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# LIGHTING CONTROLS: THE ROLE OF ADVANCED TECHNOLOGY-- PAST, PRESENT, AND FUTURE

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ABSTRACT

The role of technology in the development of lighting control systems is examined. Prior to 1973, control systems were primarily functional. They were used to switch lamps on and off, or to create a mood. Nearly all dimming was done with incandescent lamps.

Since 1973, the rising cost of electrical energy has made the operational cost of systems a design factor. Lighting controls are used to decrease power, reduce the time of use, and lower peak power demands. New lighting control equipment is based on existing technologies that have been modified to meet the needs of lighting systems. The technologies came primarily from the field of electronics.

These developments have made it technically feasible to automatically control the intensity and distribution of lighting in an area illuminated by a single fixture. These technologies form the basis for meeting future goals of lighting designs to alter illumination levels over time.

RESUMÉ

# LIGHTING CONTROLS: THE ROLE OF ADVANCED TECHNOLOGY-- PAST, PRESENT, AND FUTURE

## INTRODUCTION

The increasing use of lighting control systems has been due to the need to reduce the energy consumed by the electrical illumination of spaces. This has resulted in the adaptation of existing technologies for controlling lighting. The various types of lighting control systems have provided lighting designers with new freedom for illuminating spaces.

This paper will discuss the attributes of these new technologies with respect to their present use. Based on the changes in the lighting design needs and objectives, we will discuss the future of these technologies.

Lighting controls cannot be discussed solely in terms of technological advances; we must consider other factors that have influenced their use. These factors include design philosophies and the economic environment.

## PAST (PRE-1973)

A major change in application philosophy for lighting control systems occurred after 1973. Prior to 1973, the use of lighting controls was based on functional requirements. Lamps had to be switched on and off at or near the areas they illuminated. Special effects could also be achieved in stage lighting, theaters, and conference rooms by changing illumination levels.

TABLE I PRE-1973 LIGHTING CONTROL EQUIPMENT

| EQUIPMENT | LAMP | RANGE OF CONTROL |
|---|---|---|
| Socket Switch | Incandescent; Gas-Discharge | on or off |
| Wall Switch | Incandescent; Gas-Discharge | on or off |
| Three-Way Switch | Incandescent | 100,67,33,0% |
| Rheostat | Incandescent | 100 to 0% |
| Variable Auto-transformer | Incandescent | 100 to 0% |
| Solid-State Switch (Silicon-Controlled Rectifier, Triacs) | Incandescent | 100 to ~10% |
| Phase Control with Magnetic Dimming Ballast | Gas-Discharge | 100 to 30% |

Table I lists some of the lighting control equipment and techniques in use prior to 1973. The on-off switches could be used for all types of lamps (incandescent, fluorescent and high-intensity discharge). The three-way socket was used in conjunction with a two-filament incandescent lamp and was popular in the home. The rheostat and variable autotransformer were used to control lighting in commercial and industrial applications. Dimming with a rheostat is inefficient since the reduced power to the lamp is transferred to the rheostat. The variable autotransformer was considerably more efficient in the transfer of supply power to the lamps. Both of these rather cumbersome analog controls were used to dim incandescent lamps.

In the 1960s, solid-state switching devices were produced by the semiconductor industry. The devices (silicon-controlled rectifiers and triacs) varied the duty cycle of the input power to a load. The alternating current switch (triac) was low-cost and dissipated very little power. These devices, which could dim incandescent lamps over a wide range, became popular for home use; they were also used in place of autotransformers in commercial applications.

Near the end of this era, special magnetic ballasts became available that could dim fluorescent lamps. They applied a suitably high-voltage pulse every half cycle to maintain the gas discharge as the power to the lamps was reduced. None of these innovations brought about a philosophical change in the use of lighting controls. The general lighting in commercial and industrial buildings was still manually controlled by a few centrally located switches on each floor.

PRESENT (POST-1973)

The year 1973 is a watershed in the use of lighting controls. There was not any extraordinary technological innovation at that time, but an oil crisis occurred that had monumental impact on the lighting industry. Reducing dependence on foreign energy resources became a national concern. The cost of electrical energy increased sharply, so the operating cost of lighting systems also jumped and became a significant expense for consideration in the selection of lighting equipment.

Table II lists the possible responses to the increasing operating costs of lighting systems: i) in many existing spaces illumination can be reduced; ii) lighting designs must better meet the new Illuminating Engineering Society (IES) recommended illumination levels; iii) light levels can be reduced for short periods of time to minimize peak power demand charges; iv) more efficacious lamps and lighting systems can be used; v) use of lighting can be reduced in sporadically unoccupied spaces and, vi) use can be reduced during peak demand hours when electrical energy charges are greater. Lighting controls, by the use of one or more of the strategies listed in Table III, play a role in five of the six means to reduce operating costs. The control equipment will have a relatively small influence on the efficacy of a lighting system. These strategies have been described in a previous report[1] that did not include load shedding. Load shedding does not significantly reduce energy usage though it minimizes peak power demand charges, thereby reducing operating costs.

TABLE II PRINCIPAL MEANS OF REDUCING OPERATING COSTS OF LIGHTING

Reduce excess light levels.

Meet recommended illumination levels.

Shed lighting loads, reduce peak demand charges.

Increase lamp, ballast, and fixture efficacy.

Reduce annual time of use.

Reduce time of use during peak demand hours.

TABLE III LIGHTING CONTROL STRATEGIES

| STRATEGY | EFFECTS |
|---|---|
| Scheduling (predictable) | Annual Time of Use |
| Scheduling (unpredictable) | Annual Time of Use; Use at Peak Demand Hours |
| Tuning | Meets Recommended Levels; Reduces Excess Levels |
| Lumen Depreciation | Meets Recommended Levels; Reduces Excess Levels |
| Daylighting | Peak Demand Hours-- Reduces Excess Levels |
| Load-Shedding | Reduces Peak Demand Charges |

Existing technologies, adapted for controlling light sources, have affected lighting control equipment introduced since 1973. Because the concern has been to reduce the operating cost of general lighting, the technologies have been directed at dimming gas-discharge lamps (mostly fluorescent lamps). These types of lamps are used in most commercial and industrial buildings; these buildings are used during peak demand hours, and lighting costs are a substantial portion (30 to 50%) of the operating cost of the buildings. The semiconductor SCR and triac devices developed before 1973 are still the preferred method of controlling incandescent lamps. The lighting control equipment and the more efficacous lamp systems both add to the initial cost of a lighting system. The economic justification for the increased initial cost must be based on an acceptable life cycle cost or payback period due to reduced operating costs.

## Static Controls

The lighting industry's initial response to rising energy costs focused on the over-illuminated spaces in existing buildings. Table IV lists several types of products and concepts designed primarily for retrofitting such spaces. They can be generally characterized as low-cost, simple to install, and designed to reduce energy use by substantially reducing illumination levels. The table includes the concept of delamping--removing one or two lamps from three- or four-lamp fluorescent fixtures, respectively.

TABLE IV   STATIC LIGHTING CONTROLS

| EQUIPMENT/CONCEPT | CHANGE IN LIGHT LEVEL (%) |
|---|---|
| Delamping | 50 |
| Impedance Monitors | |
| Lamps | 30, 50 |
| Devices | 30, 50 |
| Energy-Saving Fluorescent Lamps | 5 to 12 |
| Non-CBM* Ballasts | 0 to 25 |

* Certified Ballast Manufacturers

While the devices on the above list may differ from one's concept of a lighting control device, they all result in a semi-permanent change in light level.

## Dynamic Controls

The devices listed in Table V are types of control components that can be used in automatic lighting control systems. They differ from the equipment on the static list in their ability to alter the lighting distribution in response to activities in a space. Each component will be briefly described with respect to its function and primary applications. The elements of a control system can be grouped under three functional categories: light controllers, sensors, and communicators. Light controllers are electronic devices that directly interact with lamps to turn them on or off and/or to obtain some intermediate light output. Sensors are devices that sense time, illumination levels, or occupancy of a space. The occupant is also designated as a sensor who provides an added sensitivity that the above physical sensors cannot. The communicators are elements of a control system needed to transmit information from the sensors to the lighting control. The information may have to be stored and compared to a set of stored prescriptive instructions.

TABLE V DYNAMIC LIGHTING CONTROLS

| EQUIPMENT | RANGE OF CONTROL |
|---|---|
| Light Controllers | |
| Switches/Relays | on,off |
| Power Conditioners | 100 to 50% |
| Solid-State Dimming Ballasts | 100 to 10% |
| Sensors | |
| Clocks | seconds to annual |
| Photocells | 3000 to 1 footcandle |
| Personnel | 100 to 300 sq. ft. |
| Occupants | |
| Communicators | |
| Hardwire | |
| Radio | |
| Power-Line Carrier | |
| Data processor, storage | |

## Light Controllers

Relays--Lamps can be turned on and off by relays that control input power. Light controllers that switch power lend themselves to controlling branch circuits and are effective for performing centralized types of control strategies. That is, the degree of local spatial control is limited by the supply power circuits (distribution of the branch circuits). The relays can be combined with a clock and a storage system to control the operation of lamps based on a prescribed schedule. When centrally installed, the system is low in cost and particularly suitable for retrofitting spaces.

Power Conditioners--There are various types of electrical systems that can condition the input power to gas-discharge systems and alter their light output. These new systems have been developed so that the special magnetic dimming ballasts described previously are no longer required, i.e., they can dim fluorescent lamps operated with standard magnetic ballasts. Power conditioners either alter the duty cycle or the line voltage of the supply power. Since they are based on switching power, they too are most effective for controlling large groups of lamps (branch circuits) and for centralized types of control strategies. They control the light output over a continuous range of levels. Incorporated with a control system that includes a clock, photocells, and a storage system, a power conditioner system can perform up to three control strategies, including scheduling, lumen depreciation, and load shedding. Since these systems control many lamps and are centrally installed, their initial and installation costs are reasonably low.

Solid-State Dimming Ballasts--The solid-state dimming ballast is both a ballast and a light controller. This device operates fluorescent lamps at a high frequency, improving the intrinsic lamp-ballast system efficacy by 20 to 25%. The high-frequency operation of the lamps permits them to be dimmed over a greater range of light levels (100 to 10%) than most power conditioners (100 to 50%). The ballast can dim the lamps manually at the fixture or remotely via a low-voltage signal. Dimming is accomplished by modulating the ballast's internal circuit. Thus there are no basic cost advantages in either dimming a single fixture or a group of fixtures, as is the case where the control of power is required. If a ballast is used in conjunction with a clock, photocells, and an information processor, all five control strategies can be performed. Since this system includes the premium cost of a ballast that must be installed in each fixture, it has the highest initial cost (equipment and installation). This system is more cost-effective for renovation and new construction applications where the installation costs are minimized. Since this system permits control of single fixtures over a large range of light levels, it is the most technically advanced and will result in the greatest reduction in operating costs.

Sensors

Clocks--A timing device in a control system can be as simple as a mechanical clock that operates a switch to turn lights on or off. More sophisticated electronic clocks have memory to provide a daily schedule for the operation of the lighting system over an entire year.

Personnel Sensors--Infrared and ultrasonic transmitter/receivers can be used to sense motion in order to determine the occupancy of a space. Personnel sensors are packaged as systems that include light controllers. These systems can be used for areas as large as 400 square feet. This control technique is most effective for spaces occupied by only one person, when the amount of time the space is occupied is known. For more densely occupied spaces, the probability of the space being unoccupied (lamps off) decreases. Other preferable uses are in spaces that are frequently occupied temporarily by one person (e.g., copying machine spaces in offices). Since the amount of time a space is vacant is proportional to savings in the operating costs, these systems are best used in retrofits where the unscheduled activities in the space are documented.

Photocells--Photocells are used to measure the illumination levels in an area. One photocell can be used for a large area in the lumen depreciation strategy, which is centrally controlled and where only the illumination levels from the electric lights are sensed. A higher density of photocells must be used in conjunction with daylighting to sense the illumination levels from the daylight and electric lights. The output of the sensor must be amplified and can be sent directly to the lighting controller or it can be sent to a central processor that will command the appropriate lamps.

There are photocell lighting control systems available that are designed to control two to four lamps and that operate fluorescent lamps with conventional magnetic ballasts. While these systems are relatively expensive, retrofitting them in areas with considerable amounts of daylight renders them cost-effective.

Occupants--Most existing lighting controls are manually operated by occupants. In automatic systems, even with all of the sensing devices, there will be occasions when the lighting system will not meet the occupants' needs. Thus, automatic systems must provide some means to override the information from the automatic control system. These overriding commands can be accomplished with switches and/or over telephone lines.

Communicators

Hardwiring--Most lighting control communication links are hardwired from the sensor to the light controller or to the information processor. For centralized systems, where all the elements are in the same space (an electric closet), material and installation costs are small. For systems that have photocells and lighting controllers distributed throughout the illuminated space, hardwiring becomes more costly. For this reason, these systems are best used in renovations and new construction, where the wiring installation costs are minimized.

Power-Line Carrier--The communication signals can be sent over existing power lines. This eliminates the need for stringing communication lines and allows considerable flexibility in the modular control of spaces. However, the lighting information must be discriminated from the electrical noise on the power lines. The coding and decoding format becomes more complex as the number of independent communication stations (transceivers) increases. Power-line carriers are most cost-effective in retrofits with only a few communication stations.

Radio Links--There are some lighting control systems that link the sensor and the lighting controller via radio signals. The transmitters and receivers are costly and most effective in switching large power loads that are not easily accessible. The receivers must be made impervious to stray radio signals.

SUMMARY OF PRESENT

The need to reduce the operating cost of illuminating spaces has resulted in the development of technologies that can automatically turn lamps on and off, reduce lighting levels, and reduce the time of use. Table VI lists six technologies that were initially developed for applications other than lighting systems.

TABLE VI  TECHNOLOGIES ADAPTED FOR USE IN LIGHTING CONTROLS

| TECHNOLOGY | APPLICATION<br>INITIAL | <br>LIGHTING |
|---|---|---|
| Motion Sensors | Burglar Alarms | Occupancy Sensors |
| Switching Power Supply | DC Supplies for Computers | Solid-State Dimming Ballasts |
| Radio Transmission | Garage Door Openers<br>TV Channel Changers | Communication Links |
| Power-Line Carrier | HVAC Control,<br>Home Applications | Communication Links |
| Computer/Microprocessor | General Data Processing,<br>Energy Management Systems | Lighting Management Systems |
| High-Power Semiconductor Switches | General Control of Duty Cycle of Power | Lighting Controllers |

These technologies had to be amended for lighting applications. Typical for most initial applications of new technologies, the unit costs of the equipment could be high and the volume density low. Generally, lighting equipment has a relatively high density of units in space and unit price must be minimized. In addition, lighting systems are installed in many uncontrolled environments. This requires the equipment to operate reliably at very hot and cold temperatures as well as to withstand line surges.

The initial applications provided in the table are examples of the less stringent requirements for these technologies; burglar alarm systems cost thousands of dollars, the transceiver/transmitter need control only one control point; d.c. switching supplies for computers are in conditioned environments. Automatic lighting control systems require communication between many sensing and control points to increase the effectiveness of the systems to meet the varied activities in a space. The fact that all the lighting control equipment described has found some use indicates that these technologies have been suitably amended to meet some of the stringent requirements for lighting.

The relatively few automatic lighting control installations that have been monitored have demonstrated some significant technical and economic achievements. Table VII lists eight major achievements that have been realized by the lighting controls industry. There has been a considerable reduction in cost in the equipment adapted for lighting. Several on-site demonstrations of different types of control equipment[2-5] have documented large reductions in operating cost through energy savings. The achievements related to dynamic lighting design include: the ability to independently control light output of single fixtures, to control illumination in sectors independent of the supply power layout, and to alter the illumination for unpredictable events in the space. It is almost fortuitous that an oil crisis occurred, since, as a result, a host of new equipment has been developed and applied that has provided lighting designers with additional degrees of freedom to implement the most sophisticated concepts for illuminating spaces.

TABLE VII LIGHTING CONTROL ACHIEVEMENTS

Lowering equipment costs of initial technologies.

Providing large decreases in operating costs.

Providing yearly automatic schedules for building illumination.

Maintaining specified illumination levels through lives of lamps.

Providing control of maximum light output of single fixtures.

Providing means to shed loads on a priority basis.

Controlling lighting for unpredictable schedules.

Eliminating the need for hardwired communication links.

## FUTURE

The goals and aspirations of the lighting community have continually grown due to its increased understanding of the needs of occupants with regard to visual acuity and comfort. Recommended levels are continually reviewed by the IES committees. Metrics of quality have emerged: visual comfort probability (VCP) and equivalent sphere illumination (ESI) and are employed in the design of lighting layouts. Table VIII lists other factors that presently affect or are emerging concerns in determining how spaces should be illuminated. If the goal of the lighting profession is to provide the proper level of illumination with optimum quality suited to the occupant of the space and the task, it should be evident even to the uninitiated (non-lighting-designer) that this cannot be achieved with static, dedicated lighting systems. Each of the items listed in Table VIII can only be achieved by altering the amount and the distribution of the illumination after the space has been furnished and occupied. For example; it is unreasonable to expect the lighting designer to know the occupants' ages or the speed and accuracy requirements of their tasks. Changes in the electrical illumination levels and distribution are required over relatively short periods for changes in the occupant's schedules, when daylighting is employed and when the specified light levels are maintained.

TABLE VIII SOME ISSUES THAT HAVE EMERGED RECENTLY

The expanded use of open office space.

The common and growing use of video display terminals.

The latest IES recommended light levels as related to:

- Age
- Speed, accuracy
- Task reflectance
- Room surface reflectances

The desire to improve quality of illumination.

Recognition of the limitations on the accuracy of computer programs.

Manufacturers' tolerances of equipment.

Providing and maintaing specified lighting levels through time.

Use of daylight for illuminating spaces.

Adapting illumination to the rearrangement of spaces and visual tasks.

Based on an attempt to meet the above goals and the concerns that face the lighting community, the necessary advances in lighting controls technologies will be discussed. The projected, necessary advances are listed in Table IX. The first two, reduced cost and reliability, are self-evident. In order to be universally used, equipment cost must further be reduced. While some reduction can be expected due to increased volume, improvement in the technologies are necessary.

TABLE IX NEEDED TECHNOLOGICAL ADVANCES

The following advances to equipment are needed:

Reduced equipment cost.

Improved equipment reliability.

Development of scanning photocells.

Development of scanning personnel sensors.

Installing a transceiver in each electronic ballast.

Developing a power-line carrier system for high-density control points.

Developing a lighting management system compatible with building energy management.

Photocell

A single photocell measures the average illumination over an area that is used to determine the illumination over a space. For the lumen depreciation strategy, the illuminated space is considerably greater than the area measured by the photocells. In order to suitably apply the daylight strategy, the measured area must be about the same area of the illuminated space. This requires a relatively high density of photocells, about one per 150 square feet. If a photocell can be developed that can scan a large area and provide the illumination information for local areas, one such photocell can be used for daylighting open office spaces. This can reduce the need for many photocells and communication terminals. With the new device, all of the illumination information for the room can be obtained from one point.

Personnel Sensors

The limitation to personnel sensors has been the relatively small area of their effectiveness, resulting in the control of a small amount of power, 200 to 300 watts. If a scanning personnel sensor can be designed to scan larger areas, it could be a more effective tool for large spaces, in particular for the open office spaces that are now in vogue. This would also reduce the number of sensing sites throughout the space.

Solid-State Dimming Ballasts

In the course of developing solid-state ballast technology, it should be possible to include a transceiver in each dimming ballast. With this capability it would be possible to communicate automatically with each ballast/lamp unit independently of the other systems on the floor. It would permit one to establish a multitude of lighting patterns that would reflect the arrangement of the office space. Such a system would offer the lowest operating cost for the optimum quality and quantity of illumination.

Power-Line Carrier

With the above solid-state dimming ballast innovation, the development of a power-line carrier system that can communicate without error and with a multi-channel system would permit optimum flexibility. The illumination system would be totally independent of the supply power circuit. In addition, any necessary changes in the illumination intensity or distribution could be executed rapidly at virtually no cost via a simple change in the computer program. A many-channel system would be technically feasible today if there were no noise on the line. An error-free system must be developed that is not susceptible to the ambient noise on the line or in the space.

## Lighting Management System Capability

The final development is the integration of the lighting management system with the building management system. Today there is increasing use of energy management systems for the HVAC control of buildings. Some of these systems include some simple management of the lighting system. The building management systems have relatively few control points, resulting in a high cost per control point. Lighting management systems require many control points and, for a cost-effective system, the cost of each control point must be less. If a system can be designed to compensate for these different needs, a total building system can be designed to be more cost-effective, since the same computer system can be employed to control nearly 90% of the building's energy usage (HVAC and lighting) to optimize its total energy performance.

## SUMMARY

The present need to reduce the operating costs of lighting spaces has resulted in the adaptation of technologies to control lighting systems. The new lighting equipment has had a profound effect on lighting designs by permitting changes in intensity and distribution of illumination after a space has been furnished and occupied. This has permitted the lighting system to be tuned to the visual needs of the occupants for the system's entire life.

Realization of the power of the lighting management system in optimizing of the illumination of a space indicates that such systems should be universally employed. This requires further development of the equipment that have been introduced during the past 10 years. The targets include lower cost, more reliable components, and the integration of the lighting with the building management systems.

It is interesting to note that, in the past and present, lighting controls have reflected lighting needs. However, the future of lighting control equipment and systems will be predicated on the technological advances that have shown the potential for automatically providing the type of lighting that can best approach the IES goals for illuminating spaces.

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