Optimizing the position and the field of view of photosensors in daylight responsive systems

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Abstract
The correlation of the lighting levels between the working plane and the ceiling is strongly depended from the position of the photosensor and its spatial response. A new type of photosensor was designed with variable field of view through the use of a telescopic cylinder. Selecting the proper field of view the ratio of the lighting levels can remain relatively constant for various types of sky but on top of that energy savings and lighting adequacy are also affected. The present paper presents an optimization method for the estimation of optimum position based on multiple criteria analysis Its focus is on the improvement of the commissioning of a daylight responsive system by introducing a methodology that optimizes lighting levels, energy savings and lighting adequacy through the proper selection of photosesnor position and field of view.

Keywords: Daylight, Energy saving, Adequacy of light, Photosensor, Field of view, Photosensor position

1. Introduction

Lighting control with photosensors can take full advantage of daylighting by dimming light output so that no more artificial light is produced than necessary. Many case studies have documented energy savings by exploiting daylight [1-8] but lighting control with photosensors have not been widely installed by building contractors. The reason of this lack can be either the belief that occupants dislike automatic lighting control or the perception that automatic dimming controls are unreliable. However researchers have examined analytically the behaviour of various photosensors [9-19] and have presented solutions for the best performance of the photosensors. Considering that the total operation of a photosensor is complex depending from a lot of variables, someone must examine the influence of these factors in a daylight responsive system individually. The field of view and the commissioning of the photosensor can influence considerably the performance of the photosesnor and such the operation of a daylight responsive system [20].

The ideal location for the photosensor would be on the working plane but this position isn't possible because the photosensor would likely be disturbed or shaded by activities in the room. So for practical reasons photosensors are located on the ceiling minimizing interference from activities in the room but complicating the control and commissioning of the photosensor. The correlation of the lighting levels between the working plane and the ceiling is strongly depended from the position of the photosensor and its spatial response [11, 13, 20]. Selecting the proper field of view of the photosensor in regard its position the ratio of the lighting levels between the working plane and the ceiling can remain relatively constant for various types of sky.

For this reason a new type of photosensor was designed with a field of view that can be changed with the help of a telescopic cylinder. With this fixture the photosensor is capable to adapt different fields of view in regard its position on the ceiling in order the ratio of the lighting levels between the working plane and the ceiling to remain constant for the most time of its use. Simulations were performed using the developed photosensor for the examination of its field of view in regard its position for various types and dimensions of rooms like square, wide-shallow and narrow-deep rooms and small, medium and large rooms correspondingly. Also various dimensions and orientations of windows were simulated for different fields of view and positions of the developed photosensor. The energy savings in regard the adequacy of light on the working plane were calculated. The paper focus on the improvement of the commissioning of a daylight responsive system by introducing a methodology based on current simulation approaches that takes into account the correlation of the lighting levels

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between the working plane and the ceiling, the energy savings and the adequacy of light for the optimum field of view of the developed photosensor in regard its position.

2. Correlation of the lighting levels between the ceiling and the working plane

The issue of the proper placement of the photosensors in regard their spatial response has received some attention. Mistrick et al [11] dealt with the placement of the photosensor in a small office using Radiance [21]. Based on the results of the Rubinstein et al [10] they simulated three types of photosensors with complete cover, no cover and with a partial cover in their field of view. The most suitable placement of the sensor was defined in regard the correlation of the lighting levels between the ceiling and the working plane (Figure 1). As long the correlation of the lighting levels for a given position was linear so much the position for the photosensor was proper.

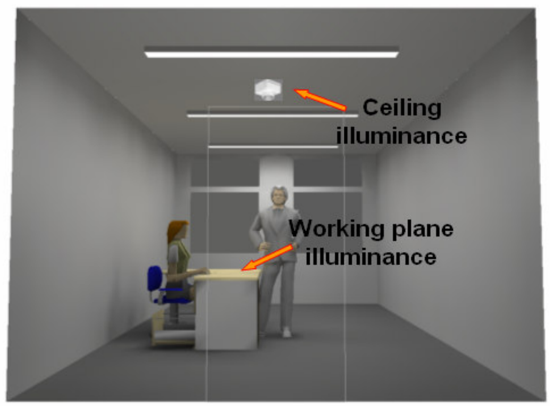

Figure 1. Working plane and ceiling illuminance inside a room with photosensor

Mistrick and Sarkar [13] continued the research with simulations of larger spaces such as five classrooms using the same criterion, namely the correlation between the lighting levels, for finding the suitable position of the photosensor. Mistrick et al [22] simulating the operation of a daylight responsive system using all the possible combinations of setting the control algorithms and the daylight conditions calculated the illuminance on the working plane and the ceiling. They compared the results with the target illuminance on the working plane and after minimizing the mean square error of the average working plane illuminance the optimum commissioning setting was selected for the control algorithms and the daylight conditions for the commissioning.

A new photosensor was designed with a field of view that can be changed with the help of a telescopic cylinder (Figure 2). Thus the photosensor can be altered from a sensor with narrow view in a sensor with wide field of view (Figure 3).

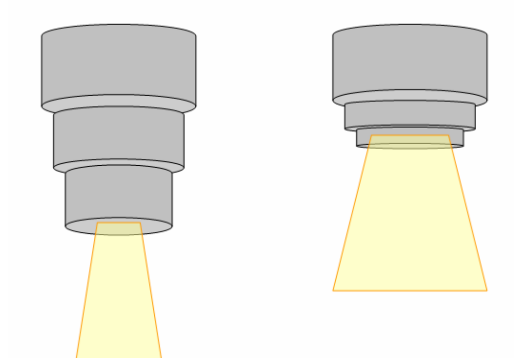

Figure 2. Photosensor with telescopic cylinder that can be altered from a sensor with narrow view in a sensor with wide field of view

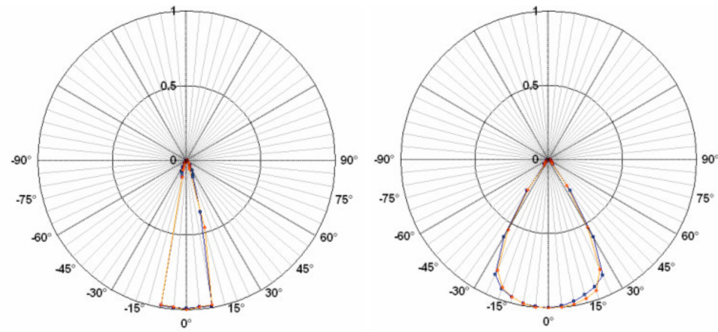

Figure 3. Polar diagrams of spatial response of the new developed photosensor with narrow and wide field of view with the help of the telescopic cylinder

This can make the photosensor capable to adapt its own field of view in a way that if it is placed in any position on the ceiling the ratio of the lighting levels between the working plane and the ceiling will remain constant for the most time of its use. With other words the field of view is adjusted to be as narrow as needed in order to track the changes of illuminance on the working plane and so wide as needed in order to be not influenced by the changes inside the room. Figure 4 shows the lighting levels and the corresponding correlations between the working plane and ceiling for the photosensor with narrow, medium and wide field of view for the same position on the ceiling, the same room, orientation and reference year. The R^2 values for this example were 0.9456, 0.8658 and 0.7348 for the photosensor with narrow, medium and wide field of view correspondingly. It seems for this example that the narrowest field of view had better correlation value than the other two fields of view. Of course many case studies have been studied with different room types and dimensions, different orientations and window openings. For each case the results were different and so it couldn't be a general rule for all the cases together.

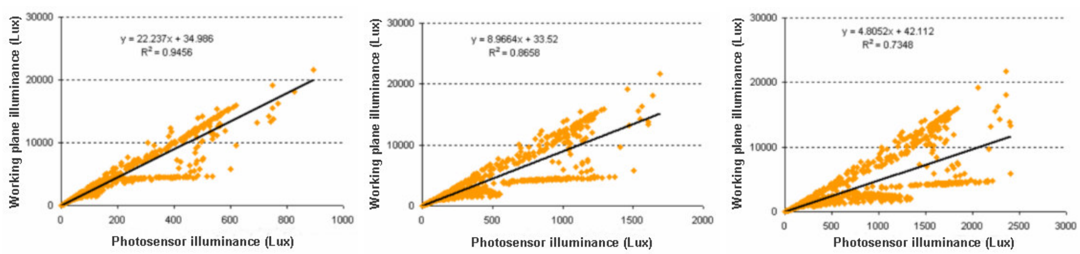

Figure 4. Lighting levels and the corresponding R^2 values between the working plane and the ceiling for the photosensor with narrow, medium and wide field of view (from left to right)

3. Introducing the methodology

The correlation of the lighting levels between the ceiling and the working plane isn't the only criterion for the optimum placement of the photosensor. Energy savings and adequacy of illuminance values are different for different positions and spatial responses of the photosensor while its correlation with the lighting levels is the same. Thus the present study examines not only the correlation of illuminance levels between working plane and ceiling but also the energy savings and the light adequacy.

In order to find the appropriate spatial response of the developed photosensor in regard to its position on the ceiling a new methodology was developed. According to this, the optimisation of photosensor placement and field of view is performed by simulations of the space in which the sensor is placed, using data of the new photosensor, climatic data, data for the control algorithm and data for the electronic dimmable ballasts [15, 17] of the lighting installation (Figure 5). More analytically the inputs of the methodology are the geometry of the room, the position and current field of view of the developed photosensor, hourly meteorological data, commissioning parameters, operational equations of each control algorithm and finally the operational functions between light output ratio and consumed power of the electronic dimmable ballasts.

Thus, using the above mentioned data, Daysim [21, 23] calculates the illuminance values on the ceiling (photosensor position) and on the working plane below. The correlation of these two illuminance values is important for the operation of a daylight responsive system [11, 13]. Combining the derived illuminance values with the operational equations of the control algorithm of the photosensor [10] and the operational functions between light output ratio and consumed power of the electronic dimmable ballasts [17] lighting energy consumption can be estimated together with the adequacy of light levels on the working plane.

It is evident that the optimum position and spatial response of the photosensor is related directly with the satisfaction of the following three criteria:

- The ratio between photosnesor and working plane illuminance (illuminance ratio)
- Energy savings achieved
- Illuminance values above a specific design value (lighting adequacy)

Performing a large number of simulations data for the above mentioned parameters are calculated. Using a multiple criteria decision method [24, 25] the best values of the three independent criteria are defined and thus the optimum spatial response and position of the photosensor.

In the following paragraph a simple example is presented along with an explanation of how this methodology works.

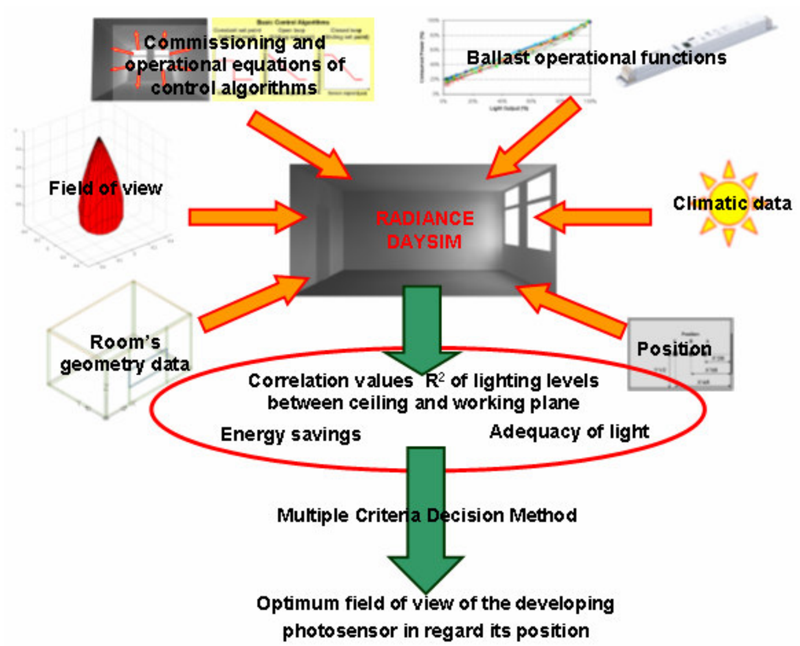

Figure 5. Diagram of the methodology for the optimisation of the placement of the photosensor

4. Simulations and results

Many case studies have been examined using simulations. As mentioned in the previous paragraph the software packages were Radiance and Daysim [21, 23] that have been used in various studies with photosensors and worked successfully [11, 12, 13, 26]. The examined case studies include:

- Three types of different room geometrical configurations (square, wide-shallow and narrow-deep) with three sizes (small, medium and large) in its configuration
- Three different window sizes for each room configuration (15%, 25% and 35% of the façade area).
- Three fields of view, wide (Sensor 1), medium (Sensor 2) narrow (Sensor 3)
- Three equidistant positions of the photosensor (Position A near the window, B and C in the middle, Figure 6)

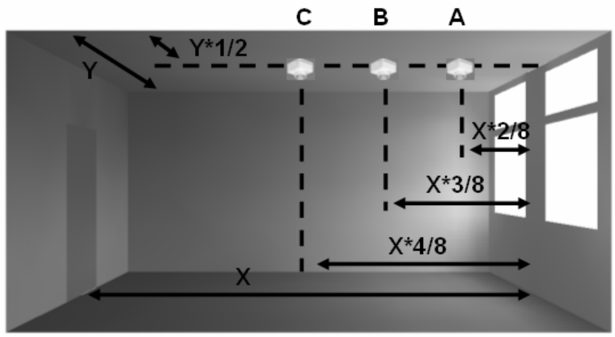

Figure 6. View of the room with the positions of the photosensor from the window

Table 1 presents the results from an example case study. In more details the table presents the R^2 values from the correlation of the illuminance ratio, the annual energy savings and the lighting adequacy on the working plane for a small, square room with 35% window opening and south orientation. The energy savings were calculated on an hourly basis for a typical year using Athens, Greece TMY. Lighting adequacy was calculated for the same typical year as the ratio of the hours that the illuminance on working plane exceeds the design illuminance to the total hours of use.

Table 1. R^2 values, annual energy savings and adequacy of light for a small, square room with 35% window opening and south orientation for three tested positions and three fields of view (Bold indicates max value)

Sensor	Criteria of the methodology								
	R^2 values			Annual energy savings (%)			Adequacy of light (%)		
	Position								
	A	B	C	A	B	C	A	B	C
1	0.576	0.691	0.720	**76.73**	76.52	76.10	96.88	94.36	95.92
2	0.717	0.857	0.786	76.70	76.47	76.06	**98.90**	97.07	97.56
3	0.842	**0.926**	0.914	76.65	76.43	76.09	96.68	96.38	93.12

The results show nine possible selections for every criterion used in relation with the optimum position and field of view of the developed photosensor. Taking into account only the R^2 values criterion, the best case seems to be for the photosensor with the narrow field of view (Sensor 3) positioned equidistant between the window and the centre of the room (Position B) with value equal to 0.926. Taking account only the annual energy savings criterion the best case seems to be for the photosensor with the wide field of view (Sensor 1) positioned near the window (Position A) with value equal to 76.73% while for the adequacy of lighting criterion the best case seems to be for the photosensor with the medium field of view (Sensor 2) positioned near the window (Position A) with value equal to 98.90%.

However according to the multiple criteria decision method the best case for the optimum field of view and position of the photosensor are the medium field of view (Sensor 2) and the position between the window and the centre of the room (Position B). The R^2 value for this optimum choice is 0.857, the energy savings value is 76.47% and the lighting adequacy value is 97.07%. Variations are also presented in Table 1. For the purpose of this paper that was introducing a new methodology the methodology was presented for one room only. This is the first theoretical part of an ongoing project. During this a large number of case studies will be examined. However, it is obvious that the methodology can estimate the optimum field of view and position of the photosensor taking account counterbalancing parameters.

5. Conclusions

The field of view and the position of the sensor is a significant factor for the proper commissioning of a daylight dimming system. Energy savings can be achieved with unsatisfactory lighting levels and vice versa. This was the reason for the development of the present photosensor with the variable field of view. Aim of the methodology presented in this paper was to achieve the optimisation of counterbalancing parameters such as energy savings achieved and lighting adequacy. These are strongly depended on the sensor position and field of view.

The methodology works satisfactory offering the commissioning team the opportunity to adjust the photosensor's field of view according to its position.

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