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The impacts of a dynamic sunlight redirection system on the energy balance of office buildings

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Abstract

The aim of this work consisted in investigating the potential of an advanced dynamic daylighting system, designed to provide higher work-plane illuminance levels deeper into the space and assess its impact on the building's energy balance. The device utilizes an array of movable mirrors capable of tracking the daily movements of the sun and projecting the reflected sunlight toward specified fixed positions onto the ceiling. This paper builds on the authors' previous work by implementing a solar tracking algorithm developed to calculate the position of the mirrors in 3D space and the area of the reflected sun-patches on the ceiling on an hourly basis.

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Keywords: Advanced daylight systems; Daylight redirection; Heliostats; Core daylighting; Solar tracking; Energy savings.

1. Introduction

The use of daylight systems can affect the building's energy balance since their adoption is subject to a compromise between shading needs and daylight provision. During the past few decades, new issues in daylighting design have been raised in conjunction with new demands by the building industry. In offices, areas located away from the perimeter zones tend to receive significantly lower illuminance values. One of the challenges is to bring usable

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daylight deep into the core of the building or into the non-daylit areas, which may result in significant savings in lighting energy consumption while creating an attractive and stimulating visual environment for the occupants.

The distance from the windows is a major concern when implementing daylighting techniques. Daylight penetration is dependent on the amount of light entering through a vertical window. Research has shown that a vertical window can effectively illuminate areas that are located near, approx. up to 5m [1, 2] from the window. Areas excluded or further away from the opening tend to receive significantly lower if any daylight, causing the core section of the space to appear darker and gloomy. In addition, the extreme differences in illuminance levels between the perimeter and secondary zones (non-daylit) often give a cave-like appearance to the space. To compensate, electric lights are used more often in secondary areas while energy saving measures are concentrated on the perimeter zone of the space, where it is most effective. While the idea of exploiting the potential benefits of sunlight redirection is not new [3-10], there are many advantages to consider from daylight design alone. However, there has not yet been an approach that has successfully been adopted or has proven to be cost-effective. The research problem of this study is to estimate the energy impacts of an advanced daylight design concept that utilizes heliostats in the Façade, capable of sunlight redirection with the purpose of illuminating non-daylight zones and improving the visual quality of the space.

2. Methodology

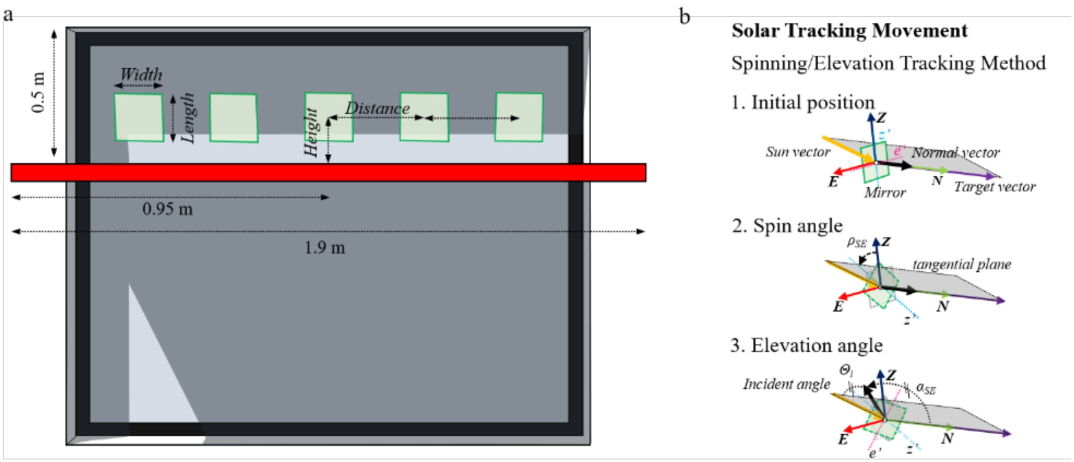

Fig. 1. (a) Presentation of the proposed advanced daylight system and solar tracking positioning of the mirrors in the 3D coordinate space; (b). One of the tracking axes (z'-Axis) of the mirror surface points towards the target and it is responsible for maintaining the reflector normal within the tangential plane, spin angle ρ_{SE}, while the other (e'-Axis) is perpendicular to the first and tangent to the mirror-frame and adjusts the reflector normal within the tangential plane until it bisects the sun position vector & the target position, elevation angle θ_{SE}.

The proposed concept system presented in figure 1 is comprised of a shelf that can be mounted at about mid-window height and has five movable rectangular mirrors in an array mounted that can actively track the daily movements of the sun and redirect sunlight into the interior space in specified locations onto the ceiling plane. The mirrors adjust their positions by implementing a dual-axis solar tracking algorithm, the spinning-elevation tracking method [11, 12] to calculate the angular movements and orient their surfaces in the 3D-space to redirect sunlight towards the predefined fixed positions. Daylight simulations were conducted using Radiance [13] to hourly calculate:

- The annual illuminance distribution on the working surface (0.8m from the floor)
- The lighting energy savings for both perimeter (daylight) and non-daylight zones of the space equipped with an ideal dimming system
- The internal heat gains due to the reflected sun-patches on the ceiling