APPLICATION NOTE

An In-Depth Examination of an Energy Efficiency Technology

Automated On/Off Controls for Lighting

Summary

Automatic on/off controls are either programmed or event-initiated to turn off lights when a space is unoccupied, or occupied by workers performing tasks that do not require full light levels (e.g. cleaning after normal operation hours). For off-hours needs, the systems require overrides so lighting control can be regained by building users.

The wide variety of simple and complex technologies for automatic lighting on/off control give the designer or retrofitter many options, including:

- **Door Jamb Controls:** Spring-loaded on/off switches located in a door jamb.
- **Time-Based Controls:** Elapsed-time switches and clock switches that turn loads on and/or off at predetermined times.
- **Photosensors:** Switching devices that sense natural light and turn lights on when light levels fall below a defined point.
- **Occupancy Sensors:** Switching devices that respond to the presence and absence of people in their field of view.
- **Radio-Controlled High Pressure Sodium (HPS) Ballast System:** Switches that turn lights on and off with radio-frequency signals
- **Microprocessor-Based Centralized Load Programmers:** Time-oriented, programmable controls that

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operate a number of loads from a central source.

How This Technology Saves Energy

Automatic on/off controls are either programmed or event-initiated. They save lighting energy by effectively managing on and off times. Automatic controls turn off lights when a building space is either unoccupied or occupied by workers performing tasks that do not require full light levels, such as cleaning after normal hours. For off-hours needs, these systems have optional overrides so that lighting control can be regained by building users.

Figure 1 shows a typical electronic processor based time-scheduling system with the following components:

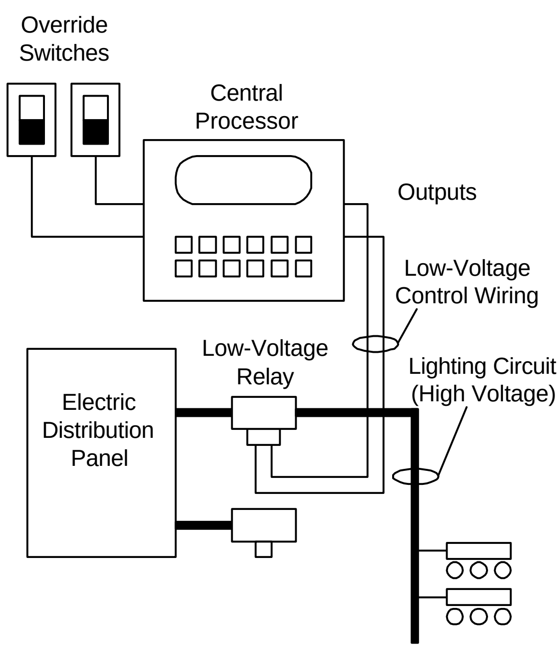

Figure 1: Time-Scheduling System Components (Source: CEC)

- **Central Processor:** Unit that independently controls a few to several thousand output channels. Lights to be controlled as a group are assigned to a single output channel. It is programmed by maintenance personnel to schedule on and off loads.

- **Relays:** Electrical switching devices, wired to the controlled lighting zones and controlled from the central processor.

- **Overrides:** User-activated switches to operate portions of the lighting system during periods of unscheduled occupancy. Often located near the lights that they affect. Telephone override systems provide the convenience of remote switching.

- **Control Wiring (generally low voltage):** Links all components in the system. Can be dedicated wiring or power line carrier.

Some vendors provide time-scheduling systems with all the above components and all the engineering, programming, and commissioning necessary for a workable system. These are known as "turnkey" systems. However, systems are often comprised of separate components from different manufacturers.

Types of Energy Efficiency Measures

A wide variety of simple and complex technologies provide the designer or retrofitter many options, several of which are described below.

Door Jamb Controls

These are spring-loaded on/off switches located in a door jamb, used primarily in closets to turn lights on when the door is open and off when it is closed. They may also be used for walk-in freezers in restaurants and supermarkets.

Time-Based Controls

Automatic time switches turn loads on and/or off at predetermined times. Used for years to control outdoor lighting, but not confined to outdoors. The two basic configurations are elapsed-time switches and clock switches.

Elapsed-Time Switches

These typically fit into or over a standard wall switch box and allow occupants to turn lights on for a period set either by the occupant or the installer. Lights go off at the end of the period, unless the time cycle has been restarted by the occupant (or manually turned off sooner). A relatively simple, low-cost ($15-$25) measure, they are an economical way to cut unnecessary lighting usage, especially where fixed-duration events occur.

The two basic types are mechanical and electronic. Mechanical units are little more than spring-wound kitchen timers connected to a small relay. Maximum settings of 20 minutes are common, though timers with periods up to 12 hours or more are also available. These simple devices can fail fairly fast when used in high traffic areas. A mechanical elapsed-time switch is illustrated in Figure 2.

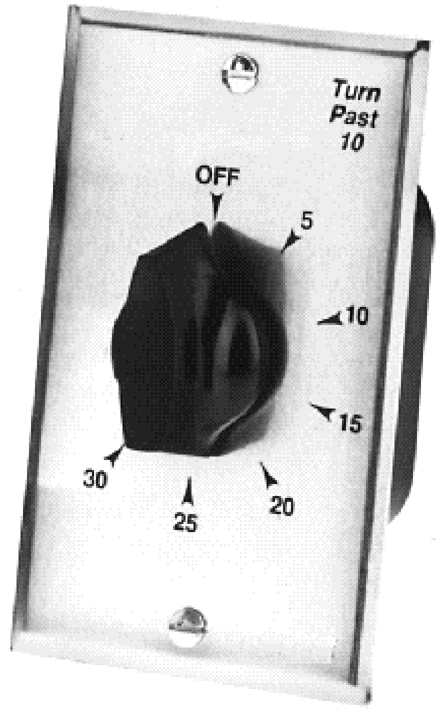

Figure 2: Mechanical Elapsed-Time Switch (Source: E-Source)

Electronic elapsed-time switches also provide a defined maximum "on" time, after which the lights go off automatically. The interval is preset by the installer using a hidden screw. Since they look like conventional toggle switches, the occupants are unaware of the electronic device's existence (when set properly), greatly reducing vandalism. These timers are an easy and economical way to comply with energy codes calling for automatic lighting controls; they cost about $30 each in quantity.

Clock Switches

Where occupancy follows a well-defined pattern (such as in merchandising), clock switches may be the most cost-effective choice. Clock switches turn lights on and off at preset times regardless of occupancy. Typically located in the closets which contain the lighting power panels, they cost relatively little to install, are generally invulnerable to vandalism or user maladjustment, and can control large loads with single sets of contactors. They can be mechanical devices employing motors, springs, and relays, or sophisticated electronic systems executing several time schedules simultaneously. Mechanical time clocks are more susceptible to user maladjustment and lower cost models can be less accurate. Typical unit prices range from $40 to over $500.

A mechanical clock switch is illustrated in Figure 3.

Clock switch controls come in many varieties. The 24-hour switch is the most basic, usually capable of turning a load on or off several times per day. Indoors it could turn lighting on at 8 a.m., off at noon, on again at 1 p.m. and off again at 6 p.m. Using two 24-hour switches, selected fixtures could be turned off and on at different times or, through ***split ballasting***[1], different lighting levels could be obtained at different times. A seven-day time switch affords the same daily selections, for a week at a time. Separate schedules can be defined for each day of the week.

Figure 3: Mechanical Clock Switch
(Source: E-Source)

Some time switches have an astronomical feature that automatically compensates for changing ambient light during the year. This reduces the amount of manual adjustment needed, and by making adjustments in a timely fashion, minimizes unnecessary use.

Most time switches are available with a back-up in case of blackout or brownout. Some are spring-wound, others use batteries. Both 24-hour and seven-day time switches are available with a day-skipping feature to keep selected loads off during holidays and weekends.

For most time-scheduling systems is to be effective, they should have a good override system. A well-designed system will allow a lighting schedule that closely follows anticipated occupancy and building operators will be assured that, in most cases, the needs of individuals for lights during programmed off times will be met.

Photosensors

Photosensors respond to changes in light. They turn on lights when the ambient light level falls below a preset level and turns them off when that level is exceeded. Like time switches, they

[1] Bold italicized words are defined in the section titled "Definition of Key Terms."

have been used for many years to control outdoor lighting. They can respond to overcast conditions during the day and provide safety and security when more lighting is needed unexpectedly. Some have time-delay devices to help prevent rapid off-on cycling on partly cloudy days.

Because of their energy-saving potential, photosensors are being used more frequently for indoor applications. Some systems rely on one or several strategically placed photosensors to operate all ***luminaires***. Others use one photosensor per fixture, aimed directly below the fixture or over the most critical area requiring illumination. Typical single-circuit photocell controls cost about $50.

Unless a space has been designed to use natural light, the daylight use of photocells is limited to fixtures within about 12 feet of outside windows; beyond that point relative darkness may result for some occupants. Photocells are usually connected to a relay or ***dimming system*** that controls a bank or pattern of light fixtures. The Dimming Controls for Lighting Application Note provides more information on this use of photocells.

Occupancy Sensors

Occupancy sensors respond to the presence and absence of movement (usually from people) in their field of view. A system consists of a motion detector, an electronic control unit and a controllable switch (relay). The motion detector senses motion and sends a signal to close or open the relay that controls power to the lights.

Passive infrared sensors (PIR), the most common type, "see" infrared heat energy, usually emitted by people. Triggering occurs when a change in infrared levels is detected, such as when a warm object moves in or out of view of one of the sensor's "eyes." They are strictly line-of-sight—they cannot "see" around corners, or detect a person behind an obstruction such as a partition. They are quite resistant to false triggering.

Ultrasonic sensors emit a high-frequency sound, above human and animal audibility, and listen for a change in frequency of the reflected sound. They can cover larger volumes than PIR sensors and are noticeably more sensitive, but also more prone to false triggering. Air motion from a person passing an open doorway, or the on/off cycling of an HVAC system, may trigger a poorly located or adjusted sensor.

Hybrid sensors are offered by several manufacturers. Using infrared and ultrasonic technologies simultaneously, they are both sensitive and resistant to false triggering.

There are two basic mounting configurations for occupancy sensors. Ceiling-mounted sensors have an independent controller and/or power supply. They may be mounted high on a wall or in a corner, as well as on the ceiling. Wallbox sensors are primarily designed as retrofit replacements for common wall switches. Ceiling-mounted and wall-mounted units are illustrated in Figures 4 and 5, respectively. Both ceiling-mounted and wallbox sensors are available with either PIR or ultrasonic sensing units. They can be combined to cover an odd-shaped or large room. Most ceiling-mounted sensors cost be-

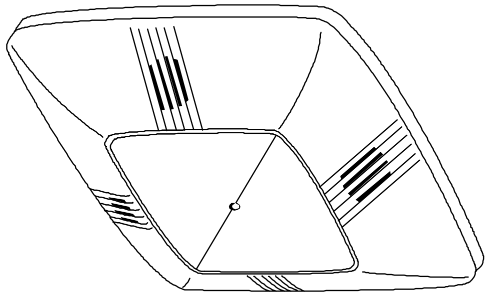

Figure 4: Example Ceiling-Mounted Occupancy Sensor

tween $50 and $120, plus installation. Wall-mounted units are less expensive at $30 to $90 per sensor. The Occupancy Controls for Lighting Application Note provides more information on use of these devices.

Radio-Controlled HPS Ballast System

A radio-controlled HPS ballast system—available for 400-watt high-pressure sodium industrial lighting—switches lights on and off with radio-frequency signals.

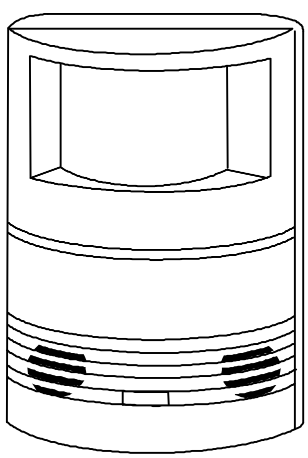

Figure 5: Example Wall-Mounted Occupancy Sensor

Its chief components are a master control, and receivers mounted in the ballast housings of controlled fixtures. The master control has an operator keyboard, data displays, a microprocessor (including memory) and radio transmitter. Each ballast system includes an electronic ballast, microprocessor and radio receiver with a unique digital address.

A lighting control scheme is entered by keyboard into the master control's memory; radio signals are then transmitted to receivers at preestablished times. Receivers accept signals and transmit them for decoding in the microprocessor, which then adjusts the ballast to any of seven different wattages or turns it off. Very flexible, the system can help assure adequate lighting despite changing task or workstation layouts.

Microprocessor-Based Centralized Load Programmers

These time-oriented, programmable controls can operate a number of loads from a central source, scheduling on/off periods for selected loads a year at a time and allowing for changing ambient light, weekends, holidays, even leap years. Most have a duty-cycle capacity, battery backup, and an entry code to prevent tampering with the program.

The lighting control program is entered into system memory from the central controller's keyboard, which can also be used to enter manual instructions. For convenience, a push-button telephone can be used for this purpose on a remote basis. The controller provides system monitoring and will drive a standard printer if a hard copy is desired.

The system can be programmed by building maintenance personnel to schedule on and off loads on each output channel at selected times throughout the day. In office buildings, for example, the lights would typically be programmed to switch off after workers had left for the day. Title 24 requires that these systems be able to automatically return to normal "sweep off" mode at regular intervals to prevent overridden lights from being left on after the occupants have left.

Photosensors can be used in such a system, as well as split-ballasting controls. The system can also control HVAC, service water heater, and motor loads. Typical per-point costs are $300 to $1,500, depending on the system, expandability, and installation cost.

Case Study: Lighting Controls Retrofit of Park District

A two-part lighting fixture and controls retrofit in a major city is expected to save 29 million kWh annually and improve light and security levels in more than 400 recreational and park facilities. The first phase of the project retrofitted over 50,000 old and inefficient lighting fixtures with high-efficiency fixtures, such as high pressure sodium, efficient full-size fluorescents, compact fluorescents and LED exit signs.

The second phase of the project will focus on improving the control of this lighting. Each park will be fitted with up to three controllers, each using relays to operate up to 48 devices, such as wall switches, occupancy sensors and photocells. The programmable panels allow time-of-day scheduling, zone control, and protection from unauthorized use. The panels are also equipped with telephone override modules to control the lighting remotely. They will be linked using lighting management and communications software, to allow units to be networked in groups of 500 for centralized control. At a cost of $16.5 million, the project should yield a payback of a little more than 5 years.

Applicability

Developing an efficient lighting control strategy requires studying how building spaces are used and matching those uses to the most appropriate control option.

Control strategies described above have the following general applicability shown on Table 1.

Many devices, such as lamp ballasts and electronic switching devices, can introduce power line harmonic distortion—a growing area of concern for utilities and lighting professionals. Impact of controls on power quality should be carefully considered for all applications.

Field Observations to Assess Feasibility

This section discusses observations to make and things to consider in selecting appropriate lighting controls, and things that can significantly influence first costs and cost-effectiveness.

Lighting Control Strategy	Application
Door Jamb Controls	Closets, walk-in freezers.
Time-Based Controls	Occupancy pattern is relatively predictable There are some hours when the lights can be off (or at low level) without adversely affecting productivity, safety, or security.
Photosensors	Daylighting can offset portions of indoor lighting load. Photosensors can be used to turn on lights at designated light levels.
Occupancy Sensors	Areas of intermittent use (e.g., conference rooms, storage rooms) where lights are not controlled automatically.
Radio-Controlled HPS Ballast System	Industrial 400-watt HPS lighting.
Microprocessor-Based Centralized Load Programmers	New buildings larger than 30,000 sq. ft. Retrofits with accessible wiring systems.

Table 1: Typical Automated On/Off Controls Applications *(Source: CEC)*

Related to Applicability

Designers or retrofitters should determine as early as possible whether lighting controls will be appropriate and cost-effective. Several clues can suggest good candidates:

- **Buildings with zones employing circuit breakers** or switch banks in electrical closets or other non-user accessible locations.

- **Buildings, such as retail stores, that operate on specific schedules** but do not have automatic on/off time controls.

- **Spaces occupied only intermittently** (i.e. storage areas and warehouses), but which generally have the lights left on due to a lack of controls.

- **Public areas, such as airports, which have large areas of periodic use**, but do not yet have any type of controls that respond to daylight or user needs.

- **Office and institutional buildings with wall switches** but without automatic controls.

Related to Implementation Cost

A retrofit must be installed easily to be cost-effective. Even if components are inexpensive, major hidden costs, including wiring, rewiring and labor can have a very negative impact. The following items should be considered:

- **Ceiling Materials:** Inspecting existing ceilings can often tell whether a retrofit is economically feasible. Exposed construction affords the ultimate ease of retrofit, and suspended layin acoustic panel ceilings are also a good indication. Gypsum wallboard and other "hard" ceilings are much more difficult to inspect and work on. Wiring in poured-in-place concrete virtually guarantees expensive rewiring.

- **Existing Wiring Methods:** It is important to determine whether the branch circuit layout or existing controls are compatible with the space partitions or use areas. The designer should select strategies that can be effective with minimum rewiring.

- **Wiring Voltages:** Mixing the wiring of systems with different voltages in the same electrical box is not permitted under some codes. Permitted or not, it is never advisable. Separate controls are required for each voltage system in each space.

- **Wiring Materials:** Wires (high and medium voltage) must be in protective conduit. In most commercial buildings, power is fed to luminaires through wires in fixed or flexible conduits. Changing permanently constructed or "hard-wired" systems is generally labor-intensive and not cost-effective; "soft-wire" flexible conduit systems may be easily reconfigured.

Estimation of Energy Savings

Energy savings from lighting controls are affected by a building's baseline (i.e., before the retrofit) condition and by how effectively the control system is programmed. Since neither factor is usually accurately known, energy savings are difficult to predict. Savings of 10 to 35 percent of baseline lighting consumption have been reported at monitored installations in the U.S. Energy savings from occupancy controls are typically 35 to 45 percent of baseline lighting consumption. A radio-controlled HPS ballast system can reduce energy consumption 40 to 45 percent and provide some demand reduction.

Standard Savings Calculation

The following equations are recommended for estimating energy savings from lighting controls. Alternative equations and further information on estimating energy savings can be found in the CEE program documentation filed with the CPUC.

$HCIF_{kw}$ and $HCIF_{heat}$ are the heat/cool interaction factors which account for reduced electric air conditioning loads and increased gas heating loads, respectively, due to the decreased lighting energy. A table of these factors is in the program documentation.

$$
\begin{aligned}
kW_{savings} &= \#\ fixtures\_controlled \\
&\times (Watts /\ fixture_{as-built} / 1000) \\
&\times Utilization\_\ factor \\
kWh_{savings} &= kW_{savings} \\
&\times \left(hours_{baseline} - hours_{as-built}\right) \\
&\times HCIF_{kW} \\
therm_{takeback} &= kW_{savings} \\
&\times \left(hours_{baseline} - hours_{as-built}\right) \\
&\times 0.034 \\
&\times HCIF_{heat} / heating\_efficiency
\end{aligned}
$$

Utilization_factor is the ratio of "on" fixtures to total installed fixtures; it accounts for fixtures or lamps which are not operational due to burned out lamps, failed ballasts, or not being turned on.

Cost and Service Life

Factors That Influence Service Life and First Cost

Decision-makers face three types of application choices: retrofit, renovation and new construction. Table 2 shows the five major cost factors to consider for each type.

Typical Service Life

The PG&E CEE program assumption for occupancy sensors, photocells and lighting time clocks is 8 years.

Operation and Maintenance Requirements

The following can be used as a checklist for a lighting control maintenance program.

- **Check time clock settings** for accuracy.
- **Adjust time clock settings** for time changes.
- **Check that occupancy sensors** are operating properly.
- **Check photocells and adjust**, if necessary, for desired illumination levels. Refer to installation manual, if available, for proper procedures.

Time-scheduling systems are most ef-

Application	Initial Cost	Operating Cost	Installed Cost	Supply Circuit Layout	Building Design
Retrofit	√	√	√	√	√
Renovation	√	√			√
New Construction	√	√			

Table 2: Major Cost Factors for Lighting Control Applications

fective if in-house building personnel are willing and able to program, maintain, and reprogram the system. At the very least, the system must be programmed when the installation is being commissioned. In addition, it is often necessary to reprogram selected zones as requirements change. So it is important that a system be easily reprogrammed without expensive outside expertise.

Laws, Codes, and Regulations

California's Title 24 requires automatic time-scheduling controls (or other automatic shutoff device) for every floor of all new nonresidential buildings. It is recommended that any written specifications for time schedulers incorporate Title 24, which stipulates that time-scheduling control units must be:

- **Able to program separate schedules** for weekdays and weekends.

- **Equipped with an automatic holiday shutoff feature** that suspends turning on the lights (except by override) for at least 24 hours, then resets to normal scheduling.

- **Supplied with backup capabilities** (usually battery operated) that keep the device's memory intact for at least 10 hours in the event of a power loss.

Title 24 also requires that all automatic time schedulers be installed so that they can be overridden by occupant-accessible devices. Overrides must:

- **Be readily accessible** to occupants, and manually operated.

- **Allow lights to remain on** for a maximum of two hours after an override command.

- **Control an area** of no more than 5000 square feet.

- **Be located in the same general area** as the lights it controls.

(Note: Reference to Title 24 or any other regulatory standard is intended for informational purposes, and any such reference is not intended to be authoritative when applying any standard.)

Definitions of Key Terms

- **Dimming System:** Controls that provides variable light output from a lighting system.

- **Luminaire:** Generic term for a complete lighting unit, consisting of lamp(s), parts designed to distribute light from the lamps, components to connect the lamp to its power source, and an electrical device to provide that power.

- **Split-ballasting:** Wiring of a ballast that allows it to control one lamp in the fixture in which it is mounted and one lamp in an adjacent fixture.

References to More Information

1. California Energy Commission, “Time Scheduling Systems,” Ad-

vanced Lighting Guidelines, Second Edition, P400-93-014, March 1993.

2. California Energy Commission, “Retrofit Control Strategies,” Advanced Lighting Guidelines, Second Edition, P400-93-014, March 1993.

3. Electric Power Research Institute, “Lighting Handbook for Utilities,” EPRI EM-4423, April 1986.

4. E-Source, “Lighting,” Technology Atlas Series, Volume 1, 1994.

5. Thumann, Albert, “Lighting Efficiency Applications,” Fairmont Press, 1989.

6. Western Area Power Administration, “Electric Utility Guide to Marketing Efficient Lighting,” October 1990.

Major Manufacturers

The Watt Stopper
2800 De La Cruz Blvd.
Santa Clara, CA 95050
Tel (800) 879-8585
Fax (408) 988-5373

Leviton Manufacturing Corp.
59-25 Little Neck Pkwy.
Little Neck, NY 11362
Tel (718) 229-4040
Fax (718) 631-6598

Lithonia Control Systems
One Lithonia Way
Decatur, GA 30035
Tel (404) 987-4400
Fax (404) 987-1002

Additional lists of lighting control manufacturers are in References 1, 2 and 4. Information on this technology can also be found by contacting trade organizations such as the National Electrical Manufacturer’s Association and the Illuminating Engineering Society of North America.