Daylight and Energy Performance of Automated Shading with Parametric Design: Case Study Bangkok

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Abstract. Ongoing rise of global warming and climate change leads to a new paradigm shift for architectural skin from passive to active system. Limitation lies in overall performance results of static shading in dynamic environment. The result emphasizes a higher performance of automated shading for adapting more to the environment. The adaptive ability to protect facade from high-intensity solar radiation and maintain indoor environment quality in all conditions result into higher effectiveness overall. Computational integration in modeling and simulation are necessary for automated shading design, evaluating daylight performance and estimating lighting and cooling loads were required in early design stage for energy-efficient design. This paper presents a study of automated shading in diamond shape with rotation movement through parametric design to explore alternative design schemes and generating parameters including size and angle of shading. The simulation are performed using DIVA-for-Grasshopper and Archsim plug-ins under Perez sky from Bangkok weather file. The experiments aim to optimize daylight performance and energy efficiency. The evaluation compares results of 3 experiment cases of an open plan office typically found in Bangkok as following; no shading, static shading and automated shading cases, all of which are evaluated on south facing façade. The outcome demonstrates that automated shading achieved higher daylight quality, more uniformity and reduce overall energy consumption compared to no shading and static shading cases. Finally, parametric design of automated shading is suggested as a tool for architects and designers to choose the most appropriate design for their project prior to construction.

Introduction

World environmental issues are increasing nowadays and continuing in the future. Reducing energy consumption in building can solve energy crisis, climate change and global warming, which getting extremely more severe. Electricity consumption in office is normally a big proportion of the overall demand in building sector, the energy consumption for cooling load is 60% and 20% for lighting load [1]. Popularity of high glazing facade for modern office buildings lets a high solar radiation through building skin causing more cooling load. To install fabric shade to shield direct sunlight caused further demand in the use of artificial lighting, effecting the increase in lighting load. Recent literatures highlight the benefit of automated shading in energy saving and improve occupancy comfort by protecting exceeding heat gain and utilizing available natural resource of the sun for sufficient daylight in indoor space.

In order to design automated shading to the most optimization in architectural projects, the development of computational tool in model and simulation helps exploring the automated shading design. At different time period throughout the day, simulating the movement of shading and examining the angle rotation and different divisions and sizes of the diamond shape, led to the design result for optimal response in dynamic environment. Compare to conventional design, the connection between generating of various designs and measuring of their performances in parametric design workflow accelerate iterative design which the form of automated shading corresponds to the best performance in optimal daylight.

The study investigates its 2 hypotheses. The first is to prove that automated shading produces the best performance when compared to no shading and static shading. The second is to create a
parametric design acting as the analysis modeling and simulating tool to enable more-efficient work flow of automated shading design.

**Background**

Automated shading is a type of climate adaptive building shell (CABS) [7], working in coordination with other buildings systems for high performance building. Automated shading can be applied both interior and exterior. For this paper, the focus is on the exterior shade in aiming to become a second skin of buildings with aesthetic outstanding façade and high quality performance.

**Rotation Movement**

![Rotation Movement Images]

- **Folding**, folds surface in and out in two dimensions.
- **Rotation**, rotates surface angle in one dimension.
- **Shift (Translation)**, moves surface overlapping in one dimension.
- **Diaphragm**, scales surface up and down in three dimensions.

For tropical climate as Thailand, **Rotation** in one-dimension movement is most appropriate form in terms of performance in shielding the direct sunlight and being easy to maintain system.

**Parametric Diamond Shape of Automated Shading**

![Diamond Shape Images]

Experiment in shape of automated shading, diamond shape is selected due to its ability to rotate in both horizontal and vertical and its edge ability to protect sunlight.

**Methodology**

The research workflow divides into 2 parts, which are the evaluation of daylight performance and evaluation of energy load. Comparing the 3 cases to investigate the performance of automated shading and search for the optimal automated shading option at each hourly calculation and evaluate dynamic performance in each time step.
Simulation Model

The study focuses on south facing façade of a low-rise open plan office (48m.x10m.x3m.) analysis on 1-span column (9.8m.x10m.). Area of the study is in Bangkok, Thailand.

The 3 cases are as follows:

- **Base case, no shading** with glazing of WWR (Window-wall-ratio) 40% according to ASHRAE Standard 90.1. for tropical weather.
- **Case 1, static shading** with full glazing of WWR 100% reference from typical modern open plan office buildings. The shading is overhang 0.85 m. derived from vertical shading angle (VSA) of critical angle of sun position.
- **Case 2, automated shading** with full glazing of WWR 100%. The shading is varied by size parameter of diamond shape, which is 3.5 m. with one division. And the angle parameter range from -90 to 90 degree.

Reflectance values of model surfaces have been assigned to 20% for floor, 50% for walls, 80% for ceiling and 20% for automated shading matte material. In case of opening, double glazing with 80% visible transmittance has been assigned.

Parametric model uses Grasshopper plug-ins, a graphical algorithm editor tightly integrated with Rhino’s 3d modeling tools (grasshopper3d, 2017), to generate cases shading.

Simulation Process

Daylight evaluation of 3 cases select hourly calculation due to automated shading adaptive effects in every hour base on surrounding environment for comparing result to no shading and static shading.

For experiment time, four critical day of the year were selected: spring equinox, summer solstice, autumn equinox and winter solstice. Measurement at 9 a.m. and 3 p.m. under Perez sky condition base on Bangkok weather file.

IES standard and LEED v4. Daylight metrics are used for evaluation, minimum value for the requirement is 300 lux in IES standard while in LEED v4 daylight consist 3 levels:

- **Daylit**, area archives between 300-3,000 lux, the best ranges for using daylight.
- **Overlit**, area archives exceeding 3,000 lux.
- **Partially daylit**, area archives lower 300 lux

Points for evaluation are reaching daylit area 75% and 90% of occupied space to receive 1 and 2 points on LEED scale w.
The daylight simulations are performed using Radiance and Daysim-based simulation through DIVA-for-Grasshopper plug-ins in Rhinoceros. The plug-in was developed at Harvard University and distributed by Solemma LLC for now.

Energy efficient evaluations are compared only in the annual energy consumption, which comprises of lighting and cooling loads. In case of automated shading, lighting and shading schedules are configured after daylight analysis, best series of shading design could be considered for editing in each hour and completed to annual schedule for the overall energy consumptions.

The Energy analysis are calculated using Archsim plug-ins, Energy Plus-based simulation for analysis energy support daylight and shading control.

**Result**

<table>
<thead>
<tr>
<th>No shading</th>
<th>Static Shading</th>
<th>Automated Shading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equinox</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer Solstice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter Solstice</td>
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</tr>
</tbody>
</table>

![Graph illustrate result of 3 cases at 3 pm. in illuminance value (lux).](image)

Daylight performance results of no shading archives *daylit* 66% in middle of the space, *partially daylit* 24% in deepest space and *overlit* 10% near opening. Meanwhile static shading archives 88% of daylit, 12% overlit and no partially daylit. For automated shading archives 97% of daylit, 1.5% overlit and 1.5% partially daylit.

No shading archives daylit space in lower percentage and archives high percentage of partially daylit space in all cases, but in summer and winter amount of daylight can enter through fenestration in high level near opening area between 3,000-15,000 lux, while static shading archives more daylit area without partially daylit, but direct sunlight can enter through building especially in winter between 3,000-29,000 lux. In case of automated shading archives daylit area more than every cases and has few of partially daylit but has least overlit area between 3,000-3,600 lux than other cases.
High contrast of illuminance in space pull down uniformity of daylight in no shading and static shading in contrast with automated shading which has the lowest illuminance contrast, resulting in more uniformity and higher quality of daylight in space.

For Energy analysis no shading uses lighting load of 16.4 kWh/m² and cooling load of 134.5 kWh/m², for static shading results in 12.8 kWh/m² and 169.8 kWh/m². In case of automated shading, the result shows in 3 kWh/m² and 120 kWh/m².

Lighting load reduces from no shading to static shading and automated shading respectively. Comparing between 3 cases, static shading uses less lighting load to no shading but has higher cooling load and automated shading performs the best in the reduction of both lighting and cooling load when compares to no shading and static shading. This result also reflects the ineffectiveness in non-responsive to environment of static system in terms of preventing direct sunlight while providing more daylight in annual performance when compares to no shading.

Conclusion

Automated shading performs best out of 3 cases in quality of daylight, uniformity, ability of harvesting sufficient daylight in space and protecting solar radiation for energy saving in lighting and cooling loads. In future research, potential of shading surface facing direct sunlight may also gives opportunity for integrating PV panel as BIPV to generating renewable energy develop into self-generating an energy system.

References


