

## ABSTRACT

Shen Hui, Ph.D., Purdue University, May 2013. Daylighting and Energy Analysis of Perimeter Spaces with Dynamic Shading. Major Professor: Athanasios Tzempelikos

Facades play an important role in commercial buildings. They separate the indoor from the outdoor environment, ensuring thermal, visual and acoustic comfort for the occupants. Driven by architectural trends and the need to maximize daylight and outdoor view, commercial building façades have become more transparent. In order to realize required comfort conditions, the deployment and impact of innovative design features such as advanced glazing systems, proper shading properties and control and lighting controls should be studied comprehensively. Daylighting is an important lighting energy saving technique for perimeter zones of buildings. Optimized fenestration system design may improve exploitation of daylight and result in significant savings in electricity consumption for lighting. At the same time, fenestration systems also have a long term effect on space heating, space cooling and thermal comfort. The domains of heating, cooling and lighting are tightly related through use of fenestration systems. It is therefore important to study the balance between daylighting benefits and energy requirements in an integrated daylighting and thermal manner. Among the different dynamic fenestration elements, shading can be controlled easily and effectively: on one hand, it can be controlled to harvest maximum daylight according to changing outdoor weather conditions; on the other hand, it can also act as solar heat gain regulator to block out excessive sunlight for comfort and allow solar radiation into the space when needed. Until now, there is no standard for operating shading devices for achieving energy savings while maintaining occupant comfort. Furthermore, daylighting calculation algorithms coupled in current whole building simulation tools are either not accurate enough or impractical. Models capable of simulating the detailed connections between daylighting and thermal performance with dynamic zone elements are in urgent need to facilitate optimal façade designs. Finally, there are very limited studies on full-scale experimental assessment of dynamic façade technologies in terms of lighting and thermal performance.

In this work, the building façade is not treated as a single building component, but as a part of building perimeter zones, which may also include controllable electric lighting, shading attachments, HVAC components and indoor environmental parameters. Consequently, façade design becomes part of perimeter zone design, and the objective is to balance the need for daylighting and view versus the need of controlling of solar gains and maintaining human comfort, while at the same time minimizing energy use for air-conditioning and lighting.

First, a flexible dynamic daylighting and thermal simulation model was developed, applicable to perimeter spaces with one or several exterior facades equipped with automated interior roller shades (the most common type of shading used in commercial buildings). The model accepts various fenestration properties as inputs, and provides several daylighting, thermal and electric lighting control options. Outputs of the model include the most advanced daylighting metrics, thermal loads, surface and air temperatures and energy consumption for every calculation step -as well as annual indices. Thermal and lighting results were presented for a variety of different envelope options and climates with recommendations for different orientations. It was found that windows occupying 30–50% of the facade can actually result in lower total energy consumption for most cases with simple shading controls, depending on glazing properties.

New, innovative and practical shading control methods were developed for maximizing daylight utilization and minimizing building energy consumption. The new control strategies were simulated using the developed integrated model to investigate their impact on outdoor view, daylighting metrics, thermal loads and energy consumption as well as on excessive illuminance that can cause visual discomfort.

For the first time, model-based control of shading devices, demonstrated in a comparative way, allowed selection of orientation-dependent control strategies and use of alternate control criteria. At the same time, the interplay between lighting energy use, solar and internal heat gains was studied considering dynamic façade systems in an integrated manner.

Experimental studies were conducted to assess the impact of façade design options and related controls and to validate the developed models. Two identical full-scale office spaces with reconfigurable façade and lighting systems were designed and built for this purpose. The rooms were full instrumented with lighting and thermal sensors and equipped with automated interior roller shades and dimmable lighting systems that can be controlled according to the new developed strategies. Shading devices with different properties and different controls were tested extensively to quantify the impact of façade and lighting controls on interior conditions and energy use.

A global uncertainty and sensitivity analysis was performed using the integrated model, to identify the most important factors with respect to building thermal and daylighting performance. The uncertainty analysis is based on the Monte Carlo method with Latin Hypercube Sampling, showing the possible ranges in performance indices. The sensitivity analysis uses a variance-based method in the extended FAST implementation. Application of the analysis to perimeter private office spaces showed the first order and total order effects of each studied parameter.

Finally, a state-of-the-art tool with a powerful engine and a simplified interface was developed to assess the overall impact of dynamic façade elements and perimeter zone performance. It is intended to provide guidelines and quick feedback to both building design professionals and non-experts and to promote the use of efficient façade controls in the buildings community.