2023

The Role of Smart Mashrabiya to Provide Daylighting in Office Buildings

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Gad, Asma Moawad; Dewer, Hosny A.; and Madkour, Mai Wahba (2023) "The Role of Smart Mashrabiya to Provide Daylighting in Office Buildings," Mansoura Engineering Journal: Vol. 48 : Iss. 2 , Article 13. Available at: https://doi.org/10.58491/2735-4202.3093

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The Role of Smart Mashrabiya to Provide Daylighting in Office Buildings

Asmaa M. Gad*, Hosny A. Dewer, Mai W. Madkour

Department of Architecture, Faculty of Engineering, Tanta University, Egypt

Abstract

Mashrabiya is a distinct feature of our architectural legacy and heritage, daylighting is one of the most significant functions of Mashrabiya. The paper aims at studying the impact of Mashrabiya; in particular, the smart Mashrabiya screen façade on daylighting performance and visual comfort. The application of this methodology occurs in two stages: In the first stage, a typical office room with dimensions of $4 \times 6$ m, and a 3-m height is studied to determine the current state of daylighting levels through the suggested eastern, southern, and western openings in the weather of Cairo, Egypt. The second stage examines the efficiency of daylight using five suggested dynamic façade motion scenarios on three fundamental orientations (east, south, and west). The parameterized simulation research is enhanced by the Grasshopper for Rhino software, and also Ladybug and Honeybee scripts for Grasshopper, that were applied to enhance daylight performance in the indoor space, were used to carry out the simulation process, with the integration of LEED V4 criteria. The metrics of spatial Daylight Autonomy (sDA 300/50%) and Annual Sunlight Exposure (ASE 1000/250) were used in the evaluation process. The research optimized the skin configuration for the east, south, and west façade orientations which yielded the best daylight levels (83% SDA), (55% sDA), and (83% sDA), respectively, and (2% ASE) for the east-oriented room, (0% ASE) for the south, and (0% ASE) western room. The research recommended the use of kinetic façade screens in accordance with LEED V4 requirements.

Keywords: Daylight performance, Daylight simulation software, Kinetic façade, Mashrabiya

1. Introduction

Climate and architecture have a complicated relationship. Extreme weather conditions exist throughout the Middle East region, necessitating the use of unique strategies to combat them. The environment is characterized by hot, dry weather as a result of the desert's presence in many sections of the area, which has had a significant impact, notably on Arab culture and architecture. In Middle Eastern desert architecture, the Mashrabiya, a lattice screen, was used to control privacy, light, heat, airflow, and humidity. It was a valuable feature in these nations due to its exquisite beauty and delicateness, as well as its extraordinary versatility and effectiveness in adjusting to the climate. Literature Review the immediately following papers generally mark the work of earlier researchers. For example, Mahmoud, A. H., and Al Ghazy, Y., 2016 examined the potential of different arrangements for ten origami cases of folded modules and achieved various Kinetic origami-based shading screens classified according to a variety of parameters, to show how the kinetic motion of origami module could significantly improve daylighting performance (Elghazi and Mahmoud, 2016). Jahanara and Fioravanti (2017) explored the potentials of dynamic patterns inspired by biomimetic design. Results indicate that the dynamic façade achieved a better daylighting performance in comparison to the static case. The experiment demonstrated the progression of daylight performance through the design and motion of kinetic facades (Jahanara and Fioravanti, 2017). Hosseini and colleagues (2021) confirmed the
high performance of the kinetic façade, particularly the best façade case achieved spatial Daylight Autonomy, and Useful Daylight Illuminance of 50.6, 85.5, respectively, improved the Useful Daylight Illuminance (UDI) 5.13 times and stopping visual discomfort in comparison with the basic window (Hosseini et al., 2021). Çakmak and Özdemir (2022) studied an office room in a hot, arid temperate zone that has a flat, adaptive (triangular cell façade) shading system to assess the daylight and glare quality. The dynamic shading system demonstrated that in comparison to the base case a 10% reduction in the ASE value of the façade while increasing the sDA value by 60% or more. Daylight Glare Probability (DGP) values of 0.38 keep the visual quality effective (Huseyin Özdemir, 2022).

This research aims at Using a dynamic façade shading system, creating sustainable design guidelines for indoor office rooms to increase daylighting without impacting occupant functional performance. The computer design software was used to complete the project, including simulation tools Ladybug and Honeybee to assess the suggested shading devices.

The research Problem A major challenge for architects today is to reduce overall energy consumption whilst also maintaining a comfortable indoor environment in light of the threats posed by global warming. Most modern office buildings’ façades have large glazed exteriors and are not climate-appropriate in hot, dry climates like Egypt, which lead to an increment in energy consumption, electrical costs, and carbon emissions. The next question is how to combine double-skin envelopes and intelligent geometrical shade to the office building’s envelope to produce a smart, efficient screen that improves indoor light quality.

The research’s importance is to combine a parametric design process with an environmental design process while the design stage is still in progress. The Mashrabiya, a well-known component of traditional Arabic architecture, is taken into consideration in the study. Then, trials are made to achieve visual comfort and to increase daylight availability in interior spaces.

2. Research methodology
Most modern office buildings’ envelope solutions are not built with the climate in mind, which leads to large glazed façades, and increased energy usage in hot dry regions like Egypt accordingly, this paper is an effort to understand and clarify the influence of smart Mashrabiya on the nature of the interior lighting in an office and encourage the use of natural illumination by:

1. Reviewing the background knowledge necessary to comprehend the traditional design and use of Mashrabiya by defining each Mashrabiya function according to climatic requirements, investigating the history of the Mashrabiya, and its roots in the Arab World.
2. Using Grasshopper for Rhino software, which supports parametric model process simulation, and the use of Ladybug & Honeybee for Grasshopper tools to assess the effects of various experiments to investigate daylight annual performance using a smart Mashrabiya model inspired by Al Bahr Tower façade to provide daylight in an office space in the climate of Cairo, Egypt.
3. Determining the best-case scenarios that provide the necessary values of sDA, ASE, and UDI in an office room by LEED V4 criteria after analyzing and debating the findings.

3. Mashrabiya background

3.1. Mashrabiya definition

The Arabic term for a particular type of projecting window covered in a carved wood latticework that is
found on the second story or higher of a building is ‘Mashrabiya’ (Rafat, 2009). Since the Mamluki period of the 12th century and through the middle of the 20th century, the Mashrabiya has been a staple of traditional Arab architecture. A Mashrabiya was typically used on the façade facing the street. On a courtyard side, though, it may also be utilized internally (Gelil and Hussein, 2014). Fig. 1.

3.2. Mashrabiya function

Mashrabiya has five functions, according to Egyptian architect Hassan Fathy, and numerous patterns have been designed to satisfy a range of settings that necessitate a focus on one or more of these functions. These duties include 1-controlling light passage, 2-regulating airflow, 3-lowering air current temperature, 4-raising air current humidity, and 5-assuring privacy (Fathy, 1986). Mashrabiya efficiently handled the challenge of retaining privacy in Islamic construction. Mashrabiya screens are said to be a visual barrier that separates private

<table>
<thead>
<tr>
<th>Classification according to LEED V4.1</th>
<th>Refused</th>
<th>Accepted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification criteria</td>
<td>ASE &gt;10</td>
<td>ASE &lt;10</td>
</tr>
<tr>
<td></td>
<td>55 &lt; sDA</td>
<td>55 &lt; sDA &lt;75</td>
</tr>
<tr>
<td></td>
<td>sDA &gt;75</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Useful daylight illuminances ranges (Nabil and Mardaljevic, 2005).

<table>
<thead>
<tr>
<th>UDI LOW</th>
<th>UDI ≥100</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDI</td>
<td>100 lux ≤ UDI &lt;2000 lux</td>
</tr>
<tr>
<td>UDI UP</td>
<td>UDI &gt;2000 lux</td>
</tr>
</tbody>
</table>

Table 3. Daylight glare probability ranges (Wienold, 2009).

<table>
<thead>
<tr>
<th>Imperceptible glare</th>
<th>DGP ≤0.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceptible glare</td>
<td>0.35 &gt; DGP ≤0.40</td>
</tr>
<tr>
<td>Disturbing glare</td>
<td>0.40 &gt; DGP ≤0.45</td>
</tr>
<tr>
<td>Intolerable glare</td>
<td>DGP &gt;0.45</td>
</tr>
</tbody>
</table>

Fig. 2. Base case plan, and a section showing its dimensions (researcher).

Fig. 3. The following software integrated into the parametric design process (McNeel, 2017).
and public locations. In a social sense, it was used to hide openings since its design idea was built on maintaining privacy by obscuring the view and preventing neighbors or passers-by on the street from peeking through what was beyond the Mashrabiya screen. At the same time, it enabled homeowners to look out the window without being viewed by strangers (Abdelkader and Park, 2017). One of the most crucial elements in architecture is

**Table 4. Summary of illumination standards used during simulation results evaluation.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASE</td>
<td>The minimum ratio allowed is 10, the desired ratios are fewer than 7, and the best case is less than 3.</td>
</tr>
<tr>
<td>sDA</td>
<td>&gt;55–2 points on LEED &gt;75–3 points on LEED</td>
</tr>
<tr>
<td>DGP</td>
<td>&lt;35 imperceptible glare - 35 &gt; DGP</td>
</tr>
<tr>
<td>UDI</td>
<td>100 lux ≤ UDI &lt;2000 lux</td>
</tr>
<tr>
<td>Target</td>
<td>300 lux</td>
</tr>
<tr>
<td>Illuminance</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5. Simulation process steps (researcher).**

Modeling of the office room

- **Table 5. Summary of illumination standards used during simulation results evaluation.**

<table>
<thead>
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</tr>
<tr>
<td>UDI</td>
<td>100 lux ≤ UDI &lt;2000 lux</td>
</tr>
<tr>
<td>Target</td>
<td>300 lux</td>
</tr>
<tr>
<td>Illuminance</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5. Simulation process steps (researcher).**

<table>
<thead>
<tr>
<th>Modeling of the office room</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
</tr>
<tr>
<td>width</td>
</tr>
<tr>
<td>height</td>
</tr>
<tr>
<td>Dynamic skin</td>
</tr>
<tr>
<td>Floor</td>
</tr>
</tbody>
</table>

- **Materials definition**

  - Walls: Fixed
  - Ceilings: Fixed
  - Floors: Fixed
  - Windows: Fixed
  - Exterior Ground: Fixed
  - Dynamic skin: Fixed

- **The simulation**

  - Direction: Variable
  - Location: Fixed
  - Sky condition: Fixed
  - Working hours: Fixed
  - Time map during the year: Fixed

- **Work surface definition**

  - Work surface height: Fixed
  - Distance between the sensors: Fixed

- **Table 5. Summary of illumination standards used during simulation results evaluation.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
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<tr>
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<td>&lt;35 imperceptible glare - 35 &gt; DGP</td>
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</tr>
<tr>
<td>Target</td>
<td>300 lux</td>
</tr>
<tr>
<td>Illuminance</td>
<td></td>
</tr>
</tbody>
</table>
natural light. However, it has three disadvantages that must be managed as well: 1. The heating brought on by solar gain directly. 2. The need for internal daylighting. 3- Light's aesthetic characteristics, such as glare. Mashrabiya can resolve these three issues by transforming the light from an unfavorable and harsh aspect of the interior space to a very positive and attractive one (Alothman, 2017).

3.3. Renovating the traditional Mashrabiya

Mashrabiya was an effective solution to earlier environmental issues, but it degenerated and became inefficient in current times. Because of its high cost, manifested in expensive production and maintenance expenses. Traditional Mashrabiya is prohibitively expensive due to the time-consuming expert work required to create one. A single square yard of latticework in the most elaborate Mashrabiya, for example, can be made up of up to 2000 pieces (Spencer, 1992). Recent improvements in, Computer-aided design software and digital manufacturing enabled architects to experiment with new shapes and materials envelope treatments in an attempt to alleviate architectural design difficulties (Gerber and Sheikh, 2011). Several designers have attempted to incorporate traditional Arabic characteristics into contemporary designs that are reminiscent of architecture from the twentieth century. Large structures with complicated thermal and visual needs are widespread in the Middle East, particularly in desert regions (Abdelkader and Park, 2017).

4. Case study parameters

In this study, a base model for a fictitious office space of 24 m² 4 m x 6 m x 3 m (height) facing various directions have been defined and built as a side-lit space. The room's location is assumed to be on the first floor. The external façade features a 10.8 m² window with a (WWR) Window-to-Wall Ratio of 90% this ratio is comparable to the majority of the building glass facades of Cairo’s office spaces. The proposed screen will be applied to this façade. The location of the study was determined to be Cairo, Egypt (30°6'N, 31°24'E). Egypt's capital and largest city, Cairo, in terms of urban and population growth is regarded as being one of the world’s 72 biggest cities, containing a large number of offices and commercial buildings. However, it has a subtropical desert dry hot climate, based on the most recent Köppen's categorization of climatic changes (Peel et al., 2007), it requires specialized external solutions to prevent direct solar radiation while providing adequate daylighting since it is associated with high amounts of direct solar radiation and clear sky (Fig. 2).

5. Daylight simulation software

One of the most crucial analyses in the development of sustainable architecture is daylight.
simulations. Due to the modern features and availability of a comprehensive collection of daylight and visual comfort studies, Grasshopper for Rhino software and Ladybug & Honeybee scripts for Grasshopper software are employed in this instance. Using Ladybug, one may develop a visual representation of the climate and its evaluation (Mackie, 2017). The honeybee is used to imitate temperature, illumination, and the usage of various scales (McNeel, 2017) (Fig. 3).

6. Stages throughout the simulation study

The phases of the simulation procedure are shown in the table below:

Table 5, Fig. 4.

7. Metrics of daylighting

The following dynamic measurements were used to determine the amounts of daylight illumination:

7.1. (sDA 300 / 50%): spatial daylight autonomy

A component of the Yearly Metrics specifies the necessary amount of daylight lighting inside of space. It is known as (sDA 300/50%) and is defined as a space area ratio that reaches an illuminance level of at least (300 lux) for a total of at least (50%) of space usage hours during the year (Heschong et al., 2012).

7.2. (ASE 1000 / 250): annual sunlight exposure

A measure indicates high sunlight exposure as well as the anticipated visual discomfort in the space. It is described as the percentage of the space area where the direct sunlight level climbs beyond (1000 lux) in the situation of zero bounces, for an overall duration that exceeds (250 h) of overall occupied hours, so it is known as (ASE 1000 / 250) (Heschong et al., 2012) (Table 1).

Fig. 5. Daylight autonomy (sDA) simulation process (researcher).

Fig. 6. (UDI) simulation process (researcher).
7.3. Useful Daylight Illuminances (UDI)

Mardaljevic and Nabil introduced UDI in 2005 as a dynamic daylight evaluation metrics regarding work area levels of illumination. Its goal, as the name implies, is to decide whether daylight levels are ‘useful’ for the occupants, neither too dark (<100 lux) or too bright (>2000 lux). The higher threshold is intended to detect instances when an excess of daylight may cause visual and/or thermal discomfort. The proposed range is based on top and lower limits of 2000 lux and 100 lux, respectively. The percentages of the occupied times of the year when the UDI was achieved (100–2000 lux), fell-short (<100 lux), or exceeded (>2000 lux) (Nabil and Mardaljevic, 2005) (Table 2).

7.4. Glare study (DGP)

Glare is defined as the sensation produced by luminance within the visual field that is sufficiently

<table>
<thead>
<tr>
<th>Performance</th>
<th>WWR 90% East</th>
<th>WWR 90% South</th>
<th>WWR 90% West</th>
</tr>
</thead>
<tbody>
<tr>
<td>sDA</td>
<td>96%</td>
<td>100%</td>
<td>64%</td>
</tr>
<tr>
<td>ASE</td>
<td>83%</td>
<td>50%</td>
<td>78%</td>
</tr>
<tr>
<td>LEED V4.1 Rating</td>
<td>Refused</td>
<td>Refused</td>
<td>Refused</td>
</tr>
</tbody>
</table>

Table 6. Space evaluation in accordance with LEED V4 standards without the use of the kinetic facade (researcher).

Fig. 7. Glare analysis (DGP) simulation process (researcher).

Fig. 8. ASE and sDA results without any shading devices (researcher). The ASE ratio did not meet the LEED V4 criteria since it is greater than 10%, meaning that solar radiation is excessive in the eastern, southern, and western space.
greater than the luminance to which the eyes are adapted, which causes annoyance, discomfort, or loss in visual performance and visibility. The Daylight Glare Probability (DGP), created by Wienold and Christoffersen, is one of the most widely used techniques for measuring daylight glare. DGP revealed an astonishingly strong association with the user’s impression of glare. The recommended threshold by Wienold J (Wienold, 2009) is shown in Table 3.

8. Evaluating steps methodology

Three stages of evaluation were used for the analysis of the following simulations. The three analyses were conducted using a simulation of daylight (with illumination standards shown in Table 4).

In order to find the cases that created enough daylight and earned points under the LEED rating system, sDA and ASE evaluations were performed for the different parameters Fig. 5.

Daylight was analyzed by using the Useful Daylight Illuminances metric, and the best performance cases were then evaluated. UDI is the percentage of occupied hours that illuminance falls between the minimum and maximum thresholds (100—2000lux). UDI—low the percent of the time that is illuminance below the lower thresholds, and UDI—is up the percent of the time that is illuminance above the upper thresholds Fig. 6.

The high-performance case scenarios from previous stages were subjected to glare analysis at 9:00 AM, 12:00 PM, and 16:00 during the various.
was assessed with 90% WWR glazing area without the screen on each main orientation (east, south, and west), and evaluates it according to LEED V4 standard. The simulation results for daylight performance is shown in Table 6.

8.2. SDA and ASE results

The ASE ratio did not meet the LEED V4 criteria since it is greater than 10%, meaning that solar radiation is excessive in the eastern, southern, and western space (Fig. 8).

8.3. UDI results

The simulation outcomes are illustrated in Fig. 9 showing that the UDI without shading device is greater than the useful daylight amount in the three differently-oriented spaces.

8.4. Daylight glare probability results

At this point, the glare was intolerable and disturbing because it was spread throughout the room. In the second stage, the kinetic façade is added to the room on each orientation opening. At this stage, a simulation of 90 scenarios was run with the following three primary parameters changed:

(1) The first parameter: studied the impact of daylighting entering through the kinetic façade on the study room model in the three determined orientations in the first phase (east, south, and west). as illustrated in Table 7.

Table 9. Analysis of the kinetic façade motion scenarios. (researcher).

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Fully opened</td>
</tr>
<tr>
<td>B</td>
<td>Partially open at 25%</td>
</tr>
<tr>
<td>C</td>
<td>Partially open at 50%</td>
</tr>
<tr>
<td>D</td>
<td>Partially open at 75%</td>
</tr>
<tr>
<td>E</td>
<td>Partially open</td>
</tr>
</tbody>
</table>

Fig. 10. sDA results for the east orientation space (researcher).

summer/winter solstices and autumn equinoxes (March 21, June 21, and December 21) Fig. 7.

8.1. The analysis processing methodology.

There are two stages to the methodology:

The first stage: In this step, the daylight performance of the hypothetical office space's base case...
(2) The second parameter: adjusting the unit’s rotation angle. The investigated angles are six values of kinetic facade unit rotated angles, which were analyzed for each simulation. These numbers ranged from 10° until they reached 60°, as illustrated in Table 8.

(3) The third parameter: the daylight's assessment for the dynamic facade simulated under five design alternatives for the kinetic shading system proposed in this research, including when the assemblies are fully open, and partially open by three different ratios ranging from 25% to 75%, as illustrated in Table 9.

There were 60 different alternatives produced as a result of parametric repetitions that represented all likely concatenations of the preceding variables. To find effective alternatives that achieve adequate
daylight performance, these options were investigated using parametric simulation.

8.5. Analysis results: for the eastern room

8.5.1. SDA and ASE results
15 cases met or were above the initial criteria for successful cases, which is the 55% sDA starting from the facade rotation angle (30°–60°) in the fully open façade, at (60°) in case C, and from (40°–60°) in case D, and (50°–60°) in case E. Below the 10% ASE, there is a second threshold for successful cases. 29 cases met minimum standards for ASE performance and did not exceed limits. Also, the illuminance levels at angles (10°–30°) did not match the necessary levels except at (30°) in the fully open façade case A. Generally, whenever the rotation angles increase, the sDA ratio increases

<table>
<thead>
<tr>
<th>Time</th>
<th>21 March</th>
<th>21 June</th>
<th>21 December</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 AM</td>
<td>Imperceptible DGP 26%</td>
<td>Imperceptible DGP 26%</td>
<td>Imperceptible DGP 25%</td>
</tr>
<tr>
<td>12:00 PM</td>
<td>Imperceptible DGP 23%</td>
<td>Imperceptible DGP 23%</td>
<td>Imperceptible DGP 21%</td>
</tr>
<tr>
<td>16:00</td>
<td>Imperceptible DGP 17%</td>
<td>Imperceptible DGP 21%</td>
<td>Imperceptible DGP 8%</td>
</tr>
</tbody>
</table>

Table 10. Glare analysis for the best case. (researcher).

Fig. 13. sDA results for the southern space (researcher).
too, and the ASE also which is not acceptable except in four successful cases as shown in Figs. 10 and 11.

8.5.2. UDI evaluation of accepted cases

Fig. 12.

The simulation’s outcomes are illustrated in Figs. 10 and 11 that the best rotation angle is in (case A) at (30°, 40°, 50°), in (case C) at (60°), in (case D) at (40°), (50°), and (60°), in (case E) at both (50°) and (60°).

The optimum case for the east facade is the fully open facade (Case A) at (40°) which achieved ASE 2% and sDA 83%, and UDI 73% (Fig. 12).

8.6. Evaluation of glare in the best performance cases

Table 10 shows that there were only slight variations in the glare’s performance for each season (21 March–21 June–21 December).

![Fig. 14. ASE results for the southern space (researcher).](image)

![Fig. 15. UDI results for the southern space (researcher).](image)
Table 11. Glare analysis for the best case. (researcher).

<table>
<thead>
<tr>
<th>Time</th>
<th>21 March</th>
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<td>Imperceptible DGP 26%</td>
<td>Imperceptible DGP 28%</td>
<td>Imperceptible DGP 23%</td>
</tr>
<tr>
<td>16:00</td>
<td>Imperceptible DGP 6%</td>
<td>Imperceptible DGP 4%</td>
<td>Imperceptible DGP 8%</td>
</tr>
</tbody>
</table>

8.7. Analysis results: for southern room

8.7.1. SDA and ASE results

10 cases met or were above the initial criteria for successful cases, which is the 55% sDA, starting from the facade rotation angle (20°–60°) in the fully open façade, (30°–60°) in case D, (40°–60°) in case E. 20 cases met minimum standards for ASE performance and did not exceed limits. Also, the illuminance levels at angles (10°–60°) at (case B, C) for the partially open façade at 25%, and 50% did not match the required sDA levels. The angles (30°–60°) did not match the required ASE levels in a fully open façade (case A). ASE and sDA were acceptable in four successful cases as shown in (Figs. 13 and 14).

8.7.2. UDI evaluation of accepted cases

The simulation’s outcomes are illustrated in (Figs. 13 and 14), that the best rotation angle is in (case A) at (20°), in (case D) at (30°), in (case E) at both (40°) and (50°) Fig. 15.

The optimum case for the southern space is the partially open façade (Case E) at (40°) which reached 0% ASE, 55% sDA, and 53% of UDI.
8.7.3. Evaluation of glare in the best performance cases

Table 11 shows that there were only slight variations in the glare’s performance for each season (21 March–21 June–21 December).

8.8. Analysis results: for the western room

8.8.1. SDA and ASE results

15 cases met or were above the initial criteria for successful cases, which is the 55% sDA, starting
from the facade rotation angle \((20^\circ)\) in the fully open façade. Below the 10% ASE, there is a second threshold for successful cases. 10 cases met minimum standards for ASE performance and did not exceed limits. In case A, ASE levels at \((40^\circ-60^\circ)\) are over the limit. Also, the illuminance levels at angles \((10^\circ-60^\circ)\) at (Case B, C) for the partially open façade at 25%, and 50% in several situations did not match the necessary levels. ASE and sDA were acceptable in two cases at the fully open façade case (Case A) as shown in (Figs. 16 and 17).

8.8.2. UDI evaluation of accepted cases
The simulation’s outcomes are illustrated in (Fig. 17) that the best rotation angle is in (case A) at \((30^\circ), (40^\circ), (50^\circ),\) in (case C) at \((60^\circ),\) in (case D) at \((40^\circ), (50^\circ),\) and \((60^\circ),\) in (case E) at both \((50^\circ)\) and \((60^\circ)\) Fig. 18.

<table>
<thead>
<tr>
<th>Angle</th>
<th>East facade</th>
<th>South facade</th>
<th>West facade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic Façade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case A</td>
<td>((40^\circ))</td>
<td>((40^\circ))</td>
<td>((40^\circ))</td>
</tr>
<tr>
<td>sDA</td>
<td>83%</td>
<td>55%</td>
<td>83%</td>
</tr>
<tr>
<td>ASE (UDI)</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>DGP</td>
<td>Imperceptible</td>
<td>Imperceptible</td>
<td>Imperceptible</td>
</tr>
</tbody>
</table>
The optimum case for the western facade is the fully open façade (Case A) at (40°) which achieved 0% ASE, 83% sDA, and 74% UDI.

8.8.3. Evaluation of glare in the best performance cases

(Table 12) shows that there were only slight variations in the glare's performance for each season (21 March–21 June–21 December).

9. Results and conclusions

The study examines how the kinetic facade affects office lighting by using parametric simulation tools to create daylighting plans for the hot, arid Middle East. In Egypt's capital city of Cairo, the simulation was run. A set of factors that influence the illuminance performance inside space are in charge of controlling the façade motion (orientation, shade unit rotation angles, and the main shading device motion). The study reached the balance between sDA and ASE and found the best solutions. It aims at eliminating direct sun exposure by increasing the sDA value while reducing the impact of ASE. According to the simulation results, the optimal motion case for the east façade is the partially open kinetic façade (Case A) at (40°) which reached (2% ASE), (83% sDA), the southern room with partially open kinetic façade (Case E) at (40°) reached (0% ASE), and (55% sDA), and the optimum case for the west facade is the fully open kinetic façade (Case A) at (40°) reached (ASE 0%) and (sDA 83%). The ASE performance improved by 100% in the east, south, and west oriented room. The research made an improvement in the ASE ratio by 100%, mostly in most of the directions, and it is needed to improve the sDA ratio in the southern direction, and this can be achieved in the future simulation by adding depth to the screen or change the unit radius (Table 13).

10. Conclusion

(1) The screen’s units’ rotation angle had the most remarkable effect on the screen’s daylight performance.
(2) It was concluded that the optimal cases that could balance (sDA) spatial daylight autonomy and (ASE) annual sunlight exposure with the best possible daylight performance could be mostly achieved by a specifically suggested selection criterion. In this study, it was based on LEED v4 criteria.
(3) For orientations, eastern and western, motion scenario A at angles 40 and 50° achieved acceptable results. The higher the angle, the higher the Annual sunlight exposure corresponding to the motion scenario opening of each unit.
(4) The kinetic façade motion scenario A exhibits the optimal daylight performance between all options with regard to DGP metric in east- and west-oriented rooms. The results show that the shading device, approximately, keeps DGP percentages in the acceptable ranges most of the time.

11. Recommendations

This paper recommended:

(1) Researching how daylighting affects visual comfort based on occupant positions and dynamic daylight.
(2) That in order to provide adequate daylighting, the authorities responsible for Egypt's architectural and urban development must keep in mind how office buildings are oriented in relation to Egypt's geographic regions.

Authors contribution

Asmaa Moawad Gad is in charge of data collecting, tools, software and analysis, as well as contributing to the article's drafting and financing. Hosny Ahmed Dewer is in charge of assessing certain data and contributing to the composition of the paper with supervision and occasional research follow-up. Mai Wahba Madkour is in charge of supervising the design process, managing the work, as well as establishing the methods and giving final approval to the published copy.

Funding statement

The author did not receive any financial support of the research authorship and publication of this article.

Conflicts of interest

The author declared that there are no potential conflicts of interest with respect to the research authorship or publication of this article.
References


Mackie, C., 2017. Mackie-Workshop [Online]. Boston, Massachusetts, United States. Available: https://docs.google.com/presentation/d/1ka7JznzpdpjhiK4Nvi5km1tN5iKOYJo4FL_RbiaC4P9g/edit?slide=id.g137c3210c2_0_881.


