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Multi-criteria decision analysis to select the optimum position and proper field of view of a photosensor

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ABSTRACT

The lack of knowledge concerning the commissioning of a daylight responsive system constitutes a serious impediment to their widespread use. Furthermore, installation details and tools regarding their photosensor position and field of view (FOV) are insufficient. This paper presents a decision making method capable to estimate the best position of a photosensor on the ceiling and its proper FOV based on multiple criteria analysis. The criteria used are (a) the correlation of the lighting levels between the working plane and the ceiling, (b) the corresponding energy savings and (c) the lighting adequacy which is defined as the percentage for occupied time with total illuminance exceeding design illuminance (i.e 500 lux EN 12464-1, 2011) and is strongly affected by the control algorithm.

A number of simulations with variable FOV and position of photosensors were performed in order to clarify the calculation procedure of the proposed methodology. Three different typical room geometries have been used with variable window sizes and orientation. Furthermore a prototype photosensor with variable FOV through the use of a telescopic cylinder was constructed and placed in a scale room (1:10) in order to verify the results of simulations. The verification was based on a set of experimental procedures concerning measurements of the spatial response of the prototype photosensor (for various FOVs) and measurements of ceiling/workplane illuminance inside the scaled room for various combinations of position and FOV of the photosensor. The proposed methodology can be used as a tool for the determination of the optimum operation of a daylight responsive system with photosensors.

1. Introduction

Harvesting daylight can be considered as a cornerstone strategy to reduce artificial lighting consumption in buildings. Lighting control systems with photosensors can take full advantage of daylight by dimming light output in an effort to maintain the design illuminance. Although the operational principle is rather simple there are a number of barriers which slow down their widespread use [2–13]. Among them are: (a) The difficulty in quantifying the energy savings and thus the subsequent payback period of the lighting control system, (b) the lack of specific guidelines for the proper setting, positioning and commissioning of the photosensor and (c) the reluctance of building contractors to install such systems because of the hypothetical unreliability in achieving predicted energy savings.

For practical reasons, photosensors are located on the ceiling minimizing any interference from activities in a space but complicating their control and commissioning. In theory, the ideal location of the photosensor is on the working plane but till now this position is not used due to possible shading from occupants' presence and the inability to power it without extra wiring. Thus, the behavior of a responsive daylight system in reality (sensor on the ceiling) can differ considerably from hypothetical cases where the sensor is located on the working plane. Depending on the control algorithm (integral reset, closed loop) there are differences not only in achieved energy savings but in illuminance values as well.

The ceiling placed photosensor corresponds to incident radiation on the ceiling and converts this radiation to a proportional control signal. However, the ratio of ceiling/workplace illuminance is not constant since it is strongly depended on the variability of daylight distribution in the room. It is therefore difficult for a photosensor placed on the ceiling to track exactly the illuminance changes on the working plane. The correlation of the lighting levels between these two positions is depended on the position of the photosensor and its FOV [14–16]. Best correlation is achieved in

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areas away from exterior openings where light distribution is more uniform. Nevertheless, these areas could not be considered as daylight zones where daylight can be exploited to its maximum extent [17,18]. On the contrary by placing the sensor near the window, increased energy savings are expected but with poorer performance in terms of achieving the design illuminance. The ability of the control system to maintain a constant ratio of ceiling photosensor to working surface illuminance can ensure the satisfaction of the operational equations of the control algorithms [17].

Littlefair et al. [19] examined the performance of three types of ceiling sensor FOV, a completely unshielded, an alternative sensor shielded by a darkened tube and a partially shielded sensor. There were different conclusions for each type of FOV. The unshielded sensor could lead to uneven control performance under different sky conditions, while the shielded one was very susceptible to the location of patches of sunlight in the space. For the partially shielded care was needed in aligning the shield correctly during installation otherwise the sensor performance could be deteriorate. Choi et al. [20] have also evaluated the spatial characteristics of photosensor response. Differences in relative spatial response to incoming luminous flux affect the photosensor signal, which ultimately affects the accuracy and reliability of the system. In addition they suggested that information on different spatial responses was necessary to determine the proper mounting location of the photosensor.

Placement of the sensor in regard with its spatial response has received attention by Mistrick et al. [14]. Based on the results of Rubinstein et al. [17], they simulated three types of photosensors with complete, partial and no cover in their FOV. According to their results, the most suitable position of the sensor was in direct relation with the constancy of the ratio ceiling/workplace illuminance for all possible climatic conditions. Mistrick and Sarkar [15] extended the above research applying simulation analysis in larger spaces (five classrooms) using the same criterion, in an effort to define the proper placement of the sensor on ceiling. However the previously mentioned ratio should not be considered as the only criterion since energy savings and lighting adequacy can vary considerably for different positions and spatial responses of the sensor although the illuminance ratio is the same. Nowadays, there is an effort to embody new technologies by developing photosensors using CCD cameras or CMOS image sensors instead of photodiodes [21–23]. These sensors are quite promising, in the sense that they can measure luminance patterns [24] replacing multiple sensor systems. However, their capabilities are still rather limited due to errors associated with the estimation of illuminance from luminance distribution on a scene image and due to calibration/commissioning difficulties [21]. Except for these, their increased cost and size can impose practical limitations during installation. A conventional photosensor even using a simple constant set point control algorithm (integral reset algorithm) performs equally well with a CMOS sensor [23].

Results point out that multiple criteria analysis which is based on simulation results, can define the best position of a photosensor with given FOV improving the commissioning procedure of a daylight responsive system. This analysis counterbalances the following antagonistic criteria: (a) the ratio of photosensor to working plane illuminance, (b) the corresponding energy savings and (c) the lighting adequacy on the working plane.

2. Description of the methodology

All commissioning procedures should be considered during the design phase where critical decisions on component selection have to be taken. Since there is no standard rule among manufacturers, usually a trial and error method is used by the contractors in order to obtain descent dimming response. Therefore it is important to develop a model that calculates the optimum position for any given photosensor's FOV from the early stages of design.

As mentioned in the previous paragraph the performance of a daylight responsive system is strongly affected by the position of the photosensor and its FOV. A narrow FOV tracks more accurately the changes of illuminance on the working plane than a wider one, while the latter is not so sensitive to illuminance changes inside the room. Thus, the perceived illuminance values by the sensor do not correspond proportionally to the illuminance levels on the working plane. Moving the photosensor further back improves the ratio of sensor to working plane illuminance but deteriorates achieved energy savings.

The proposed methodology resolves these problems by satisfying three criteria (a) FOV and sensor position (b) lighting energy savings and (c) illuminance levels, resulting in the optimum sensor position.

Fig. 1 presents the flowchart of the proposed methodology. As mentioned it optimizes the placement of the photosensor and/or its FOV using three criteria, namely the correlation of the lighting

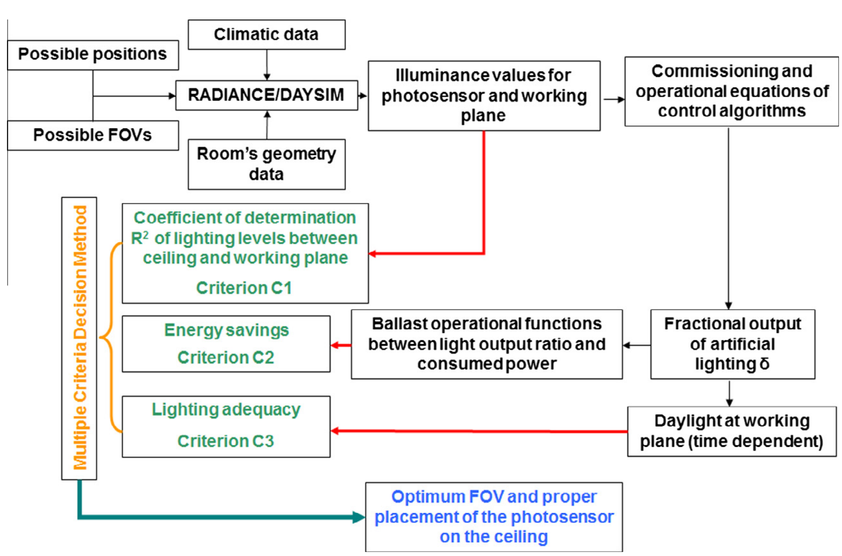

Fig. 1. Flowchart of the proposed methodology.