Use of kinetic facades to enhance daylight performance in office buildings with emphasis on Egypt climates

Article in Journal of Engineering and Applied Science - August 2015

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Use of Kinetic Facades to Enhance Daylight Performance in Office Buildings with Emphasis on Egypt climates

A. WANAS1, S.S. ALY2, A.A. FARGAL3, AND R.B. EL-DABAA4

Abstract
Daylight performance is important factor in office building design. Kinetic facades are introduced in enhancement of indoor daylight. Parametric Daylight simulation was performed using Rhino software, algorithmic modelling developed by Grasshopper and Diva with Radiance interface to explore the applicability of parametric design to enhance daylight performance. Two types of kinetic movements, rotation and vertical transition are applied on horizontal louvers of an office building’s south façade. The aim of this study is evaluating the effect of louvers configuration on achieving a balance point between sufficient illuminance level and light uniformity inside selected space. Also, it aims at determining the optimum hourly pattern for louvers movement. The simulation was performed on a virtual prototype of office space in desert hot arid climate, Cairo, Egypt. The study focused on three hours “8:00, 12:00 and 16:00” of three critical days in the year “21st June, 21st December and 21st March”. The proposed algorithm converts the illuminance values to a percentage format showing day-lit, under-lit and over-lit zones. Results show that using well-studied kinetic louvers increase the percentage of day-lit zone to 63 percent instead of 53 percent without shadings and the percentage decrease to 35 percent if unstudied kinetic system is used.

KEYWORDS: Daylight performance, parametric daylight simulation, kinetic facades; daylight algorithms, simulation

1. INTRODUCTION

Egypt is classified as a desert and hot-arid climate according to Köppen’s climate map [1]. It is a climatic zone that is characterised by solar abundant throughout the year and high irradiation potential, particularly in Upper Egypt and Western region of

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Egypt, i.e., an annual irradiation potential of 2000 to 3200 Kwh/m² [2]. This level of long solar hours “9-12 hours daily” provides an opportunity for building designers to utilise such abundant daylight for use of natural light inside buildings’ spaces to lower energy use [3]. According to the Egyptian code for energy consumption “residential and commercial” buildings use 46 per cent of electrical energy [4]. In Egypt, buildings are responsible for up to 55 per cent of the total electrical energy consumed in these facilities due to lighting, cooling and heating demands in summer and winter, whereas artificial lighting consumes 36 per cent of the total electrical energy between 1999 and 2000 [5].

Due to the awareness of energy consumption and technology development architects are trying to develop intelligent buildings that help in improving light quality in offices that affects the heat gain and increases cooling loads and energy conservation [6]. For the energy efficiency demands, sustainable architecture and constructive decisions are needed. A well designed building envelope will affect the lighting and HVAC performance inside spaces. Special in the buildings covered with transparent materials as commercial and retail buildings [7].

2. Objectives

The aim of this research is to decrease electrical energy consumption through evaluating the effect of louvers configuration to achieve a balance point between sufficient illuminance level and light uniformity in space, to determine the optimum hourly pattern for louvers movement.

3. Literature review

Façades are the direct link between interior space and the outer environment, its main role is to protect the indoor space from outer environment. The continuous change in outer climatic conditions affects the human’s comfort in space, so facades are in need to be environmentally responsive to outer conditions. Kinetic facades is the physical movement of façade to respond to the surrounding changing conditions [8].
Daylighting is a common field of interest in many careers, thus it’s difficult in evaluating the building performance strategy. This issue gives strength in daylighting design as different professions focus on different aspects of daylighting [9].

Illumination level is the amount of light on a plane and is measured by lumen per square meter or Lux [10]. Many daylight metrics and rules of thumb were developed to evaluate illuminance in spaces. A study was done to validate the sequence of daylight rules of thumb for side-lit spaces. Results were validated through Radiance simulations for 2300 side-lit spaces. The study worked on four rules of thumb and their relation to the potential day-lit zones within a building. The rules were introduced in a sequence that tests the effective sky angles and targeted daylight factor, daylight feasibility and room dimensions with relation to interior surfaces reflection and room’s depth [11]. This study will use this rule of thumb in order to deduce the depth of the tested space.

Daylight performance study of two spaces in an office building in Singapore was done through a parametric approach. Four passive design categories were tested; interior surface reflectance, glazing visual transmittance, light shelves and shading control. Annual metrics were used for Daylight Autonomy “DA con and DA max”. Results show four findings for each of the passive design technique used. First, the interior surface reflects more light in case of rooms with small openings, thus tends to decrease glare. Second, to decrease in spaces with large openings, low-transmittance glazing needs to be applied and vice versa. Third, the design of false ceiling highly affects daylight performance when applying light shelves. Finally, the shades used in this study was venetian blinds which was found that it’s lowered all the time to prevent glare but this results in low daylight performance. Thus, applying an automatic shading system with relevant to the daylight requirement is needed [12]. A parametric study was conducted on a 7-storey office building in Moncalieri “a town in the suburbs of Turin”. The Study tested heating, cooling and lighting. Two metrics were used for lighting daylight factor and illuminance levels. The variables used for this parametric study are: orientation, room layout, glazing, layout of the façade module, Presence of blinds and lighting control. Results show that; an office building need to be north -
south oriented for less energy consumption. For the room layout a cellular design with corridors in the middle is more energy efficient than an open plan due to light penetration limits. Results also revealed that the blinds are preferable to be movable and light control system need to be a responsive control system. Finally, the façade with an opaque head shows the best results regarding thermal gaining and loss; in the case of cellular offices the glass with visual transmittance 59 per cent gives the best results while in an open plan the one with visual transmittance 76 per cent gives the best results [13].

A study tested the effect of semi silvered reflective louver system on a clerestory portion facing north façade of a deep office cellular space. The study focused on the energy consumption and cost reduction of the daylight system. Correlation studies was done between on-site and simulation measurements. The results shows that reflective louvers provides 70 per cent illuminance under clear sky, but the system failed in cost reduction side [14].

A comparison was done between kinetic aluminium louvers, fixed aluminium louvers and non-shaded cases of a south oriented office facades in the life cycle cost and energy consumption. The results shows that the operation cost of the kinetic aluminium louvers are less than the fixed and non-shaded cases. While the initial cost of the kinetic aluminium louvers is higher than the other cases [15].

It’s preferred to use dynamic than static daylight performance metric that uses a single sky condition as daylight factor. Some examples were tested to show the benefits on dynamic daylight metrics [16]. A research was done and deduced three main findings from analysing different papers. The findings were: mainly explaining and justification daylit design, reaching the equilibrium between daylight and solar gain and finally deciding which type of solar shading is used. These findings were deduced from these papers. The first paper tested the relation between luminous distribution and glare in 70 cases. It deduced a new evaluation tool to predict glare that is Radiance based called Daylight Glare probability. The second paper tested both remotely and manually controlled blinds in 15 offices for 30 weeks. They concluded that the remote
controlled blinds that is better due to the variation of needs between users. The third paper showed the differences between static daylight factor metric and dynamic daylight metric. This revealed that daylight factor metric is limited as it not only based on a single overcast sky condition, it also don’t count the climate, orientation and function of building. While the dynamic daylight simulation tests the daylight levels with time sequence through the year. At the end, a comparison was done between daylight factor metric, daylight autonomy “DA” and useful daylight illuminance “UDI” metrics. It was found that UDI is the best as it deduces both of under-lit and over- lit spaces through space [17]. Another study recommended a method for daylight availability metric. The method was validated through 60 students testing a studio space in carpenter centre in Cambridge, USA. This was done through highlighting the current daylight availability metrics and comparing them to the student’s results. Results revealed that rule of thumb of window head and maximum daylight penetration gives accurate results. Also, results showed that spatial daylight illuminance which was at that time still in development and useful daylight illuminance are best annual metrics [18]. A study was done to highlight and analyse the current situation of daylight performance to understand how it should be going. It shows the current problems of daylighting simulation process. Daylight performance was classified into three groups; daylight availability, visual comfort and thermal loads. The study reviewed metrics that can evaluate each category on a side-lit space in Boston. The tested space has an unshaded south façade. The simulation was done on working days with and without manually controlled venetian blinds. Daylight simulations used Radiance based Daysim version 3.0 while thermal simulation used design builder. The measurement of daylight availability was discussed through climate based metrics. The study showed series of decisions needed to be taken before beginning in simulation as: choosing time, date and location of simulation. The metrics discussed were an annual way in evaluating a daylit space as Daylight Availability “DA”, Useful daylight illuminance “UDI” and DA max that shows the oversupply of light by Rogers. The second part of the study focused on the visual comfort which was illustrated as discomfort glare and the view to outside.
The authors showed the differences between Daylight Glare Index “DGI”, Unified Glare Rating “DGR” and Daylight Glare Probability “DGP” this showed the DGI and DGR are used for artificial light. The modified version of DGP by Wienold was discussed and illustrated why it is the best method till now. The availability of the view is discussed according to the LEED and how to overcome points that LEED neglected. It was done through testing four cases due to occupant behaviour “passive and active users” no blinds, two types of active blinds for direct sunlight and glare and always lowered blinds. Finally the thermal analysis was done by Energy Plus to deduce annual energy used for heating, cooling and lighting. This revealed that the external blinds lowered the cooling and electric lighting loads while it increases the heating load. The paper gives an overview where computer simulation is standing and where to go [19]. But this didn’t show how to test daylight, energy and view in case of kinetic facades where hourly metrics are needed. At the current time of the research there were no completed metric for hourly evaluation.

Most daylight simulation studies done were depending on annual daylight metrics to evaluate the daylight performance in space. This paper will use hourly daylight simulation method on a kinetic façade with reflective louvers that where were stated as an energy efficient shading system, to test its effect on uniformity of light and daylight illuminance on a north - south oriented cellular office.

4. Method

The method is discussed upon four categories:

a) Study Area: This paper evaluates the daylight performance on an hourly pattern to deduce the louvers configuration pattern needed in a virtual office space in Cairo. Two types of kinetic movements are tested; rotation and vertical transition are applied on horizontal louvers of an office building’s south façade.

b) Procedures: A parametric algorithm was set to divide the resulted illuminance values into three categories: Day-lit, under-lit and over-lit zones. The Simulation will consider 300-1500 lux as a day lit zone. While below 300 lux is under lit zone and more than
1500 lux as over lit. The results will be presented in the form of percentage. The study targets to maximize both the percentage of day-lit area and light uniformity.

The Illuminating Engineering Society of North America “IESNA” recommends 200-1500 lux according to the task [20]. In addition, the Egyptian code for commercial buildings which encompasses the daylight requirements of Egypt’s offices recommends not less than 300 lux for office spaces [4]. Table 1 shows the categories of illumination and their required values according to general tasks.

Table 1. Illumination categories and their illuminance values in general tasks [21].

<table>
<thead>
<tr>
<th>Activity</th>
<th>Illuminance (Lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual tasks with high contrast or large size</td>
<td>200 - 300 – 500</td>
</tr>
<tr>
<td>Visual tasks with medium contrast or small size</td>
<td>500 - 750 – 1000</td>
</tr>
<tr>
<td>Visual tasks with low contrast or large size</td>
<td>1000- 1500 – 2000</td>
</tr>
</tbody>
</table>

Distribution of light shows variation of light from one point to another on the working plane. Non-uniform light distribution causes visual discomfort, because human eye is forced to adapt quickly to variation of light levels. The higher value means more uniform illuminance [21].

It was stated that IESNA suggests a ratio between maximum and minimum illuminance won’t exceed 1:10 [20]. This study managed to increase light uniformity to reach 1:10 that will decrease light contrast on the working plane so the range of 300-1500 lux is listed as an accepted range for illuminance level.

c) Subject “case study”: Simulation is done through working hours from 8:00 to 16:00. Two kinetic movements are tested; rotation and vertical transition are applied on horizontal louvers of the office building’s south façade. Tested days are chosen according to the Solstice and Equinox days where sun angle is at maximum and minimum on 21st of June, 21st December and 21st of March where day and night have equal duration [22].

d) Equipment: The proposed method used parametric daylight simulation tools; Rhinoceros version 5, Grasshopper version 0.90076 and Diva version 2. Rhino was used as a viewer for Grasshopper script. Grasshopper is a parametric modelling plugin for Rhinoceros that was established by David Rutten in 2007. It does not require
programming experiences, as it depends on graphical components to generate relation between elements to build parametric model [23]. It was used to build the parametric office space and generate algorithms to evaluate daylight in space. Diva is a grasshopper plugin that calculates daylight and energy [24]. Diva stands for Design Iterate Validate which is a near concept to parametric modelling [25]. This process helps in automatically finding many solution alternatives through computer simulations, then the architect can choose a suitable solution.

A study was done using Grasshopper and Diva to enhance daylight performance on a south façade of a living room in Cairo. Origami based façade called Kaleidocycle was tested with a parametric workflow. The study was divided to two parts analysing the daylight performance of the base case. The second part depended on a parametric optimization technique to reach an optimum façade configuration. Two variables were tested; the Kaleidocycle opening size and its rotation angle. The results reached optimum solution which gives a better daylight performance than which was equivalent by LEED v4 [26].

4.1. Script and Algorithm Documentation

A closed loop algorithm was created through Grasshopper and Diva to achieve the required daylight performance. An exhaustive simulation technique tested the vertical transition and rotation of louvers, to reach an optimum louver’s configuration that enhances illuminance level and uniformity of light. The Simulation Script is generated in Grasshopper for a completely parametric modelling with easy modification process. The whole script is divided into 8 labelled groups, each responsible for a certain task as shown in the Appendix. Each group is discussed as:

4.1.1. Modelling script

The first group is the modelling script of an office space as shown in Fig. 1. In this part walls, ceiling, floor and ground level were modelled. The tested façade was oriented towards the South with a 60 cm space between the wall and the facade. Finally, a 60cm square analysis grid was determined at 80 cm above floor. The internal office space dimensions are 4*6.5 and height 3m. These proportions depend on rule of
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thumb which illustrates a relation between room’s proportions and internal material reflectivity. By this formula “1” a well-adjusted ratio of illuminance can be balanced between half front and half back of room at about 3:1. Room’s Length “L” couldn’t exceed the value of:

\[
\frac{L}{W} + \frac{L}{H} \leq \frac{2}{1 - R_{\text{back}}} \quad (1) [27]
\]

Where L, W and H are Length, width, height of the room and R_{\text{back}} is average reflectivity of the back half of room [27]. Simulation parameters are shown in Table 2.

![Fig. 1. Group 1 script of the room modelling and grid.](image)

**Table 2. Simulation Parameters.**

<table>
<thead>
<tr>
<th>Indoor Space parameters</th>
<th>Simulated room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Area</td>
<td>$24 \ m^2$</td>
</tr>
<tr>
<td>Floor level</td>
<td>(+6.00 m.) above ground</td>
</tr>
<tr>
<td>Tested façade orientation</td>
<td>South</td>
</tr>
<tr>
<td>Window wall ratio (WWR)</td>
<td>25per cent including 0.05 m. frame</td>
</tr>
<tr>
<td>Analysis grid</td>
<td>0.6*0.6 m.</td>
</tr>
<tr>
<td>Working Plane height</td>
<td>0.8 m.</td>
</tr>
</tbody>
</table>
4.1.2. **Window wall ratio script**

The relation between window wall ratio “WWR” and energy consumption is complicated. Increasing WWR, decrease the energy needed for lighting but increase cooling energy. WWR of 25 per cent is an energy efficient ratio for hot climates in south facades [29]. The second group is WWR and window modelling as shown in Fig. 2.

![Fig. 2. Group 2 script of window wall ratio calculation.](image.png)

WWR script was modelled by a 17 value slider that represents ratios of WWR from 10 per cent to 90 per cent. The WWR was evaluated over 3 steps. First, maximizing window head, then window width is maximized; finally lowering the window sill.

4.1.3. **Louver’s calculations script**

The third group uses Ladybug an open source environmental plugin for Grasshopper. Ladybug was used to calculate the sun’s cut-off angle in Cairo. Louver’s width and number are determined according to the cut-off angle as shown in Fig. 3.
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Fig. 3. Group 3 script for calculating the cut-off angle in Cairo.

4.1.4. Kinetic louvers script

The fourth part of the script is setting the movement of the kinetic louvers. It was done by dividing the height of glass into 3 segments. Louvers are set to move between points 0-1, 1-2 and 2-3. The divided segments distances are given the value x, y and z. So louver moves x, ¼ x, ½ x and ¾ x. Points 1, 2, 3 moves up and down, so x is variable according to the louver’s movement. The same concept was applied in y and z. The variable distances between segments are re-evaluated with a value between 0 and 1 and numbers of variables are shown in Table 3 which shows the final number of cases in this simulation.

Table 3. Simulation variables and number of cases.

<table>
<thead>
<tr>
<th>Façade parameters</th>
<th>Tested values</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louver 1 distance</td>
<td>x, ¼ x, ½ x and ¾ x</td>
<td>4</td>
</tr>
<tr>
<td>Louver 2 distance</td>
<td>y, ¼ y, ½ y and ¾ y</td>
<td>4</td>
</tr>
<tr>
<td>Louver 3 distance</td>
<td>z, ¼ z, ½ z and ¾ z</td>
<td>4</td>
</tr>
<tr>
<td>Angles</td>
<td>-40, -30, -20, -10, 0, 10, 20, 30, 40</td>
<td>9</td>
</tr>
<tr>
<td>Number of cases per hour</td>
<td>576</td>
<td></td>
</tr>
<tr>
<td>Tested hours</td>
<td>8, 12, 16</td>
<td>1,728</td>
</tr>
<tr>
<td>Simulation days</td>
<td>3 days</td>
<td>5,184</td>
</tr>
<tr>
<td>Total number of cases</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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4.1.5. Radiance settings

DIVA for Grasshopper is used for daylight simulation. DIVA simulation type was set as Illuminance test and sky condition is set as clear sky with sun. “Ambient bounces” is the number of reflected bounces, where zero is the direct light without any reflection [20]. The value 6 is used as ambient bounces, although this number will take more time in simulation but will give accurate results. Radiance materials used in Diva is shown in Table 4 and Fig. 5.

Table 4. Diva materials.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>50 per cent reflection Generic walls</td>
</tr>
<tr>
<td>Floor</td>
<td>20 per cent reflection Generic floor</td>
</tr>
<tr>
<td>Ceiling</td>
<td>70 per cent reflection Generic ceiling</td>
</tr>
<tr>
<td>Glazing</td>
<td>Clear Double Glass (visual transmittance VT = 80% )</td>
</tr>
<tr>
<td>Window frame and Louvers</td>
<td>Metal Diffuse</td>
</tr>
</tbody>
</table>

Fig. 4. Group 5 Kinetic louvers movement.

Fig. 5. Radiance materials
4.1.6. Daylight algorithm

The sixth group shows the closed algorithm proposed to evaluate daylight performance in space. The Algorithm separated illuminance values resulted from DIVA simulation into three categories according to their values. This illuminance values are on the working plane height 0.8 m. The space is divided as under-lit zone < 300 Lux, Day-lit zone 300 Lux - 1500 Lux and over-lit zone > 1500 Lux. This was done through sorting the list of illuminance level and then dispatching it according to the desired illuminance values as shown in Fig.6.

Fig. 6. Group 6 daylight algorithm calculation.

4.1.7. Exhaustive Simulation and recording results

The seventh group is the exhaustive simulation part. Four variables “3 louver distances and angles” were animated via cross-reference option. Through the eighth group, results are linked with Excel to record all simulation process results. This gives an opportunity to trace the effect of each variable. For organizing the results of 5,184 cases; fragment option was used to rename simulation pictures with specific names. Best cases are chosen according to highest day-lit and uniformity values as in Fig. 7.
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5. Results and Discussion

Results are divided into 3 parts; best case configuration of louvers, worst case and base case without any shading devices as shown in Table 5. It was shown that rotation angles of louvers play a main role in having either best results or worst results. It was found that the worst cases louvers were looking down, while best cases louvers were looking up. The best case resembles the best kinetic louvers configuration while base case doesn’t have any shading device; finally the worst case shows the worst alternative in the kinetic louvers configuration. Analysis is done on these results to deduce the average percentage of day-lit zone in each case through the year. It was found that when comparing the average percentage of day-lit zone in best case results of simulation is 63 per cent while the base case with no shading devices is 53 per cent as shown in Table 6. Also it was clear that if using unstudied kinetic louvers could lead to the worst case with a 35 per cent day-lit zone; where the base case is better. The uniformity levels are not mentioned as the difference between previous alternatives is neglectable. Also the uniformity levels can be in the best ratios although the room is all under-lit or over-lit, so it could not be measured alone without illuminance value measurement.
The abbreviations in the table are:
DL = Day-Lit, UL = Under-Lit, OL = Over-Lit, UN = Uniformity, A = Angle, L1, L2, L3 = Louver 1, Louver 2 and Louver 3 distances from room's floor

It was shown that rotation angles of louvers play a main role in having either best results or worst results. It was found that the worst cases louvers were looking
Table 6. Comparing average percentage of Day-lit zone of three cases, hours and days.

<table>
<thead>
<tr>
<th></th>
<th>21&lt;sup&gt;st&lt;/sup&gt; June</th>
<th>21&lt;sup&gt;st&lt;/sup&gt; Dec.</th>
<th>21&lt;sup&gt;st&lt;/sup&gt; March</th>
<th>Average DL %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>46 %</td>
<td>60 %</td>
<td>53 %</td>
<td>53 %</td>
</tr>
<tr>
<td>Best Case</td>
<td>63 %</td>
<td>63 %</td>
<td>62 %</td>
<td>63 %</td>
</tr>
<tr>
<td>Worst Case</td>
<td>36 %</td>
<td>30 %</td>
<td>40 %</td>
<td>35 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>8:00</th>
<th>12:00</th>
<th>16:00</th>
<th>Average DL %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>46 %</td>
<td>70 %</td>
<td>43 %</td>
<td>53 %</td>
</tr>
<tr>
<td>Best Case</td>
<td>52 %</td>
<td>90 %</td>
<td>47 %</td>
<td>63 %</td>
</tr>
<tr>
<td>Worst Case</td>
<td>28 %</td>
<td>54 %</td>
<td>25 %</td>
<td>35 %</td>
</tr>
</tbody>
</table>

The results show the importance of using suitable kinetic louvers in preliminary design process. Table 6 shows that the average percentage of Day-lit zone is fixed when deducing it by different ways. The left side table compares the 3 tested cases through the three studied days in different months to deduce an average percentage of day-lit zones. While the right side table, shows a different analysis by comparing the tested hours to the tested cases. It was clear that both comparisons gave the same percentage which gives an overview for average day-lit zone percentage through the year in the three cases.

Percentage of Day-lit zone in table 6 is translated in graphically way in Fig. 8, to show Day-lit zone in base case, best case and worst case in the 3 tested days and hours. Figure 8 clearly shows that the best case proposal have better results than the base case. Also it revealed that applying an un-studied kinetic system cause negative results where base case will be better at that case. It was concluded that the effect of louvers is the best on 21<sup>st</sup> June then March and finally the December has the least effect compared to other months. When having a closer look on each month to know the impact of the proposed louvers at the tested hours; it is found that the best impact is at 12:00 then 8:00 then 16:00, but on 21<sup>st</sup> of December there is not a significance difference in percentage of day-lit zone between 8:00 and 16:00. It was also found that although 21<sup>st</sup> June and 21<sup>st</sup> March where having the highest percentages at 12:00 and 16:00, but 21<sup>st</sup> December at 8:00 have the highest percentage followed by 21<sup>st</sup> of June.
then 21st of March. Also it was clear that on 21st of June and 21st of March at 12:00 and 16:00 there’s nearly no difference between the in percentages of day-lit zone, although these are the highest and lowest months in the best cases. Thus, it revealed that in the best case proposal the highest and lowest reading of the day are closely to each other giving early each day the same light level at that time.

Going to the base case results, it revealed also that the best percentages of day-lit zone also found at 12:00 in all months, and at 16:00 the percentages are also the least. The difference in the base case is that the 21st of December has the highest percentages while the 21st of June has the lowest percentages which are the opposite of the results in the best case. On the other when comparing best cases and base case at each month alone per hour, it’s found that results are having the same categorization of highest and lowest percentage as 12:00 is always the highest percentages. Another finding is added that the base case doesn’t have the homogeneous result of the same reading each month at the same hour.

The worst cases are illustrated to show that if the kinetic louvers are designed without study, then it will have lower percentages of day-lit zone than the base. As an example for that, on 21st of December at 8:00 the base case shows it has the highest percentage while worst case shows it has the lowest percentage. Another issue is revealed in the worst case reading of 21st June through the day as the percentage of
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day-lit zone is the same showing that the uniformity of light can be great at this case but it has the lowest percentage day-lit zone. Thus, uniformity of light couldn’t be analysed alone without illuminance value of space.

As discussed in the literature this simulation shows that using the rule thumb in room’s proportion and material maintains an acceptable level of light uniformity. For comparing results with other studies it was calculated as an annually average; due to the lacking in evaluating the hourly daylight metrics. It was shown that were in [12] the results of continuous Daylight Autonomy > 80 per cent covers 41 per cent of the area in case of passive users with movable blinds. It means that 41 per cent of the area is well-lit for more than 80 per cent of annual working hours with 500 lux. While in this study the percentage of the day-lit zone achieved reached 63 per cent of the area. This shows the need for using automated kinetic facade than manual movable blinds.

6. Conclusion

Finally, comparisons between best vs. base cases and worst vs. base case is held in Table 7 through the tested days and hours, to deduce the percentage of day-lit zone achieved. It was found that at 12:00 the studied kinetic system has the greatest influence especially in June, then March and December.

Table 7. Percentage of Day-lit zone achieved by comparing best and worst results.

<table>
<thead>
<tr>
<th>Date</th>
<th>Case type</th>
<th>8:00</th>
<th>12:00</th>
<th>16:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>21-Mar</td>
<td>Base case</td>
<td>45%</td>
<td>68%</td>
<td>48%</td>
</tr>
<tr>
<td></td>
<td>Best case</td>
<td>48%</td>
<td>90%</td>
<td>48%</td>
</tr>
<tr>
<td></td>
<td>Worst case</td>
<td>34%</td>
<td>53%</td>
<td>34%</td>
</tr>
<tr>
<td></td>
<td>DL % achieved best vs. base</td>
<td>3%</td>
<td>22%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>DL % achieved worst vs. base</td>
<td>-14%</td>
<td>-37%</td>
<td>-14%</td>
</tr>
<tr>
<td>21-Dec</td>
<td>Base case</td>
<td>56%</td>
<td>81%</td>
<td>44%</td>
</tr>
<tr>
<td></td>
<td>Best case</td>
<td>58%</td>
<td>88%</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>Worst case</td>
<td>23%</td>
<td>52%</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>DL % achieved best vs. base</td>
<td>2%</td>
<td>7%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>DL % achieved worst vs. base</td>
<td>-35%</td>
<td>-36%</td>
<td>-31%</td>
</tr>
<tr>
<td>21-Jun</td>
<td>Base case</td>
<td>38%</td>
<td>62%</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>Best case</td>
<td>52%</td>
<td>91%</td>
<td>47%</td>
</tr>
<tr>
<td></td>
<td>Worst case</td>
<td>26%</td>
<td>26%</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>DL % achieved best vs. base</td>
<td>14%</td>
<td>29%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>DL % achieved worst vs. base</td>
<td>-26%</td>
<td>-65%</td>
<td>-21%</td>
</tr>
</tbody>
</table>
The positive percentage shows the achieved percentage of day-lit zone when using the best case louver’s configuration. While the negative pattern shows that no achievement was added, but less day-lit zone percentage occurred. From the best cases; it was concluded that when sun is at the highest position, the proposed kinetic louvers will have a great impact, while the least impact is found at the time where sun is at the lowest angle position. Thus, at the lowest angle “December” may need more number of louvers are needed or more fractals to diffuse more daylight into the space, but it will affect the view.

7. Limitations of study and future research

The office space is located in an upper floor, where no indirect light is reflected neither from ground level nor surrounding context. This focused on testing the effect of kinetic louvers and internal materials on light diffusion in space. For time saving issues simulation was set on 3 critical hours and days, while it was supposed to be hourly, it decreases the cases from 5,124 to 1,728.

A further research can be added to this study by, testing the hourly energy consumption of the kinetic louvers on the office space in addition to the daylight.
References


use of kinetic facades to enhance daylight performance ....

استخدام الواجهات المتحركة لتحسين كفاءة الإضاءة الطبيعية في المباني الإدارية

استخدم البحث التصميم البرمتهري على نموذج افتراضي لغرف إدارية بأبعاد 3 × 6.5 × 4 متر يقع في مناخ صحراوي جاف بالفاهرة وتتم التجربة على ثلاث ساعات 8 و12 و16 على ثلاث أيام حرجة من العام هي 21 يونيو و21 ديسمبر و21 مارس، ويقدم البحث طريقة حسابية لمعرفة شدة الإستضاءة للساعات المحددة عن طريق تحويل القيم الناتجة إلى نسب مئوية للمناطق المضاءة، وأوضحت النتائج أهمية الدراسة الدقيقة قبل استخدام الواجهات المتحركة حيث أن نسبة المناطق المضاءة قد تصل إلى 63% بدلاً من 53% في حالة عدم استخدام أي كاسرات شمسية بينما قد تقل إلى 35% في حالة عدم الدراسة الجيدة لحركة الكاسرات الشمسية المتحركة.
Appendix:

The Whole Script is shown in this section.