REVIEWING DRAWBACKS OF CONVENTIONAL PHOTOSENSORS: ARE CCD/CMOS SENSORS THE NEXT GENERATION?

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ABSTRACT

Harvesting daylight is undoubtedly one of the most energy efficient ways to minimize energy consumption in office buildings, not only in new installations but also during building retrofitting. Conventional photosensors are mainly photodiodes or photoresistors. Their drawbacks, on what concerns their operation are holding back their wide spread use. These are in relation with their position, field of view, spectral response, control algorithms, commissioning and the associated user's response. New technologies with CCD or CMOS image sensors show some promise, but it is not clear if they can be widely incorporated in the building sector.

Keywords: Daylight harvesting, CCD photosensor, Energy saving, Photosensor

1. INTRODUCTION

The key element for a daylight responsive system is the photosensor. There are two conventional types of photosensors used in today's dimming systems: photodiodes with stable performance and linearity between their signal and incident light and photoresistors which don't need spectral correction, can withstand high voltage, show non- linear behaviour over a range of light levels and with memory effect problems (LRC 2007). Today, efforts are being made to develop photodetecting devices using CCD or CMOS image sensors. However this particular use is in its infancy. Energy consumption in lighting represents a significant percentage in a building's energy balance (Li et al 2009, Danny et al 2010). Quite substantial energy savings are possible due to the new design techniques, efficient technology available and the use of control systems. There are many types of buildings such as schools, in which national regulations should force contractors to install lighting systems with daylight control. This inactivity is partly due to the difficulty installing, commissioning and maintaining the operation of the sensors. Furthermore, existing controllers, ballasts and conventional photosensors are not always mutually compatible, while the lack of information concerning their actual performance prohibits their widespread adoption. While many studies (Doulos et al 2008, Doulos et al 2008, Mistrick et al 2000, Mistrick and Thongtipaya 1997, Mistrick and Sarkar 2005) have been conducted examining the potential of lighting energy savings, there are only a few, which focus on the identification of the underlying causes of the difference between theoretically calculated and measured savings. The aim of this paper is to point out the main drawbacks associated with conventional photosensors and underline ways to deal with them. Factors affecting daylight response system performance are the positioning of the photosensors on the ceiling, their field of view (FOV), their spectral response, the control algorithms, the lack of a common commissioning procedure and possible user reactions. Although CMOS or CCD image sensors can be used, there is a number of issues that have to be investigated, such as the conversion of measured luminance values into work plane illuminance. One way of dealing with this, is to use a predefined area of known reflectance on the working plane and use its luminance to control the lighting system. The angular area as seen by the sensor is a parameter that obviously affects the system's performance. Issues related to their spectral response can be easily overcome using their digital signals. The following paragraphs analyze four major characteristics of conventional sensors and their effect on system performance.

2. POSITION AND FIELD OF VIEW (FOV)

For practical reasons, photosensors are located on the ceiling in an effort to minimize any interference with activities in a space. Through the use of proper control and commissioning, the dimming system tries to maintain a predesigned illuminance on the working plane. The ceiling placed photosensor corresponds to incident illumination and converts it to a control signal. Selection of proper FOV according to the geometrical characteristics of the space is quite crucial in optimizing the performance of the system. Different luminance patterns on the room surfaces can create the same sensor signal, resulting in the same dimming state of the lighting system although work plane illuminaces differ significantly. In addition, if a shading system is used, any unwanted reflected illuminance can increase the signal of the sensor, reducing lighting levels. Thus, position of the sensor and FOV should ensure a relatively constant ratio of ceiling to working-plane illuminance (Figure 1) which of course is strongly depended on the variability of daylight distribution in the room. For an unshielded - ceiling placed - photosensor, it is quite difficult to track the illuminance changes on the working plane with precision, thus various shield designs have been proposed by the manufactures. Therefore, energy savings and adequacy of lighting are both affected by the selected position of the sensor and FOV.

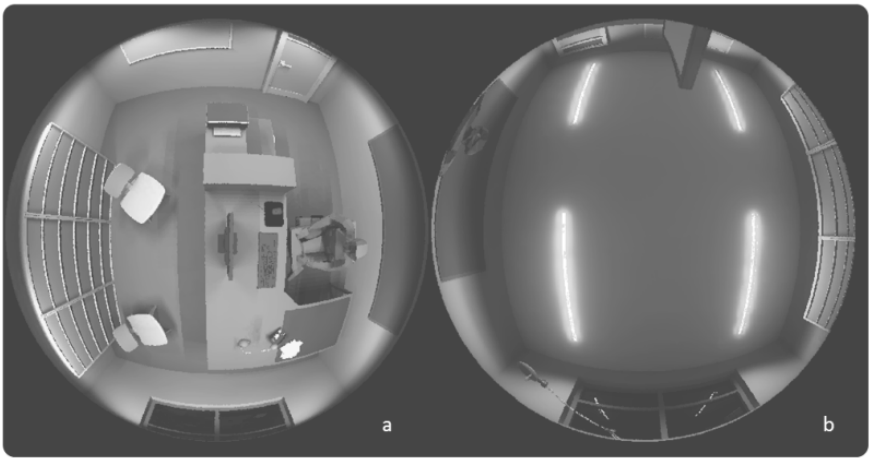

Figure 1 – Different photesensor views a) ceiling placed and b) working plane

In order to present the relation between the position and FOV to the energy savings achieved, a typical office room was defined (Room Index k=1, Width : Depth=1/1.5, east orientation, with WFR: 30%) (Figure 2). Three possible ceiling positions (A, B and C, Figure 2) have been tested with three different FOVs (1, 2 and 3, Figure 3). DAYSIM (http://daysim.ning.com/) was used to estimate hourly values of illuminance for Athens, Greece TMY. Results concerning coefficients of determination (R^2) between work plane and ceiling placed sensor illuminance, together with energy savings and lighting adequacy are presented in Table 1. When position of the sensor increases from the window, energy savings decrease while lighting adequacy increases. Lighting adequacy is defined as the percentage for occupied times with total illuminance exceeding design illuminance (i.e 500 lux).

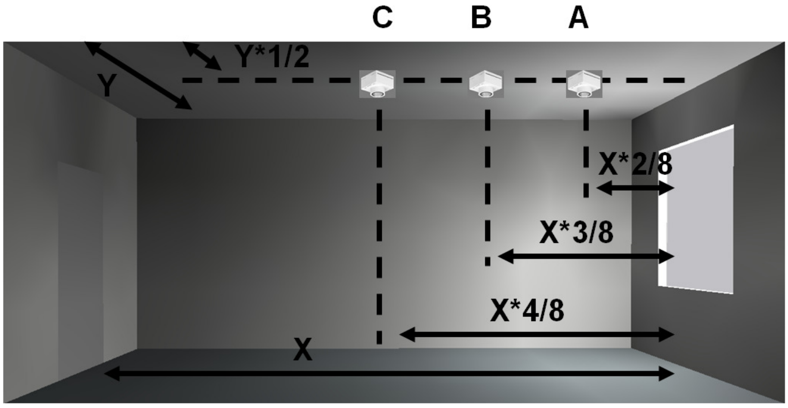

Figure 2 – Positions of the photosensor

Table 1 – Coefficient of determination (R^2) of lighting levels between ceiling and working plane, energy savings and adequacy of light of the example room for different position but the same FOV (FOV 1)

Position	Coefficient of determination (R^2) of the lighting levels between ceiling and working plane	Energy savings (%)	Adequacy of light (%)
A	0,371	74,98	74,68
B	0,437	72,91	81,04
C	0,502	63,77	90,33

Table 2 presents the impact of FOV for the same position (Position B). Narrower FOV causes a decrease in energy savings and an associated increase in lighting adequacy.

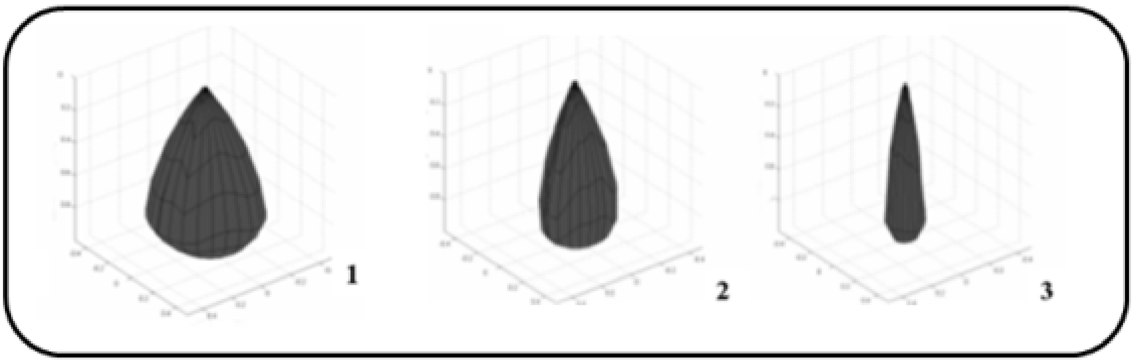

Figure 3 – FOV of photosensors

Table 2 – Coefficient of determination (R^2) of lighting levels between between ceiling and working plane, energy savings and adequacy of light in the example room for different FOV but the same position (Position B)

FOV	Coefficient of determination (R^2) of the lighting levels between ceiling and working plane	Energy savings (%)	Adequacy of light (%)
1	0,437	72,91	81,04
2	0,582	70,59	89,15
3	0,781	69,25	93,56

Furthermore, shielding of the photosensor may considerably decrease the light output fluctuation caused by outdoor lighting conditions fluctuation especially when blinds are used. A CMOS/ CCD image sensor can be placed almost anywhere on the ceiling and using a wide field of view lens, time series of images can be captured. Implementing an image-processing algorithm, these images can be converted to images with luminance distribution. Therefore any part of the image can be used as input signal to control the lighting system. Using a target with known photometric properties (such as a perfect diffuser of known reflectance), illuminance can be estimated. Since in a real working environment a medley of surfaces with various optical properties coexist, conversion of luminance to illuminance values can be difficult. Nevertheless, if illuminance values are known, any comparison with a predefined set point can drive the dimming system. It should be noted at this point that driving a control system in real time asks for a really fast image processing analysis. Newsham and Arsenault used a calibrated camera with CMOS sensor and obtained similar results with conventional sensors.

3. SPECTRAL RESPONSE

Spectral response curve of photodiodes is wider than the photopic human eye sensitivity $V_{(\lambda)}$ curve. Therefore, UV and IR filters are needed but even then, their response curve remains wider. As a result, photosensors perceive more light than the human eye sees and artificial lighting is erroneously dimmed. Figure 5 present spectral response curves for various sensors. Doulos et al (2007 and 2008) using simulation for taking into account the spectral response of photosensor presented the differences in estimated energy savings for a typical room equipped with various glazing types. The total maximum annual difference in energy saving values was estimated equal to 10.54%.

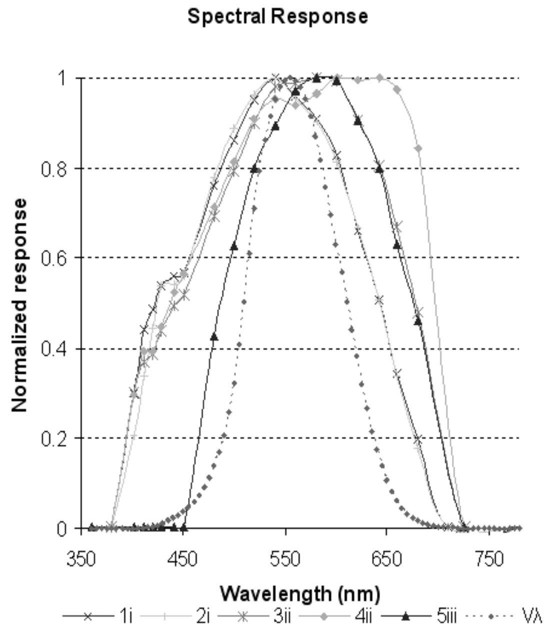

Figure 4 – Relative spectral responses of various conventional photosensors with the photopic function $V_{(\lambda)}$ of the human eye sensitivity

A Bayer filter that is commonly used in colour CCD sensors, filters the light intensity in RGB spectral regions. The spectral response curve of the green pattern can correspond to photopic human eye sensitivity $V_{(\lambda)}$, thus using only the green component, luminance values can be extracted.

4. CONTROL ALGORITHMS

When specifying the control system for a conventional photosensor, the control algorithm is the most important characteristic that should examined. The control algorithm describes precisely the exact output signal that drives the controller/ballasts as a function of the input data. Three basic control algorithms exist (closed loop, open loop and integral reset). They not only affect energy savings but also the adequacy of light (percentage of hours that the total illuminance levels exceed the target illuminance). The choice of a control algorithm must be initially based on the ability of the daylight responsive system to maintain target illuminance. The differences in light adequacy are quite substantial regarding different control algorithms (Doulos et al 2008).

5. SIMULATING THE PERFORMANCE OF PHOTOSENSORS

The majority of building energy simulation tools use time series of work plane illuminance to estimate the energy savings due to the adoption of a dimming system with known characteristics. This information is useful when various design alternatives are compared but it is of a limited value when a close to reality estimation of savings is needed. C. Ehrlich et al. (2002) used Radiance to simulate photosensor FOV and had validated the method. Annual analysis can be performed by SPOT (Sensor Placement and Optimization Tool, http://www.archenergy.com/SPOT/), which offers the ability to establish the optimal placement of the photosensor for the space, in relation to the annual energy savings. SPOT can use a number of various typical and commercially available sensors. DAYSIM can be used in some cases, for hourly based annual sensor signal calculation provided that the sensor shield has been modeled accurately. Alternatively, the sensor's FOV can be simulated by modifying ray weight emitted from the sensor's position using a transparent hemisphere with transmittance replicating the spatial sensitivity distribution (Younju 2006). The combined use of rsensor and rtcontrib Radiance commands to simulate time series of sensor signals seems quite promising.

6. CONCLUSIONS

CCD sensors are quite promising (Granderson et al, Howlett et al 2010, Newsham and Arsenault 2009, Sarkar et al 2008, Sarkar and Mistrick 2006), in the sense that they can measure luminance patterns approximating those of the human visual system. However, their capabilities are yet rather limited due to errors associated with the derivation of illuminace from luminance and some problems associated with their calibration procedure and commissioning. In addition, their increased cost and size can impose practical limitations during installation without mentioning privacy issues. However, their ability to control a shading system and be used for occupancy sensing might prove to be cost effective.

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