Reviewing the role of photosensors in lighting control systems

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Abstract: - The application of innovative technologies of automatic control in lighting systems gains daily the interest of engineers, constructors and users. The main purpose of these applications is the energy savings. Daylight control is a form of automatic control that replaces the manual control of the users. The core of this system is the photosensor, which creates a signal in proportion to the amount of the daylight that detects, using its spatial and spectral response. The signal of the photosensor can be combined with dimming electronic ballasts which adjust the electric light output giving a great potential for energy savings in areas with high levels of daylight.

Nevertheless, the daylight responsive systems are widely misunderstood and they have been characterized hastily as problematic systems. The lack of knowledge and comprehension of these systems is a great withdraw against their widespread use and a lost opportunity for energy savings. In this present study becomes effort to overcome these difficulties clarifying the operation procedures of the photosensors and their function as part of the lighting system. Also the characteristics that influence their operation are presented with advices for their optimum placement in spaces of application.

Key-Words: - Daylight; Lighting Controls; Photosensor;

1 Introduction

Lighting controls that perform on-off operations due to occupant presence, time scheduling, manual dimming, automatic dimming in connection to daylighting, demand control and lumen depreciation, have great potential in reducing lighting energy consumption [1, 2]. These systems can also moderate peak demand in commercial buildings by implementing one or more lighting control strategies [3]. Centralized controls are used in buildings where it is desirable to control large areas of the building on the same schedule. Localized controls are designed to affect only specific areas.

Daylighting can be considered as a very important strategy to substitute electric energy for the artificial lighting. Many case studies have documented energy savings by exploiting daylight [4-9] 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. Although researchers have examined analytically the behaviour of various photosensors [10-17] manufacturers of photosensors seems not to comply with them. On the other hand with the advent of inexpensive manual dimmers and handled remote controls, occupant controlled manual dimming has become an affordable option. Users have been familiar with them while it has been shown to have some energy saving potential and high occupant satisfaction rating [18].

One more successful lighting control strategy is occupant sensing with occupant sensors. These sensors switch lights on and off according to the presence of individuals that is detected. Despite their relatively widespread use, few well documented studies exist showing that occupant sensors actually decrease the energy use in a lighting system [19, 20]. Less common control strategies like task tuning and lumen maintenance have been described in the literature [21, 22] but have not been examined extensively in real installations.

In this present study the characteristics that influence the operation of a photosensor are presented in order to overcome the difficulties that withdraw their use in daylight responsive systems. Their operation procedure and function as part of the lighting system is been clarified and advices for their optimum placement in spaces of application are given.

2 Lighting controls [2, 22-24]

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There are two major objectives for the use of lighting controls:

- Controls for energy management: Their main purpose is to provide energy savings through reduced power or reduced time of use.
- Controls for aesthetic reasons: Their purpose is to provide smooth adaptation of lighting levels depending on the application and use of the space by controlling the quality of the optical environment.

Energy management controls limit the application of light only when there is a demand and therefore reduces unnecessary lighting energy. On the contrary, lighting controls for aesthetic reasons provide the ability to change space functions and create emotional appeal, offering control of lighting quality, mood, color, and attitude.

These different benefits are not necessarily in conflict between them. The strategies of energy management can improve considerably the quality of space as well as the lighting control for aesthetic reasons can contribute in important energy savings. The suitable use of these controls can help in the conformity of energy use with the national directives of energy code and decrease the functional cost of buildings. Below are exposed analytically lighting controls for various applications.

2.1 Energy management strategies

2.1.1 Scheduling

It is used in a building in which the activities are repeated at the duration of a day and illuminates spaces according to their occupancy (Fig.1). For predictable schedules such as working hours, lunch periods, weekends, holidays and evening maintenance, lighting patterns and illumination levels may be programmed on computer. Prevision for overriding the schedule must be provided in case there are variations in the schedule. For unpredictable schedules the designer can specify occupancy sensors that switch the light on and off depending on whether a space is occupied.

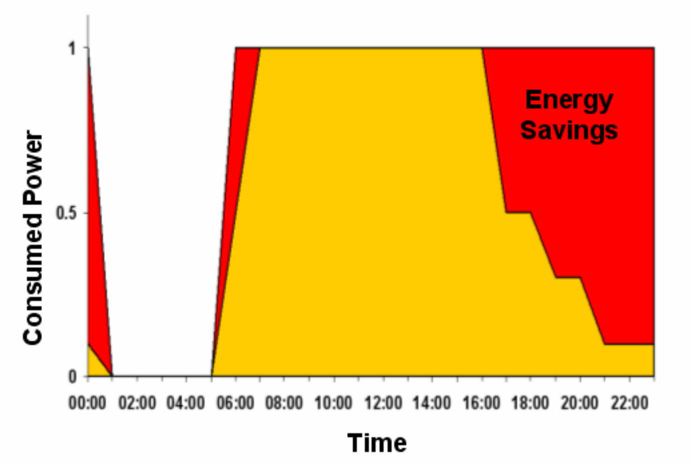

Fig.1 Consumed power using scheduling as lighting control strategy

2.1.2 Daylighting

In areas near windows and skylights part of the desired illumination can be provided by daylight. This control strategy adjusts the electric lighting level according to the amount of daylight that detects and thus reduces energy consumption (Fig.2). In offices, schools and other spaces where critical visual tasks are performed and disturbances must be minimized continuous dimming is preferable to step or on-off techniques.

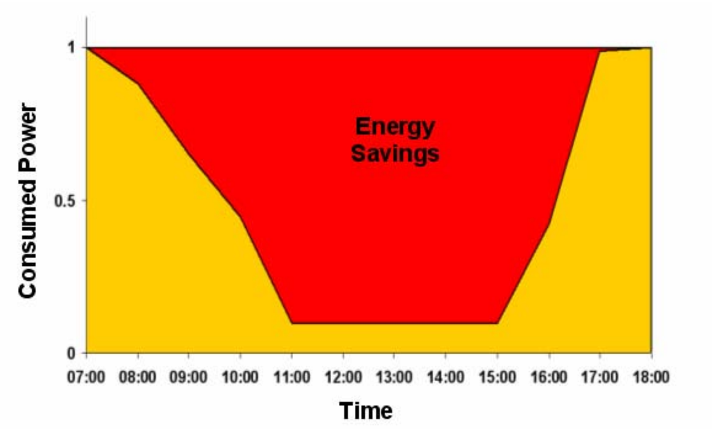

Fig.2 Consumed power using daylighting as lighting control strategy

2.1.3 Brightness Balance

In some cases the different brightness levels that occur within or among spaces must be balanced in order that glare and shadows are reduced. Brightness balance limits light entering the space with blinds or louvers in a case of a room with great amounts of daylight (Fig.3) or increases the illuminance produced by the electric lights in a case of tunnel lighting when a driver enters the tunnel.

Fig.3 Brightness balance limits light entering the room with blinds [25]

2.1.4 Lumen maintenance

The poisoning of the phosphors of a lamp over time (lumen depreciation of the lamp) and the accumulation of dirt in the luminaires cause reduction of the illumination of an area with time. This decrease in light level can exceed 30% during a two year period. Consequently, the installed lighting system must produce an initial illumination higher than the specified level. When the illumination falls under the minimum allowed level, the luminaires must be cleaned and relamped. Lumen maintance control strategy reduces the initial illumination to the designed minimum level consuming less energy. With time, when the illumination is decreased due to lumen depreciation, lumen maintance control strategy increases the electric power so that is avoided the reduction of illumination (Fig.4, 5). Full power is applied only near the end of the lumen maintenance period when the luminaires are cleaned and relamped.

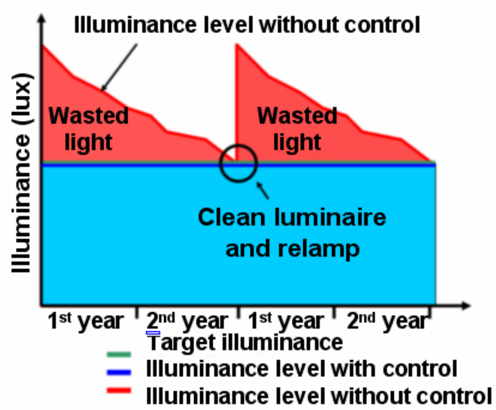

Fig.4 Light levels drop over time with conventional lighting systems, but power remains constant

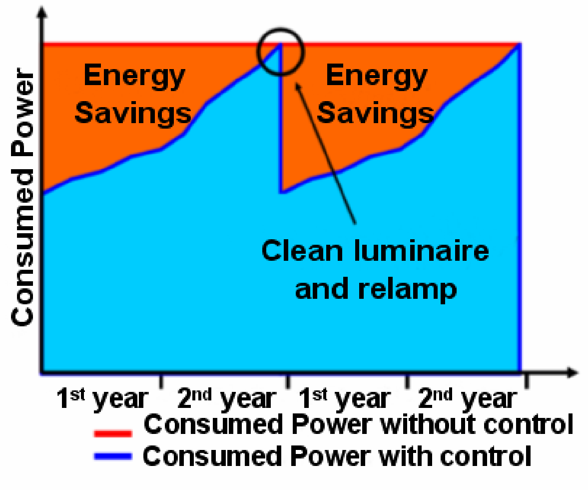

Fig.5 Consumed power using Lumen maintenance as lighting control strategy

2.1.5 Task Tuning

Usually, lighting designers adapt uniform illuminances throughout a space. The tuning strategy adjusts the light output of individual or small groups of luminaires based on local lighting needs. Tuning reduces the light output of the lighting system that illuminates corridors and other spaces with less visually critical tasks and raises it in spaces with higher requirements in lighting levels.

2.2 Aesthetic Control Strategies

Areas usually in commercial, residential and institutional applications are used by their users for more than one purpose. The different applications in these areas require also different lighting conditions. Lighting control for aesthetic reasons provides a variety of lighting conditions for the different tasks and the means to adjust the lighting by creating different scenes of lighting with the touch of one button. Thus, the space changes function in proportion its temporal application, the human visual performance is maintained and the mood of the space is changed. For example, in a conference room different tasks such as reading, slide presentation, lectures and debates require different lighting conditions. Aesthetic control using preset control systems that control several lighting channels simultaneously provide the proper scene of lighting for each application of the conference room (Fig.6). They are also used in residential applications for areas such as living rooms, dining rooms, and media rooms.

Fig.6 Scenes of lighting in a conference room [26].

3 Daylighting [22, 25, 27-31]

In the perimeter areas of buildings, part of desired illumination can often be supplied by daylight via their windows or skylights. In these areas, photosensors force ballasts in luminaires to reduce power for the electric lighting in response to the amount of available daylight and thus the consumption of energy is decreased. For the successful application of this strategy high levels of daylight must be present and an optimum installation, setting and calibration of the photosensor must be performed by the experts. Thus there will be always sufficient illumination for the tasks (Fig.7).

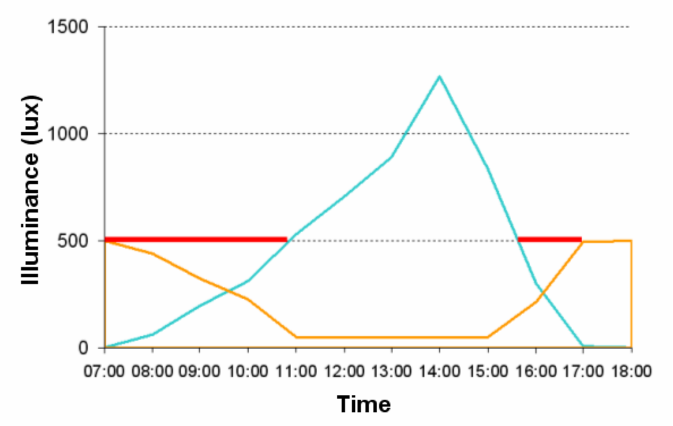

Fig.7 The control strategy of daylighting maintain a constant light level by adjusting the output of electric illumination according to changing daylight

A typical daylighting control concept usually consists of integrated lighting control zones equipped with one or a number of photosensors. The integrated lighting control zones are areas in the building that use daylight and electric lighting jointly to provide task, background or general illuminance. The size and shape of a zone depends upon aperture configuration, sky condition and solar location. Also, they are constrained by the rapid falloff of horizontal illuminance from the window wall. The electric lighting supplements daylight as the distance from the window is increased (Fig.8). The amount of the energy savings by exploiting daylight with photosensors depends on many factors such as:

- The climatic factors
- The form, orientation and design of building
- The control algorithm, installation, location and calibration of the photosensor
- The activities that are realised within the building.

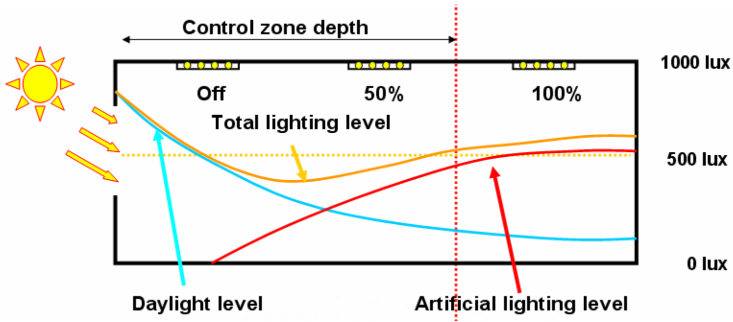

Fig.8 Section of a room with the profiles of daylight, artificial and total lighting

4 Photosensors [10, 11, 15, 22, 32-35]

The basic operation of a photosensor is the production of a signal that is related to the amount and the distribution of lighting in a space in which it is placed. The performance of the photosensor can be complex because it depends from a lot of variables, such as:

- The distribution of daylight and artificial lighting in the space in which it is placed
- The spectral composition of lighting
- The adjustment settings of the commissioning control
- The ambient light level
- Its field of view

The photosensor is a complete control unit that contains a light-sensitive photocell, input optics, an electronic circuit needed to convert the photocell signal into an output control signal and a housing and mounting device. The complex operation of the photosensor can be divided into smaller and more flexible sub-functions. The total response of the photosensor is the combination of the responses of each sub-function. Fig.9 shows schematically the basic simplified sub-functions of a photosensor as part of its overall response.

The basic sub-functions are divided in regard the optical and electric characteristics of the photosensor. The optical sub-functions collect the incident radiation from the environment and drive it into the photocell (spatial response), limit the wavelength of the incident radiation by filtering, so that it can be related to photometric quantities (spectral response) and then converted into a electric signal. The spatial response describes the sensitivity of the photosensor to incident radiation from different directions, in other words, what the photosensor "sees". Spatial response is analogous to a luminaire intensity distribution but describes sensitivity instead of light output. The spectral response describes the sensitivity of the photosensor to optical radiation of different wavelengths. In sequence the electric sub-functions of the photosensor and particular the control algorithm, modify the signal that is derived from the photocell in order to be produced the total response of the photosensor.

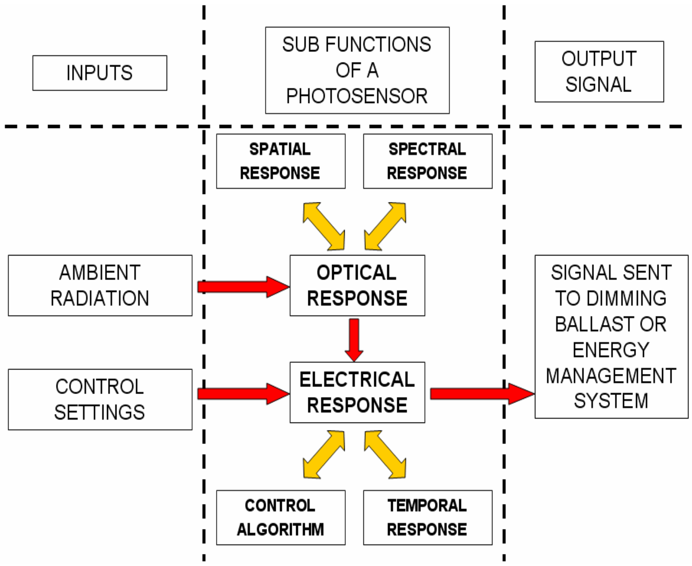

Fig.9 System diagram of the photosensor

Consequently, the optical and electric sub-functions convert the input data (ambient radiation and control settings) in an output signal that controls electronic dimming ballasts or the energy management system of the building. The output signal is typically a 0-10Volt signal, unless the photosensor and the electronic dimming ballasts are incorporated together as a system, therefore the electronic dimming ballast is specifically designed to work with a particular photosensor.

4.1 Control Algorithms [10, 11, 32, 34]

When specifying a photosensor control system, the control algorithm is the most important characteristic that should examined initially. The control algorithm describes precisely the exact output signal of the photosensor as a function of the input data (Fig.10). The existing photosensors use usually one or a combination of three basic control algorithms:

- Closed loop
- Open loop
- Integral reset

All three types of control algorithms are applied easily in either analog or digital designs.

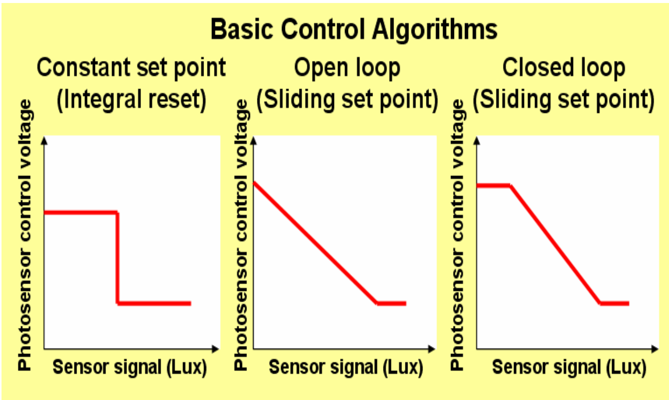

Fig.10 Plots of response functions for the three basic control algorithms

Despite of that the ideal location of a photosensor is the workplane, photosensors are mounted on the ceiling for practical reasons and receive light from the workplane below. Because of their placement on the ceiling their optical response does not correspond with the illuminance of the workplane. The changes in ceiling illuminance do not correspond linearly with the changes in workplane illuminance mainly due to the different light distribution within a room when daylight is present compared to electric light alone (Fig.11, 12). Daylight enters a room through vertical windows in a horizontal, or even an upward direction due to the window treatments diffusing and redirecting the direct sunlight. Luminaires usually direct electric light down onto the workplane. Therefore when daylight enters the room the ceiling illuminance increases much more than the workplane illuminance. The Integral reset control algorithm that maintains a constant optical signal on the photosensor, which is similar to keeping a constant ceiling illuminance, will conceive erroneously that exists more lighting in the room and will decrease the electric lighting in the room creating visual discomfort to the users.

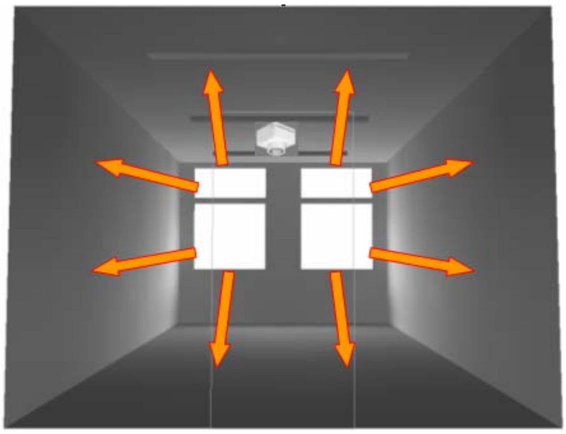

Fig. 11 Daylight distribution within a room

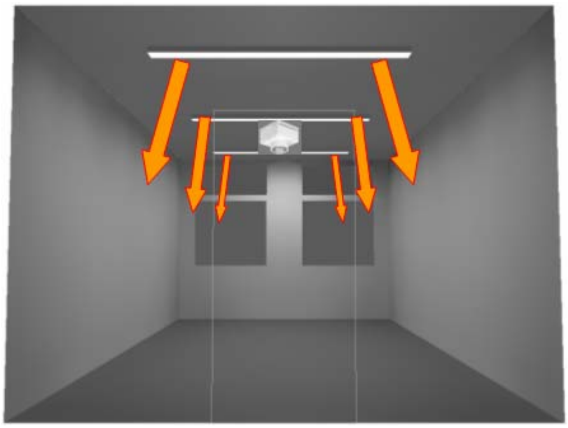

Fig. 12 Electric lighting distribution within a room

The closed loop proportional control algorithm can react to and compensate for changes in the illumination level in the room using feedback. It allows flexibility in setting the constant of proportion between dim level and input optical signal. This flexibility allows for increasing light levels on the work plane as daylight enters the room as well as for a constant work plane illuminance.

4.2 Spatial response [32, 35]

Many commercial photosensors, from various manufactures, were examined in the Photometry Laboratory of National Technical University of Athens. The tested photosensors were categorized as either narrow or wide due to the shape of their measured spatial response (Fig.13).

Photosensors with narrow spatial sensitivities track better the changes of illuminance in the workplane provided that the reflectance properties of the surface don't change. On the other hand their small field of view is not representative of the entire workplane. In the real word, the reflectance of the workplane changes depending on the activities that occur in the room. White papers in a dark desktop (Fig.14) or the daily different clothing of the users can change the response of a narrow photosensor. This can make the narrow photosensors very sensitive making them function unpredicted influencing the optical comfort of users by changing rapidly the light levels. This effect can also be intensified by specular reflections from glossy mirror-like surfaces. Reflections of light directly back into the photosensor's field of view can cause erratic performance.

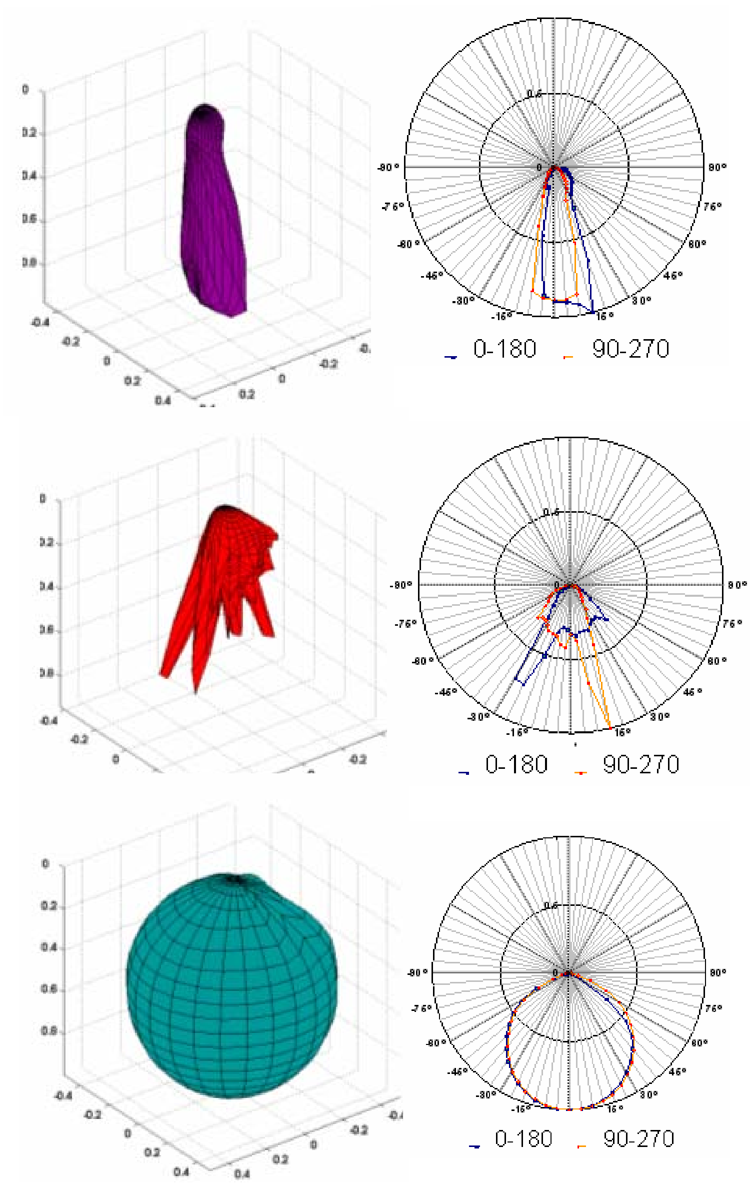

Fig.13 3D renderings and the corresponding polar diagrams of spatial responses of the tested photosensors

The specular reflections have relatively less effect in the photosensors with wide spatial response. Large fields of view diminish that kind of effects. The main advantage of photosensors with wide spatial response is that the optical signal that they sensed is very representative of the overall workplane or the entire room and is less affected by normal activity in the room. On the other hand the illuminance of the ceiling does not correspond to the illuminance of the workplane and therefore the wide photosenor needs a suitable control algorithm in order to compensate this non correspondence in illuminance levels.

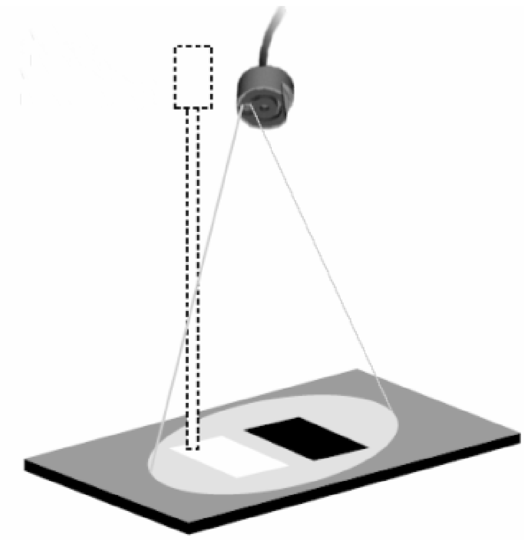

Fig.14 Photosensors with different field of view aiming a workplane with varying reflectance [26]

4.3 Spectral response [32, 35]

The photocells used in photosensors are sensitive to a wider range of wavelengths than what the human eye sees. In other words, photocells respond to portions of the ultraviolet (UV) and infrared (IR) spectrum as well as the visible spectrum. Filters that incorporated into the photocell element, limit the sensitivity to ultraviolet (UV) and infrared (IR) radiation. In the Photometry Laboratory of National Technical University of Athens were measured also the spectral response of the same commercial photosensors (Fig.15).

The differences in spectral composition between daylight and fluorescent lighting can influence differently the photosensors. The greater content of ultraviolet and infrared radiation of daylight combined with the wider spectral response of photosensors makes them more sensitive to daylight than to electric lighting. Greater sensitivity in the daylight means that a photosensor reacts like there is more daylight than really exists. As a result, the photosensor decreases the lighting levels of the artificial lighting system too much and turns visual discomfort in the users.

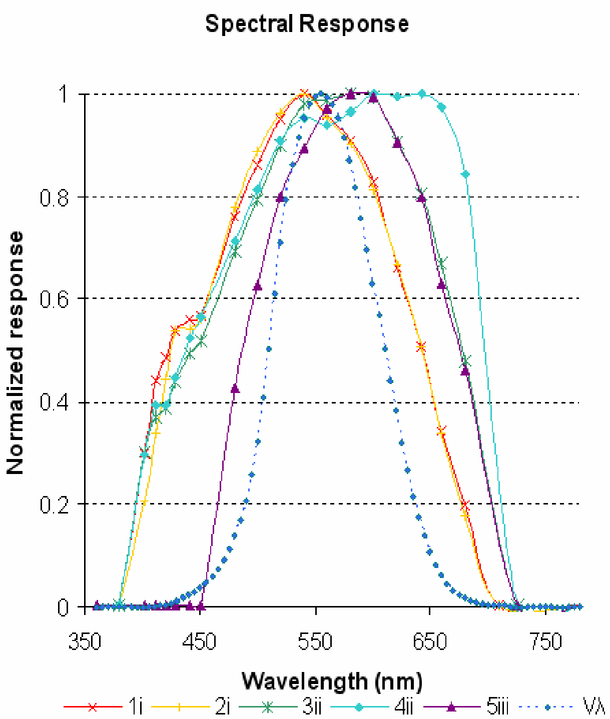

Fig. 15 Relative spectral responses of various photosensors with the photopic function V(λ) of the human eye sensitivity.

5 Conclusion

Lighting control systems are a complex technology that changes rapidly. A variety of controllers, software, sensors and devices are currently available, but there is a lack of information concerning the actual performance of these systems and control strategies. In order to fully exploit their capabilities and implement the most energy efficient control strategies, simulation software, reliable data from these components measured or provided from the manufacturers, official directives and guidelines are needed during the initial design phase. To overcome this barrier many studies have been conducted. The control algorithm dominates the performance of the daylight responsive dimming system. Of course the spatial and spectral response functions of the photosensor, calibration and commissioning affect the overall operation as well. A high performance control algorithm could possibly, but not likely, compensate for both a non-ideal spatial response and a poor spectral correction.

However, the better the spatial response tracks change in workplane illuminance and the better the spectral correction of the photosensor, the finer will be the overall operation of the photosensor system.

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