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Three approaches to optimize optical properties and size of a South-facing window for spatial Daylight Autonomy

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ABSTRACT

This study presents optimization approaches by a recent Climate-Based-Daylight-Modeling tool, EvalDRC, to figure out the necessary area for a daylight redirecting micro-prism film (MPF) while minimizing the glazing area. The performance of a window in terms of spatial Daylight Autonomy (sDA) is optimized by its geometry and optical properties. Data implemented in simulation model are gathered through on-site measurements and Bidirectional-Scattering Distribution Function (BSDF) gonio-measurements. EvalDRC based on Radiance with a data driven model of the films' BSDF evaluates the window configurations in the whole year. The case to achieve an sDA of at least 75% is a South-facing window of a classroom in Switzerland. A window zone from 0.90 m to 1.80 m height provides view to the outside. The upper zone from 1.80 m to 3.60 m is divided into six areas of 0.30 m height in three optimization approaches including the operation of sunshades as well. First, the size of the clear glazing is incrementally reduced to find the smallest acceptable window-to-wall ratio (WWR). Second, micro-prism films are applied to an incrementally varying fraction the initial glazed area to determine the minimum film-to-window ratio (FWR). Finally, both approaches are combined for a minimum FWR and WWR. With clear glazing and WWR of 75%, the sDA of 70.2% fails to meet the requirements. An sDA of 86.4% and 80.8% can be achieved with WWR 75%, FWR 1/9 and WWR 50%, FWR 1/2 respectively. The results demonstrate the films' potential to improve the performance of windows with reduced WWR.

1. Introduction

The utilization of daylight in buildings has been a significant concern to reduce the electrical energy demand for lighting and cooling of buildings [1]. Such widely known benefits of daylight's presence are better work/or learning performance, motivation and health. However, to achieve these goals, it is necessary to control its negative impacts such as visual discomfort and glare [2,3]. The recognized importance of daylight in buildings is contrasted by the inconsistent use of terminology and planning tools by practitioners, mostly based on rules of thumbs especially in the early design stage [4]. Climate-Based Daylight Modeling (CBDM) allows quantitative performance predictions based on local weather data. The resulting annual records of illuminance are reduced to comprehensive annual metrics such as Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA) [5,6]. UDI defines both lower (100 lux) and upper (2000 lux) boundaries for horizontal illuminance to be counted as useful, while DA considers only the lower boundary. DA, is an annual, task-illuminance based metric of daylight performance [5–7]. It is recently named as spatial Daylight Autonomy (sDA) by IES; and is defined as "*the percent of an analysis area that meets a minimum daylight illuminance level for a specified fraction of the operating hours per year*" [8]. In other words, it reveals the adequate daylight on workplane area throughout the year. sDA considers not only the temporal but also the spatial dynamics of daylight in buildings. It has been recommended for the evaluation of entire occupied spaces in combination with Annual Sunlight Exposure (ASE), replacing the fixed upper boundary of UDI by an indicator of direct sun penetration into the occupied space. IES definition of ASE is "*the percent of an analysis area that exceeds a specified direct sunlight illuminance level more than a specified*

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number of hours per year." [8]. By all means, it is an indicator for visual discomfort and the amount of direct sunlight which hits the workplane in the whole year.

The most initial and relevant concern which is analyzed here has become the window design; since, the opening characterization determines the amount of daylight penetration and the path of its distribution inside the room. The basic design indicator to denote its performance is *window-to-wall-ratio (WWR)*. It is an instructive parameter in making design decisions due to its numerical simplicity but its complexity in extracting thermal, visual and environmental consequences/or information in architectural design. The impact of window geometry and methods to optimize window size and optical properties of glazing for thermal and visual performance have been demonstrated using computational simulation [9–13].

Complex Fenestration Systems (CFS) enhance the daylight performance of buildings. Redirecting daylight from the often overexposed building perimeter deeper into the occupied space, they reduce discomfort close to the façade and distribute daylight evenly. The technology allows substituting artificial lighting by daylight even in deep plan buildings [14]. The integration of such systems' within the façade has been identified as a major obstacle to wide-spread application. The miniaturization and integration into double glazing units of CFS such as micro-prism films (MPF) and acrylic lamellas address this challenge and ease both installation and maintenance, and allow applications in building retrofits. MPF are assemblies composed of micro structured prisms on an optical film. The performance of such systems for the case of side-lit spaces has been compared through simulations and monitoring of experimental setups [15–18].

The optical characterization of a CFS and conversion into models for use in Radiance [19–21] are further research areas. Previous studies involved measurements of the optical properties of CFS using specialized instruments in laboratories [22,23], using virtual instruments [24] and their integration in performance assessments [25]. Measurements display their behavior in refracting, reflecting and redirecting the light at certain angles. That outcome is called the Bidirectional Scattering Distribution Function (BSDF) data. This is a kind of indicator which quantifies how light scatters as a function of light incident direction. This concept involves reflection and transmission distributions on any type of materials (specular, non-specular). Several experimental studies and recent approaches deal with its use in the field of daylight performance and its integration in daylight simulations [19–21].

In view of the recent and ongoing research mentioned above, evaluations about the application details and performance of CFS have been continuous broadly, however, it is also necessary to widen the research to relate their design, function and integration to architectural considerations, one of which is specifically is the window design in this study. Thus, the optimization problem, here, is to achieve the necessary MPF area while minimizing WWR to meet the required sDA value which is 75% (denoted as preferred value by IES). In this case, obtaining essential MPF area means to reach the minimum film-to-window ratio (FWR). This is a case study which covers design alternatives of the glazed area with the integration of MPF. Specifically, the case room is typically has large window area (WWR is 75%) and the floor aspect ratio is almost 1. The daylit area is satisfactorily large but may cause discomfort glare and overheating. So, it may be necessary to improve daylight performance and environmental conditions with the application of MPF in window area. Utilizing such integration, it is crucial to find the minimum size of the glazing area to satisfy the 75% of sDA in the city of Lucerne, Switzerland. This study involved discussions about the design variants of MPF size to be mounted in the fenestration in a specific location and under sky/climatic conditions in Lucerne. The main performance indicator is sDA. However, to compare findings between variants and to construct a deep and full understanding of MPF performance, ASE, msDA (monthly daylight autonomy) and MSE (monthly sunlight exposure) were assessed. The application of dynamic sunshade in simulations provided avoidance of direct sunlight due to climate data. The outcome of this was the percentage of sunshade operation during the year. To test the

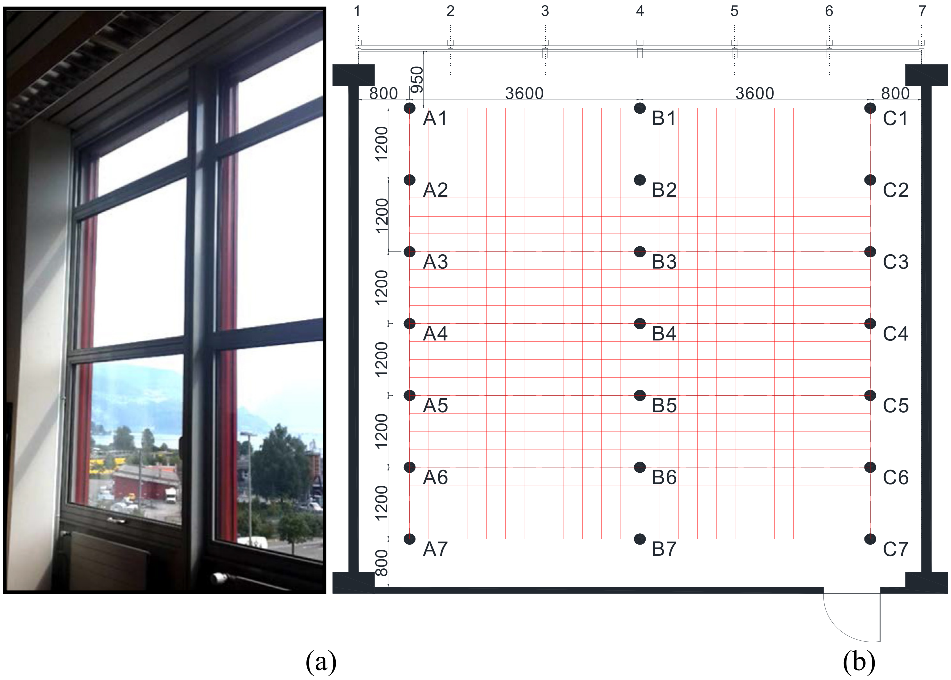

Fig. 1. (a) Window configuration; (b) Measurement points and sensor plane (the red grid). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)