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Dynamic operation of daylighting and shading systems: A literature review

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ABSTRACT

The primary goal of dynamic building envelopes is to meet and balance antagonistic performance criteria utilizing automatic operation. As opposed to static systems, automated shading and daylighting systems are increasingly being used in façade design with the intent to improve building performance. Taking this into consideration, the question that arises is whether such systems can significantly improve buildings energy performance and occupants' visual and thermal comfort. The present paper is a review of dynamic operation methods of shading/daylighting systems and their associated implications in building energy balance. Based on the subject distribution of the reviewed studies, the majority of the systems examined are versions of motorized blinds while the analysis of new emerging ideas on deployable and foldable façade systems is limited. User acceptance is quite crucial and is strongly dependent on the system's intuitive operation. According to the paper findings, energy savings with automatically controlled blinds depend on the type of control strategy and their connection to dimmable electric lighting systems. Even though control strategies enhance energy performance and occupants' comfort, their level of complexity highly affects their efficiency and therefore influences their performance.

Contents

1. Introduction

Over time, building envelopes have been progressively transformed into lightweight and transparent multilayered skins resulting in decreased thermal mass and therefore a possible increase in peak loads [1]. To improve the envelope's performance,

Abbreviations: EC, Electrochromic glazing; dPOE, dynamic prismatic optical elements; CFS, Complex Fenestration Systems; BSDF, BiDirectional Scattering Distribution Functions; ISAS, illuminance based Slat Angle Selection

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an integrated design approach is increasingly being used with carefully engineered facades using decentralized units for daylighting, heating/cooling, and ventilation (natural and mechanical) in façade design [2]. The demanding façade requirements are linked with the associated technological achievements on integrated systems forming the notion of “intelligent”, “adaptive” or “responsive” building skins. Their operation aims to either counterbalance antagonistic phenomena (shading/daylighting) or to act as environmental moderators. Building envelopes may regulate the heat transfer between the interior and exterior, control humidity levels and heating/cooling loads, produce electricity through building integrated photovoltaics and support integrated ventilation and daylighting systems [2,3]. To address the above mentioned issues, dynamic operation of façade integrated systems has been introduced [4,5]. Responsive facades adapt to an intricate environment by measuring and processing multiple source information (for example outdoor and indoor environmental conditions, occupancy patterns and systems' condition) to respond to occupants' instructions and preferences and to address the evolving environmental conditions in an appropriate timing and motorized [8] and can be controlled by central processing units using control algorithms that get activated by sensors located in strategically selected locations [6]. Related recent research also focuses on the use of smart materials and nanotechnology in façade systems [7]. Electro-responsive polymorphic materials, such as dielectric electro-active polymers (DEAP) for example, change their shape to an electric charge and can be used both as sensors and actuators [2]. In addition, there is a limited number of non-electric alternatives using passive thermo-hydraulic drive operation [8].

Out of the continuously increasing number of commercially available and under development responsive systems, this study focuses on dynamic shading/daylighting systems that can provide shading while balancing direct solar radiation, visual glare, and view to the outside (Fig. 1). “Dynamic” window technologies often refer to conventional components such as louvers, venetian blinds and shades that can be located internally, externally or in between panes [9].

Static shading/daylighting systems might perform sufficiently enough in terms of solar protection and daylighting harvesting under specific circumstances. Christoffersen et al. [10] examined static and manually operated systems such as venetian blinds and light shelves and summarized that horizontal blinds achieve the best utilization of daylight. However, occupants often adjust the blinds position and tilt angle according to their preference. Thus, manually operated shading systems are frequently deployed to “worst-case scenario” position and remain in that for a long period which results in an error source for overoptimistic energy savings predictions and failing performance [11,12]. This issue can be resolved with the use of automated daylighting/shading systems since they allow for continuous adjustment in cases where this is impractical or impossible to be done by users. With regards to all the performance requirements that should be balanced in façade operation, the question that arises is whether the performance of static facades may get improved with the utilization of dynamic systems that make use of favorable exterior conditions.

2. Outline

The present paper reviews the dynamic operation of building skins using three levels of analysis: (a) the system level which reviews the performance of dynamic shading and daylighting systems (b) the control strategies level and (c) the building level that examines how dynamic facades affect the buildings energy balance and occupants comfort as shown in Fig. 2.

3. System level

3.1. Categories of shading-daylighting systems

Similar to static daylighting systems, dynamic shading/daylighting systems can be categorized based on their primary functions such as to provide shading, to redirect daylight deeper into the space, to improve visual comfort and reduce glare. According to the IEA handbook, Daylight in Buildings [13], daylighting systems can be divided into two main categories depending on the type of their function. The first category includes daylighting systems with shading that blocks direct solar radiation and diffuses light. A representative example of such a system is venetian blinds. In the second category there are daylighting systems without shading that redirect solar radiation in areas away from the perimeter zone. Daylighting systems that belong to this category are light shelves [14]. Another way of categorizing shading devices involves their location in the façade and their movement as shown in Table 1 according to Bellia et al. [15].

An extensive list of daylighting and sun control technologies is available in the Database of Light Interacting Technologies for Envelopes (D-LITE) [16]. Based on the systems performance characteristics, the D-LITE database classifies technologies into categories depending on their main functions and characteristics such as placement and operation type. The systems' character determines their static and automated performance and it is divided into four sub-categories: static, dynamic manual, dynamic auto and dynamic passive. In the dynamic, manual and auto categories

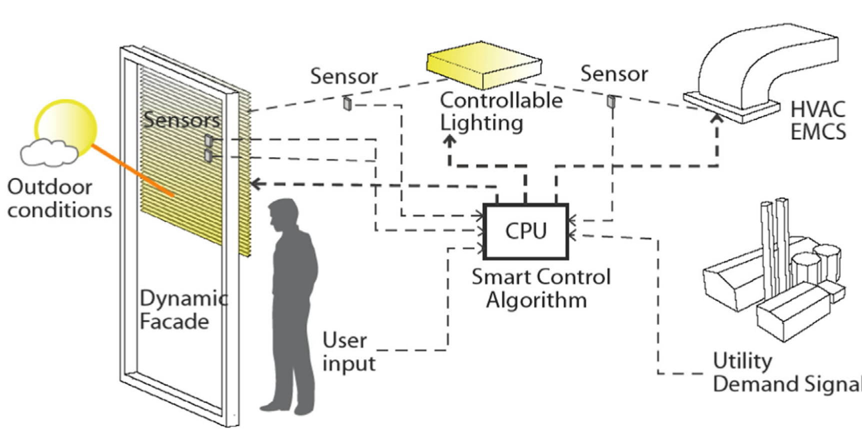

Fig. 1. Control system diagram.