A new approach to lighting system control

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In recent years, the number of switches for lighting system control has been reduced to save initial installation costs. In commercial buildings, large areas or even whole floors may have only one or two switches for the entire general lighting system. The author examines the development of a practical low cost lighting control system that can vary the illumination within an exterior or interior space. The system is designed to suit the changing needs of the lighting user, conserve energy, and lower lighting costs.

With new emphasis being placed on the need to reduce costs and utilize energy effectively in commercial structures, more attention is being focused on ways to control the functional operation of the lighting system. Better ways are needed to optimize system performance without sacrificing the lighting quality or quantity that the user needs to perform visual tasks.

As recent studies have indicated,[1–3] simply reducing overall illumination may be counterproductive, eventually requiring the expenditure of greater quantities of labor, energy and materials to get the job done. Removing lamps and disconnecting luminaires not only detracts from the appearance of the space and building but, more importantly, a portion of the lighting equipment investment is lost and the effect on other building systems, such as heating, may require expensive modifications. Further, if lighting needs change and equipment must be reactivated, additional costs are incurred. Designing new facilities with less than adequate illumination extracts a continuous visual penalty on some workers while virtually committing the building owner or tenant to higher long term expenses for upgrading and remodeling the lighting system as conditions and requirements change.

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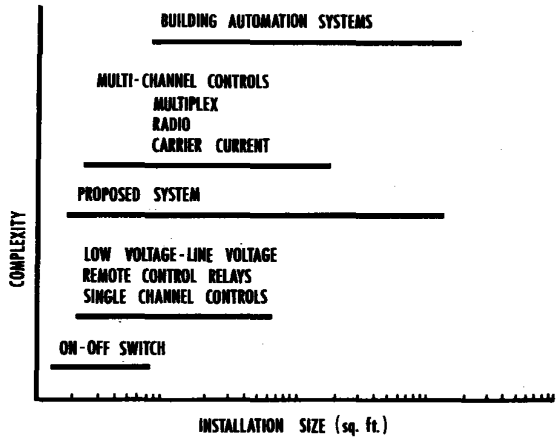
Described in this paper is a developmental control system that can be applied as a practical solution to these problems, and can be designed to greatly increase the flexibility of new or existing general lighting systems. Thus, they can be made to respond, both in time and in space, to the changing needs of lighting users, energy limits, and cost considerations without compromising lighting requirements. An experimental installation of the system is discussed which provides lighting control for an office instal-

Figure 1. Control system complexity and installation size as a function of applicability.



lation on a luminaire-by-luminaire basis. Extensions of the basic idea lead to the concept of a distributed control system applicable to lighting, heating, cooling and other major building electrical loads.

The hierarchy of some control systems applicable to lighting might be roughly ranked as shown in Fig. 1. Larger and more complex systems, of course, generally lend themselves to more complicated control functions, perhaps involving feedback and monitoring as well as control. The "applicability lines," while somewhat arbitrary, suggest that each system must be analyzed and fitted to the application. Equipping the six luminaires in the corner grocery store with individual hand-operated switches may be a convenient, inexpensive and workable solution, but if the same technique were to be applied to thousands of offices in a large building complex, the installation expense may never be paid back by operational cost savings and the nuisance involved in operating each switch ensures that most will not be used as intended.

The developmental control system as envisioned may be applied on a much broader basis. It permits:

(1) Variation in illumination level throughout the space in small enough spatial increments so that task illumination can be matched to task difficulty and criticalness.

(2) Control of the direction of the major incident flux to minimize veiling reflections.

(3) Flexibility so that the lighting can be tuned to the activities of the people working in the space; as well as allowing for the movement of furniture and other changes in the room.

(4) Coordination of the lighting with other building services for occupant comfort, minimum operating cost and optimum energy utilization.

System description

The basic components of the developmental system are a central control device and a receiver/switch which is located in the electrical supply line to the load. This is a standard control arrangement, but it differs from more traditional approaches in that it can control small loads individually by using low cost logic elements and digitally coded signals for the functional and address commands. This has the result of greatly increasing the system capacity since, by carefully defining the control hierarchy and digital word structure, the number of remote control points can be made virtually limitless.

One possible configuration of the system designed to control general lighting is shown in Fig. 2. Triggered by some type of input device, the microprocessor carries out a planned sequence of control operations according to a stored memory program. Inputs may be generated by a clock, photocell, touch pad, etc. The processed commands properly coded are then sent to the remote receivers where they are decoded and cause the appropriate control function to occur. In this case, the signal is shown traveling between the transmitter and receivers by means of the normal power wiring, but coaxial cable or twisted pair could be used as well. This power wiring arrangement, however, is particularly advantageous for existing lighting systems since installation is simplified.

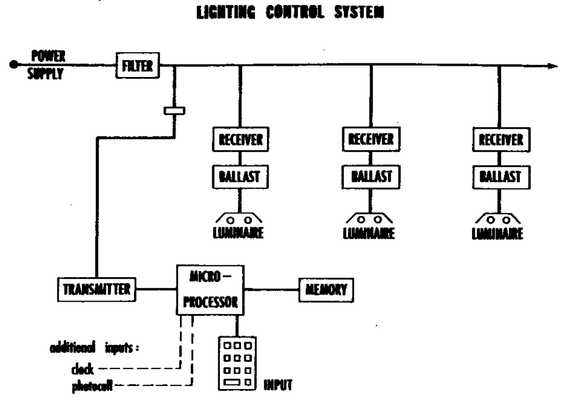


Figure 2. Block diagram of development lighting control system illustrating control on an individual luminaire basis.

In one configuration the system might utilize a "lighting map" or a stored pattern of luminaires set to go on or off according to the functional needs of the space. During working hours, a clock would call for the appropriate patterns from memory switching to different patterns as needed or at the end of the day. One set might be: arrival—working—lunch—working—departure—cleaning and nighttime. Local controls could be used to override the normal pattern at any time by injecting address and command codes for the particular luminaires involved. A standard telephone may be used as an input control device simply by setting up a telephone station as an input line and adding a suitable interface to the microprocessor.

From a functional standpoint, the variety of different control inputs to the microprocessor can be easily handled by an input/output bus either by programming the microprocessor to periodically scan a number of input ports for data inputs or on an interrupt basis, in which case the normal program sequence is interrupted to service the request. For the former case, the microprocessor is programmed to access input ports as part of the normal program and read the contents of a buffer storage at the input port(s). In the case of the interrupt mode, several request lines may be used on an assigned priority basis. Once the interrupt request has been acknowledged and executed, the microprocessor returns to its normal program sequence. In a typical lighting control system, local switch inputs or light sensors might be handled by sequentially scanning a number of input ports; a telephone input would be handled on an interrupt basis.

Overall, the use of stored programs to generate the desired control action, accessible through a variety of input devices, greatly reduces the number of local control points and associated wiring without reducing flexibility. Changing lighting patterns to suit new floor, partition, or work space arrangements would not involve changing power wiring or moving switch legs, but only a new set of memory instructions.

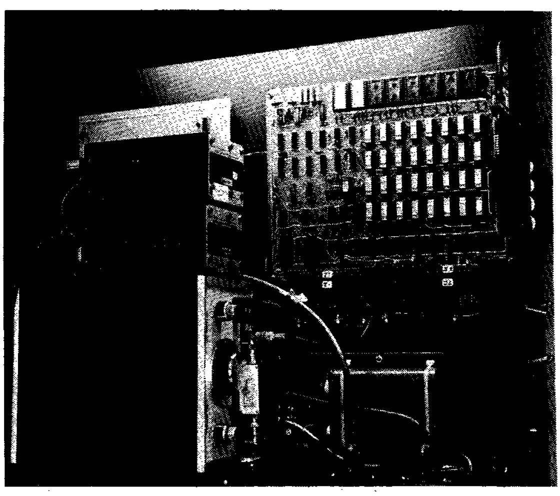
Additional functions could be added to the control system at any time without greatly adding to costs or complexity. For example, a power limiting circuit added to the input would ensure that the number of luminaires turned on would not exceed a precalculated demand limit.

The key to the practicality of this developmental control system is the utilization of standard logic elements such as the microprocessor. These devices are now being mass produced in a variety of the configurations and prices have dropped from hundreds of dollars per unit to several dollars per unit and forecasts suggest a cents/unit price is not far off. Microprocessors themselves are becoming the ubiquitous heart of numerous electrical and electronic devices from pocket calculators to electric ranges and automobile ignition systems. One report[4] estimates that the United States' shipments of "chip sets," which include microprocessors and their auxiliary devices, will climb to some ten million units per year by 1980 from the 1971 level of 1000 units and the 1974 level of 200,000 units.

Experimental installation

To test the practicality of the idea and gain experience with an actual operating system, a small scale installation was built and put into operation in a 14-by 17-foot two-person office containing 18 two-lamp, 40-watt recessed fluorescent troffers. For maximum flexibility, it was decided to equip each luminaire with a receiver and switch plus a two-level ballast so individual off-low-high operation could be obtained. Installation was easily accomplished by adding a control module to each luminaire and replacing the usual room wall switches with the control unit. Existing power wiring was utilized to carry the signals as indicated in Fig. 2. A standard kilowatt hour meter was added to the room's input power line to monitor lighting energy.

Figure 3. Microcomputer and transmitter control for the experimental office lighting installation.



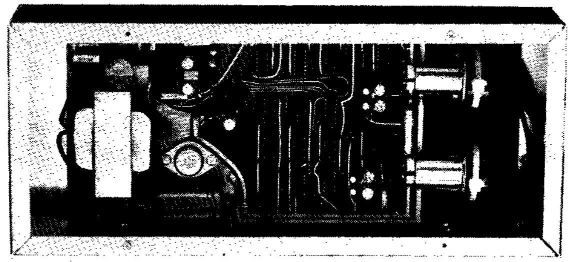


Figure 4. Receiver/switch for the experimental installation. At the left is the receiver and power supply. Logic circuits containing address and control functions are at the center with the relay drivers and power relays at the right.

The physical arrangement of the experimental control/transmitter is shown in Fig. 3. Commands are fed into the system via a numeric touch pad located on the right side of the cabinet. These signals first go into the microprocessor, which is a standard catalog unit, but which operates under the control of a special program written on two Read-Only Memory (ROM) chips located on the upper portion of the circuit board. The processed commands are then fed into a signal generator which modulates them on to a 50 kilohertz carrier. From there, the signal is coupled to the power line using the circuit at the lower right of the cabinet. Power supplies and a circuit board containing a clock for timing the logic circuits complete the microcomputer and the transmitter portions of the system.

The ROM chips contain memory locations that permit addressing each of the 18 luminaires individually and switching them either to high, low, or off. In addition all of the luminaires in the room may be controlled sequentially by pressing one button that sets them to any one of the three states.

Expanding this system to control additional luminaires, accept other inputs, or utilize a different program can be accomplished simply by adding memory modules and exchanging the ROM chips with alternate units containing different programs. Should frequent program changes be required, Programmable Read Only Memories (PROM) could be utilized in conjunction with standard programming equipment. Similarly, peripherals normally used with data processing devices such as tape readers, magnetic tape cassettes, printers and readout equipment might be added to increase flexibility and expand the operational convenience of the system.

Once the coded signal leaves the transmitter, it travels throughout the wiring system until attenuated by line impendance or blocked by filters. At the luminaire, it is decoded by the receiver (shown in the upper left of Fig. 4) and sent to the logic section. If the incoming address code matches that of the receiver, the command is passed through to the driver circuits and finally to the power relays.

The circuit design used for the experimental installation contains several provisions that add to system reliability and immunity to power line interference. The receiver is a frequency-modulated phase lock type having high noise immunity. The decoding circuits operate such that two out of a chain of three correct signals must be received before the control signal is given to the power relay. The system is clocked to the 60-hertz power line with both zero crossings used to obtain a 120-hertz clock rate. This means that a long time constant is applied to the data and a narrow data bandwidth is the result. Frequency shift keying of the transmitter ensures that unless noise is very near the carrier frequency and lasts for a duration of eight milliseconds, it will not interfere with system operation. This type of noise is not at all typical of transient noise found on power lines.

Experience accumulated during more than one year of normal operation has not included any unexpected switching incidents.

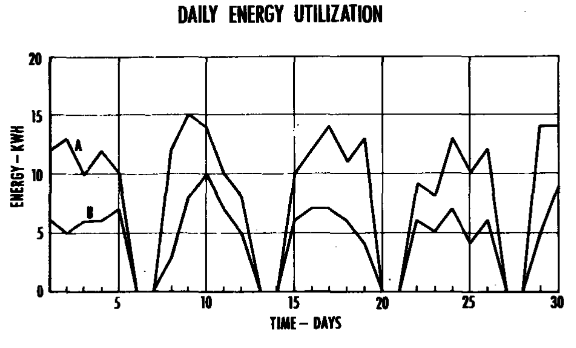
Costs and operational experience

The experimental installation was constructed using standard electronic components and off-the-shelf hardware. Consequently, little effort was made to integrate the parts into optimal configurations. Using integrated circuit techniques, for example, the receiver/switch can be made much smaller, and, in large quantities, less costly. Over the long-term, its functions might be integrated with the ballast so that circuits, such as power supply and current regulation, can be shared.

The key to lower costs is to minimize the number of receivers since they represent the greatest hardware cost segment of the system and increase costs in direct proportion to system size. The control/transmitter is the economic opposite. The more receivers the less the transmitter cost per receiver, because expanding the system to control more receivers only means adding more memory capacity, a relatively small expense. Techniques for "sharing" receivers among luminaires might also be employed. One way to do this is by multiplexing signals to a receiver and then distributing control functions directly via power or low voltage wiring and relays.

Overall, the preliminary cost studies have indicated the system as installed is economically feasible for typical office buildings based just upon energy savings if energy rates are above five cents per kilowatthour and if expected kilowatthour reductions amount to 20 percent or more. Adding in other factors, such as reduced electrical renovation costs during remodeling and savings that would occur from better integration of building electrical loads, pushes the economics well into the favorable area.

Figure 5. Daily energy profile for the experimental installation over a typical month: Curve A is energy usage before installation of the control system; and Curve B, after. Both are for an eight-hour day, five-day week work schedule.



In the experimental system, which is somewhat atypical because of the above average lighting system already in the room, energy savings amounted to as much as nine kilowatthours per day, depending upon whether or not both occupants were in the room and for what period. During a typical month, lighting energy reductions averaged 47 percent. Figure 5 is a daily energy profile of that situation.

Illumination levels on the two desk-top work surfaces can be varied in 5- to 10-footcandle steps from dark to 130 footcandles. Full room illumination is 70 or 140 footcandles average maintained. Asymmetric lighting arrangements to minimize veiling reflections are usually provided since one of the occupants faces an end wall and the other a side wall with a common work space in between. (Figure 6 shows an office with the experimental installation in use.) Figure 7 illustrates some of the usual lighting patterns.

Typically, the first occupant to arrive in the morning turns the system on and sets it to a comfortable lighting arrangement for the task at hand. The second occupant does likewise for his portion of the room. Since the office is used for light drafting and informal meetings as well as general office work, lighting patterns change perhaps two or three times during the day. Almost always, all lighting is turned off at lunchtime and a new pattern reset for the afternoon.

At the end of the day, if daylight is gone, the last to leave turns all of the luminaires off except for the one or two needed for cleaning. After cleaning, the custodial staff is instructed to turn the system completely off.

Distributed control system

The system as described need not be limited to lighting control since, even with the most complex lighting system, the control microcomputer would be idle much of the time. Adding additional loads increases only the complexity of the control program, not the system itself. Figure 8 shows an idea for an alternative approach that would be capable of handling an extensive array of building electrical loads. Here, control signals for load switching are generated by each subsystem microcomputer and distributed to each switched device in the subsystem. A common bus connects the slave microcomputers to a central or master computer which interfaces the total system to any external command and sensor inputs that apply to all.

In the Heating-Ventilating-Air-Conditioning (HVAC) system, the same simple type of receiver/switch might be used to control, on a zone basis or an individual basis, heat pumps or other heating/cooling devices. Various sensor inputs can be provided to the slave microcomputer dedicated to this particular

Figure 6. A portion of the office with the experimental control system in use. The microcomputer and controls are in the cabinet at the left side of the door.

system in order to optimize its performance consistent with overall constraints. For example, the power inputs to various building zones might be monitored and signals fed into the slave microcomputer for the HVAC system in order to modulate or control that system consistent with lighting or power demand.

An important advantage of a master control and freestanding slaves is that the master or its associated transmission system may fail without affecting the normal operation of the slaves. Of course, master functions such as power limiting and overall system coordination would be lost, but the local systems could still operate. Conversely, the master and slaves might be organized so that, upon failure of a slave, the master could take over essential functions at some reduced level.

Additionally, communication complexity is minimized with the master-slave arrangement since appropriate sensor data is sent to a local slave rather than longer distances to a central computer. Very little data need be sent from the slaves to the master and such data as might be required would already be partially evaluated by the slaves. An example would be the continuous monitoring and computation of instantaneous power in which the slave would carry out the monitoring function plus the sum of squares computation before sending the results to the master.

Communication is also reduced because the master need only send single commands for a desired function leaving the slave to carry out the details. Thus, the master may be less complex even to the point of being a microcomputer itself. It should be pointed out, however, that microcomputers used for either slaves or masters can be readily interfaced with any central process computer and with other small signal digitally oriented equipment.

Overall, the most important benefit of any full-scale system that might grow out of these ideas is flexibility. For the building owner and operator, there is the opportunity to upgrade present structures to modern lighting and energy utilization requirements. Lighting in new structures may be optimally designed and installed at the most economical time—during building construction so that fewer changes and renovations are required over the useful life of the building. The tenant or user thus benefits through lower lighting costs and by having good lighting that can be easily adjusted locally, both in quantity and quality.

The methods and equipment presently available, and in use today, have provided ways to control large centralized electrical loads economically. Sophisticated building automation systems have expanded the idea and have made possible the integration of various building loads to improve performance and better control costs. Now with this developmental control system, the next important steps can be taken because it provides a way to control both economically and practically much smaller loads; a way to better interface with existing control systems; and,

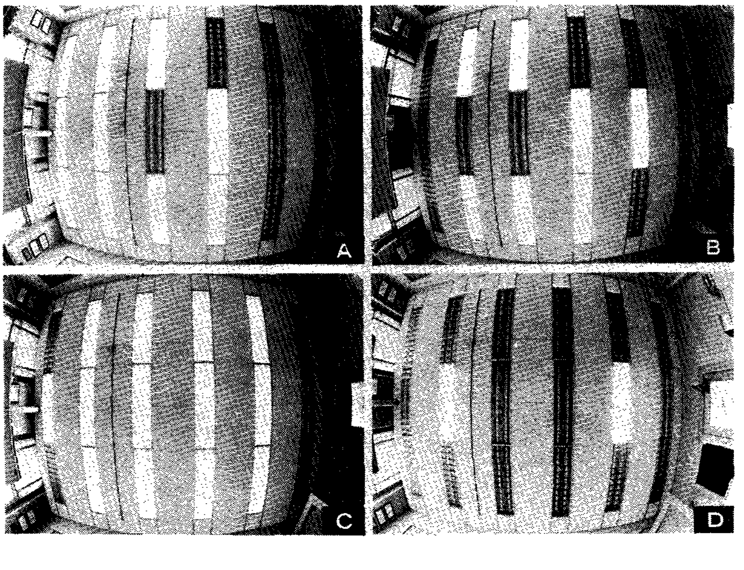


Figure 7. Typical lighting patterns used in the experimental installation: (a) desk lighting—little daylight; (b) desk lighting—daylight contributing to work area illumination; (c) desk and drafting area lighting; and (d) cleaning and security lighting. Note: photographs do not reproduce those luminaires set at reduced output.

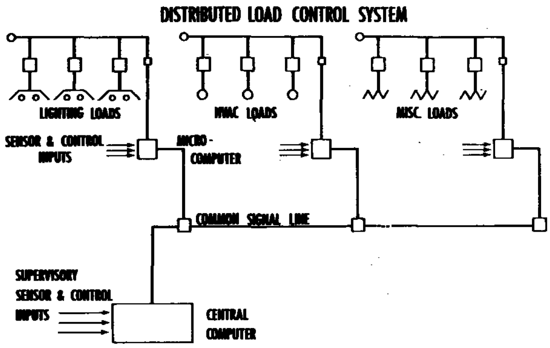


Figure 8. Block diagram of a distributed control system.

most importantly, a way to put under control the hundreds of thousands of commerical installations that utilize some 18 percent[5] of the primary energy in the United States—all without sacrificing the performance and comfort of those who must use the spaces and for whom the spaces exist.

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