KINETIC SHADING FOR OPTIMIZATION OF DAYLIGHTING

Siva Ram Edupuganti

Abstract

Buildings consume more than one third of India’s total electricity. According to the National Habitat Standard Mission, building energy consumption has increased from 14% in 1970 to 33% in 2004-05. In Commercial buildings, lighting accounts for 59% of the total electricity usage (Chowdhury, 2012). Thus, substantial deduction in energy consumption of buildings can be achieved by optimizing daylighting in commercial buildings by reducing the use of artificial lighting (Lee & Selkowitz, 2006). However, because the availability of natural light changes dynamically; the design of static shading systems adhering to both high and low levels of daylight is difficult. This paper hypothesizes kinetic shading systems and analyses the benefits when compared to a fixed shading system for optimizing a space for daylighting.

Key Words: Kinetic Shading, Dynamic Shading, Adaptive Facades, Daylighting, Responsive Architecture, Intelligent Facade

1. Introduction

Buildings account for more than one third of total energy consumption in India and similarly there is clear statistical evidence that they consume 40% in IES Countries. (Aelenei, Aelenei, & Vieria, 2016) Climate, energy, information and human agents are in constant flux and keep changing. Hence flexibility is essential in building systems to adapt to these constant changing conditions (Tashakori, 2014) Building Facades act as a bridge between inside to the outside of the buildings and are considered as the main parameter in determining the energy efficiency of the building (Aelenei, Aelenei, & Vieria, 2016). Advances in manufacturing and fabrication processes, construction materials, and control technologies have opened up the possibility of dynamic and adaptive facades. (Hanafin, Hobbs, & Datta, 2011) Significant energy savings can be achieved by using adaptive facades when compared to static facades. Further a data analysis study was done on 130 buildings with adaptable facades to assess

Fig 1: Distribution of External Factors on adaptable facades

Global Distribution of External Factors %

- radiation: 76%
- temperature: 26%
- wind: 13%
- humidity: 6%
- precipitation: 28%

1 Pillai HOC college of Architecture, siva@mes.ac.in
the external factors associated with facades. This has revealed that solar radiation and temperature are the most prominent factors associated with adaptive facades (Fig: 1). Further the analysis of external factors was done for non commercial buildings (Fig: 2) and finally for glazing and opaque wall separately as both of them have different adaptive technologies used. This revealed that solar radiation was a factor for all adaptive solutions for windows (Fig:3) This clearly reveals the importance and relevance of Adaptive Facades and also establishes solar radiation as one of the most important factor the adaptive facades have to respond to. (Modin, 2014) (Aelenei, Aelenei, & Vieria, 2016)

Adaptive Facades act as adaptable filter between external and internal conditions and play a predominant role in human comfort by controlling Solar thermal control, Daylighting Control (Illumination), Ventilation (Air Quality) (Kensek & Hansanuwat, 2011) and Sound Quality (Modin, 2014). In this research daylighting is the main optimization emphasis due to its importance to life within the building especially in office building where apart from minimizing artificial light it also promotes human well being and comfort. (Kim, 2013)

Adaptive facades can be defined as a system where the building envelope is able to change its behaviour in response to an external or internal stimulus for improving the performance of the building (Loonen, Treka, Costola, & Hensen, 2013) . Another common term for Adaptive facades are climate adaptive building shells.

“A climate adaptive building shell can adapt itself to the needs of the user of the building and to the changing climatic conditions to which the building skin is exposed, while at the same time the energy use needed for maintaining desired comfort is minimized.” (Boer & Ruijg, 2011)

One of the foremost examples of Adaptive Facades is L’Institute du Monde Arab by Jean Nouvel in Paris, France, 1988. This Facade is among the first to employ an adaptive facade responsive to the incorporated sensors. This south facing wall is divided into 240 sub grids of photosensitive mechanical devices which act like camera lens to control light inside the building (Fig: 5). All the light sensitive diaphragms are connected to a central computer and open or close based on the lighting levels computed inside(Fig: 4)
The adaptivity of a façade can manifest in different scales. In micro scale, adaptivity is related to the intrinsic qualities like thermo physical properties or optical properties or spectral selectivity of glass. At the Macro scale, the adaptivity is through movable parts; either in terms of integration with the entire facade like in L’Institute du Monde Arab or through movable components like shading systems. For this study, adaptivity in terms of kinetic shading components is adopted which is comparatively simpler in complexity and these add on components can be possibly used in retrofitting old buildings. (Adriaenssens, Barbarigos, Charpentier, Matthew, & Buzatu, 2014)

2. Objectives and Limitations:

The research objective is to quantify the benefits in terms of daylighting for the adopted kinetic shading system when compared to a fixed shading system. The same process is repeated for three different locations selected based on their geographical location (Quito (0.18 S, Delhi (28.7 N), Seattle (47.6 N)) to understand its impact on the benefits of the kinetic shading system.

Limitations:
An optimal building envelope has to balance the optimized daylighting with the solar heat gain in the space (Karagianni, 2014). But for this paper daylighting optimization is considered singularly without considering heat gain in the space.
Glare, an important aspect of human comfort wasn’t accounted in the simulations even though upper thresholds of maximum possible illuminance was considered and some qualitative analysis was done in terms of contrast ratio for the space considered.
Simulations for the space were done without incorporating furniture; the type of furniture and material quality of furniture can have a significant impact on daylighting

3. Metrics:

Metrics to measure the benefits of daylighting for a kinetic system were adopted so that they can take advantage of the dynamic nature of the Kinetic System.
Useful Nodes: Percentage of nodes in the analyzed space that are between the specified maximum and minimum threshold values. The threshold values used in the analysis are 200 lumen and 2000 lumen respectively. This metric is a hybrid of Useful Daylight Illuminance and Spatial Daylight Autonomy.

Benefit Ratio (Useful Nodes): Benefit Ratio is the percentage increase in useful nodes between the two configurations. In this Analysis, the kinetic configuration is compared to static configuration.

\[ \text{UND} = \text{Useful Nodes in Dynamic Configuration} \]
\[ \text{UNS} = \text{Useful Nodes in Dynamic Configuration} \]
\[ \text{BR} = \frac{\text{Benefit Ratio (Useful Nodes)}}{\text{UNS}} \]

Annualized Daylit Hours (ADH): Percentage of hours in a year in which 80% of the total nodal points (total no of nodes considered are 200) fall between the maximum and minimum threshold Illuminance values considered. Annualized Daylit Hours is a hybrid between Useful Daylight Illuminance and Temporal Daylight Autonomy. For this analysis, the maximum threshold is 2000lumen and the minimum threshold is 200lumen and only the office working hours (8:30am – 5:30pm @ 60min intervals) are counted. (Edupuganti, 2013)

4. Simulation Space and material Specifications

The dimensions of the simulated space are 12m X 5m x 3.3m (height) similar to a small office space. This space has a 11.6m long and 1.3m high south facing window with 0.9m sill level. The material properties of the space are a 100mm thick concrete slab on ground with 110mm brick wall with plaster and a single glazed timber framed 6m glass window. All the material properties are default specifications as per ‘AUTODESK ECOTECT’. In this paper the comparative analysis is done between a static shading system and a kinetic shading system. In Static Shading system the chajja /projection is .8m. And in the kinetic shading system the 0.8m deep projection which is perpendicular to the wall can rotate 30 and 60 degrees both ways. And hence there are 5 possible configurations in this kinetic shading system.
5. Methodology:

The basic modeling is done in ‘ECOTECT’ and material properties are defined and analysis grid is created with 200 sample points/nodal points in the space. In ‘RADIANCE’, material definitions are fine-tuned if necessary, and sky profiles are generated. Using the generated sky profiles, ‘DAYSIM’ generates Annual Illumination Profiles for all the sample points in the simulated space. These profiles include hourly Illuminance values for all the sample points for the considered time interval throughout the year. These values are further processed using custom scripts written in java to convert them into the metrics adopted for the analysis. For the kinetic shading systems the illumination profiles are generated individually for all the possible configurations (each Kinetic shading system has 5 possible configurations). A custom java script sifts through these 5 different annual illumination profiles and selects the best possible value for each hour and generates an optimized annual illumination profile for the kinetic shading system to compare with the static shading system. To make the kinetic shading system more intelligent, thresholds are incorporated while generating optimized files. For example, a threshold of 10 useful nodes is used in the analysis while generating optimized profiles. The kinetic shading system will change only if there is a gain of at least 10 useful nodes between the two configurations. Thus, the kinetic shading system avoids movements with minimal gains. (Edupuganti, 2013)

6. Results and Analysis

There is a significant rise in Benefit ratio/number of useful nodes in the kinetic shading system (Fig 7). Similarly there is a significant increase in number of annual daylit hours when compared to the static system (Fig 8). In terms of geographic location with respect to angle adaptivity, the gains are more evident in Delhi and less so in Quito. And, the Annualized benefit ratio was plotted for all the three locations to get a sense of how it varies throughout the year and how does the benefit graph change with respect to the geographical location (Fig 9).
From the results generated for the whole year, for further analysis, the comparison of number of useful nodes at hourly intervals is also plotted for Dec 21 (Winter solstice), June 21 (Summer solstice) and 21 March (Equinox). This is repeated for all the three geographical locations considered. In case of Delhi, during summer solstice the difference between the number of useful nodes between kinetic and static system is less. This difference increases in favour of the kinetic system more during equinox and further more during winter solstice where the impact of kinetic shading system in optimization of daylighting is clearly visible (Fig 10). While in Seattle, the benefit of Kinetic system is most obvious in equinox and less so in the solstices (Fig 11). In Quito, the benefits of kinetic shading system are consistent throughout the days but the benefits of the kinetic system are comparatively lesser than Seattle and Delhi (Fig 12).
7. Conclusions and Future Directions

Based on the results, the impact of kinetic shading system in terms of daylighting when compared to a static shading system is very clear. The benefits of a kinetic shading system do vary a lot with respect to geographic location; the kinetic shading system is least effective in Quito and most effective in Delhi. Future research should look at daylighting and solar heat gain together and try to optimize the kinetic shading system for both the factors while quantifying the benefits of the kinetic system. The other direction would be to classify the kinetic systems based on their types of adaptivity in terms of depth or variable optical characteristics of glass etc and quantify the benefits with respect to a fixed shading system. Another direction could be to incorporate qualitative aspects along with quantitative aspects while quantifying the benefits of a kinetic shading system.
8. References


