incorporates a performance-oriented design, improvements in daylight availability and glare control were achieved through the application of an optimized dynamic shading system rather than through modifications to the glazing type. The classroom is designed to accommodate 40–45 occupants, with an average area of approximately 1.55 m^2 per person. This standardized configuration provides a consistent basis for evaluating daylighting performance, and visual comfort-related indicators under varying climatic conditions, as demonstrated in the simulation and optimization stages.

- **University Classroom theoretical model:**

This research deals with the following case study of the classroom according to the design requirements of the Egyptian Educational Buildings Authority in three Egyptian regions, as shown in Fig. 4. Table 2 presents a case study of characteristics that comply with the architectural specifications set out by the Egyptian Educational Buildings Authority.

The chosen classroom dimensions and southern orientation exemplify a prevalent arrangement in Egyptian public universities. Although this limits full generalization, the proposed optimization framework is scalable and can be applied to different classroom geometries and orientations in future studies.

The selected classroom geometry ($10 \times 7 \times 3.5$ m) represents a common modular classroom size in public Egyptian university buildings constructed during the last decades. A south-facing orientation was selected as a critical case due to its high exposure to direct

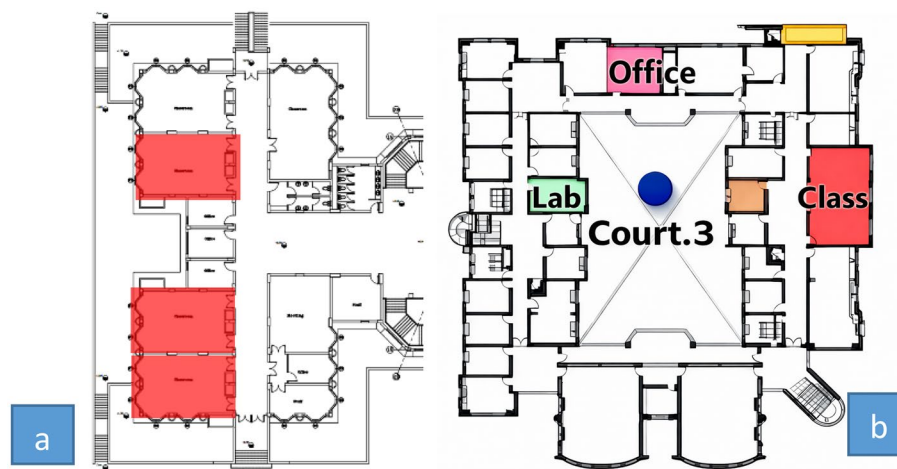


Fig. 3 The figure illustrates the standardized classroom geometry derived from previous Egyptian university case studies. Red shapes are classes, **a**): classrooms MSA University, **b**): classroom in Sohag University, Source: a-Author, B: [14, 31]

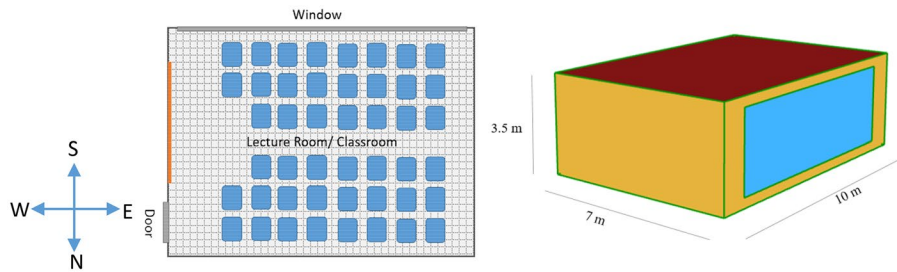


Fig. 4 Classroom theoretical model and north arrow direction, Source: Grasshopper Model created by the Author

Table 2 Characteristics of the University Classroom model (one module from the previous building, Modeled base case configuration:

Location	Cairo (Giza), Alexandria, Aswan, and Hurghada
Type of Building	Classroom/ Educational Building
Space Dimensions (L*W*H)	10*7*3.5
WWR	80%
Number of Windows	1
Window dimension	8.75*3.2
Windows Orientation	South
Façade treatment Orientation	South
Single glass: Transmittance of glass	0.68
Number of Occupancy	40–45 people
Occupancy Schedules	8:00 AM – 5:00 PM
Sun Exposure Angle	Giza: sun's altitude in mid days (12:00–13:00) Range: 37–41 Aswan: sun's altitude in mid days (12:00–13:00) Range: 42–47 Alexandria: sun's altitude in mid days (12:00–13:00) Range: 36–39 Hurghada: sun's altitude in mid days (12:00–13:00) Range: 38–43

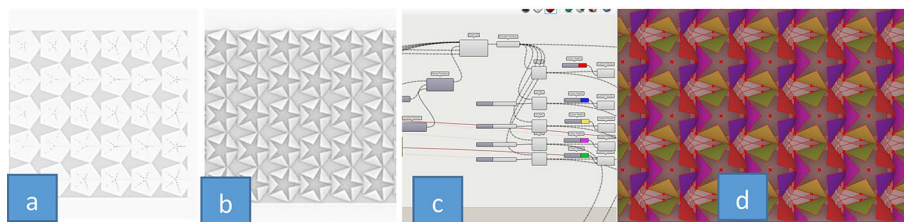


Fig. 5 (a) Responsive Façade design when it's closed, (b) script from grasshopper for parametric modeling of facade, and (c) zoom in on shading-colored panels from Grasshopper highlighted the border of on unit, (d) partially open facade. Source: Author

solar radiation, making it suitable for evaluating the effectiveness of responsive shading systems under demanding daylight conditions.

• **Characteristics of facades 5-polygon shading geometries configuration:**

The Grasshopper-modeled façade design optimizes daylight and visual comfort by transitioning between closed and partially open states, adapting to changing environmental conditions, as shown in Fig. 5. The responsive façade was parametrically defined as a

Table 3 Characteristics of façade configuration (Responsive Façade)

Shape of modules	Polygon 5 segments
Number of modules	5*9=45
Dimensions of modules	0.45
Angles of Geometry	0-100
Materials for shading and windows	Frame: light metal/shades: transparent Glass modifier transmittance 0.67 simple glass

Table 4 Optical and thermal properties of the model based on literature ranges and assumed base-case values

Surface	Type	Reflectance	Transmittance	u-value
Walls	Brick (0.02 m cement plaster) + 0.25 m red brick + 0.02 m cement plaster	0.5	-	1.826
Floor	Plain concrete	0.2	-	2.3–2.7
Windows	Simple glass	-	0.9	5.6–6.0
Roof	Plain concrete	0.6 (white coatings)	0	2.3–3.0
Shading	aluminum	0.6–0.85	0–0.3	-

modular five-segment system capable of controlled angular rotation to regulate daylight penetration, as shown in Table 3.

Material characteristics: Roof U-value (uninsulated concrete): from 2.3 to 3.0 W/m²·K. Aluminum shading has no U-value if it's external and not part of a glazed envelope; only reflectance and geometry affect performance. Reflectance for white-coated concrete roofs is assumed at 0.6, which aligns with common in Egyptian buildings aiming to reduce heat gain, as shown in Table 4.

According to the previous Table 4, the objective of this study is not to predict absolute illuminance accuracy, but to compare façade performance under controlled and uniform simulation settings. Therefore, relative performance is unaffected by exact reflectance calibration.

3.2 Parametric and simulation framework for classroom daylighting in Egyptian universities

In order to enhance the daylighting performance and visual comfort of the case study of a theoretical model based on earlier research pertaining to classroom design needs in Egyptian universities, this study suggested a coupled simulation methodology. This chart illustrates the structured research methodology employed in a study aimed at optimizing facade design for enhanced visual comfort and daylight performance, particularly in region-specific climatic conditions. It is divided into four main parts, as shown in Fig. 6.

3.3 Methods and simulation framework

This study employed Rhino 8 and Grasshopper (version 1.007) as the primary parametric modeling environment. Environmental simulations were conducted using Ladybug Tools (Ladybug 1.7.0 and Honeybee 1.8.0 plugins).

These tools were selected due to their validated integration with EnergyPlus and Radiance-based daylight and glare simulations. A representative classroom was modeled using Honeybee zones, incorporating room dimensions, occupancy schedules, construction materials, and HVAC systems. The room program and HVAC settings were defined

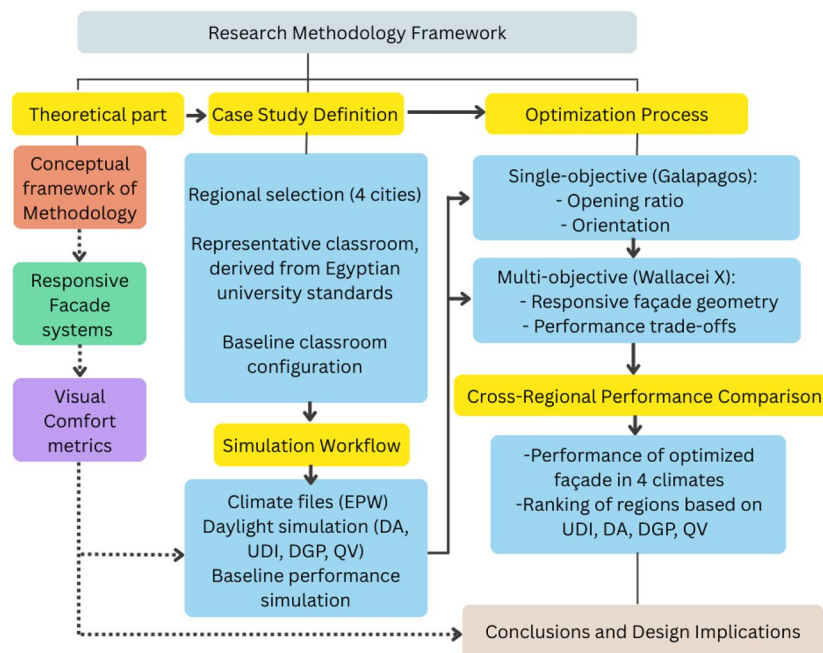


Fig. 6 Research methodology and simulation framework illustrating the sequential workflow of the study, including case study definition, daylight simulation, single- and multi-objective optimization, and cross-regional performance comparison across different Egyptian climatic zones. Source: Author

in accordance with ASHRAE Standard 90.1–2019 to ensure consistency with international building performance benchmarks. The simulation workflow was developed as an explicit Grasshopper script, allowing parametric control over façade geometry and shading configurations. Galapagos was employed as a preliminary single-objective optimization step to identify feasible solution boundaries and eliminate geometrically inefficient façade configurations. This step reduced the search space and ensured that the subsequent multi-objective optimization using Wallacei-x explored only physically meaningful and computationally efficient design alternatives. This sequential optimization approach improves convergence stability, reduces computational cost, and enhances the diversity of the Pareto front in the multi-objective stage. The overall research methodology and simulation workflow are illustrated in Fig. 7. The multi-objective optimization was configured with a total of 180 evaluated solutions, corresponding to 15 individuals per generation over 12 generations. The genetic algorithm parameters were set as follows: a crossover probability of 0.9, a mutation probability of $1/n$ (with n representing the number of variables), a crossover distribution index of 20, and a mutation distribution index of 20. A fixed random seed of 1 was used to ensure reproducibility. These settings provided sufficient population diversity and stable Pareto evolution at a reasonable computational expense. Increasing the population size further would have substantially increased Radiance simulation time without proportional improvement in Pareto.

- Part 1: climate data for different regions in Egypt (Giza, Aswan, Alexandria, and Hurgada).
- Performance indicators.
- Part 2: Seasonal glare evaluation was conducted for December 21, March 21, June 21, and August 21 at 1:00 PM to capture climatic variability, and a simulation for the base case. While higher DGP values were observed during winter and equinox

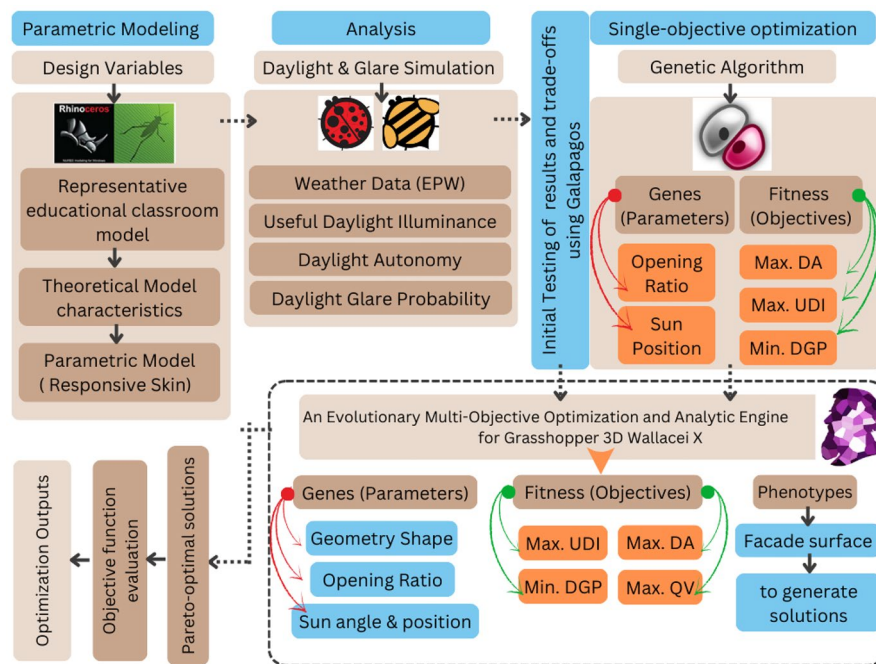


Fig. 7 Simulation & optimization execution illustrating the parametric modeling process, simulation, and optimization process, and its outputs. Source: by the Author

periods due to low solar altitude, August was adopted as the primary optimization case as it represents the most critical combined thermal and solar stress condition in the Egyptian climate.

- **Climate data and Study context:**

Detailed charts of solar radiation, wind speed, and temperature/humidity graphs can clarify patterns and guide design strategies for facades and building elements, as shown in Table 5.

It appears from Table 5 that Giza experiences higher temperatures and solar radiation than Alexandria, but less than Aswan. Alexandria’s climate is milder and more humid, with lower solar radiation due to its coastal position. Dry bulb temperature is most extreme in Aswan, with a maximum temperature of 48 °C and a mean temperature of 32 °C, followed by Hurghada with similarly high temperatures but slightly lower means. Source: by the author.

- **Performance Indicators:**

A set of performance indicators was established to evaluate the proposed responsive façade system’s effect on building performance comprehensively. These metrics form the foundation for assessing the system’s performance in various climatic circumstances across the various areas of Egypt, as shown in Table 6.

The 500-lux threshold for Daylight Autonomy was selected in accordance with international daylighting recommendations for educational spaces as classes, art rooms, laboratories, as both EN 17,037 and CIBSE LG7 specify 500 lx as the required horizontal illuminance for classrooms and learning-focused visual tasks [32]. Accordingly, DA500 lux has been widely adopted in building-performance research as a benchmark for assessing daylight sufficiency in teaching environments. The Quality of View (QV) was

Table 5 Climate data for the 4 regions in Egypt using EPW files with the Ladybug tool

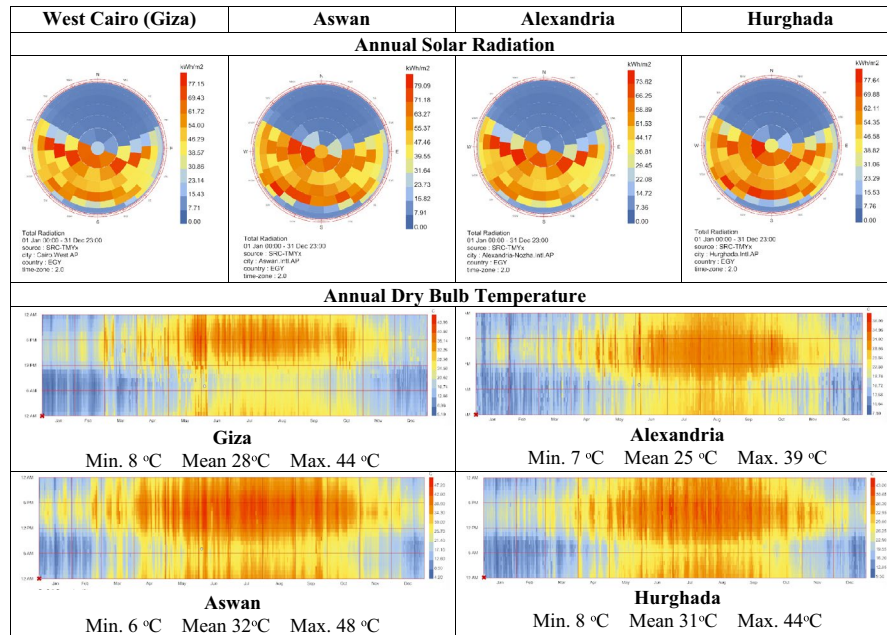


Table 6 illustrates the performance metrics used in the simulation process to evaluate the responsive façade system across different Egyptian regions

Daylight metrics	Threshold	Grid size	Work plane height	Acceptable amount
DA	500 lx	0.5	0.8	-
UDI	100–2000 lx	0.5	0.8	-
DGP	-	-	1.2	< 0.35
QV	number of unobstructed rays $n = 20$	0.5	1.2	Acceptable quality view ≥ 50 Good quality view $\geq 75\%$

evaluated using the Sky-View factor view type via Honeybee (View Type 5), measured at a seated eye level of 1.20 m. To conform to the quality standards of EN 17,037, the raw data (number of unobstructed rays) were standardized to a maximum ray count of $n = 20$. This normalization allows the results to be expressed as a percentage, where a value above 50% indicates compliance with the standard’s comfort requirements.

Daylight Glare Probability (DGP) is a crucial metric for evaluating indoor visual comfort. A value below 0.35 indicates imperceptible glare, between 0.35 and 0.40 signifies perceptible glare, from 0.40 to 0.45 indicates disturbing glare, and exceeding 0.45 results in intolerable glare, significantly affecting visual performance [33].

- **Seasonal glare assessment.**

The seasonal glare analysis enables determining which period of the year exhibits the highest risk of direct solar penetration and visual discomfort in a south-facing classroom, as presented in Table 7, to test in different times of year (21 December / 21 March / 21 June/ 21 August).

Higher DGP values observed in December and March are primarily attributed to low solar altitude angles, which increase the likelihood of direct sunlight penetration into the visual field, even under lower thermal conditions. This behavior has been widely

Table 7 Seasonal DGP Evaluation to Determine Peak Glare Risk in a South façade Classroom

21 March	21 June	21 August	21 Dec.	21 March	21 June	21 August	21 Dec.
0.417	0.353	0.376	0.457	0.392	0.349	0.360	0.460
West Cairo				Aswan			
0.422	0.356	0.381	0.447	0.402	0.348	0.365	0.455
Alexandria				Hurghada			

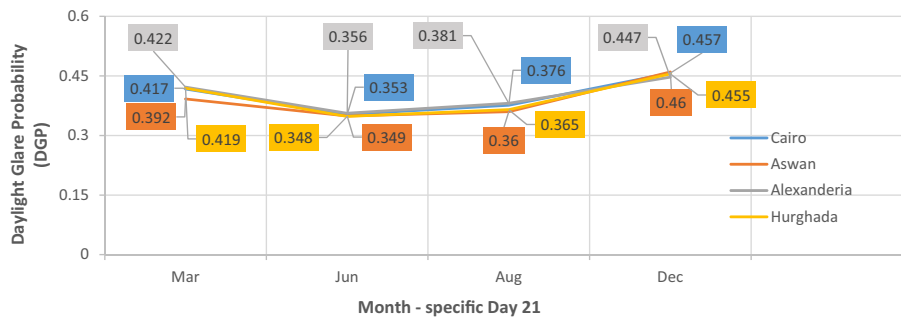


Fig. 8 illustrates the conceptual seasonal variation of Daylight Glare Probability (DGP). Source: Author based on seasonal simulation.

reported in glare studies and does not contradict the optimization outcomes. August represents the most critical combined condition of high solar intensity, elevated ambient temperatures, and long daylight exposure. Therefore, it was selected as the primary reference case for completing the detailed optimization and performance assessment. The occurrence of high glare levels during December and March is consistent with low sun-angle conditions rather than excessive solar radiation. The study, therefore, distinguishes between seasonal glare verification and design optimization, focusing on detailed performance analysis in August as the worst-case scenario. As illustrated in Fig. 8, high glare levels during winter and equinox periods in Egyptian climates are primarily associated with low sun angles.

Elevated glare levels observed during December and March are mainly attributed to low solar altitude angles and direct sun penetration. In contrast, August represents the worst-case design condition due to the combined effects of high solar intensity and elevated thermal stress. Accordingly, August was selected as the reference case for detailed optimization and comparative analysis.

4 Findings and results

This section reports the results of the daylight and glare performance analysis across different shading configurations and Egyptian climatic regions.

4.1 Comparative analysis of shading device configurations

This phase aims to test and compare the daylight performance of various shading device types applied to the base case model. Daylight performance maps are presented in plan view; the horizontal appearance reflects the projection of vertical shading fins. As shown in Table 8 include evaluation of the static and responsive shading configurations across diverse climates, identifying optimized façade solutions that balance daylight performance and glare control.

- **Annual Daylight Simulation for the 4 case studies in 4 scenarios:**

The results presented in Table 6 demonstrate clear performance differences among the investigated shading configurations across the four Egyptian climatic regions, as shown in Table 9 of the findings.

- **Key Findings:**

1. Base Case provides the highest DA but results in significant overlit areas, as indicated by low UDI values.
2. Static Vertical Shading improves daylight uniformity but reduces DA, especially in lower ranges.
3. Static Horizontal Shading achieves a better balance, reducing overlit areas and maintaining reasonable DA levels.
4. Responsive Shading shows the most potential for dynamic optimization, with the 80% opening ratio performing better than 50%, particularly in terms of uniformity and maintaining high DA in most locations.

- **Daylight Glare Probability for the 4 case studies in 3 scenarios:**

The Daylight Glare Probability (DGP) results indicate variations in glare levels among different design scenarios, identifying layouts that effectively minimize glare risk and highlighting conditions that lead to disturbing or intolerable glare. To assess the visual comfort performance of the proposed responsive shading system, Daylight Glare Probability (DGP) was evaluated for the four selected case studies under three different façade scenarios. The analysis was conducted on 21 August at 1:00 PM, representing peak summer solar exposure conditions in the Egyptian climate, as summarized in Table 10.

- Key Findings, as shown in Table 11:

1. Without Shading: All cities have DGP values above 0.39, indicating unacceptable glare levels, with Alexandria (0.459) being the most affected.
2. 80% Openings Treatment (South Façade Shading): Reduces glare moderately across all cities. Aswan (0.341) achieves glare levels just below the comfort threshold (DGP = 0.35).
3. 50% Openings Treatment (South Façade Shading): Provides significant glare reduction, bringing DGP below 0.35 (comfortable) for all cities. Alexandria sees the largest improvement (25% reduction).

Table 8 Annual Daylight Simulation for the 4 case studies in 4 scenarios: (Base Case- Static Vertical shade - Static Horizontal shade – Responsive shade with 50% opening & 80% opening)





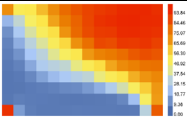
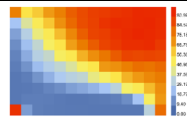
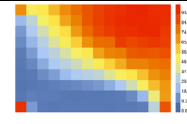
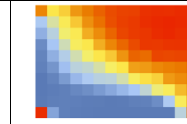
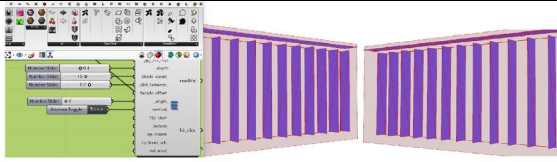
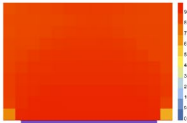
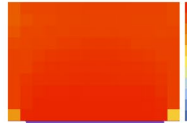
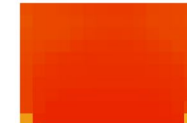





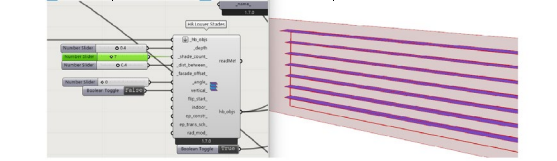
West Cairo (Giza)	Aswan	Alexandria	Hurghada
Scenario A: Base Case			
Daylight Autonomy (DA) & Useful Daylight Illuminance (UDI) Windows from South and West WWR 80%			
DA			
 <p>Highest: 96.77 Lowest:94.90</p>	 <p>Highest: 96.80 Lowest:94.65</p>	 <p>Highest: 96.88 Lowest:94.79</p>	 <p>Highest: 96.27 Lowest:93.51</p>
UDI			
 <p>Highest: 93.84 Lowest:3.21</p>	 <p>Highest: 93.97 Lowest:4.34</p>	 <p>Highest: 93.73 Lowest:2.96</p>	 <p>Highest: 93.45 Lowest:3.97</p>
<p>Scenario B: Static Vertical Shade plan-view representation Treatment for South façade Depth 0.4/ Shade Count 15/ Distance between 0.6/ Angle 0</p>			
DA			
 <p>Highest: 96.77 Lowest:62.36</p>	 <p>Highest: 96.71 Lowest:57.73</p>	 <p>Highest: 96.88 Lowest:62.38</p>	 <p>Highest: 96.27 Lowest:85.27</p>
UDI			
 <p>Highest: 96.49 Lowest:42.52</p>	 <p>Highest: 96.68 Lowest:50.49</p>	 <p>Highest: 96.79 Lowest:43.04</p>	 <p>Highest: 96.19 Lowest:50.08</p>
<p>Scenario C : Static Horizontal shade plan-view representation Treatment for South façade Depth 0.4/ Shade Count 7/ Distance between 0.4/ Angle 0</p>			

Table 8 (continued)

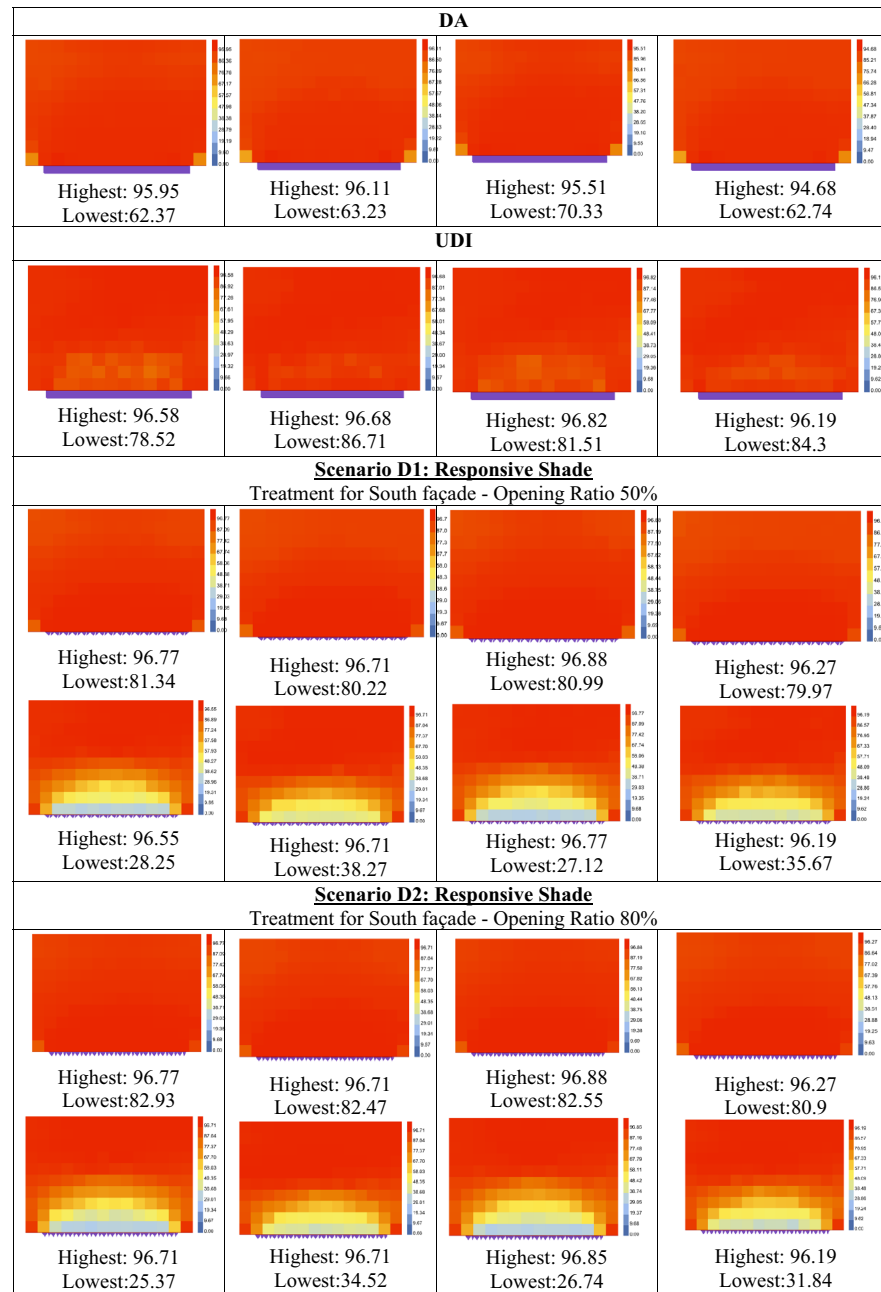
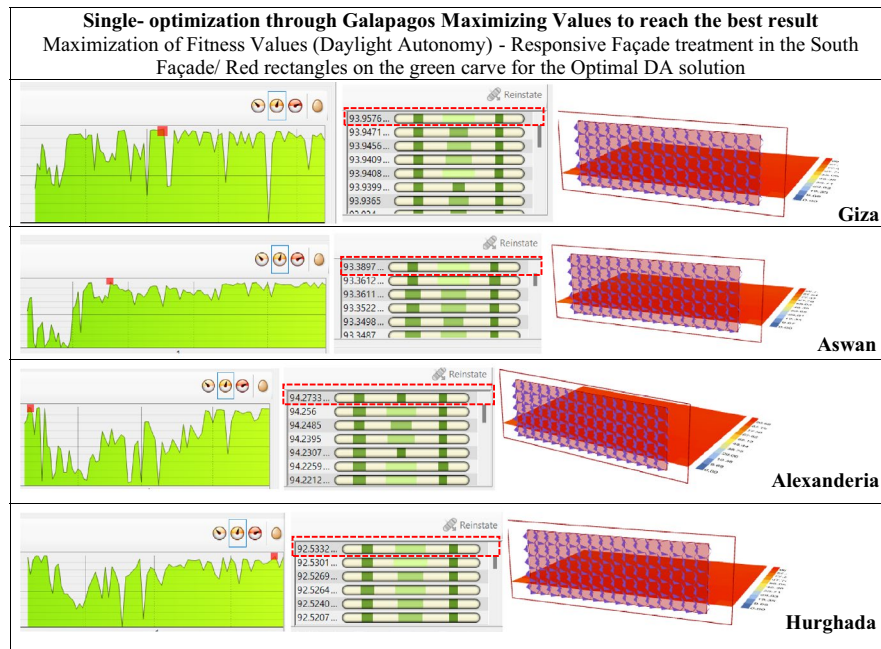


Table 8 (continued)



4. Overall Performance: The 50% openings treatment is the most effective solution for glare mitigation. Tailored shading strategies could further optimize glare performance for specific cities.

• **Observation of the efficiency of responsive façade shading systems:**

As illustrated in Tables 8 and 10, Hurghada had a higher UDI and a lower daylight absorption (DA) (38.27%) than Giza and Alexandria, which both performed best under 50% openness. Hurghada had one of the weakest DGPs (0.326), just above Aswan, although it also decreased overlit areas in a manner comparable to others. The biggest improvement was in Alexandria (25%).

As illustrated in Table 12, adaptive façade shading systems are more effective than static systems in reducing glare and improving daylight performance, enhancing visual comfort.

Table 12 summarizes the performance of the responsive façade system across different climatic locations. While Giza and Alexandria achieved higher daylight autonomy at 50% opening, Hurghada demonstrated superior glare control with one of the lowest DGP values, highlighting the trade-off between daylight sufficiency and visual comfort across climates.

4.2 A single and multi-objective optimization results

Optimization process using the optimization approach as a comparative analysis between 4 Egyptian Regions (Cairo, Alexandria, Aswan, and Hurghada). Using Galapagos and Wallacei-x, respectively, to evaluate and minimize the trade-offs among parameters, will be employed to:

- Compare the performance of the optimized shading designs in diverse climates.

Table 9 Findings from the Annual daylight analysis: (South façade treatment – South façade treatment), Source: By author

Annual Daylight Analysis Result	
Scenario A	DA Highest values across all cities range between 96.27% and 96.88%, while the lowest values remain high, between 93.51% and 94.90%.
	UDI Highest values range from 93.45% to 93.97%, with lowest values between 2.96% and 4.34%, indicating significant overlit areas.
	DA Highest values are similar to the base case (96.27%-96.88%), but lowest values significantly drop, ranging from 57.73% (Aswan) to 85.27% (Hurghada).
Scenario B	UDI Improved uniformity with the highest values reaching 96.49%-96.79%, while the lowest values improve significantly to a range of 42.52%-50.49%.
	DA Highest values range between 94.68% (Hurghada) and 96.11% (Aswan), with lowest values improving compared to Scenario B, ranging between 62.37% and 70.33%.
	UDI Highest values reach 96.58%-96.82%, with much-improved lowest values ranging from 78.52% to 86.71%, showing reduced overlit areas.
Scenario C	DA Highest values stay consistent (96.27%-96.88%), but lowest values vary widely depending on location, with Giza and Alexandria performing well (81.34%-80.99%), while Aswan and Hurghada drop significantly (27.12%-38.27%).
	UDI Highest values remain high (96.19%-96.88%), with better control of over-lighting compared to the base case.
	DA Highest values are stable (96.27%-96.88%), while the lowest values improve slightly compared to the 50% opening ratio, ranging between 25.37% (Aswan) and 82.93% (Giza).
Scenario D1	UDI Highest values maintain consistent performance (96.19%-96.88%), showing improved daylight uniformity, though issues with over-lighting persist in some cases.
	DA
	UDI
Scenario D2	

- Identify the regions where responsive façades yield the most effective balance between daylight availability and glare control.
- Determine the regional suitability and adaptability of the proposed responsive façade strategies using parametric simulations and multi-objective optimization (e.g., Genetic Algorithm).

A Parallel Coordinate Plot (PCP) is a way to visualize multidimensional data (several objectives at once).

Each vertical axis = one objective (e.g., DA, DGP, UDI, Qv).

Each line across = one solution/individual from the evolutionary process.

The line shows how that solution scores on each objective (Table 13).

For Giza Region: This shows the trade-offs among the four objectives across all solutions.:

Table 10 Daylight glare probability for the 4 case studies in 3 scenarios: (Base Case- Responsive shade with 50% opening & 80% opening)/ 21 August at 1:00 pm

West Cairo (Giza)	Aswan	Alexandria	Hurghada
Daylight Glare Probability Without shades / 21 August at 1:00 pm (Summer Time)- Windows from South and West WWR 80%			
Daylight Glare Probability 80% - opens 80 / 21 August at 1:00 pm (Summer Time) Windows from South and West WWR 80% - Treatment only for South Façade			
Daylight Glare Probability 50% - opens 50 / 21 August at 13:00 pm (summer Time) Windows from South and West WWR 80%- Treatment only for South Façade			

Table 10 (continued)

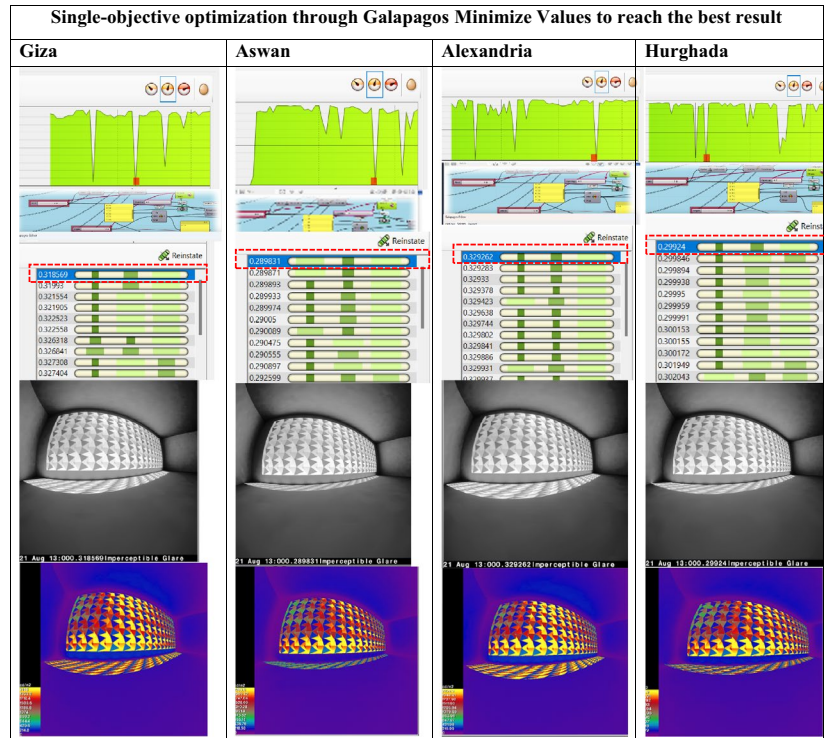


Table 11 Findings from the Daylight Glare Probability analysis, Source: By author

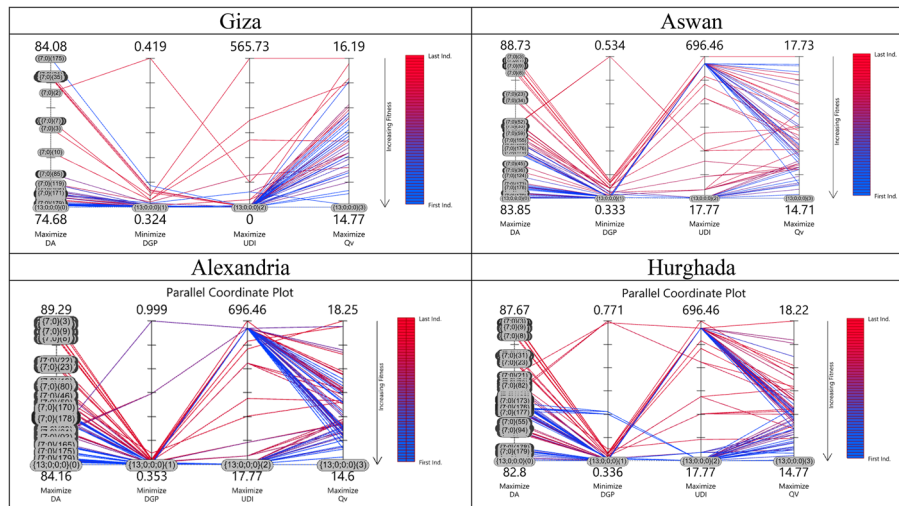
City	Without Shades	80% Openings (South Shading)	50% Openings (South Shading)	Reduction (Baseline to 50%)
West Cairo	0.445	0.370	0.347	22%
Aswan	0.392	0.341	0.320	18%
Alexandria	0.459	0.378	0.344	25%
Hurghada	0.415	0.337	0.326	21%

Table 12 Evaluation of responsive façade shading systems' effectiveness:

City	DA Performance	UDI Performance	DGP Performance	Key Observation
Giza	High DA at 50% opening	High UDI	Higher DGP than Hurghada & Aswan	Good daylight, moderate glare
Alexandria	High DA at 50% opening	High UDI	Moderate DGP	Highest relative DGP improvement (25%)
Aswan	Moderate DA	High UDI	Low DGP (0.320)	Effective glare reduction
Hurghada	Lower DA (38.27%)	High UDI	Lowest DGP (0.326)	Best final glare control

- DA (74.68–84.08%): Most solutions maintain a high DA range, indicating that the façade systems effectively support daylight autonomy. However, the variation suggests that increasing DA further may sometimes negatively impact other objectives, especially glare.
- DGP (0.324–0.419): Lower is better. Some solutions achieve minimal glare (<0.35, which is good), but as DA or UDI increases, glare generally tends to rise. This reflects a common trade-off: more daylight often leads to increased glare risk.

Table 13 Multidimensional data can be seen using a Parallel Coordinate Plot (PCP), which enables the simultaneous display of many objectives for Giza, Aswan, Alex, and Hurghada. Source: Wallacei Analytic.



- UDI (0–565.73): There is considerable variation here. Some shading solutions keep UDI very high (suitable daylight levels), while others drop near zero, likely due to over-shading or poor control.
- QV (14.77–16.19): Usually stable across solutions, with only slight differences. This suggests most façade designs preserve a decent outside view, but the narrow range indicates QV isn't as conflicting with glare and daylight objectives.

For Aswan Region: This illustrates the trade-offs between the four objectives across all solutions:

- Daylight Autonomy (DA: 83.85–88.73%) Consistently high across all solutions. Not the main challenge, small improvements in DA often increase glare.
- Daylight Glare Probability (DGP: 0.333–0.534), Critical trade-off variable. Tends to rise when DA or UDI increases.
- Useful Daylight Illuminance (UDI: 17.77–696.46) Vast range, most sensitive objective. High UDI = better daylight quality but usually higher glare. Low UDI = over-shaded façades, reducing comfort.
- Quality of View (QV: 14.71–17.73), Narrow range largely unaffected by shading variations. Secondary factor in optimization.

For Alexandria Region: This illustrates the trade-offs between the four objectives across all solutions:

- DA Range shown: 84.16 to 89.29. Interpretation: DA remains consistently high across all solutions; only small variations exist. Increases in DA usually correspond with a rise in glare (DGP).
- DGP Range shown: 0.353 to 0.999. Interpretation: DGP is the critical trade-off variable. It increases when DA or UDI improves, making glare control the main design challenge.
- UDI Range shown: 17.77 to 696.46. Interpretation: UDI has the widest spread, showing it is the most sensitive objective. Higher UDI means better daylight quality,

but it often leads to higher glare. Low UDI reflects over-shading and poor daylight distribution.

- Qv Range shown: 14.6 to 18.25.

For Hurghada Region: This illustrates the trade-offs between the four objectives across all solutions:

- Daylight Autonomy (DA: 82.8–87.67) Values remain consistently high with only a narrow variation. This indicates that DA is not a major limiting factor in the optimization, though small improvements in DA often lead to increases in glare (DGP).
- Daylight Glare Probability (DGP: 0.336–0.771) A sensitive variable and the main source of trade-offs. As DA or UDI increases, DGP tends to rise, highlighting the conflict between achieving high daylight availability and controlling glare.
- Useful Daylight Illuminance (UDI: 17.77–696.46), the widest range among all objectives, making it the most sensitive. High UDI values indicate better daylight quality but are often associated with higher glare. Conversely, lower UDI values suggest over-shaded façades, which reduce comfort and daylight quality.
- Quality of View (QV: 14.77–18.22), A narrow range across all solutions, suggesting that QV is relatively stable and less affected by design variations. It plays more of a secondary role compared to UDI and DGP.

4.3 Comparative Analysis findings of Egyptian Regions' Responsive Façade Shading

The comparative analysis reveals clear climatic distinctions in the effectiveness of responsive façade shading systems across the four Egyptian regions to:

- - Compare results between different climatic zones and façade types.
- - Identify the most effective façade designs for balancing visual comfort.
- - Provide design recommendations for future educational buildings in Egypt.

The extracted ranges and trends for each region are summarized in the following Table 14, along with an analysis of whether responsive shading improves performance.

Best Generation refers to the generation and individual index at which the optimal Pareto trade-off between DA, DGP, UDI, and QV was achieved during the multi-objective optimization process. Table 14 summarizes the performance ranges and identifies the optimal Pareto solutions for each climatic region. The reported best generations represent balanced trade-offs among daylight availability, glare control, and quality of view rather than single-metric optimization.

4.4 Comparison of regions for responsive façade systems in educational buildings

From Table 15, Hurghada is the best fit for balanced daylight and views, while West Cairo requires complex façade strategies to stabilize UDI. Alexandria is stable and doesn't need a complex response, while Aswan has severe glare problems.

The regional ranking highlights that responsive façade effectiveness is strongly climate-dependent, with humid coastal regions benefiting most, while hot arid regions remain glare-dominated.

Table 14 Summary of Extracted Ranges and Performance Trends across Egyptian Regions, with Analysis of Responsive Shading Effectiveness

Region	Performance Range (DA, DGP, UDI, QV)	Best Generation (Optimal Pareto Solution)	Interpretation
West Cairo	DA: 85–91% DGP: 0.37–0.65 UDI: 5–72% QV: 70–88%	G8–Ind.5 G9–Ind.6	High UDI with low DGP; moderate-to-low QV indicating controlled view obstruction
Aswan	DA: 83–90% DGP: 0.40–0.95 UDI: 10–75% QV: 72–90%	G5–Ind.9 G11–Ind.7	Strong glare reduction with high DA and UDI; QV values indicate limited view openness
Alexandria	DA: 84–89% DGP: 0.35–0.99 UDI: 2.1–78.4% QV: 73–91%	G10–Ind.4 G14–Ind.8	High UDI and DA with improved QV; glare remains above comfort threshold
Hurghada	DA: 80–88% DGP: 0.33–0.77 UDI: 15–70% QV: 75–89%	G8 G11	Best glare control with consistent UDI and highest QV, indicating balanced visual comfort

Table 15 Regional Comparison of Responsive Façade Effectiveness Based on Daylight, Glare, UDI, and View Quality

Region	DA (Daylight Autonomy)	DGP (Glare Probability)	UDI (Useful Daylight Illuminance)	Qv (Quality of View)	Suitability of Responsive Façade	Rank
Hurghada	80–88% (stable)	0.33–0.77 (moderate)	15–70% (moderate variability)	75–89% (high, stable)	Most effective: balanced daylight and views; responsive shading successfully mitigates moderate glare and UDI variability	1st
West Cairo	85–91% (very high, stable)	0.37–0.42 (moderate)	5–72% (high variability)	70–88% (good)	Effective but complex: glare is controlled, but unstable UDI requires robust façade strategies	2nd
Alexandria	84–89% (moderate-high)	0.35–0.99 (unstable)	2.1–78.4% (very high variability)	73–91% (consistently good)	Limited benefit: daylight and view are already stable; the responsive façade offers marginal improvement	3rd
Aswan	83–90% (high)	0.40–0.534 (high glare risk, most values in different generations up to 0.40)	10–75% (high variability)	72–90% (good, stable)	Least effective: extreme glare dominates, limiting façade performance in classrooms	4th

Table 16 Design priority recommendations depending on the values of regions

Region	Design Priority
Hurghada	Emphasize façade transparency combined with adaptive shading modulation to maximize daylight availability and outdoor views while maintaining glare control.
West Cairo	Prioritize dense and highly responsive shading systems to block high-angle solar exposure while preserving high daylight autonomy.
Aswan	Adopt hybrid shading strategies combining responsive and static elements to mitigate severe glare and overheating while maintaining acceptable daylight levels.
Alexandria	Apply moderate shading strategies focusing on uniform daylight distribution and preservation of visual connection, as complex responsiveness provides limited additional benefit.

5 Discussion

This study examined the effectiveness of responsive façade shading systems in enhancing daylight performance and visual comfort across four climatically distinct regions in Egypt: West Cairo, Aswan, Alexandria, and Hurghada. The findings reveal that façade responsiveness does not yield uniform benefits across climates, emphasizing the importance of climate-specific design strategies for educational buildings. While simulation-based studies constitute an accepted approach in early design and optimization phases, onsite measurements are planned in future work to validate the comparative performance trends reported in this study and to assess real occupant visual responses.

It is acknowledged that the study is based on a single classroom size and a south-facing orientation, which limits the generalizability of the findings to all university building typologies and orientations in Egypt. However, the adopted model serves as a representative and critical test case commonly found in Egyptian universities. The aim of the study is not to generalize absolute daylight performance values, but rather to compare the relative effectiveness of different shading configurations under consistent and controlled conditions.

The analysis of various shading configurations across different climatic regions reveals that façade responsiveness is not universally beneficial, reflecting a significant climate sensitivity in educational daylight behavior. While daylight autonomy was generally high, the annual simulations indicated a conflict between sufficient daylight and visual discomfort, particularly in scenarios leading to over-illumination. Static shading types had varied impacts; vertical systems reduced excessive lighting but negatively affected daylight availability in regions with strong sun, while horizontal shading offered better balance, minimizing both over-lighting and maintaining adequate daylight levels. The responsive façade, contingent on opening ratios and climate, effectively modulated daylight, with an 80% opening maintaining stable levels and reducing over-illumination. The 50% opening scenario provided the most reliable glare reduction across all studied cities, effectively decreasing glare from unacceptable to comfortable levels.

Climatic divergence in performance was observed regionally, with Hurghada showing a balanced profile of stable daylight autonomy (DA), moderate glare, and high view quality, indicating humid coastal conditions favor adaptive modulation. West Cairo had high DA but significant variability in UDI, suggesting a need for precise façade control in densely urban areas. Alexandria maintained stable DA and high view quality, benefiting modestly from responsive shading. In contrast, Aswan struggled with persistent glare despite high DA, highlighting that responsive shading alone is inadequate without additional measures to manage solar penetration. Multi-objective optimization revealed that improvements in DA and UDI often correlated with increasing glare, particularly

in Aswan due to its extreme solar conditions. Regional design rankings emphasized that responsive strategies are most effective in humid coastal areas, complex in dense inland environments, marginal in mild coastal climates, and inadequate in extreme glare situations.

Based on the comparative regional findings, targeted design priorities are proposed to align responsive façade strategies with local climatic conditions and visual comfort requirements, as summarized in Table 9.

Overall, the findings emphasize that future classroom façades in Egypt should adopt location-dependent responsive strategies rather than standardized shading assumptions, with adaptive control prioritized in regions where daylight instability and glare risk most directly affect visual comfort.

6 Conclusion

This study demonstrated that responsive façade shading systems can substantially improve daylight quality and visual comfort in university classrooms, but their effectiveness is highly dependent on regional climatic conditions. Across all four Egyptian locations, responsive shading maintained high daylight autonomy while reducing excessive illuminance compared to static configurations. The 50% opening ratio produced the most consistent glare mitigation, lowering DGP below perceptible levels in all regions, whereas the 80% opening ratio enhanced daylight uniformity without compromising daylight penetration. Regional performance comparisons confirmed that humid coastal climates, particularly Hurgada, benefited the most from adaptive modulation, while hot–arid Aswan remained glare-dominated and required additional control strategies. These findings reinforce the need for climate-specific shading responses rather than universal façade prescriptions for educational buildings. The study is limited by the use of a single classroom geometry, one dominant south-facing orientation, and simulation-based evaluations without field measurements. The reliance on annual daylight metrics and a single hourly glare assessment introduces simplifications that may not capture temporal adaptation or occupant perception. In addition, the optimization framework used a moderate population size, which emphasizes exploratory performance trends rather than exhaustive solution coverage.

Future research could extend the proposed framework by investigating multiple classroom proportions and orientations to further enhance the generalizability of the results across diverse educational building typologies. Expanding the parametric space to include multiple classroom typologies, different orientations, and hybrid internal controls would enhance generalizability. Further optimization, combining daylight, energy demand, thermal comfort, and dynamic control systems, will support integrated envelope intelligence. Machine learning based adaptive shading or sensor-based real-time control also presents a promising extension of this research.

Abbreviations

DA	Daylight Autonomy
UDI	Useful Daylight Illuminance
DGP	Daylight Glare Probability
QV	Quality of View
sDA	Spatial Daylight Autonomy
EUDI	Energy Use Density Index
ASE	Annual Sunlight Exposure
EUI	Energy Use Intensity
GA	Genetic Algorithm

MOO	Multi-objective optimization
NSGA-II	optimization Non-dominated sorting genetic algorithm II
WWR	Window-to-Wall Ratio

Author contributions

Author Contribution: collecting all data, writing, conceptualization, Methodology, visualization, analysis, review and editing, and creating the model and all Grasshopper scripts.

Funding

This research received no external funding.

Data availability

The data analysed during the current study are available from the corresponding author on request.

Declarations

Ethics approval

This study did not involve human participants, human data, or animals. Therefore, ethical approval was not required.

Consent to participate

The study did not involve human participants or the collection of personal data. Therefore, consent to participate was not applicable.

Consent for publication

The manuscript does not contain any individual person's data in any form. Therefore, consent to publish was not applicable.

Clinical trial number

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 26 September 2025 / Accepted: 16 February 2026

Published online: 22 February 2026

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