NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

# Specifier Reports

## Photosensors

Light-sensing devices that control output from
electric lighting systems

Volume 6 Number 1 March 1998

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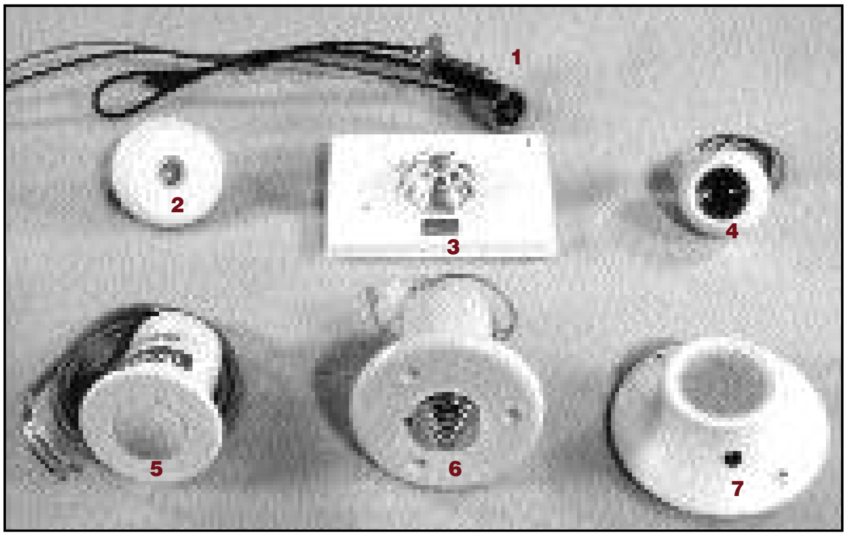
## Introduction

A photosensor is an electronic control device that adjusts the light output of a lighting system based on detected illuminance. While some photosensors simply switch lights on and off, *Specifier Reports: Photosensors* focuses on photosensors that are used with dimming electronic ballasts to adjust the light output of fluorescent lighting systems over a continuous range. These photosensors are most commonly used in daylight applications to dim electric lighting when total illuminance exceeds a preset level.

Photosensors have seen limited application for three principal reasons. First, the actual energy savings that photosensors can achieve is difficult to predict, making it hard to justify the purchase of a photosensor control for a lighting system. Second, although properly located, installed, or positioned photosensors may reduce energy expenses, they may also be a source of occupant complaints. Third, anecdotal reports of difficulties in properly installing and adjusting photosensors may have limited many specifiers' willingness to use them.

**Figure 1. Photosensors Used for Dimming Fluorescent Lighting Systems**



The products illustrated are: **1** ETTA FO-1; **2** The Watt Stopper Lightsaver LS-30; **3** UNENCO Daylight Tracker DT-D; **4** PLC Multipoint EDS/AB; **5** Lutron microPS MW-PS-WH; **6** Honeywell Ambient Light Sensor EL7365A1014; **7** Sensor Switch CM-ALC.

## Contents

The technology behind photosensors is generally not well understood by specifiers and other users. The National Lighting Product Information Program (NLPIP) produced this issue of *Specifier Reports* to promote better understanding of this technology, to document the performance characteristics of photosensors, and to provide guidance to specifiers on selecting, installing, and adjusting photosensors.

## Technology Overview

NLPIP defines a *photocell* as the light-responding silicon chip that converts incident radiant energy into electrical current. A *photosensor* is defined as the complete unit that houses the photocell and the circuitry that converts the electrical current into a control signal suitable for a dimming electronic ballast (or other control device). Most photosensors include a filter over the photocell to make the spectral response of the photocell approximate the response of the human eye (photopic correction). The term *photosensor-controlled system* refers to the photosensors, ballasts, lamps, and any other control devices included in a lighting system.

For simplicity and clarity, NLPIP uses *photosensor illuminance* to describe the incident radiant energy to which photosensors respond. *Task illuminance* refers to the illuminance on the work plane, typically the desktop in office applications.

Photosensors monitor illuminance only at the location of the photocell, which is often at the plane of the ceiling. However, the main purpose of any lighting system is to provide illumination for the tasks in a space. Therefore, understanding the relationship between task and photosensor illuminance is important to specifying a photosensor-controlled system. Factors such as the arrangement of furniture and partitions, the reflectances of surfaces, the direction of incoming sunlight, the use of task lighting, the positions of the occupants, and, in some photosensors, the direction the photocell faces all affect the relationship between task and photosensor illuminance. For example, spreading white papers across a dark-surfaced desk, will increase the light reflected to the ceiling. The sidebar "Task-to-Photosensor Illuminance Ratio" on p. 4 further discusses the relationship between task and photosensor illuminance.

Most photosensors work by modulating current through the input control wires of a dimming ballast. The current flow in the control wires (which are usually gray and purple) determines control voltage, which has been standardized to a range of 0–10 volts (V). Changes in photosensor illuminance change the current flow and voltage in a control circuit. The lower the voltage the ballast senses across the control input wires, the more it dims the lamps. For most photosensors, the control wires also carry the small amount of power needed to operate the photosensor.

When a photosensor detects a low photosensor illuminance, it limits current flow in the control wires, causing the control voltage to rise to a maximum of approximately 10 V, which typically produces full light output from the lighting system. When a photosensor detects a high photosensor illuminance, it increases current flow in the control wires, causing the voltage to drop, approaching 0 V. In this case, the lamps will be dimmed as much as the dimming ballast allows (usually 10–20% of maximum light output).

Some photosensor-ballast systems use a different strategy. Rather than responding to a control voltage, the dimming electronic ballast interprets digitally encoded pulse signals from the photosensor. By modulating the frequency of the control signal, the photosensor varies the light output from the lamp-ballast system. Since pulse-coding methods are often proprietary, these dimming ballasts typically must be used with special photosensors made by the same manufacturer. However, some manufacturers also offer interface devices that can convert the control signal of a low-voltage photosensor into a digital signal.

For both types of photosensors, the photocell and the control circuit of the photosensor determine how photosensor illuminance is converted into a control signal. NLPIP defines the relationship between the photosensor illuminance and the control signal from the photosensor to the dimming electronic ballast to be the *response function* of the photosensor. Photosensors also have a manually adjustable sensitivity setting that modifies the response function. The "Performance

Characteristics" section describes photosensor response functions in detail. NLPIP believes that understanding these response functions is necessary to implementing a photosensor-controlled system successfully.

## Performance Characteristics

Photosensor-controlled systems can be either closed- or open-loop systems, depending upon whether the photosensor detects illuminance from the light source it controls. In an open-loop system, the photosensor is typically located on the exterior of a building, controlling the electric light system based upon illuminance from daylight. In a closed-loop system, the photosensor detects electric light in the room it controls as well as any daylight in the space. When the photosensor adjusts the output of the electric lighting system, the photosensor illuminance detected by the photosensor changes, requiring a further change in the output of the electric lighting system.

Some photosensor manufacturers recommend locating their products on the ceiling near the window. While this arrangement approximates an open loop, the photosensor still detects a combination of daylight and electric light. Thus, NLPIP considers these to be closed-loop systems. Because closed-loop systems are much more common than open-loop systems, NLPIP focuses on closed-loop systems in this report.

### Understanding the Performance of Photosensor-Controlled Systems

The overall performance of a closed-loop photosensor-controlled system depends upon the response functions of the photosensor and the ballast and changes in photosensor illuminances, which are affected by the placement of the photosensor.

**Photosensor-response functions.** NLPIP classifies the response functions of photosensors either as threshold or continuous response. NLPIP tested samples of both types.

**Threshold response.** Threshold-response photosensors are designed to maintain illuminance. If photosensor illuminance increases a given amount, the photosensor sends a control signal to the ballast to reduce the output of the electric lighting system the same amount. If photosensor illuminance decreases, the photosensor sends a control signal to the ballast to increase the output of the electric lighting system.

**Shielding**

By definition, photosensors in a closed-loop system respond to both electric light and daylight. Light received by the photocell directly from a window, a skylight, or a luminaire may cause the photosensor to fully dim the electric light, even if there is insufficient illuminance on the work plane. Most photosensors shield the photocell from direct light so that only light reflected from room surfaces such as desktops and walls reaches the photocell. Some photosensors have external baffles; in others, the photocell is recessed into the housing.

### Task-to-Photosensor Illuminance Ratios

Predicting the performance of a photosensor-controlled system requires an understanding of the relationship between task and photosensor illuminance. Proper shielding (see the sidebar "Shielding" on p. 3), is essential if the ratio of task-to-photosensor illuminance is to remain relatively constant.

NLPIP measured task-to-ceiling illuminance ratios in several offices of different sizes having exposure to daylight and varying surface reflectances. Directly over desktops, the ratios ranged from 3:1 to 10:1, but clustered near 5:1. Rubinstein, et al. (1989) found task-to-ceiling illuminance ratios ranging from 5:1 to 9:1, while Choi and Mistrick (1997) estimated the task-to-ceiling illuminance ratio in an office space to range from 2:1 to 5:1. In spaces with very low reflectance characteristics, such as offices with dark carpeting or walls or very high ceilings, an estimated task-to-ceiling illuminance ratio greater than 5:1 would be more appropriate. In small spaces with very high reflectances or very low ceilings, a task-to-ceiling illuminance ratio lower than 5:1 may be appropriate. Similarly, changes in conditions outside the building, such as snow cover, can also change the task-to-ceiling illuminance ratio. For these reasons, NLPIP suggests using a 5:1 task-to-ceiling illuminance ratio as an estimate of the photosensor illuminance for a given task illuminance; however, in practice, higher or lower ratios may be required to accommodate space characteristics as well as the directionality of a photosensor.

Computer software packages may help predict the task-to-ceiling illuminance ratio for a particular application or design. See the sidebar below.

### Predicting Daylight in Spaces

NLPIP uses the terms *daylighting* and *daylight* to refer to the sky's contribution to illuminance in indoor spaces, excluding direct sunlight. Exterior horizontal illuminances from daylight (excluding direct sunlight) can be as high as 10,000 to 20,000 lux (lx) [10.76 lx = 1 footcandle (fc)] on clear or overcast days and as high as 40,000 lx on partly cloudy days (IESNA 1993). White (1986) suggested that office spaces with windows should be designed to produce task illuminances from daylight of at least 2% of the exterior horizontal illuminance produced by daylight, which would yield task illuminances of at least 200–400 lx on clear and overcast days and at least 800 lx on partly cloudy days.

In the same study, White also found task illuminances from daylight exceeding 10% of the exterior horizontal illuminance on work surfaces 0.5 meters (m) [1.6 feet (ft)] from the window. However, task illuminances from daylight decreased rapidly with increased distance from the window, to about 1.5% of the exterior horizontal illuminance on work surfaces 2.5 m (8.2 ft) from the window.

The contribution of direct sunlight to task illuminances usually is excluded when discussing daylighting because occupants generally find the brightness of direct sunlight on visual tasks objectionable. In such cases, occupants usually will use window shades or blinds to reduce or eliminate the contribution of direct sunlight, especially from south-facing windows (Rubin et al. 1978; Rea 1984). Even in rooms with east- or west-facing windows, window shades or blinds are often used by occupants to exclude sunlight.

Several computer software packages that help specifiers predict illuminances from daylight in a space, based upon geographic location, site characteristics, time of year, time of day, orientation of the space and windows, window size and placement, room surface reflectances, and room geometry can be found in the IESNA's software survey (1997).

Figure 2 on p. 5 shows the response function for a hypothetical threshold-response photosensor. The photosensor varies its control voltage to maintain the target photosensor illuminance, $E_{v2}$. When photosensor illuminance exceeds $E_{v2}$, the photosensor decreases the control voltage to reduce the output of the electric lighting system to achieve the target photosensor illuminance. When photosensor illuminance is less than $E_{v2}$, the photosensor increases the control voltage to increase the output of the electric lighting system to achieve the target photosensor illuminance. $E_{v1}$ represents a reset level. Some photosensors suspend operation at a point after control voltage reaches minimum. $E_{v1}$ must be reached before the photosensor resumes normal operation seeking the target illuminance $E_{v2}$.

**Continuous response.** Continuous-response photosensors establish a constant relationship (or function) between the photosensor illuminance and the control voltage sent to the ballasts. Figure 3 on p. 5 shows a sample response function for a hypothetical continuous-response photosensor where $E_{v1} = 0$. Continuous-response photosensors begin to reduce control voltage when photosensor illuminance exceeds $E_{v1}$, which also may be greater or less than 0. Unlike threshold-response photosensors, most continuous-response photosensors allow photosensor illuminance to increase as the illuminance from daylight increases throughout its response range.

If photosensor illuminance is below $E_{v1}$ (the point at which the photosensor starts to reduce control voltage), such as in a daylighting application when there is little or no illuminance from daylight and $E_{v1} > 0$, the control voltage to the ballast is maximized and the electric lighting system produces full light output. When illuminance from daylight increases such that the resulting photosensor illuminance exceeds $E_{v1}$, the photosensor will send a control signal to the ballast to reduce the output of the electric lighting system. In a closed-loop system, the photosensor continues to adjust the output of the electric lighting system until photosensor illuminance stabilizes. These adjustments are not perceptible to the occupants.

As illuminance from daylight increases such that the photosensor illuminance exceeds $E_{v2}$ (the point at which the photosensor maximizes its dimming signal), the photosensor sends a control signal to the ballasts to fully reduce the output of the electric lighting system. At this point, further increases in photosensor illuminance do not affect the output of the electric lighting system.

**Ballast compatibility and response.** While some dimming photosensors may be used only with ballasts from the same manufacturer, most manufacturers list the Advance Mark VII, the Motorola Helios, or the MagneTek Ballastar dimming electronic ballast as approved for use with their photosensors. Other low-voltage dimming electronic ballasts, including those for T5FT lamps and compact fluorescent lamps, have control circuits similar to the listed products and should function with photosensors. Specifiers should consult both the photosensor and ballast manufacturers if they are unsure about whether a photosensor can be used in a system with a dimming electronic ballast.

Specifiers should know that different ballasts respond differently to photosensor control signals. Dimming electronic ballasts respond to only a part of the control voltage range of a photosensor, and different ballasts respond to different parts of the control voltage range. Therefore, a dimming electronic ballast may not respond as soon as a photosensor sends a dimming signal, and it may fully dim the lamps before the photosensor sends its minimum control voltage. NLPIP defines the photosensor illuminance at which a photosensor-ballast system begins dimming the electric lighting system as $E_{d1}$ and the photosensor illuminance at which the photosensor-ballast combination stops dimming the electric lighting system as $E_{d2}$.

NLPIP used two ballasts in testing photosensors: the ETTA EC2S-120A8D ballast for use with the ETTA photosensor and the Advance Mark VII ballast for use with the other photosensors. Figures 4 and 5 on p. 6 show the response functions of these two ballasts, respectively. The output of the electric lighting system is shown as a function of the control signal sent by a photosensor.

**Figure 2. Response Function of a Hypothetical Threshold-Response Photosensor**

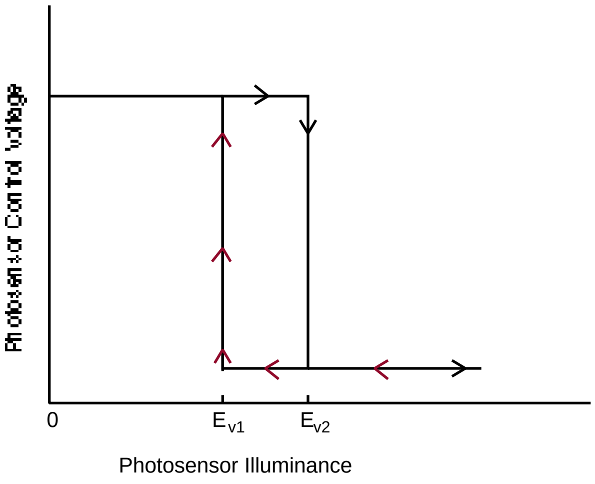
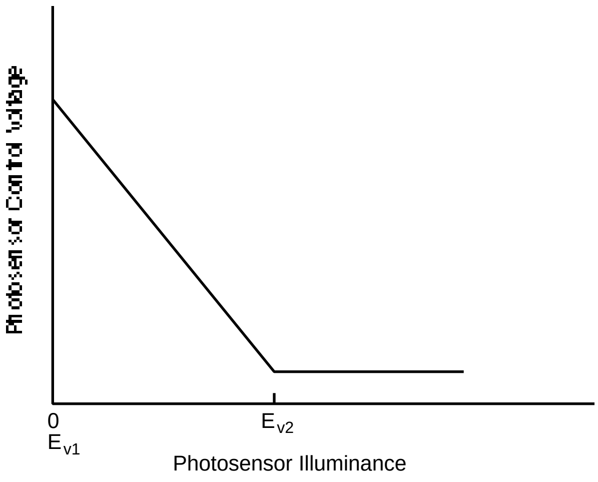


**Figure 3. Response Function of a Hypothetical Continuous-Response Photosensor**



The figures show that the ballasts both have nearly linear responses between two voltages. NLPIP calls the range between these two voltages the *control voltage response range*. The table below gives the control voltage response ranges for several dimming electronic ballasts for T8 fluorescent lamps, as measured by NLPIP.

| Dimming Electronic Ballast | Control Voltage Response Range |
|---|---|
| ETTA EC2S-120A8D | 1.5–3.0 V |
| Advance Mark VII | 1.5–8.5 V |
| MagneTek Ballastar | 0.5–9.5 V |
| Motorola Helios | 0.0–10 V |

**Sensitivity settings.** Photosensors have adjustable sensitivity settings. For threshold-response photosensors, the sensitivity setting changes the target photosensor illuminance and the distance between $E_{v1}$ and $E_{v2}$. For continuous-response photosensors, the sensitivity setting can affect one or more of the following: the photosensor illuminance at which the photosensor begins to send a dimming signal to the ballast ($E_{v1}$ in Figure 3 on p. 5), the photosensor illuminance at which the photosensor sends a signal to the ballast to fully dim the lamps ($E_{v2}$ in Figure 3 on p. 5), and the range of photosensor illuminances at which dimming takes place (the distance between $E_{v1}$ and $E_{v2}$ in Figure 3 on p. 5). Possible implications of these changes are discussed below in the section "Interpreting Response Functions."

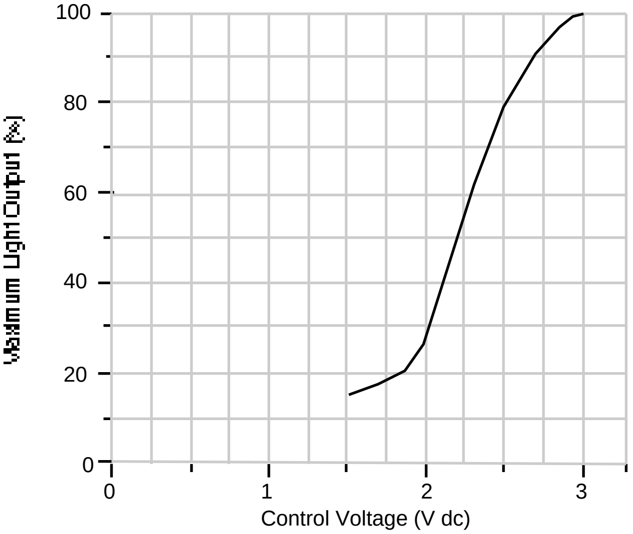
**Time response.** Momentary fluctuations in photosensor illuminance may result from passing clouds or someone walking under the photosensor. To prevent electric lighting from fluctuating in response to these momentary changes, most continuous-response photosensor manufacturers incorporate a time-averaging response into the circuit design.

The two threshold-response photosensors tested by NLPIP had two time response settings, slow and fast. The slow settings reduce the likelihood that occupants will be distracted by fluctuations in electric light output.

## Interpreting Response Functions

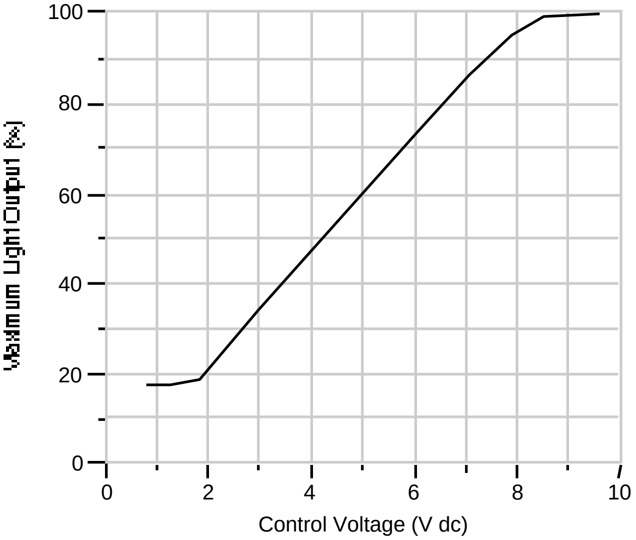
**Threshold response.** Figure 6 on p. 7 is the system-response function of a hypothetical threshold-response photosensor-controlled system. The figure shows the result of combining the response function of a threshold-response photosensor with the response function of a ballast. The system-

**Figure 4. Ballast-Response Function of the ETTA EC2S-120A8D Dimming Electronic Ballast**



Response characteristics of the ETTA EC2S-120A8D dimming electronic ballast, as tested by NLPIP.

**Figure 5. Ballast-Response Function of the Advance Mark VII Dimming Electronic Ballast**



Response characteristics of the Advance Mark VII dimming electronic ballast, as tested by NLPIP.

response function combines the hypothetical photosensor response shown in Figure 2 (on p. 5) with the linear ballast response shown in Figure 5. Figure 6 shows the illuminance produced by the electric lighting system as a function of the task illuminance produced from daylight. (Task illuminances are assumed to be five times the photosensor illuminance as discussed in the sidebar "Task-to-Photosensor Illuminance Ratios" on p. 4.)

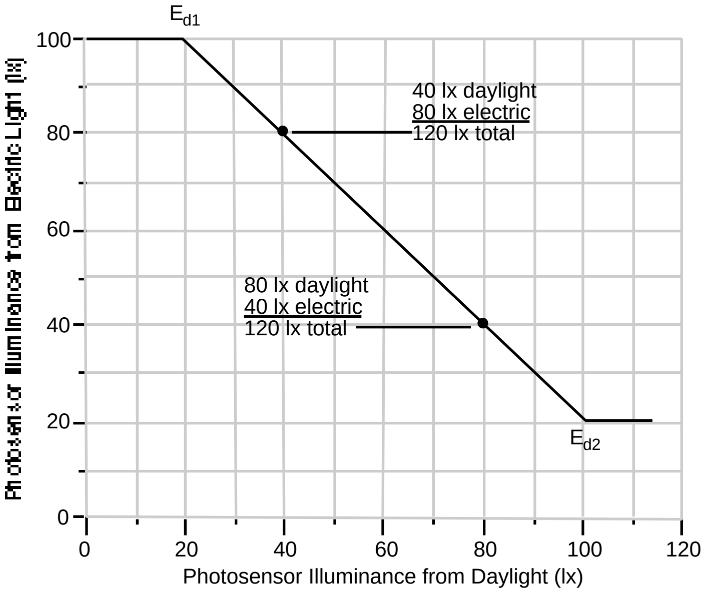
NLPIP assumed that when the electric lighting system is operating at full output, it contributes 100 lx (10.76 lx = 1 fc) to photosensor illuminance, which corresponds to a task illuminance of 500 lx. The minimum photosensor illuminance that can be produced by the electric lighting system is assumed to be 20 lx, or approximately 20% of maximum output.

When daylight adds illuminance to the space, the photosensor decreases the output of the electric lighting system only when photosensor illuminance exceeds 120 lx. For example if the daylight contribution to photosensor illuminance increases from 0 to 40 lx, the photosensor will reduce the output of the electric lighting system so that it contributes approximately 80 lx on the ceiling on the task. If the daylight contribution to photosensor illuminance increases further, to 80 lx for example, the photosensor will reduce the light output of the electric lighting system to 40 lx. At any given time, however, the total photosensor illuminance will be approximately 120 lx.

The target task illuminance from electric lighting and daylight over the range of dimming is, therefore, 600 lx, according to the 5:1 task-to-photosensor illuminance ratio. For this example (and the examples using continuous-response photosensors), NLPIP did not factor in the effects of either lamp lumen depreciation or luminaire dirt depreciation, which are explained in the section "Lumen Maintenance Applications on p. 11."

**Continuous response.** The response functions of continuous-response photosensors vary widely, and their shapes vary depending upon the sensitivity setting. NLPIP provides response functions at maximum and minimum sensitivity for each photosensor in the "Performance Evaluations" section of this report. NLPIP believes the specifier can use these response functions as limits for the potential performance of these photosensors. To estimate system performance, the specifier must determine the photosensor control voltage from the photosensor-response function and use that value to determine electric light output from the appropriate ballast-response range or ballast-response function (p. 6).

**Figure 6. System-Response Function of a Hypothetical Threshold-Response Photosensor**
**for 120 lx of Photosensor Illuminance**



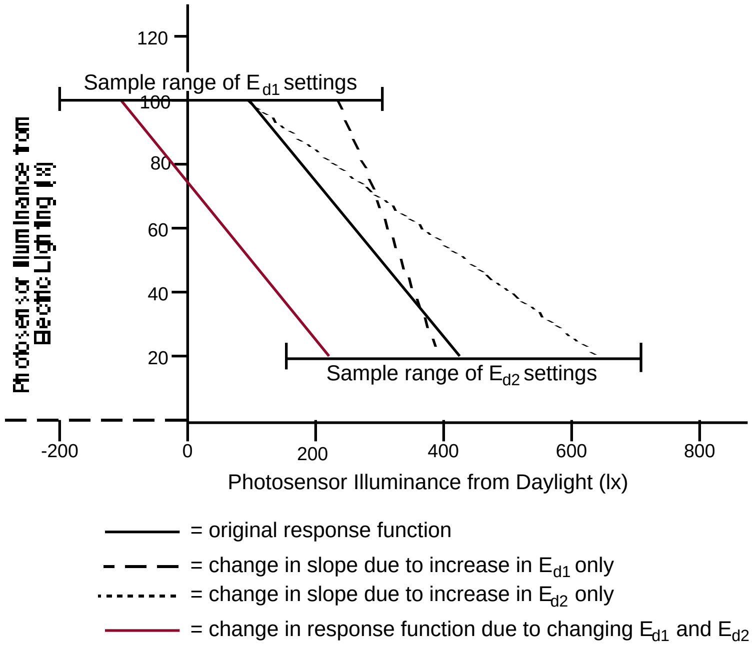
Example of a response function for a threshold-response photosensor-controlled lighting system (illuminance from the electric lighting system alone versus photosensor illuminance provided by daylight alone) for a daylighting application.

Adjusting the sensitivity of a continuous-response photosensor will change the system-response function by changing

- the illuminance at which the photosensor starts to send its dimming signal to the ballast, which changes the slope of the response function,
- the illuminance at which the photosensor stops its dimming signal to the ballast, which changes the slope of the response function, or
- the illuminances at which the photosensor starts and stops sending its dimming signal to the ballast, which shifts the curve without changing its slope.

Figure 7 illustrates these three possibilities for a hypothetical continuous-response photosensor-controlled system. For the original system it is assumed that the electric lighting system produces 100 lx on the ceiling at full output and 20 lx on the ceiling at minimum output. It is further assumed that the system begins to dim when photosensor illuminance reaches 200 lx ($E_{d1}$) (100 lx from daylight and 100 lx from the electric lighting system). The system stops dimming when photosensor illuminance is 420 lx ($E_{d2}$) (400 lx from daylight and 20 lx from the electric lighting system). Note that for continuous-response photosensor-controlled systems, $E_{d2}$ must be greater than $E_{d1}$.

**Figure 7. Adjusting the Sensitivity of a Hypothetical Continuous-Response Photosensor-Controlled System**



The dashed line (– – –) shows the result when $E_{d1}$ changes while $E_{d2}$ remains fixed (the UNENCO photosensor, described later in this report, exhibits this characteristic). Note that it is sometimes possible to set $E_{d1}$ to a negative value at very high sensitivity settings, which means that the system will be partially or fully dimmed even when no daylight is present in the space. For some very low sensitivity settings, if $E_{d1}$ has a large value the photosensor system may never dim even when a great deal of daylight is present in the space.

The broken line (- - -) shows the result when $E_{d2}$ changes while $E_{d1}$ remains fixed (the ETTA, Lutron, and Sensor Switch photosensors, described later in this report, exhibit this characteristic). At very high sensitivity settings, when $E_{d2}$ is very close to $E_{d1}$, a continuous-response photosensor can behave much as a threshold-response photosensor. However, if $E_{d2}$ has a very high value, the system-response function will be very flat, and the system may not begin to dim noticeably even if a great deal of daylight is present in the space.

The red line shows the result when $E_{d1}$ and $E_{d2}$ change together (the Honeywell photosensor, described later in this report, exhibits this characteristic). In this case, the slope of the response function does not change.

The specifier must take care to understand how adjusting sensitivity affects illuminance and energy. The specifier risks setting sensitivity so high that no energy savings are realized or so low that occupants complain because of excessive luminance ratios in daylight applications. The specifier should realize that the slope of the response function for most continuous-response photosensors reduces the impact of daylight on dimming the electric lights. The shallower the slope, the smaller the reduction in electric light in response to daylight. This strategy helps minimize occupant complaints but also minimizes energy savings.

## Application Considerations

Photosensor response functions must be understood in the context of two factors: placement and orientation of the photosensor and the characteristics of the space in which it will be installed. Specifiers should also know how to install, set, and adjust photosensor-controlled lighting systems and how to use photosensors in lumen maintenance applications.

### Photosensor Location

Photosensors in a closed-loop system are often installed on the ceiling and should be located where changes in illuminance relate to variations in illuminance on the work surface. Selecting the appropriate location for a photosensor is complicated; in any given space, different locations may be appropriate for each manufacturer's photosensor. Some photosensors can control more than one luminaire, which further complicates the job of selecting an appropriate location.

Specifiers should check manufacturer's specifications for instructions on positioning and aiming photosensors. For instance, some manufacturers suggest placing the photosensor on the ceiling near the luminaires it controls and directly above a work surface that receives a representative amount of daylight. Other manufacturers suggest aiming the photosensor toward an interior wall to avoid the effect of changing reflectances on the work surface or of sensing direct sunlight. Yet another manufacturer suggests aiming the photosensor at a point near the window while shielding it from direct exposure to daylight (See the sidebar, "Shielding," on p. 3). Ideally, the installer will test the responses of photosensors in multiple locations and orientations to see which provides the best correspondence between photosensor and task illuminance and to be sure that the position complies with manufacturer recommendations before choosing a product and location.

As a rule of thumb, the California Energy Commission (CEC 1993) recommends that a photosensor should be located away from the window a distance equivalent to approximately two-thirds the depth of the area controlled by the photosensor. The CEC qualifies this recommendation by suggesting that there is rarely sufficient daylight for a photosensor-controlled system more than 5 m (15 ft) from the window. Therefore, a ceiling location approximately 3 m (10 ft) from the window is a reasonable starting point for selecting a location for a photosensor.

In an area that uses an indirect or direct-indirect electric lighting system, the photosensor should be located where it is not exposed to direct light from luminaires. This may mean mounting the photosensor on the bottom or side of the luminaire, suspending the photosensor from the ceiling at the same height as the luminaire, or adjusting the photosensor's baffles (if so equipped) to block its view of the luminaires. Some photosensor manufacturers recommend against using their products with indirect or direct-indirect electric lighting systems. NLPIP recommends that specifiers check with the photosensor manufacturer before installing a photosensor as part of an indirect or a direct-indirect electric lighting system.

### Space Characteristics

Geometry and the reflectance characteristics of the building site, which may include plantings or nearby buildings, can also affect a specifier's decision about which photosensor to install because of their effect on daylight's contribution to photosensor illuminance in a space. Sites in the northern regions of North America, for example, may experience significant periods of snow cover (see sidebar "Predicting Daylight in Spaces" on p. 4).

In North America, the characteristics of the building site may not be as important as it might seem. Contributions to interior illuminances from natural light through south-facing windows may be overestimated, for example, because occupants often use window blinds or shades to minimize sunlight (Rubin *et al.* 1978; Rea 1984). The specifier must consider the impact of window treatments on daylighting's contribution to photosensor and task illuminances and the resulting impact on potential energy savings with photosensor-controlled systems.

### Installing, Setting, and Adjusting

Most photosensor manufacturers suggest adjusting photosensor sensitivity at night or during the day with the window blinds or shades closed. Manufacturers usually suggest setting the initial sensitivity to minimum so that the lamps will operate at maximum output. To accommodate lamp lumen depreciation (see section "Lumen Maintenance Applications" on p. 11), the electric lighting system should initially provide an illuminance greater than the design task illuminance at maximum light output. The sensitivity should then be increased (which will dim the electric lighting system) until the desired task illuminance on the work plane is reached.

Another approach to adjusting the photosensor involves adjusting its sensitivity on a partly cloudy day (when daylighting is likely to provide the maximum illuminance within the space). Window blinds or shades should also be adjusted to avoid glare from direct sunlight and excessive luminance ratios between windows and room surfaces (see preceding section on "Space Characteristics"). The first step in this approach is to set the photosensor to its maximum sensitivity setting and then gradually decrease its sensitivity. As the sensitivity decreases, the output of the electric lighting system should begin to increase. In this way, the electric lighting system will never be dimmed below an acceptable level.

A combination of approaches may be required to achieve the best sensitivity setting of a photosensor-controlled system in a given space.

The installer should make sure that the lighting system produces adequate illumination on all the work surfaces in a photosensor-controlled space, especially if the photosensor controls more than one ballast. Luminance ratios between windows and room surfaces should be acceptable to occupants (IESNA 1993), so it is advisable to involve them at this point in the process.

Anecdotal evidence suggests that improperly commissioned photosensor-controlled systems may cause occupants to be dissatisfied, which may lead them to disable the system, negating potential energy savings.

As an added note, the installer should take care not to allow shadows to obscure the photosensor or luminaires during sensitivity adjustments. However, since most sensitivity controls are located on the photosensor housing, avoiding blocking or casting shadows on it during installation can be difficult or impossible. Often, the installer must make repeated trips up and down a ladder, adjusting the sensitivity, walking outside the photosensor's view, and checking the resulting illuminance. Anecdotal evidence also suggests that installers may eventually respond to this exercise by setting the photosensor to its minimum sensitivity. NLPIP tested one product that allowed these adjustments to be made from a wall switch (see Table 2 on p. 19).

NLPIP recommends setting the speed at which the photosensor responds to light changes to a relatively slow setting (longer than 1 minute to traverse the full dimming range), if it is adjustable. This setting should reduce occupant complaints about fluctuating light levels, but at some cost to energy savings.

### Target Illuminance for Threshold-Response Photosensors

When designing a lighting installation that includes a threshold-response photosensor, the specifier must set the target photosensor illuminance carefully because increases in photosensor illuminance correspond equally to decreases in electric light. If the target is too low, even small contributions to photosensor illuminance from daylight may cause the photosensor to send a signal to the ballast to dim the electric lighting system, and the electric lighting system may dim rapidly to its minimum light output and remain there for much of the day. Although energy savings will be maximized, the low light output of the electric lighting system may result in high luminance contrast between windows and room surfaces. High contrast between the windows and the room surfaces can cause occupants to perceive spaces as gloomy, even though task illuminance is adequate.

If the target is too high, the daylight may never contribute sufficient illuminance to cause the photosensor to send a dimming signal to the ballast. In such a case, no energy savings will be achieved.

Finding the appropriate target illuminance in a daylight application is difficult, particularly in spaces with windows. The unit-for-unit response of threshold-response photosensors to daylight illuminance means that the range of interior illuminances from daylight vastly exceeds the photosensor's response range.

## Lumen Maintenance Applications

Threshold-response photosensors can be useful for compensating for lamp lumen depreciation (LLD) and luminaire dirt depreciation (LDD) in applications without daylight. LLD is the phenomenon whereby the light output of a fluorescent lamp decreases gradually (typically by approximately 10%) over the life of the lamp. LDD is caused by dirt that collects on the surfaces of lamps and luminaires and can decrease the total output of the lighting system by an additional 5–20%, depending on the luminaire type, the application, and the intervals between cleanings (IESNA 1993). Luminaires in dirtier areas or that are infrequently cleaned will experience greater LDD.

Because of these factors, lighting specifiers typically design lighting systems to provide higher initial task illuminances than the design level. A threshold-response photosensor system in such an application could be set to maintain a constant illuminance corresponding to the design illuminance. Initially, the system would be designed to exceed the design illuminance but would be dimmed by the photosensor to provide the design level. Later, as LLD and LDD reduce the maximum light output of the electric lighting system, the photosensor would adjust its dimming signal to maintain the design illuminance.

Threshold-response photosensors, which compensate for each unit of illuminance gained (or lost) on a unit-for-unit basis, will provide significantly higher energy savings than continuous-response photosensors in lumen maintenance applications. Furthermore, since the rates of LLD and LDD are gradual over relatively long periods, occupants are unlikely to notice changes in illuminance produced by the photosensor-controlled system.

## Economics

**Initial cost.** NLPIP acquired photosensors for testing, either directly from manufacturers or from Albany, New York, area distributors. Prices ranged from $12 to $120 each. Based on 50 units, the unit cost is generally between $50 and $59. Costs may vary depending on shipping and other variables.

**Variability of reported energy savings.** The energy savings realized by using a photosensor to control a lighting system are influenced by many variables, including the following:

- the actual photosensor-to-task illuminance ratio,
- reflectances of surfaces within a space,
- changes in the geometric relationships between the photosensor, the daylight sources (windows or skylights), the luminaires, and the task areas,
- the adjustments to the photosensor,
- the use of window shading devices.

Wide ranges in claimed energy savings, from 7% to 52% (Rea and Maniccia 1994), have been reported. Generally the lower end of the range represents the effect of photosensors as the only control. The higher end of the range generally represents a photosensor combined with another control strategy such as manual dimming, automatic switching, or occupancy sensors used with energy-efficient luminaires.

**Predicting energy savings using response functions for daylight applications.** To predict the performance of a photosensor-controlled system, the specifier must have the response functions of the photosensor and the ballast and understand the range of possible ceiling and task illuminances from daylight for the particular space and photosensor location (see sidebar "Predicting Daylight in Spaces" on p. 4 for a discussion of daylight prediction). With an understanding of the application (daylighting or lumen maintenance), the specifier can determine the photosensor illuminances at which dimming will start and stop as well as the rate of dimming.

NLPIP acknowledges that many issues complicate these estimates. For instance, it may be difficult or even impossible for a specifier to accurately estimate illuminances from daylight because of occupant preferences for open or closed blinds, which may change by season and according to weather or because of changing office layouts or tasks.

Continuous-response photosensors are more likely than threshold-response photosensors to be made to work in daylighting applications with windows. The response functions of the threshold-response photosensors allow for gradual increases in total illuminance with increasing amounts of daylight through windows. This seems to limit contrast ratios between the window and room surfaces. However, the large variations in spaces and occupant preferences indicate that a great deal of site work may be required to get satisfactory performance and that estimates of energy savings may prove inaccurate, and probably lower than expected.

## Alternative Approaches

### On-Off Switching Photosensors

On-off switching photosensors are a less expensive alternative to dimming photosensors. These photosensors do not require dimming electronic ballasts; they simply turn lights off when a target photosensor illuminance is detected. However, occupants may object to the abrupt changes caused by this control scheme (Boyce 1984) and may override the system or tape over the photosensor if manual control is not available. Selective control of groups of luminaires to provide multi-step switching levels may be appropriate in some cases.

### Manual Dimming

Manual dimming controls should also be considered. Occupants can manually dim lights when daylight is available, which may increase their satisfaction with the lighting system.

In a recent study of lighting controls in private offices, manual controls, which are easier to install and adjust than photosensors, saved at least as much energy as photosensor controls in single-person offices with daylight (DiLouie 1996).

## NLPIP Performance Evaluations

NLPIP identified manufacturers of photosensors and requested that they submit product literature and data. Seven manufacturers responded, and NLPIP tested one photosensor from each manufacturer. Of the seven photosensors, two were threshold-response and five were continuous-response types. One sample of each photosensor was tested. Testing was conducted at the Lighting Research Center's laboratory in Watervliet, New York. NLPIP measured photosensor response at minimum and maximum sensitivity settings.

### Testing Methods

NLPIP used an adjustable luminance standard apparatus (Photo Research model number LRS-450), consisting of a 6-inch (in.) (15 cm) diameter integrating sphere with a 2 in. (5 cm) aperture. NLPIP positioned each photosensor in front of the aperture in the sphere. A BG14 Schott glass filter was placed between the aperture and the photosensor. The resulting filtered illuminance had a correlated color temperature (CCT) of 6000 K. NLPIP varied illuminance at the photocell from 0 to approximately 10,000 lx, while keeping CCT constant. The photosensors were shielded from all other light sources.

Six of the photosensors were tested using the Advance Mark VII ballast. The Lutron photosensor was tested using the Lutron microwave lighting controller to interface with the Mark VII ballast. The ETTA photosensor was tested twice using the ETTA EC2S-120A8D dimming electronic ballast. The two tests produced identical results.

For each test, NLPIP varied photosensor illuminance, waited for the photosensor-control voltage to stabilize, then recorded both the voltage and the illuminance. NLPIP varied changes in illuminance to map the photosensor response at the most sensitive parts of the light-response range. NLPIP did not test photosensors controlling multiple ballasts.

NLPIP tested all the photosensors by increasing and decreasing illuminance on the photosensor. The results were used to determine whether the photosensors responded consistently to increasing and decreasing illuminance.

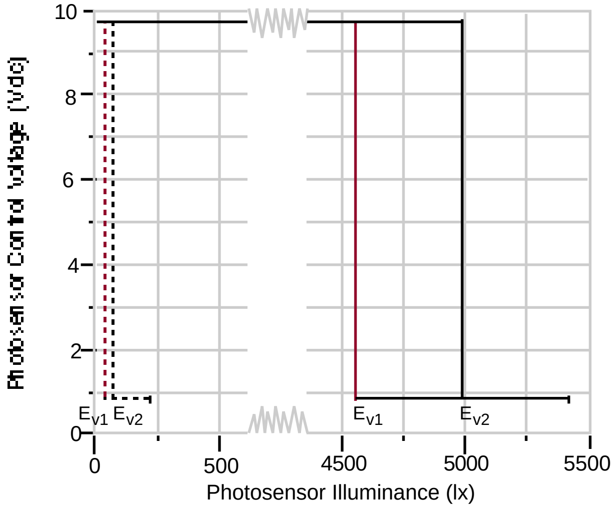
## Results

**Threshold-response photosensors.** NLPIP evaluated two threshold-response photosensors for this report. Both manufacturers recommend locating their photosensors 6–8 ft (1.8–2.4 m) from the windows, and both state that the photosensor should only detect reflected light from luminaires and windows; no direct light from these sources should illuminate the photosensor. Both of these products have restricted and apparently symmetrical downward fields-of-view, which helps to avoid direct light. Both manufacturers also recommend making initial adjustments after installation with no daylight present. The sensitivity adjustment on both units is difficult to access without affecting the amount of light incident on the photosensor.

Figures 8 and 9 show response functions for these two products at their minimum and maximum sensitivity settings. The primary difference between these products in terms of their response functions is the total range of response: the PLC/Multipoint unit responded to illuminances up to 5000 lx, while the Watt Stopper unit responded only up to 850 lx. NLPIP does not believe that this difference is important for applications with task-to-ceiling illuminance ratios of 5:1, since either product provides for setting a range of target task illuminances from almost 0 to more than 4000 lx. However, for applications with ratios that are much less than 5:1, a limited response range may add to the difficulty of finding a ceiling location that will provide good correspondence between photosensor illuminance and desired task illuminance.

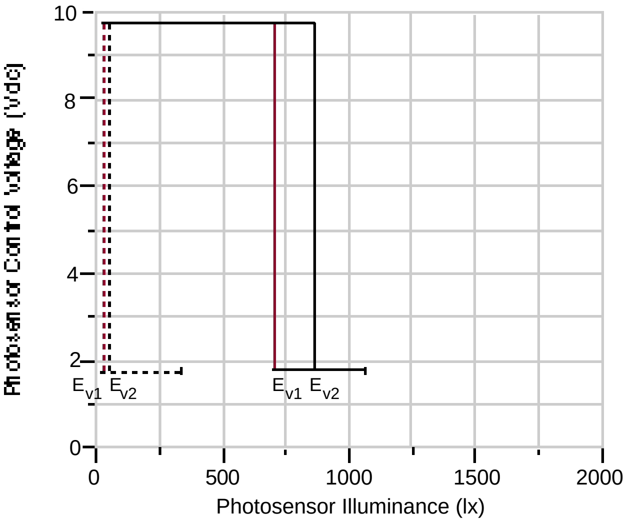
Both threshold-response photosensors responded differently to increasing and decreasing photosensor illuminance. NLPIP believes that the threshold photosensors default to a reset value ($E_{v1}$) when the control voltage nears 0, effectively turning off the circuit.

**Figure 8. Response Functions for PLC MULTIPOINT EDS/AB Photosensor**



Response functions at the maximum (broken lines) and minimum (solid lines) sensitivity settings of the PLC MULTIPOINT photosensor, as tested by NLPIP. NLPIP measured and recorded data at individual points until the photosensor began to respond. NLPIP then recorded the voltage at which the photosensor stabilized.

**Figure 9. Response Functions for Watt Stopper Lightsaver Photosensor**

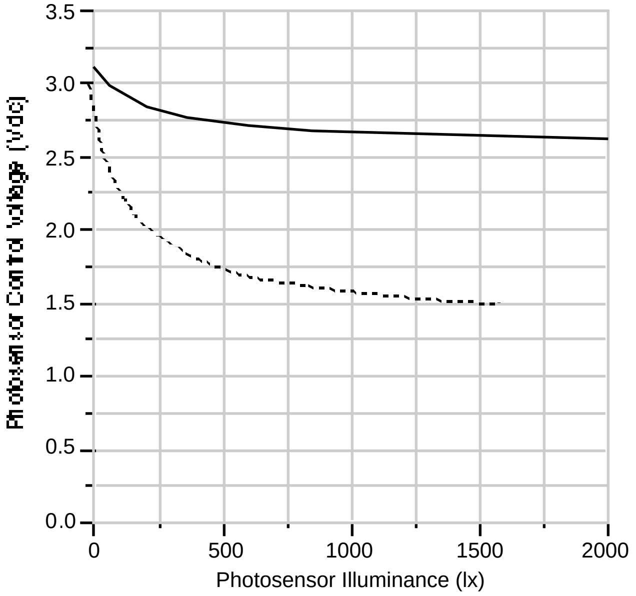


Response functions at the maximum (broken lines) and minimum (solid lines) sensitivity settings of the Watt Stopper photosensor, as tested by NLPIP. NLPIPmeasured and recorded data at individual points until the photosensor began to respond. NLPIP then recorded the voltage at which the photosensor stabilized.

### Continuous-Response Photosensors

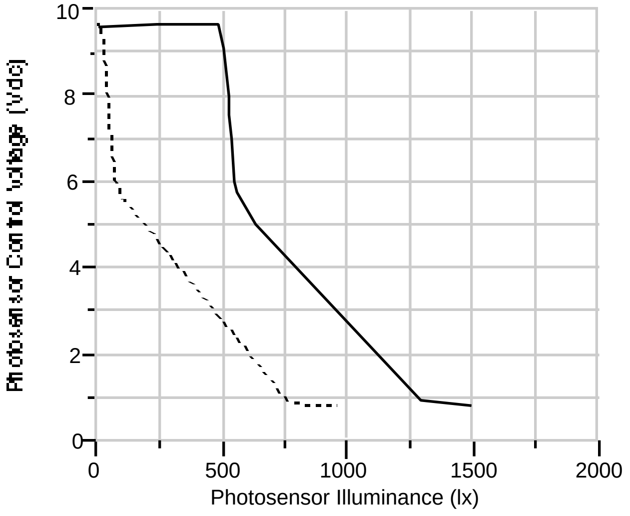
Figures 10–14 show response functions (maximum and minimum sensitivity) for five continuous-response photosensors evaluated by NLPIP, which differed in important ways. NLPIP found that all five responded consistently to increasing and decreasing photosensor illuminance.

**Figure 10. Response Functions for ETTA FO-1 Photosensor**



Response functions at the maximum (---) and minimum (–) sensitivity settings of the ETTA photosensor, as tested by NLPIP.

**Figure 11. Response Functions for Honeywell Ambient Light Sensor Photosensor**



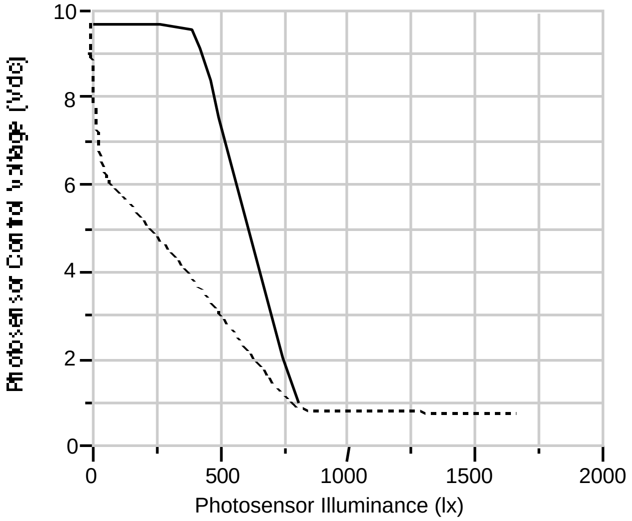
Response functions at the maximum (---) and minimum (–) sensitivity settings of the Honeywell photosensor, as tested by NLPIP.

According to ETTA's product literature, the ETTA photosensor is to be used as part of a system that provides independent control of each luminaire; therefore, one photosensor must be installed for each luminaire. With these products, a prism directs light into a fiber optic cable and through that to the photocell which is at the other end of the cable. The sensitivity adjustment is a trim pot located on the circuitry housing. This housing should be installed at the end of the luminaire nearest the ballast about 12 inches from the prism. The manufacturer provides specific instructions for orienting the prisms. The response functions measured by NLPIP for the ETTA product are shown in Figure 10, which shows that for this product changing sensitivity changes the illuminance at which the photosensor stops dimming. At the minimum setting, the photosensor and ballast dim the lighting system only to approximately 85% of full light output even at photosensor illuminances greater than 2000 lx. At the maximum sensitivity the photosensor-controlled system dims to approximately 15% of full light output.

The Honeywell and the UNENCO products both provide a relatively wide angle, symmetrical field-of-view. Both manufacturers emphasize that the photosensors must detect both daylight and electric light, without receiving direct light from any source. Consequently, both provide a means for blocking direct views of windows and luminaires. The manufacturers recommend that initial adjustments be made at night. The UNENCO photosensor uses a seven-position dip-switch arrangement for the initial adjustments, then a trim pot for fine tuning; Honeywell offers a trim pot for making adjustments. In both products, the screw adjustment is located on the body of the photosensor, making it difficult to adjust sensitivity without blocking the photosensor in the process.

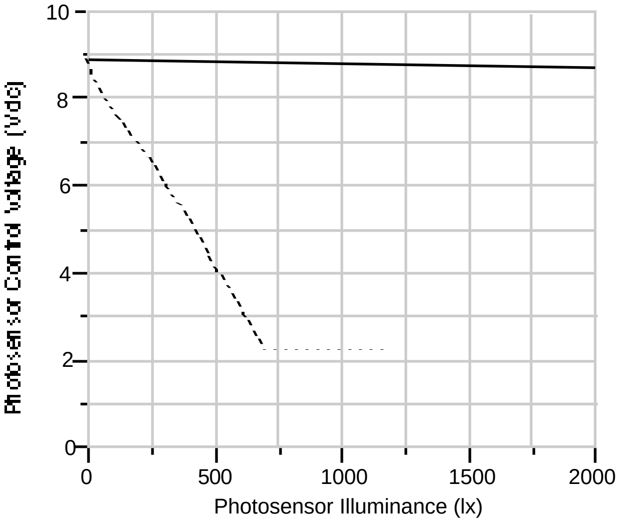
Figure 11 shows the response functions of the Honeywell product. This figure shows that the slope of response and the total dimming range is constant for this product regardless of the sensitivity setting; only the illuminance at which the photosensor begins to dim the lights ($E_{v1}$ increases from approximately 0 to 500 lx) and the illuminance at which the lights have been

**Figure 12. Response Functions for UNENCO Daylight Tracker Photosensor**



Response functions at maximum (---) and minimum (–) sensitivity settings of the UNENCO photosensor, as tested by NLPIP.

**Figure 13. Response Functions for Lutron microPS Photosensor**



Response functions at maximum (---) and minimum (–) sensitivity settings of the Lutron photosensor, as tested by NLPIP.

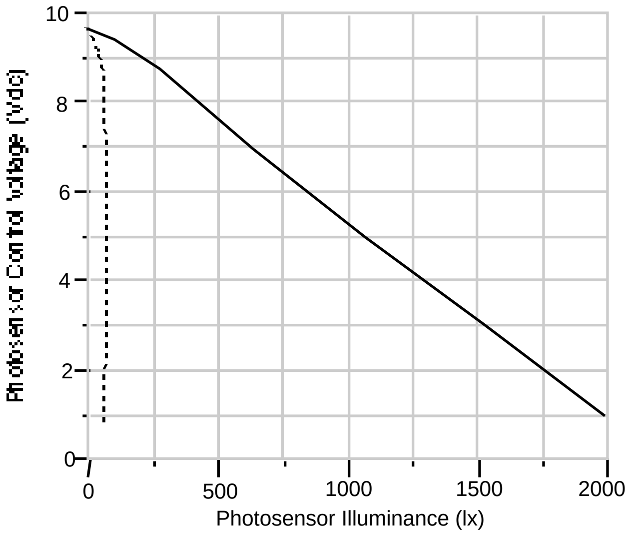
## Table 1. Interpreting the Continuous-Response Functions

| | | | Photosensor Response | | | | System Response | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Maximum Sensitivity | | Minimum Sensitivity | | Maximum Sensitivity | | | Minimum Sensitivity | | |
| Manufacturer | Trade Name | Catalog Number | $E_{v1}$ (lx) | $E_{v2}$ (lx) | $E_{v1}$ (lx) | $E_{v2}$ (lx) | $E_{d1}$ (lx) | $E_{d2}$ (lx) | Minimum Light Output (%) | $E_{d1}$ (lx) | $E_{d2}$ (lx) | Minimum Light Output (%) |
| ETTA International | FO-1 | NS | 0 | 1600 | 0 | >2000 | 0 | 1600 | 15% | 150 | >2000 | 93%[a] |
| Honeywell | Ambient Light Sensor | EL7365A1014 | 0 | 750 | 500 | 1300 | 50 | 700 | 18% | 500 | 1200 | 18% |
| Lutron | microPS | MW-PS-WH | 0 | 700 | 0 | >2000 | 50 | 700 | 25% | >2000 | >2000 | 100%[a] |
| Sensor Switch, Inc. | Sensor Switch | CM-ALC | 0 | 100 | 0 | >2000 | 70 | 75 | 18% | 350 | 1900 | 18% |
| UNENCO, Inc. | Daylight Tracker | DT-D | 0 | 800 | 350 | 800 | 0 | 700 | 18% | 450 | 800 | 18% |

[a] Value is light output at photosensor illuminance of 2000 lx.

The specifier can use the photosensor response curves to determine the photosensor illuminance at which the photosensor starts to send a dimming signal to the ballast ($E_{v1}$) and the photosensor illuminance at which the photosensor stops sending a dimming signal to the ballast ($E_{v2}$). The specifier can use the ballast-response function to determine the photosensor illuminance at which the photosensor-controlled system begins to dim ($E_{d1}$) and the photosensor illuminance at which the photosensor-controlled system stops dimming ($E_{d2}$) (see p. 7). The table shows $E_{v1}$, $E_{v2}$, $E_{d1}$, and $E_{d2}$ for five continuous-response photosensors and the minimum light output for each photosensor-controlled system at both maximum and minimum sensitivities. System response is calculated assuming an Advance Mark VII Ballast for each photosensor, except the ETTA FO-1, which requires an ETTA ballast.

**Figure 14. Response Functions for Sensor Switch Photosensor**



Response functions at the maximum (---) and minimum (–) sensitivity settings of the Sensor Switch photosensor, as tested by NLPIP.

dimmed to their lowest level changes ($E_{v2}$ increases from approximately 750 to 1300 lx). For the UNENCO product (Figure 12 on p. 15), the illuminance at which the photosensor reduces its control voltage varies as the sensitivity setting is changed ($E_{v1}$ increases from approximately 0 to 350 lx), as does the slope of response, but the illuminance at which the lights have been dimmed to their lowest level is unaffected by sensitivity adjustments ($E_{v2}$ = 800 lx).

The Lutron photosensor works as part of a central control system that can have photosensor input. This product has an asymmetrical field-of-view, and the manufacturer recommends that it be oriented to receive a greater amount of light from near the windows (without a direct view of the windows) than from the interior portions of the space. In this way, this product approximates the operation of an open-loop system, since it emphasizes the daylight contribution more than the electric light contribution. Since it is part of a central system, the Lutron photosensor is adjusted from a wall-mounted control, providing the advantage of easier commissioning and adjustment.

Figure 13 on p. 15 shows the response functions for the Lutron photosensor. At its minimum sensitivity setting, this product reduced its control voltage only slightly over the range tested by NLPIP. At maximum sensitivity, the product reduces its control voltage immediately upon detecting illuminance and signals full dimming at 700 lx ($E_{v2}$).

The Sensor Switch product integrates an occupancy sensor and a photosensor. In this product, the photocell is located in the side of the housing, so that the field-of-view is very directional. For installation, the manufacturer recommends rotating the product until task illuminance is close to the desired value, then using the potentiometer for fine adjustment. The potentiometer adjustment is located on the opposite side of the housing from the photocell, so the installer may be able to avoid blocking the photosensor while making the adjustment. Nevertheless, the adjustment still must be made at the photosensor location, which will require a ladder.

Figure 14 shows the Sensor Switch product's response functions, showing that both the slope of response and the illuminance at which the lights are fully dimmed varies as the sensitivity setting is changed ($E_{v1}$ remains at 0). At the maximum sensitivity setting, the lights almost immediately dim to their minimum level, but at minimum sensitivity photosensor control voltage decreases at a slower rate, ($E_{v2}$ increases from approximately 0 to 2000 lx).

Table 1 on p. 15 presents the illuminance values at each end of the photosensor-response range at both minimum and maximum sensitivity settings, as determined from the photosensor-response functions (Figures 10–14) of the five continuous-response photosensors.

The table also shows the minimum light output produced by each photosensor at both sensitivity settings when operated with the Advance Mark VII or ETTA ballast, as indicated. These results can be adjusted for other ballasts by using the photosensor-control voltage from the photosensor-response functions and the appropriate ballast-response function (p. 6).

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# Data Table Terms and Definitions

## Definitions

The following data tables present product information supplied by manufacturers. Most of the performance characteristics listed in this table are discussed previously in this report, but the column headings are defined here.

**Compatible ballasts.** An abbreviated list of common ballasts that will provide the necessary circuitry for a photosensor to operate correctly. Other ballasts may be compatible with these photosensors; contact the photosensor manufacturer for details.

**Maximum electronic ballasts/sensor.** The number of dimming electronic ballasts that can be controlled by a single sensor.

**Price/single sensor.** The unit cost for a photosensor, as reported by the manufacturers. Cost may vary for different quantities and amount of shipping and handling.

**Options for time response adjustment.** A setting to regulate the time it takes to go from dim to bright or bright to dim. There are usually two settings, fast and slow.

**Sensitivity adjustment.** A trim potentiometer (trim pot) or a set of dip switches used to refine the response function of a photosensor. Some photosensors include a remote trim pot which allows for adjustment at a distance from the photosensor housing.

## Table 2. Manufacturer-Supplied Information

| Manufacturer | Trade Name | Catalog Number | Price/ Single Sensor ($) | Maximum Electronic Ballasts/ Sensor | Compatible Ballasts[a] | Warranty (yrs) | Sensitivity Adjustment | Options for Time Response Adjustment (sec) |
|---|---|---|---|---|---|---|---|---|
| **Threshold Response** | | | | | | | | |
| PLC MULTIPOINT<br>206-353-7552<br>206-353-3353 (fax) | EDS/AB | EDS/AB | 70 | 80 | 1, 2, 4 | 2 | trim pot | 3 or 8 |
| The Watt Stopper<br>408-988-5331<br>408-988-5373 (fax) | Lightsaver | LS-30 | 65 | 100 | 1, 2 | 5 | trim pot | 3 or 8 |
| **Continuous Response** | | | | | | | | |
| ETTA International<br>303-499-7084<br>303-554-0341 (fax) | FO-1 | NS | 12 | 2 | ETTA[b] | NS | remote trim pot | none |
| Honeywell<br>612-951-2907<br>404-987-1002 (fax) | Ambient Light Sensor | EL7365A1014 | 74 | 50 | 1, 2 | 1 | trim pot | none |
| Lutron<br>800-523-9466<br>610-282-6314 (fax) | microPS | MW-PS-WH | 100 | 16 A[c] | 1, 3 | 1 | remote trim pot | none |
| Sensor Switch, Inc.<br>203-265-2842<br>203-269-9621 (fax) | Sensor Switch | CM-ALC | 70 | 50 | 1, 2, 3 | 5 | trim pot | none |
| UNENCO, Inc.<br>214-442-5493<br>214-442-4198 (fax) | Daylight Tracker | DT-D | 60 | 50 | 1, 2 | 5 | dip switches | none |

NS = Not Supplied

[a] Compatible Ballasts

1 = Advance Mark VII
2 = Motorola Helios
3 = Lutron Hi-Lume
4 = MagneTek Ballastar

[b] ETTA has a new model, FO-2, that is compatible with the Advance Mark VII ballast.

[c] A = amps; format as supplied by manufacturer.

NATIONAL
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# Specifier Reports

## Photosensors

Volume 6, Number 1
March 1998

Program Director: Robert Davis
Technical Writers: John Bullough and
Robert Wolsey
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Production of this report involved important contributions from many staff members at the Lighting Research Center:
A. Buddenberg conducted the early stages of this effort. A. Bierman and C. O'Rourke conducted the product testing. J. Bullough developed the figures. M. Rea provided detailed suggestions for content throughout this effort. J. Ceterski, E. Gandorf, Y. He, K. Miller, C. Hunter, Y. Ji, R. Leslie, and S. Sechrist also contributed.

Also providing assistance were J. Buttridge, Rensselaer Polytechnic Institute; T. Griffin, photographer; M. Netter, private attorney; R. Mistrick, Pennsylvania State University, who provided helpful technical comments; and S. Yetto, Design One.

The products described herein have not been tested for safety. The Lighting Research Center and Rensselaer Polytechnic Institute make no representations whatsoever with regard to safety of products, in whatever form or combination used, and the results of testing set forth for your information cannot be regarded as a representation that the products are or are not safe to use in any specific situation, or that the particular product you purchase will conform to the results found in this report.

## The National Lighting Product Information Program

The National Lighting Product Information Program (NLPIP) was established in 1990 and is administered by the Lighting Research Center at Rensselaer Polytechnic Institute. The Lighting Research Center is a nonprofit educational and research organization dedicated to the advancement of lighting knowledge.

NLPIP's mission is to rapidly provide the best information available on energy-efficient lighting products. NLPIP strives to provide complete, current, and valuable manufacturer-specific performance data in useful formats to guide lighting decisions. Priority is given to information not available now or not easily accessible from other sources.

The National Lighting Product Information Program tests lighting products according to accepted industry procedures. If procedures are not available or applicable, NLPIP develops interim tests, focusing on those performance issues that are important to the lighting specifier and end user. The program does not accept funding from manufacturers.

ISSN 1067-2451

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