2.5 Conduct exploratory investigations and analysis of operational parameters required for each of the control technologies (occupancy sensors, photosensors, dimming electronic ballasts) in common commercial and industrial applications, such as private and open offices and warehouses.

Exploratory Analysis of Operational Parameters of Controls

A convenient way of analyzing control devices is to consider a device as a system of inputs and outputs. Inputs to control devices are usually sensors and commissioning set points, and the outputs are control signals that govern the operation of the controlled equipment. Once the inputs and outputs are identified, then the operation of the control device is described by how the inputs affect the outputs. The input/output relationships can either be logical relationships, continuous functional relationships, or a combination of the two. This type of analysis is effective for both small, local control systems such as an occupancy sensor in a room, and for large, distributed control systems where the outputs of devices such as occupancy and photosensors are used as inputs to higher-level building automation control systems. In fact, communication protocols for building automation systems, such as BACnet and LonWorks, are specified in terms of inputs and outputs. This report focuses on photosensors, describing them in terms of inputs and outputs.

The information for this report was gathered from the publications cited as well as those listed in the bibliographies, and from manufacturers' web sites, conference seminars, product briefs and interviews with manufacturers.

Photosensors

Available sensor inputs:
    Illuminance (wide field of view)
    Luminance (narrow field of view)

Other inputs:
    Sensitivity (gain)
    Light level set point
    Hysteresis (dead band)

Outputs:
    On/off power relay
    Bi-level switching on/off power
    Continuous dimming level (e.g. 0-10V)

Background

The input to a photosensor is optical radiation. Loosely speaking, the input is light, but because some photosensors respond to infrared (IR) and ultraviolet (UV) radiation as well, it is necessary to make a distinction between optical radiation that is visible light and other kinds of optical radiation. The response of a photosensor to optical radiation is fully described by the *spatial response* and the *spectral response*.

The spatial response describes the sensitivity of the photosensor to incident radiation from different directions—in other words, what the photosensor "sees" at different locations. Spatial response is analogous to a luminaire intensity distribution, but describes sensitivity instead of output.

The spectral response describes the sensitivity of the photosensor to optical radiation of different wavelengths. This is important because only a small part of the optical radiation spectrum is visible. Daylight and fluorescent lighting differ substantially in spectral composition. Daylight has a comparatively uniform distribution of energy over the near-UV, visible, and near-IR regions of the spectrum. Fluorescent lamps, on the other hand, have most of their output concentrated in the region of the spectrum where visual sensitivity is high. This is one reason fluorescent lighting is so efficient. Even though the exact spectrum of daylight changes depending on weather conditions, times of the day and season, as well as being affected by surrounding buildings and foliage, these differences are small compared to the relative differences in UV and IR content between daylight and fluorescent light sources. The greater UV and IR content of daylight, combined with the broader than ideal spectral response of most photosensors, makes most photosensors much more sensitive to daylight than to light from fluorescent lamps. A greater sensitivity means that a photosensor will respond as if more daylight were present than actually exists. This can lead to problems where precise switching or dimming levels need to be realized.

Illuminance sensors (wide field of view)

The signal produced from illuminance type sensors is useful for detecting ambient light levels. A wide spatial response corresponds closely to what an illuminance meter would measure.

Advantages

The advantage of a wide spatial response is that the optical signal sensed by the photosensor is representative of the illumination on the whole workplane, or over the entire room, when the sensor is located on ceiling. The optical signal is also less affected by normal activity in the room than for a narrow response sensor.

Limitations

The difficulty with a wide spatial response is that the ceiling illuminance does not usually correspond to the workplane illuminance as the balance between daylight and electric light changes. In fact, the ratio of ceiling to workplane illuminance typically changes by a factor of five or more in offices with vertical windows as the proportions of electric light and daylight change. However this non-correspondence in illuminance levels can be largely overcome by the photosensor control algorithm and the above advantages can be realized.

Luminance sensors (narrow field of view)

Not as common as illuminance type sensors, luminance sensors detect light from a particular direction and over a small field of view. They are used to detect brightness from a distant location; for example, to detect desktop luminance from a mounting position in the ceiling.

Advantages

The narrower the photosensor's spatial response, the more closely it responds to the luminance (brightness) of the surface at which it is aimed. The luminance of a surface, in turn, is directly proportional to the illuminance falling on the surface provided that the reflectance factor of the surface is constant. Therefore, provided that the reflectance properties of the surface do not change, a narrow spatial response can effectively track illuminance changes; the narrower the response, the better the tracking for a particular location.

Limitations

The narrower the spatial response, the smaller the sensor's field of view, so what the sensor "sees" may not be representative of the whole surface or workplane. Therefore, a narrow response makes the sensor very sensitive to changes in the reflectance properties of what it is viewing. In practice, the reflectance of the workplane is not constant, but changes depending on the activities going on in the room. Examples include a dark desktop that is sometimes covered with white papers, the colors of peoples' clothing, such as a white shirt versus a dark suit, and even rearrangement of the room's furniture.

Another limitation of a narrow spatial response is increased sensitivity to mirror-like, specular reflections off shiny surfaces. Illuminance on a surface is directly proportional to luminance only for diffusely reflecting surfaces. Most surfaces in a room are diffuse, but some, like a glass table top, can reflect overhead light directly back into the photosensor's field of view causing erratic performance. Specular reflections have proportionally less effect on photosensors with a wider spatial response.

Other Photosensor Inputs

The following inputs are set during the commissioning of photosensors. Depending on the type of output (on/off or continuous dimming), as well as the type of control algorithm employed in the particular device, one or more of these inputs will be available to the user. On some photosensor products, the sensitivity and certain set points are combined into one input that controls both together according to some programmed relationship.

Sensitivity (gain)

The spatial sensitivity and the spectral sensitivity of the photosensor characterize the optical gain. Electronic gain amplifies the weak signals from the photocell to practical signal levels. These two gain mechanisms (optical and electronic) determine the sensitivity of the photosensor. Sensitivity adjustments are required for open-loop sensors where the sensitivity adjustment determines the relationship between electric light levels and the sensed signal. For photosensors that do not have a sensitivity adjustment, or those that combine sensitivity with other set-point adjustments, the sensitivity alone can always be adjusted optically by the positioning of the photosensor. While positioning the photosensor differently for different sensitivities is an option, it not very practical and it certainly is not a systematic way of commissioning photosensors.

Set-points

The signal level that must be attained before an action occurs is known as a set-point. For photosensors, set-points determine the signal level at which lights will be switched, or at what light level dimming will start and/or end. The type and number of set-points that are employed in a photosensor depends on the type of control algorithm used. Simple, open-loop photosensors that switch lights on and off only need to have one set- point that determines the level at which the lights will switch. Often, two set-points are used, however, to give the switch some hysteresis, or a deadband, whereby the light switches on at a higher signal level than that which turns them off. This is to prevent unstable frequent switching when signal levels are near the set-point.

More complicated closed-loop control algorithms may employ several set-points, which might be measurements that determine sensor and task illuminance ratios used in the algorithm to determine the electric light level.

Photosensor Outputs

Photosensors fall into two main categories depending on the output. The most familiar and the most prevalent use of photosensor control is on/off control output which is used to turn lights on, or off, based on the light level detected. Far less prevalent is the continuous level output photosensor, which is used with dimming systems to dim the electric lighting level based on some dimming function or control algorithm.

The light-sensing element within a photosensor might be a photodiode, a phototransistor, or a photo-resistive cell. It is important to make a distinction between this, the photocell, and a complete photosensor device that includes additional circuitry to produce the desired output signal(s).

Photosensors for on/off control

Photosensors for on/off control work most effectively in applications where a large difference in light level exists between the on condition and the off condition. Photosensors for outdoor street lighting is such an example. The set-point at which the output is switched does not have to be precise due to the large difference in illumination levels between night and day. Photo-resistive sensing elements are commonly used in this application because of low cost and relatively simple circuit design. Photo-resistive sensors do not have a linear response with light, part-to-part consistency is poor, and they have a large temperature dependency. Taken together, these characteristics make precise action at specified set-points difficult. A further disadvantage of photo-resistive devices is that many common types use cadmium, a heavy metal that is considered harmful to the environment.

When switching at precise light levels is needed, silicon photodiode detectors are commonly used. Used in conjunction with an amplifier circuit, these devices offer very predictable and linear output that is stable with time and temperature. This allows switching at precise set-point levels. These types of detectors are useful for indoor applications where the overall range of acceptable light levels is orders of magnitude less than that encountered outdoors.

The output from an on/off sensor is a two-state binary signal. Such a signal can be connected directly to a power relay to switch lights on and off, or used as a low level logic-level signal that is connected to some other lighting controller.

Photosensors for dimming

Photosensor control for dimming is divided into two main types: open loop and closed loop:

Open loop - the photosensor does not respond to, or “see” the electric light that it controls. An example of an open-loop system is a photosensor mounted on the outside of a building that controls the electric light level inside the building. In such a case the photosensor is exposed only to daylight. The electric light level is determined from the daylight signal alone. In the case of on/off control, such systems can be designed to simply turn electric lights off when outside daylight reaches a predetermined level. In the case of a dimming system, a signal proportional to the outside daylight instructs the system to dim the electric light by an amount proportional to the amount of available daylight sensed by the photosensor. No feedback control is used for an open loop system.

The drawback of open-loop feedback control is that the system cannot compensate or correct for any changes in the light distribution that affects the constant of proportionality between interior light levels and outside daylight levels. For example, the system will not respond to the use of window blinds, so if the occupant draws the blinds to block direct sunlight, the system will not increase the electric light to compensate for the decreased daylight levels inside the room.

Closed loop - the photosensor senses and responds to the electric light that it controls. An example of a closed-loop system is a photosensor mounted on the ceiling of the room where the electric lighting is being controlled. In this case the photosensor is exposed to both the daylight and the electric light in the room. The sensing of the electric light forms a feedback loop.

Closed-loop systems use negative feedback to respond to changing conditions. Negative feedback is a means of error correcting or compensating whereby an increase in an input signal level causes a decrease in the output signal. Conversely, a decrease in input signal causes an increase in output signal. This is the desired action of photosensor control; an increase in the amount of light in the room causes a decrease in the electric light intensity, and a decrease of daylight causes an increase of electric light. The overall feedback loop of a photosensor system must be negative for proper operation. The control algorithm characterizes the negative feedback of a photosensor.

The amount of feedback can vary for different systems and different locations of the system components. In systems where the photosensor is mounted near a window, the feedback is proportionally less than in systems where the photosensor is mounted deep within the room. This is because near the window the proportion of daylight is greater than electric light and the photosensor “sees” proportionally less of the electric light that it is controlling. The opposite is true for a photosensor mounted deep within a room. The amount of feedback is also governed by room geometry and surface reflectances. A room with light-colored finishes will have a greater feedback gain than a room with dark-colored finishes. The gain caused by room geometry and surface reflectances combines with the optical and electrical gain of the photosensor to determine the actual signal level received by the photosensor.

***Effect of photosensor output on light level*:** For dimming systems, the dimming ballast controls the electric light level based on input from the photosensor. The amount of dimming as a function of input signal is characterized by the dimming response function. For many dimming ballasts, the dimming response function is linear, meaning that it reduces the electric light level in proportion to the input signal. However, the active input dimming range is usually less than the specified range of input control voltage. For example, for a ballast with an input signal specification of zero to 10 V, dimming may actually take place over a more limited range from about 1.5 V (minimum light output) to 8.5 V (maximum light output).

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