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The rapidly rising cost of electrical energy makes its conservation increasingly more important. Electrical consumption can be reduced in a number of ways. One of the simplest is through lighting reduction; within this area are a number of options. One easy and often used approach is by removal of lamps; however, lamp removal without proper guidance can have seriously adverse effects on health, safety, productivity, and security. Another option is through use of controls; this may be as simple as installing switches.

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Automatic control systems to maintain required illumination levels are necessary if natural daylight from windows are to be effectively used. This report covers (1) an industry survey for commercially available control systems, (2) an evaluation of one commercial automatic control system, and (3) the development and evaluation of two different control systems developed by the Civil Engineering Laboratory. Evaluation of the control systems determined that electrical conservation was realized.

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The rapidly rising cost of electrical energy makes its conservation increasingly more important. Electrical consumption can be reduced in a number of ways. One of the simplest is through lighting reduction; within this area are a number of options. One easy and often used approach is by removal of lamps; however, lamp removal without proper guidance can have seriously adverse effects on health, safety, productivity, and security. Another option is through use of controls; this may be as simple as installing switches. Automatic control systems to maintain required illumination levels are necessary if natural daylight from windows are to be effectively used. This report covers (1) an industry survey for commercially available control systems, (2) an evaluation of one commercial automatic control system, and (3) the development and evaluation of two different control systems developed by the Civil Engineering Laboratory. Evaluation of the control systems determined that electrical conservation was realized.

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CONTENTS

INTRODUCTION

At Naval shore facilties, many buildings that house offices, working areas, and storage space (warehouses) have large window areas and skylights. On bright, sunny, and moderately overcast days, windows and skylights provide sufficient natural illumination in these areas that the need for artificial lighting is eliminated, at least reduced. At most facilities, however, it is common practice for the building custodian, or whoever arrives first in the morning, to turn on all the lights. As the day progresses and natural light provides sufficient lighting levels, the lighting system remains on, resulting in a waste of electrical energy. Although the oil crisis was alleviated temporarily in early 1974, the rapidly rising cost of electricity and inflation make conservation of energy increasingly more important. Many Naval shore facilities have conservation plans, such as removing some of the lamps from incandescent and fluorescent luminaires. While this approach may save some energy, it also can reduce visibility and productivity. The need, therefore, exists for a light sensing and control system that will automatically dim, partially turn off, or completely turn off the lighting systems when sunlight provides part of all of the required lighting level.

CEL conducted an industry survey for off-the-shelf hardware that will provide a light sensing and control system for use at Naval activities. Many companies manufacture hardware for off-and-on exterior lighting (such as parking lot, security, and safety lighting and outdoor signs). All manufacturers of electric lamps offer some type of energy-saving lamps (such as high intensity discharge, mercury vapor, high and low pressure sodium, and metal halide lamps). Some of the companies (such as General Electric, Westinghouse, Lutron, ATMOS Corp., and Wide-Lite) manufacture manually controlled lighting systems that will conserve energy if properly adjusted during daylight hours. Appendix A lists those companies that returned information in the form of brochures, catalogs, and manuals in response to the request by CEL for information on their energy-saving systems.

Only two companies - General Electric (GE) and Wide-Lite Corporation - manufacture a light sensing and control system for use on inside lighting systems. Appendix B describes the Wide-Lite system, which operates only high intensity discharge lamps. Because this type of light is not generally used for office and work area lighting, this system was not evaluated by CEL.

The General Electric system and two CEL-developed light sensing and control systems were evaluated: test results are included in this report.

DESCRIPTION OF SYSTEMS EVALUATED

General Electric Light Sensing and Control System

The General Electric light sensing and control system (hereafter called GE system) consists of a photo-relay, a remote-control interface, a low-voltage transformer, a rectifier, relays, local switch, and override switch. All but the photo-relay are housed in a 12 x 12 x 3-1/2-inch metal cabinet. Figures 1, 2, and 3 show the sytem hardware. Cost of the GE system was $150. Appendix C is an operational description of the GE light sensing and control system.

CEL Two-Level Automatic Light Sensing and Control System

The CEL two-level automatic light sensing and control system (hereafter called two-level control) consists of a photocell sensor, threshold level control, initial instant-on, override switch, automatic on/off delay, switch gate driving circuit, and solid state switch. All the electronic circuitry is mounted on a circuit board and can be located in one of the fluorescent luminaires if used to control a fluorescent lighting system. Figure 4 is a block diagram of the two-level control circuit. Power consumption of the two-level control is 9 watts. The theory of operation and circuit description are contained in Appendix D.

CEL Constant Illumination Level Lighting Control System

Preliminary Investigation. Before development of this system was begun an investigation was conducted to determine how fluorescent lamp, dimming ballast, power factor, and efficiencies change as lamps are dimmed and whether dimming can conserve energy. All equipment used in the investigation is commercially available. The luminaire used contained two 40-watt, 48-inch rapid-start lamps and a single dimming ballast designed for 120-volt power supply. The ballast was a General Electric 8G500L two-lamp ballast, and the dimmer was a 600-watt General Electric DF61U fluorescent dimmer which can control up to twelve 40-watt rapid-start fluorescent lamps.

Figure 5 illustrates the basic test setup for this investigation. The principal instruments used were:

1. John Fluke Model 8200A digital voltmeter
2. Simpson 0- to 150-watt single-phase wattmeter
3. Simpson Model 460 digital voltmeter (current)
4. Weston Model 614 foot-candle meter

Results of Preliminary Investigation. Tests were made with the ambient temperature at approximately 22°C and in a windowless room with the absence of all light except from the luminaire under test. The following measurements were made:

1. Input power, from full to minimum brightness in 5-watt steps
2. Supply voltage adjusted to maintain a constant 120 volts
3. Current, in amperes
4. Illuminance from lamps in foot-candles

Apparent power (volt-amperes), power factor, and illumination efficiency were calculated from this information. Tabular results are listed in Table 1. Explanation of the symbols is as follows:

E – Illuminance (foot-candles)

W – Power (watts)

I – Current (amps)

V – Supply Voltage (volts)

VA – Apparent Power (volt-amps)

PF – Power Factor (percent)

E/W – Illumination efficiency (foot-candles per watt) relative to full brightness.

Figure 6 contains graphic plots of (1) illuminance (2) power factor and (3) illumination efficiency as functions of input power. To determine if dimming would cause any degradation of the lamps and ballast, the luminaire under test was cycled from full to minimum brightness 7,000 times. After this cycling was completed, the measurements taken in the first test were repeated. All readings were identical with the original measurements.

For dimming, rheostats and autotransformers control the amplitude of the voltage sinewave; whereas, solid-state dimmers only allow the current to flow during a portion of each source voltage half-cycle. For full lighting intensity, current flows during the full time of each half-cycle, as shown in the upper trace of Figure 7. For half power intensity (corresponding approximately to half-light intensity), the solid-state dimmer allows no current to flow until the 90 degree peak of each half-cycle is reached. The bottom trace of Figure 7 shows these half-cycles. Solid-state dimmers have one undesirable condition: generation of radio frequency interference (RFI). This RFI can be effectively controlled by commercially available filter chokes that are installed in series with the load on a power-line. Information on RFI reduction on dimming lighting systems is furnished by the manufacturer of dimming hardware, such as General Electric and ATMOS Corporation.

From the information gathered it was determined that dimming is worthwile for energy conservation. However, the following are important points to consider:

1. Fluorescent dimming controls are designed for use with 40-watt rapid-start lamps only.

2. For best results, lamps of one color should be used in any specific application. Because different color lamps can dim at different rates, this can result in an undesirable color shift.

3. Loose lamp pin holders may prevent proper starting and result in shorter lamp life and poor performance at lower light intensities.

4. The use of dimming ballasts requires the installation of special circuit-interrupting lamp holders.

5. All connections throughout the system must be tight, and all luminaires should be grounded.

6. For optimum performance, all lamps should be aged 100 hours.

System Components. The CEL constant illumination level lighting control consists of a photocell sensor, input amplifier, level setting comparator, null-indicator, electromechanical driver, and dimmer. Figures 8 and 9 are photographs of the control system housed in a 15 x 8-3/4 x 4-inch metal cabinet. Figure 10 is a block diagram of the controlling system. Power consumption of the control system is 10 watts.

Appendix E contains the theory of operation and the circuit operation of the controlling system.

INSTALLATION OF EACH SYSTEM FOR EVALUATION

General Electric Light Sensing and Control System

The GE system was first installed to control the fluorescent lighting system in a portable office building (560-2) at CEL. The building consists of two sections with office spaces in each half. The southern half receives the most natural light and was selected for the evaluation. The lighting system for the southern half is powered by a single-phase 120-volt branch circuit with a 20-ampere circuit breaker in the power distribution panel and standard light switches in each office space. Installation of the GE system only required rewiring at the panel and 2 man-hours of labor. The GE control cabinet was mounted on the wall just below the power panel. The source power from the circuit breaker was controlled through relay No. 1 as shown in the wiring diagram (Figure C-2 of Appendix C). The photorelay was mounted on the southern outside wall as shown in Figure 11. A 2 sq ft area of the outside wall was painted with flat black paint, and the aperture of the photorelay was positioned to face this painted surface. The cell position was adjusted to turn off the lights on sunny days. After 2 weeks of controlling the lighting in the southern half of building 560-2, the GE system was removed and was relocated in CEL building 560.

In building 560 the GE system was used to control the lighting in the upper northwest hallway. Installation did not require rewiring of the hallway lighting system except at the panel and required 6 man-hours. Cost of installation, material plus labor, was $220.00. The fluorescent lighting system for the hallway consists of 16 two-lamp, ceiling-mounted luminaires. The lamps are positioned end-to-end, and all the luminaires are butted end-to-end to form a straight line down the center of the hallway. The electrical distribution for that area of the building is controlled from a power distribution panel in that hallway. The hallway lighting is controlled by a single-phase, 20-ampere circuit breaker. The GE control cabinet was wall-mounted just below the power panel. The output of the hallway lighting circuit breaker was controlled by relay Number 1 in the GE system shown in Figure C-2. The photorelay sensor was located in a four-sided, louvered ventilator located on the roof of building 560. This is an ideal location for the photo relay because the natural light that surrounds the photo relay is diffused by the louvers and remains at a fairly uniform level throughout the daylight hours. The system was adjusted to turn on the hallway lights only on fully cloudy days. On bright and sunny days sufficient light (natural and artificial) is provided in the hallway from the offices along the hallway and a window at the end of the hall. The average lighting level in the hall on a bright sunny day with the lights off is 10 foot-candles and on a fully cloudy day with the lights on, 30 foot-candles.

Another GE system was installed to control part of the fluorescent lighting system in the Instrumentation Division's work area (building 560, room 242). This particular area was chosen because the room has windows on three sides (east, south, and west exposures) that provide a large quantity of natural light. The lighting system consists of eight rows each containing nine luminaires, each luminaire with two 40-watt lamps. The lighting system was controlled by four wall-mounted switches. Because only the outer perimeter lights were to be controlled by the GE system and the other lights by the existing switches, some rewiring was required. Figure 12 shows the light luminaire layout, switches, power panel, and GE control cabinet location. The darkened areas are the lights controlled by the GE system. The photorelay was installed in a southern-facing, louvered ventilator located in the attic of building 560. The installation required 30 man-hours and cost $450.00, including the cost for the GE system.

CEL Two-Level Automatic Light Sensing and Control System

The CEL-developed, two-level, control was installed to control the fluorescent lighting system in the office of building 1195 at CEL. The lighting system consists of four luminaires, each containing two 75-watt, 96-inch lamps and a single ballast. The lighting system is powered by a single-phase, 120-volt, 60-Hz branch circuit with a standard ON-OFF wall switch. Figure 13 shows the lighting system layout in the office of building 1195. Figure D-1 in Appendix D is a schematic diagram of the two-level control. The photocell sensor was ceiling-mounted midway between the two rows of luminaires facing an 8-foot by 40-inch window. The two-level control circuit board was mounted on the end of luminaire 4 shown in Figure 14, and the two solid-state switches (triacs) were mounted on the inside of that luminaire. Luminaires 1 and 3 are controlled by level control one, and luminaires 2 and 4 are controlled by level control two. Eight man-hours were required to rewire the lighting system and to mount the sensor, two-level control circuit board, and solid state switches. The retail cost of the components used for the circuit board, solid state switches, and photocell sensor was approximately $40.00.

CEL Constant Illumination Level Lighting Control System

The CEL-developed, constant illumination level lighting control (hereafter called dimming control), four fluorescent dimming luminaires, and a photocell sensor were installed in the office of building 1195. Each of the four ceiling-mounted luminaires contained two 40-watt lamps and one dimming ballast. The photocell sensor was mounted in the center of the ceiling facing the floor. The location of the dimming system luminaires are numbered 5, 6, 7 and 8 in Figure 13. Power to the dimming system is 120-VAC, 60-Hz, single phase, and was monitored with a Weston wattmeter with a full-scale reading of 500 watts. Each luminaire consumes 100 watts at full brightness, and the dimming system control circuitry with the dimmer consumes 10 watts, giving a maximum power consumption of 410 watts.

EVALUATION RESULTS

General Electric Light Sensing and Control System

The GE system was first installed to provide controlled lighting in the southern half of portable office building 560-2, but soon it became apparent that the system was not suitable for that type of building. Although each office has a window for natural lighting, as shown in Figure 11, the window size and location convey insufficient or excessive lighting levels to each desk at various times on bright sunny days. Repositioning the desks did not help appreciably. Glare and shadows from direct sunlight required the closing or partial closing of venetian blinds. Consequently, the controlling system was mostly on override.

So, for proper evaluation, the GE system was relocated to control the upper northwest hallway lighting of building 560. The GE system has controlled the hallway lighting, trouble free, since January 1976. Because the hallway is normally used for the passage of personnel to and from their offices, only low illumination levels are required. The GE system turns the lights out on all but fully overcast days. By using this turn-off level, the maximum energy and cost savings can be achieved.

The GE system controlling the lighting in the Instrumentation Division working area has operated, trouble free, for approximately 4 months. Since this working area contains desks and electronic workbenches, an illumination level of 50 foot-candles or greater is required. Several adjustments of the photorelay were required to provide the 50 or more foot-candles of illumination necessary at workbench level under all areas of the controlled lights. Light meter readings were taken on several partly cloudy days with the controlled lights out, until a day that all areas under the controlled light locations had 50 foot-candles of illumination or greater. The photorelay was adjusted so the turn-off threshold was at this level.

A human element was immediately encountered: people are creatures of habit, and habits are hard to break. The personnel working in this room normally keep the venetian blinds closed and all the lights on. Because the sensor senses outside light, on most sunny days the GE system turned off the controlled lighting. By adjusting the blinds to compensate for glare and to direct sunlight as the day progresses, personnel can take full advantage of the natural light. Instead of opening the venetian blinds to take advantage of the natural light, however, the override switch was activated.

One undesirable condition encountered during the evaluation was that on certain days the controlled lights would periodically turn on and off. This was caused by clouds passing by and momentarily shading the sensor. This turn-on/turn-off cycle is very distracting to working personnel, and on some days the system had to be turned off or the override switch activated. This condition does not occur on the GE system controlling the hallway lighting because the sensor is adjusted to turn the lights on only on fully cloudy days.

CEL Two-Level Automatic Light Sensing and Control System

The two-level control has controlled the office lighting of building 1195 for 9 months without failures. System adjustments were made to light luminaires 2 and 4 (as shown in Figure 13) when the illumination level on the desk top under luminaire 2 was just below 50 foot-candles. When the illumination level on the top of the desk under luminaire 1 was just below 50 foot-candles, the other control section was adjusted to turn on luminaires 1 and 3. Adjustments in this sequence allow luminaires 1 and 3 to turn off before 2 and 4. All lights normally come on at the start of the day. As the natural light increases enough to maintain 50 foot-candles on the desk surface under luminaire 1, luminaires 1 and 3 will turn off. Then, when the natural light increases enough to maintain 50 foot-candles on the surface of the desk under luminaire 2, lights 2 and 4 turn off.

The two-level control operated in this manner for approximately 5 months. During this time it was found that when either set of lights turned on or off, the eyes required considerable time to adjust to the new illumination level because of the sudden change. A different control configuration was devised to help eliminate this problem. The lighting luminaires were rewired so that section one of the controlling circuit would turn on one row of the two rows of lamps in each luminaire, and section two of the control would turn on the other row of lamps in each luminaire. One section of the two-level control was adjusted to turn on half of the lamps in each luminaire when the natural light level was just under 50 foot-candles at the desk top under luminaire number 2. Then, when the natural light level of the desk under luminaire 1 was just under 50 foot-candles, the other section of the two-level control was adjusted to turn on the other lamp in each luminaire. The configuration allowed the eyes to adjust to new illumination levels more quickly and with less distraction.

Over the long evaluation time (9 months), it was found that as the seasons and the sun angles changed, the natural light level distribution changed in the office. This required a readjustment of the threshold setting of the two-level control circuit. For optimum operation, two adjustments per year will be required. The geographic location of CEL required these adjustments in November and April. At other geographic locations, these dates probably will differ.

CEL Constant Illumination Level Lighting Control System

The CEL dimming system has operated in the office of building 1195, trouble free, between March and August 1976. To determine the optimum location for the photocell sensor (PCS), many locations were tried. The PCS was first located on the ceiling next to the two-level control photocell, facing the window. This location was completely unsatisfactory. The PCS sensed only natural light in this location. This caused the dimming system control to turn off the lighting before the proper levels of natural light were reached. Next, it was placed on the ceiling at the opposite end of the office. In this location the dimming system lights would dim as the natural light increased, but the dimming system would remain on longer than was necessary. The PCS was then located on top of the desk under luminaire 6 shown in Figure 13. Although the dimming system operated satisfactorily with the PCS in this location there were undesirable conditions. A person standing in certain locations in the office would shade the PCS, causing the dimming system to unnecessarily brighten. Also, persons standing in front of or leaning over the desk caused the dimming system lights to brighten. After trying many locations it was found that for this office the optimum location was on the ceiling facing down in the center of the room. At this location the PCS has maximum advantage of both natural and artificial light.

CEL is located on the Pacific coast and during the period (April) of evaluation there were many foggy and overcast days; on some mornings, fog and a totally overcast sky. With these conditions, by 7:30 a.m. the dimming system lights would start to dim. The total power indicated on the wattmeter for full brightness of the system is 410 watts, but by 7:30 a.m. the wattmeter would typically indicate 350 watts; at 8:00 a.m., 300 watts; 9:00 a.m., 200 watts; and around 10:00 a.m., the lights would be off. The fog would be gone and replaced with a broken overcast sky. The average illumination level throughout the office would be approximately 70 foot-candles. A person working in the office usually doesn't notice when the dimming system lights go off because the illumination changes are so subtle. As evening approaches or the day darkens, the dimming system comes on so subtly that it usually is not noticed. The dimming system is easily adjusted to maintain a specific illumination level by using the bright or dim button, as explained in Appendix E.

ECONOMIC ANALYSIS

To determine the monetary and energy savings, data on climatic conditions at five geographical locations around the continental United States was used. This information was extracted from the Climatological Data National Summary.* The data used was the number of clear, partly cloudy, and cloudy days that occurred during the years 1970 through 1974. The data was averaged to give a 5-year mean of these weather conditions for the following cities:

		Clear	Partly Cloudy	Cloudy
1.	Indianapolis, Indiana	89	100	176
2.	Los Angeles, California	146	116	103
3.	Miami, Florida	80	170	115
4.	Minneapolis, Minnesota	98	101	166
5.	Washington, D. C.	101	104	160

*Climatological Data National Summary, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

General Electric Light Sensing and Control System

The analysis was done using the following: two 40-watt rapid-start lamps and a single ballast in a luminaire consuming approximately 100 watts during an 8-hour day. The number of days the lights would be off are divided into 7-day weeks, then a 5-day week to allow for the days falling on weekends. Half of the partly cloudy days are assumed to be days the lights would be off for systems that had the turn on/off threshold adjusted for partly cloudy days. The installation and system costs are those that prevailed at CEL. The kilowatt-hour charge is currently 3.3 cents at CEL.

For the controlled hallway lighting 16 luminaires consume 100-watts each (1.6 kW total), and the system was adjusted to turn on only on fully cloudy days. Table 2 shows the economic analysis for the hallway lighting computed for the five geographic locations.

The controlled lighting in room 242 consists of 34 luminaires consuming approximately 100 watts of power each (3.4 kW total). The GE system was adjusted for a turn on/off threshold on some partly cloudy days. For the economic analysis, the lights are assumed to be off for half of the partly cloudy days. Table 3 shows the economic analysis for the controlled lighting in room 242 computed for the five geographic locations.

CEL Two-Level Automatic Light Sensing and Control System

The power consumed by each luminaire used for evaluation of the two-level control is approximately 175 watts for a total of 700 watts for the office lighting. In making the economic analysis, one difference between the GE system and the two-level control was noted. The GE system was off for some partly cloudy days and on for others, so the total partly cloudy days were divided in half, yielding 50% clear and 50% cloudy. To compute the savings for the CEL two-level control, 75% of the partly cloudy days were considered clear, and 25% were considered cloudy. Although the two-level control was off for the same partly cloudy days as the GE system was off, only half of the two-level control was on for the same partly cloudy days as the GE system was on. Thus, the two-level control produced greater economic and energy savings. Table 4 shows the economic analysis for the small office in building 1195 computed for five geographic locations.

CEL Constant Illumination Level Lighting Control System

First, it should be pointed out that it would not be cost-effective to retrofit an existing fluorescent lighting system with an automatic dimming system. All the ballast and lamp holders in each luminaire would require replacement. The retail cost of a dimming ballast is approximately $30.00 compared to $10.00 for a standard ballast. The circuit-interrupting lamp holders are inexpensive ($.70 each), and a solid-state dimmer costs approximately $30.00. The greatest expense would be for labor to replace the hardware in an existing lighting system. For new construction, or for replacement of an archaic existing lighting system, a dimming lighting system would be cost-effective because of the energy saved. Luminaires that are designed with dimming hardware are less expensive than if existing luminaires were retrofitted. The cost of the automatic dimming system control if commercially available should be approximately $150.00. The cost of a commercially available modular manual dimming control is $98.00. The cost of the electronic circuit to automate the unit should be $50.00 or less.

The cost of the constant illumination level lighting system installed in the office of building 1195 is as follows:

1. Luminaires with ballast and special lamp holders, $39.68 each
2. Automatic control, $150.00
3. Installation labor, $80.00

The total cost of the installation was $388.72. Table 5 shows the economic analysis of the dimming system computed for the five geographic locations based on the following conditions:

On about half of the partly cloudy days, the lighting system will be off 4 hours. On the remaining partly cloudy days, the lighting stays on all 8 hours. The average power consumed while the lights are on is 60%. On fully cloudy days, the average power consumed is 72%. Total power consumed by the lighting system at full brightness is 410 watts. Again, the cost per kW-hr is 3.3 cents.

A more realistic economic analysis is made for a hypothetical constant illumination level lighting system using the above conditions. The lighting system contains 100 luminaires. Each luminaire contains two 40-watt fluorescent lamps. Each luminaire consumes 100 watts for a total of 10 kW. Installation cost is as follows:

1.	100 luminaires $39.00 each	= $3,900.00
2.	Control system with eight dimmers	= 390.00
3.	Labor, 120 man-hours at $10.00/man-hour	= 1,200.00
	TOTAL	= $5,490.00

The analysis shown in Table 6 is computed for the five geographic locations. It must be emphasized that with the escalating utility rates the payback times will probably decrease.

DISCUSSION

If the foot-candle level in offices, hallways, work areas, or other spaces is higher than the recommended light levels, several ways can be used to save energy: (1) remove lamps from some luminaires; (2) turn off selected luminaires; (3) replace lamps with lower wattage lamps; (4) automatically control the lighting system to maintain required lighting levels. The basic idea is energy conservation.

Some believe that removing lamps or leaving burned-out lamps in luminaires will save the wattage of the lamps removed or burned out. This is not always the case. For incandescents this is true, but not for fluorescents. In multiluminaire lighting systems, when both 40-watt fluorescent lamps are removed from alternate luminaires, the ballasts in these luminaires will continue to consume 8 to 9 watts. Removing only one lamp will cause the other lamp to be extinguished, but the luminaire will continue to consume 11 or 12 watts. Also, the lamp remaining in the luminaire may become inoperable, and the ballast may be damaged. If lamps must be removed, both lamps should be removed from a luminaire.

Connecting selected luminaires to convenient switches is a better way to control lighting levels. Selected luminaires can be turned off when not needed or on again when required. This may work in those cases where conscientious personnel work in that area. Since the human element is now involved, someone must operate the switch. As time passes, the switches are often forgotten.

Replacing lamps with lower wattage lamps will save energy, but again the human element is involved. At some time during most working days sufficient natural light exists to maintain required illumination levels, but again someone must operate the switch. Usually the lighting system is ignored.

The most logical method of saving energy in a lighting system would be to automatically control the system to maintain the required lighting level. As previously stated, an industry survey was conducted to find what light sensing and controlling systems are commercially available. Of the two that are commercially available, only the GE system can control incandescent or fluorescent lighting systems. Because most indoor lighting systems are either incandescent or fluorescent, only the GE system was evaluated. The GE system meets the requirements for many applications to save energy by automatically controlling lighting systems but has limitations because the photorelay reacts instantaneously to sudden changes of light. This sudden reaction causes the lighting system to cycle on and off, which can be very distracting if it is controlling a lighting system in an office where people are working. Sudden lighting changes in some lighting systems, such as in a hallway, would not normally be distracting to working personnel. To control more than one portion of a GE controlled lighting system requires additional GE controls. In some applications, this may be justified by the increased energy saved. To retrofit existing incandescent or fluorescent lighting systems for control by the GE system would not, in most cases, require extensive rewiring, making it a potentially cost-effective system.

The CEL-developed two-level control is much more flexible than the GE system. It is easy to adjust, and a built-in time delay eliminates the lights turning off and on as clouds go by. It can be installed inside a fluorescent luminaire with a minimum of effort and can have multiple levels of control using one sensor. The initial cost of the two-level control is inexpensive, installation is simple, making it cost effective. To retrofit existing incandescent or fluorescent lighting systems would require a minimum of rewiring in most cases. The two-level control circuit board and solid-state switches can also be installed in a power distribution panel, and the wires to the photocell sensor have low voltage (12 volts) with a wire size no larger than AWG 20.

The CEL-developed constant illumination level control lighting system is operationally the most ideal system. By maintaining a constant illumination level, the dimming system only consumes the lighting energy needed and not an excess amount. The automatic dimming system control is analogous to a thermostat, continually adjusting lamp lumen output to maintain a pre-set level. Personnel working in an area where the lighting is controlled by automatic dimming are not distracted by sudden light-level changes, being so slow that they normally are not noticed. Also, because the illumination level changes are slow, the eyes adjust without straining. Retrofit of an existing incandescent lighting system can be accomplished with a minimum of rewiring, making the system potentially cost effective. To retrofit an existing fluorescent lighting system is not presently cost effecive, but may become cost effective as the cost of electrical power increases or if the cost of dimming ballasts decreases. For new construction or for replacement of an archaic lighting system, it is cost effective. The payback time is longer than for the GE system or CEL two-level control, but because of the more desirable effect of dimming than turning lights off and on, the tradeoff may be worth the longer payback time. In the economic analysis of each of the systems, the current CEL rate per kW-hr was used; at many other facilities, this rate may be as much as double the CEL rate. So the cost-effectiveness of the system will vary for different facilities.

On any lighting system that is automatically controlled using a photosensor, the lights should be automatically cycled off at a pre-set time. This is to prevent the lighting system from unnecessarily turning on at dusk. An inexpensive means would be a time clock.

CONCLUSIONS

1. Controlling lighting systems with light sensing and controlling equipment can save energy.

2. Automatic dimming of a lighting system is the most ideal system evaluated by CEL.

3. The two-level light sensing and control system developed by CEL is the most cost-effective system evaluated by CEL.

4. The GE system can be used in many applications, but as evaluated by CEL has some undesirable conditions such as:

a. Sudden changes in natural light causes sudden turn-on and turn-off.

b. For more than one level of control a separate GE system is required for each controlled level.

RECOMMENDATIONS

1. Automatic lighting control should be used where practical, instead of removing lamps to save energy.

2. Automatic lighting control should be utilized where practical on all new construction.

3. When existing lighting systems are replaced or updated, controlled lighting should be utilized where it is practical.

4. Further research is required to improve the performance and cost-effectiveness of the CEL constant illumination level dimming and control system.

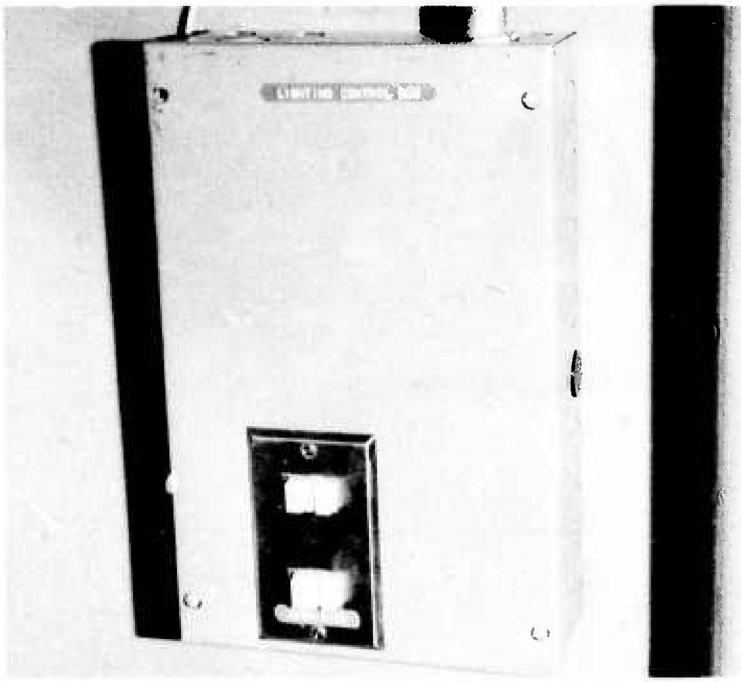


Figure 1. GE control for light sensing and control system.

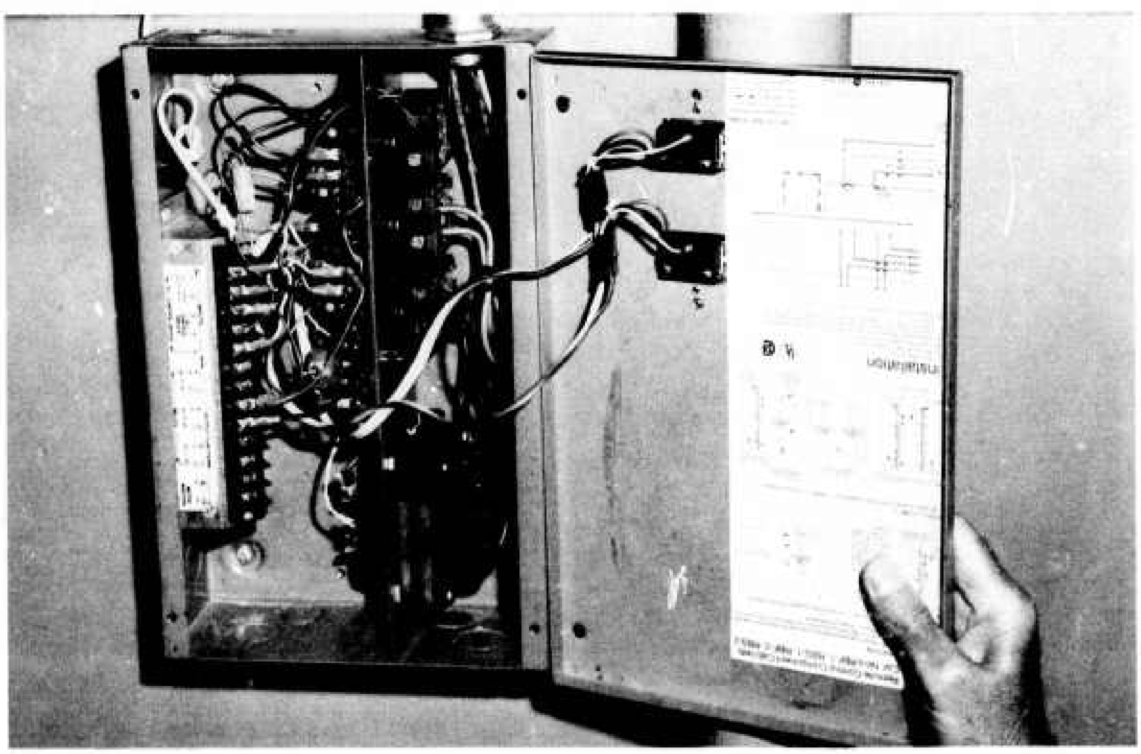


Figure 2. GE control with cover removed.

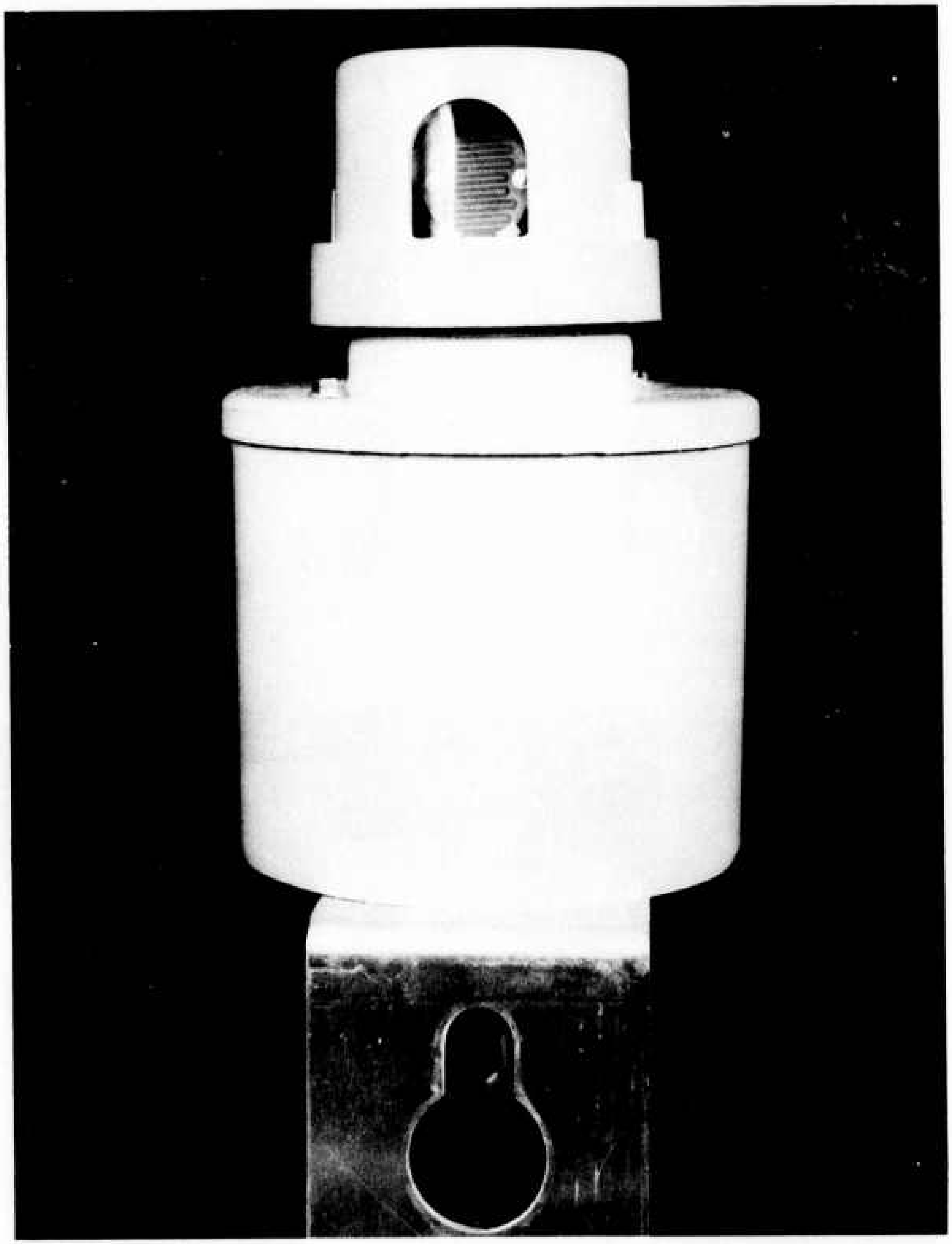


Figure 3. Photorelay used with GE light sensing and control system.

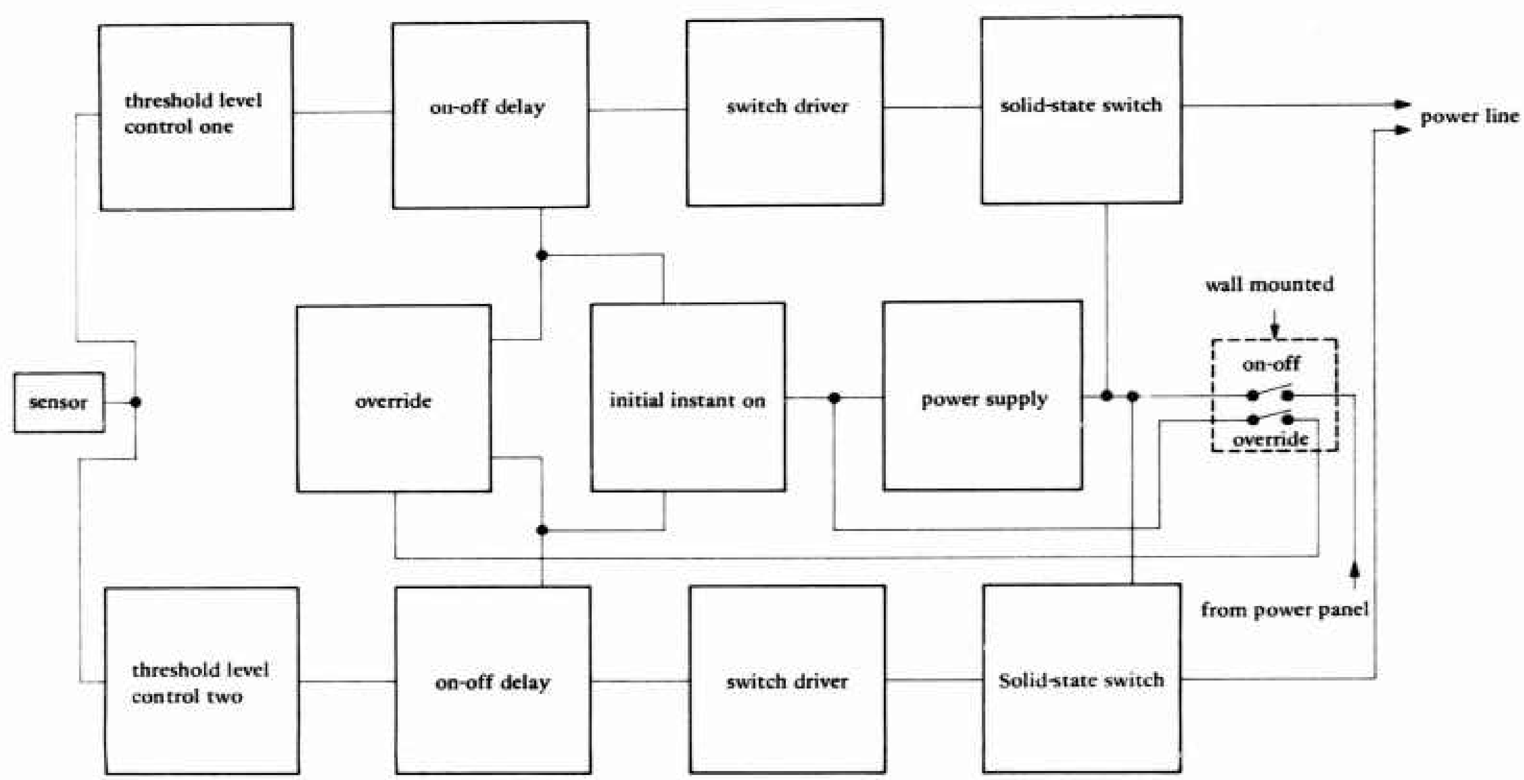


Figure 4. Block diagram of automatic two level light sensing and control.

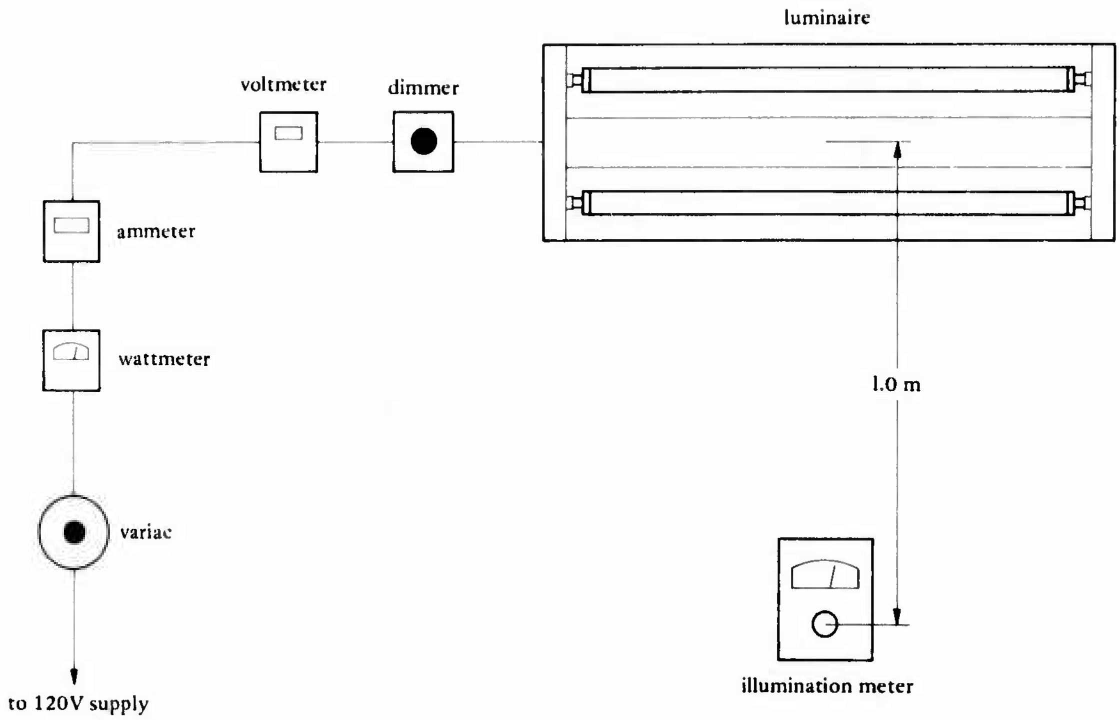


Figure 5. Test setup for dimming evaluation.

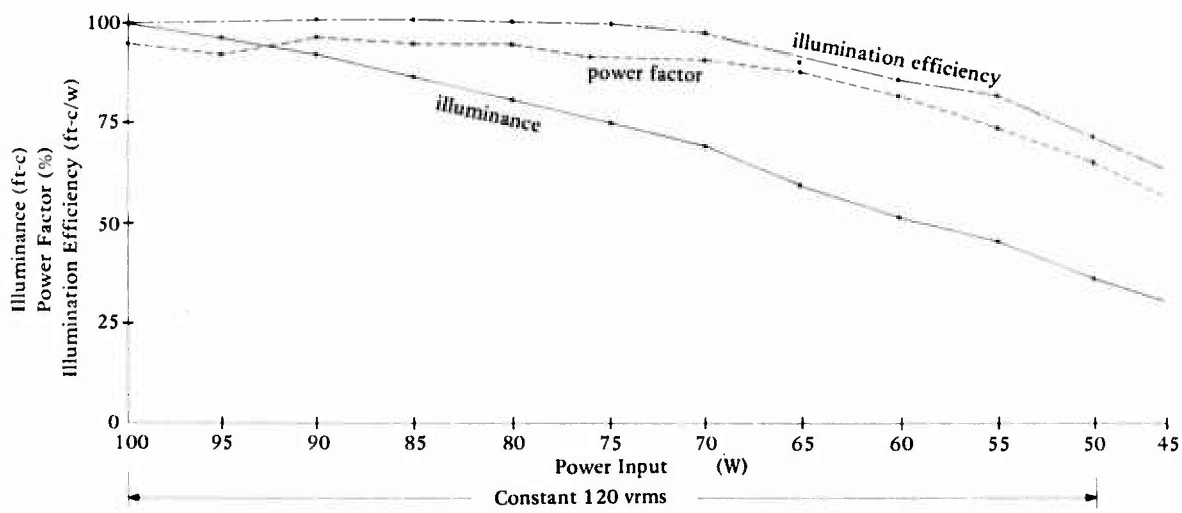


Figure 6. Graphic plots of dimming test results.

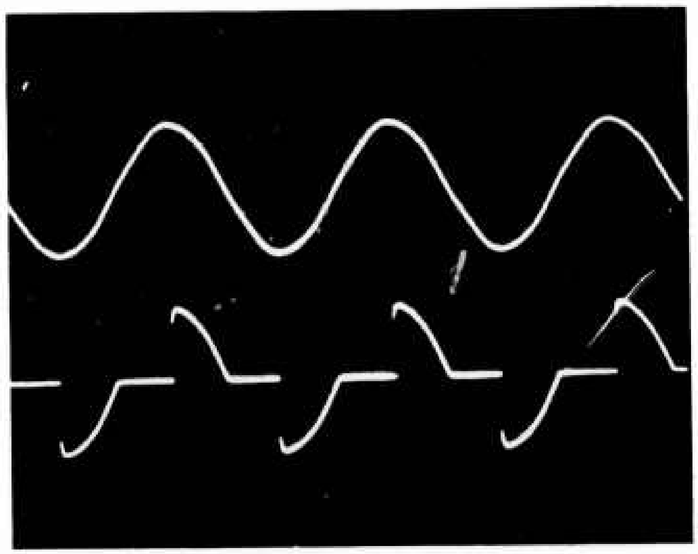


Figure 7. Oscilloscope traces showing voltage sinewave, top without solid-state dimmer and bottom with solid-state dimmer.

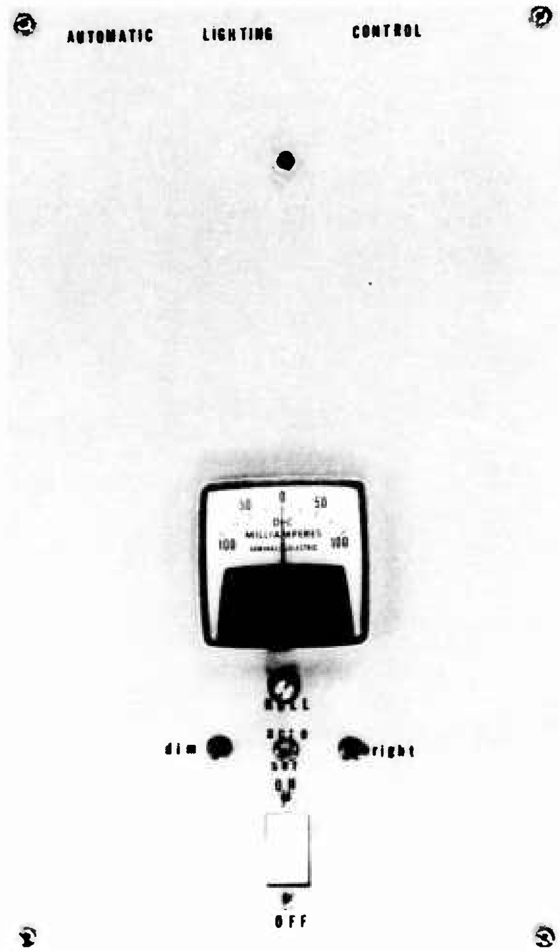


Figure 8. Constant illumination level lighting control box.

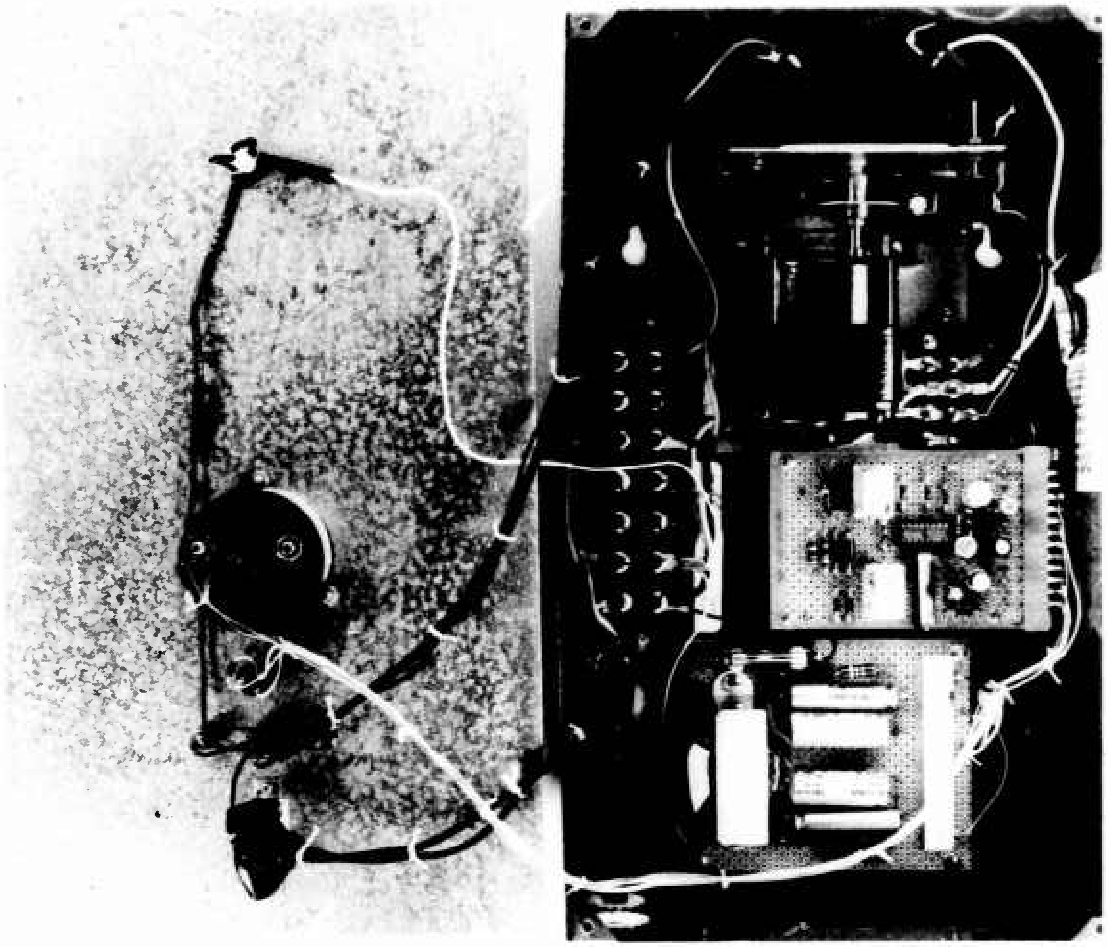


Figure 9. Constant illumination level lighting control box with cover removed.

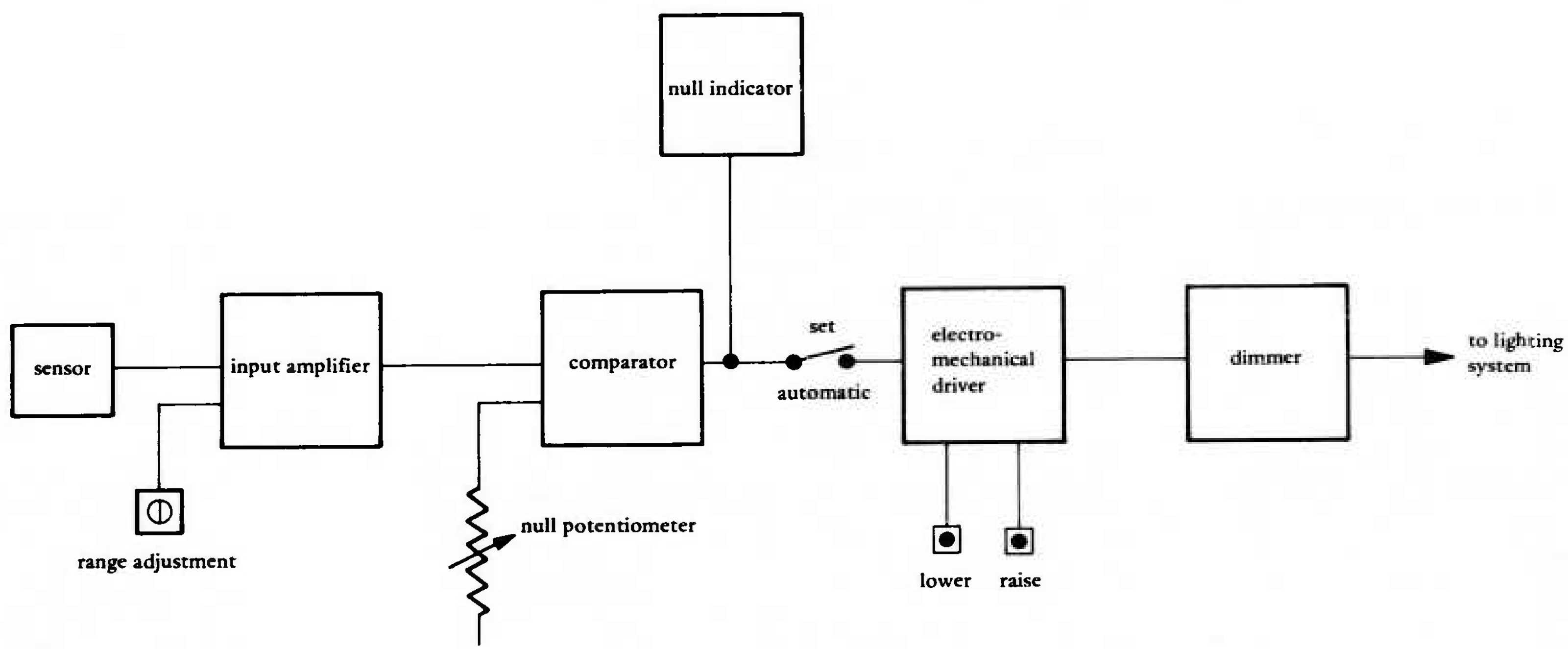


Figure 10. Block diagram of constant illumination control.

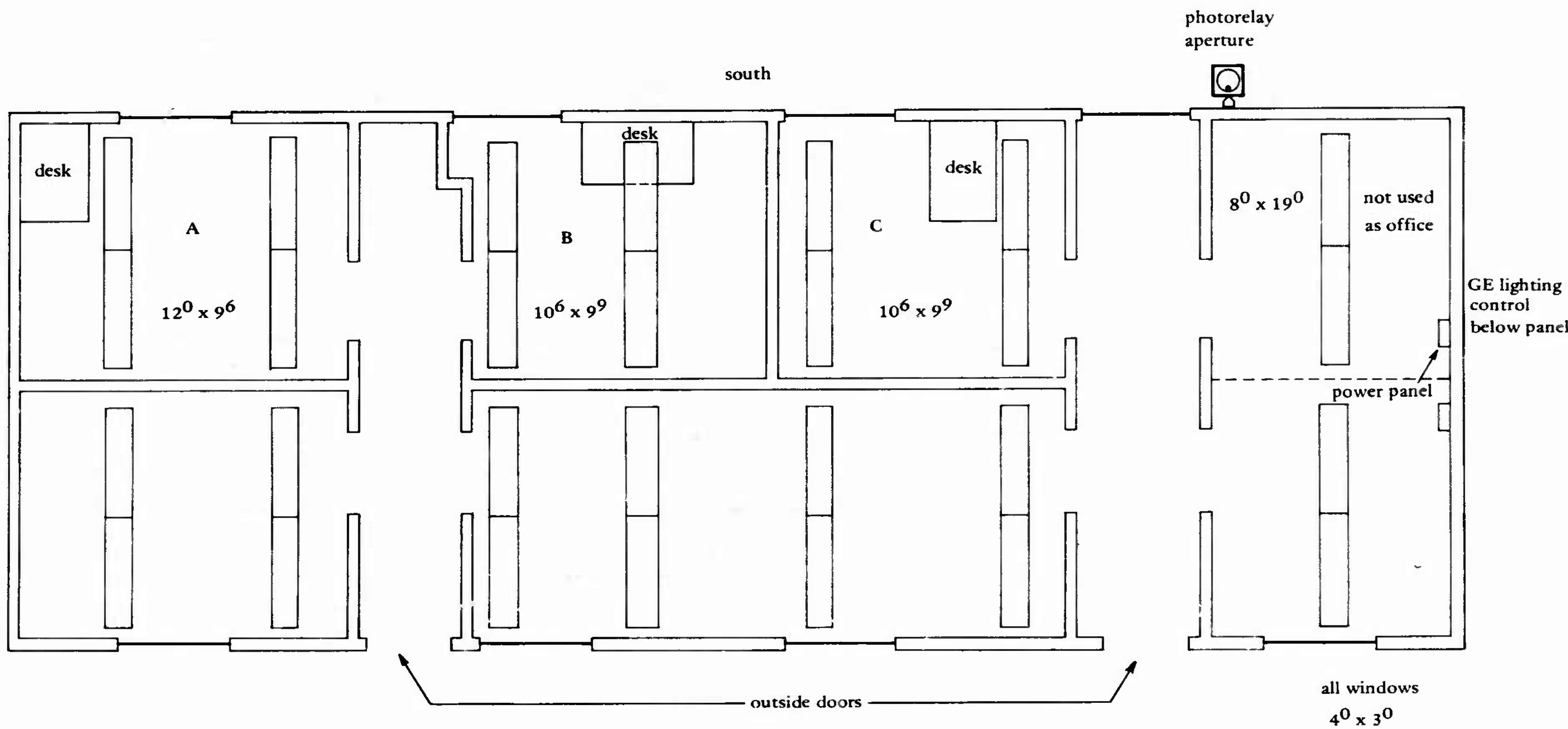


Figure 11. Physical layout of portable office building 560-2.

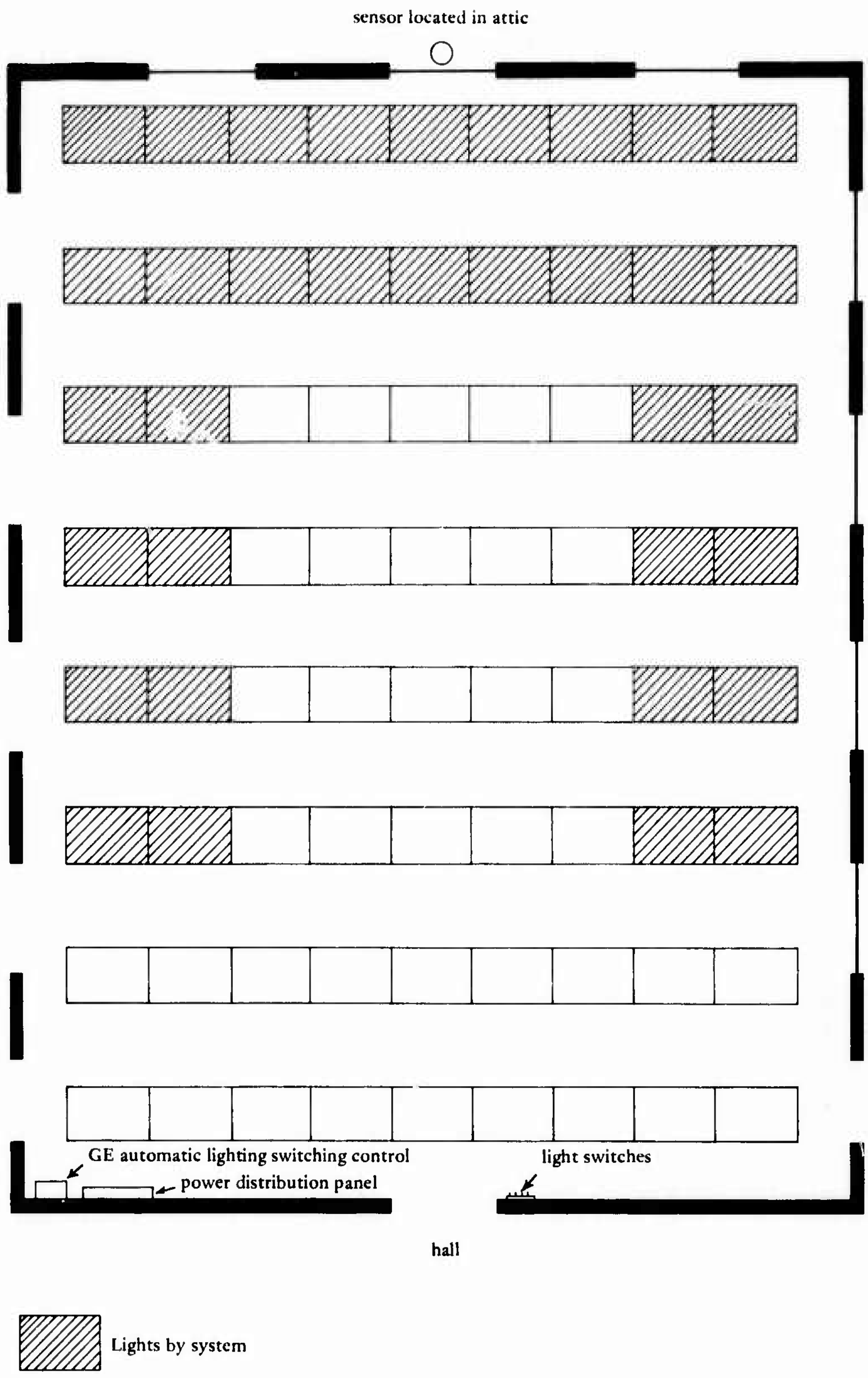


Figure 12. Layout of luminaires, switches, power panel and General Electric control.

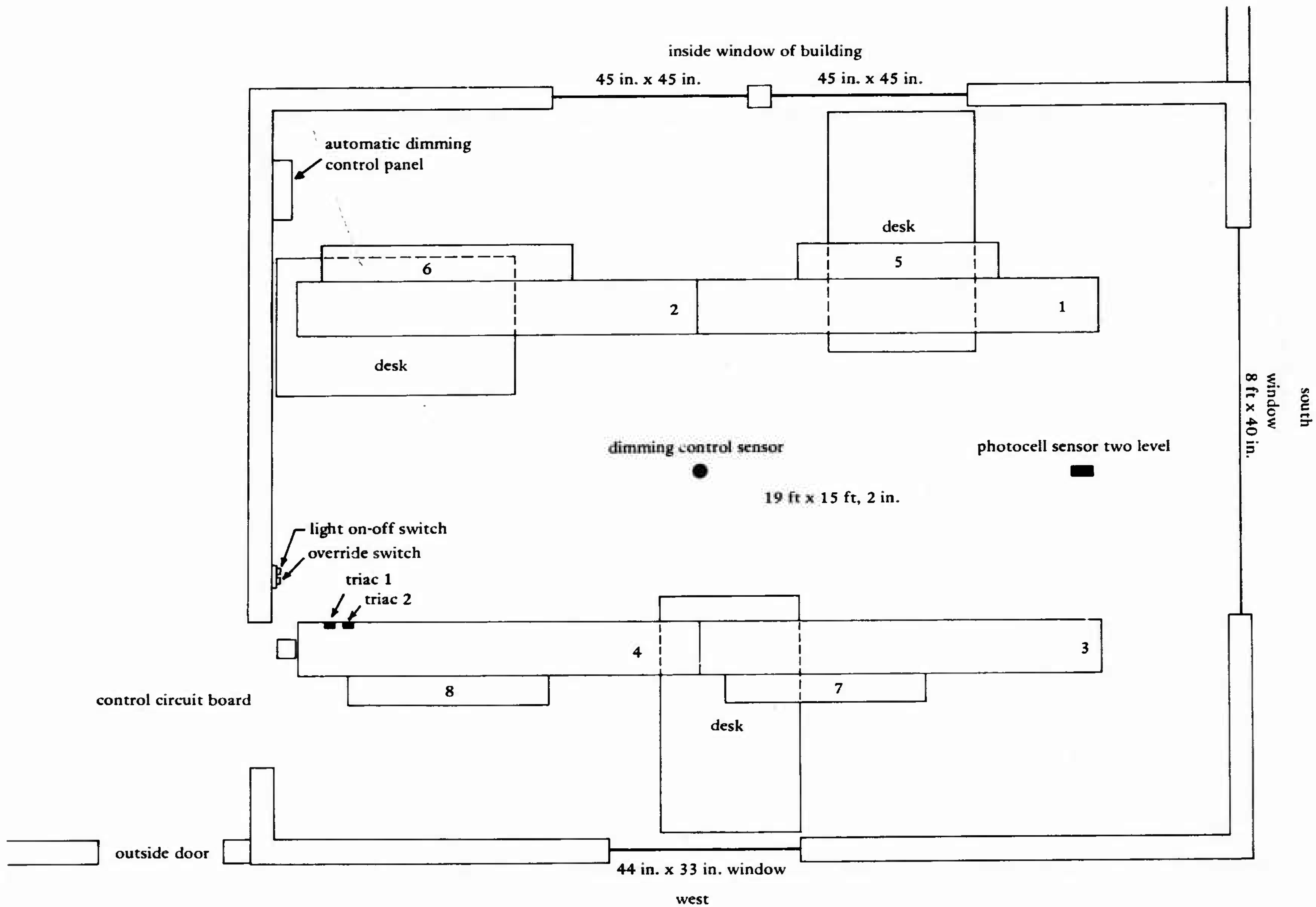


Figure 13. Lighting system layout in office of building 1195.

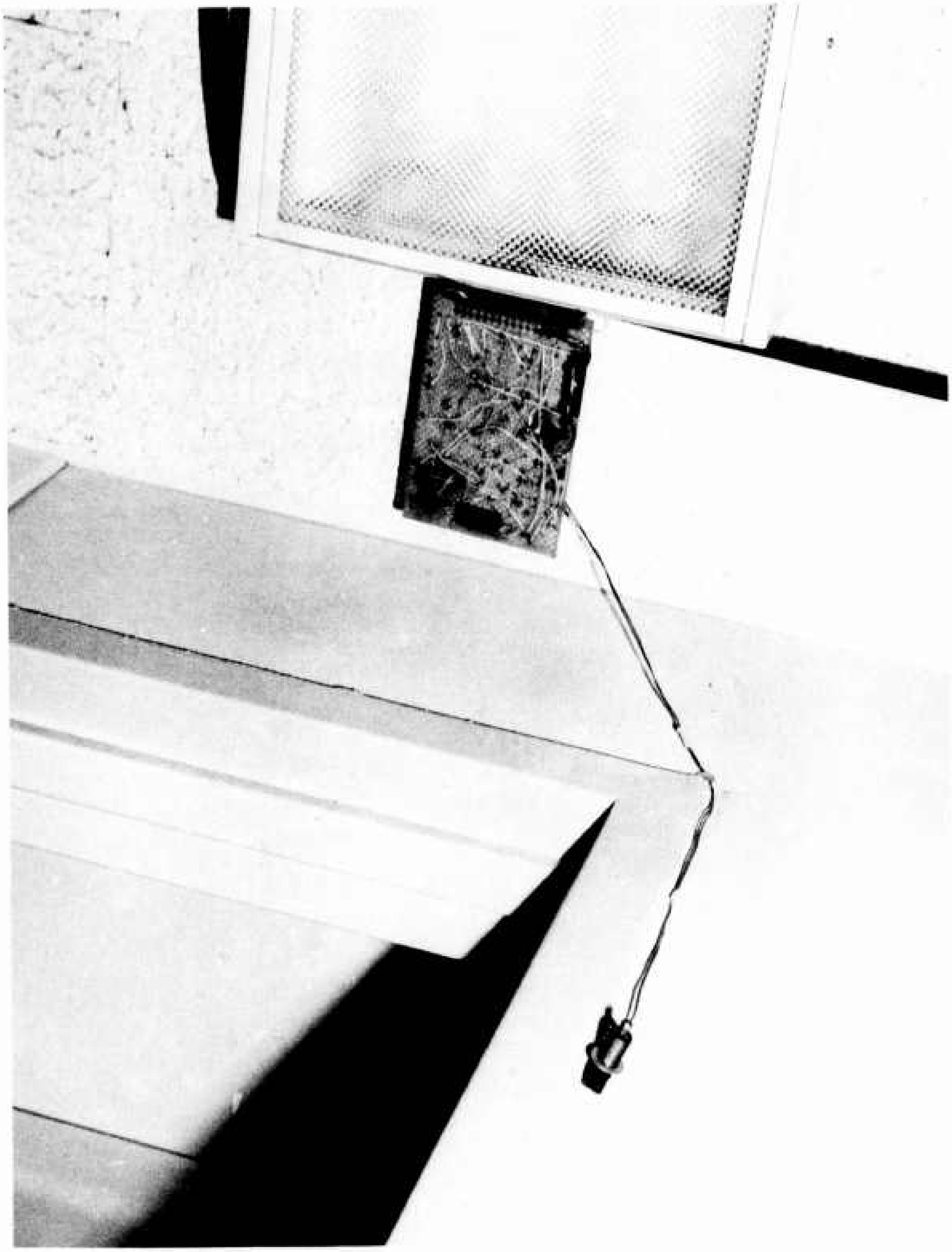


Figure 14. Two-level lighting system control board mounted on end of luminaire.

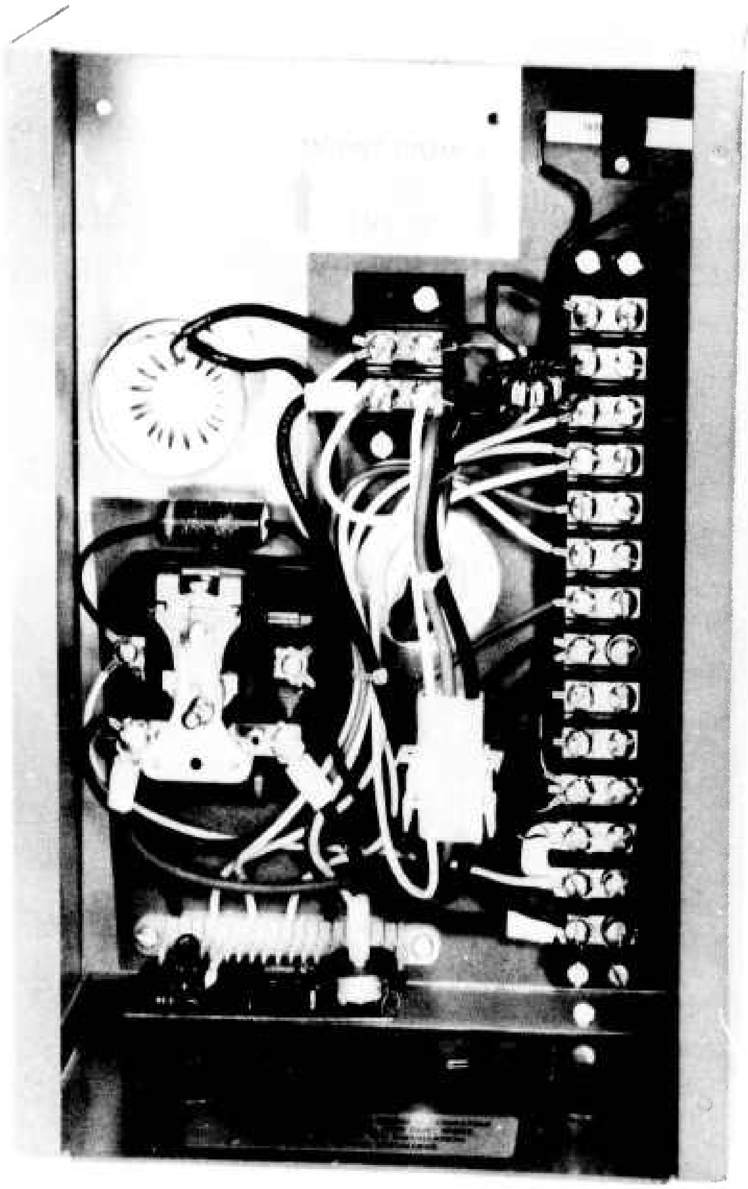


Figure 15. Commercially available modular manual dimming control that can be automated with the CEL-developed circuit.

Table 1. Tabular Results of Dimming Investigation

Illuminance E (ft-c)	Power W	Current I (A)	Supply Voltage (V)	Apparent Power VA (V-A)	Power-Factor (%)	Illumination Efficiency, E/W (ftc/W)
100	100	0.877	120	105	95	1.00
96	95	0.864	120	104	92	1.01
92	90	0.787	120	94	96	1.02
86	85	0.746	120	90	94	1.01
80	80	0.704	120	85	94	1.00
74	75	0.687	120	82	91	0.99
68	70	0.647	120	78	90	0.97
58	65	0.626	120	75	87	0.89
51	60	0.619	120	74	81	0.85
45	55	0.624	120	75	73	0.82
36	50	0.640	120	77	65	0.72
28	45	0.712	120	85	53	0.62
21	40	0.819	120	98	41	0.53

Table 2. Economic Analysis for GE System Used for Hallway Lighting

City	Days On	Days Off	Installation Cost ($)	Cost/Year Without Control kW-hr at 3.3 ($)	Saving/ Year ($)	Without Control (kW-hr/Yr)	With Control (kW-hr/Yr)	Savings (kW-hr/Yr)	Payback Years[a]
Indianapolis	176	189	220.00	109.82	57.02	3,328	1,600	1,728	3.8
Los Angeles	103	262	220.00	109.82	79.20	3,328	928	2,400	2.8
Miami	115	250	220.00	109.82	75.43	3,328	1,043	2,285	2.9
Minneapolis	166	191	220.00	109.82	57.63	3,323	1,581	1,747	3.8
Washington, D. C.	160	205	220.00	109.82	61.85	3,323	1,448	1,875	3.5

[a]Simple amortization.

Table 3. Economic Analysis for GE System Used for Large Office Lighting

City	Days On	Days Off	Installation Cost ($)	Cost/Year Without Control kW-hr at 3.3 ($)	Saving/ Year ($)	Without Control (kW-hr/Yr)	With Control (kW-hr/Yr)	Savings (kW-hr/Yr)	Payback Years[a]
Indianapolis	226	139	450.00	233.38	89.35	7,072	4,365	2,707	5
Los Angeles	161	204	450.00	233.38	130.21	7,072	3,128	3,944	3.5
Miami	200	165	450.00	233.38	105.96	7,072	3,862	3,210	4.2
Minneapolis	216	149	450.00	233.38	95.64	7,072	4,202	2,870	4.7
Washington, D. C.	212	153	450.00	233.38	98.33	7,072	4,120	2,952	4.6

[a]Simple amortization.

Table 4. Economic Analysis for CEL Two-Level System Used for Small Office Lighting

City	Days On	Days Off	Installation Cost ($)	Cost/Year Without Control kW-hr at 3.3 ($)	Saving/ Year ($)	Without Control (kW-hr/Yr)	With Control (kW-hr/Yr)	Savings (kW-hr/Yr)	Payback Years[a]
Indianapolis	204	162	130.00	48.04	21.24	1,456	812	644	6.1
Los Angeles	131	234	130.00	48.04	30.49	1,456	532	924	4.2
Miami	157	207	130.00	48.04	27.72	1,456	616	840	4.7
Minneapolis	196	174	130.00	48.04	23.09	1,456	756	700	5.6
Washington, D.C.	186	179	130.00	48.04	23.49	1,456	744	712	5.5

[a]Simple amortization.

Table 5. Economic Analysis for CEL Constant Illumination Lighting System Installed in Building 1195

City	Days On	Days Off	Installation Cost ($)	Cost/Year Without Control kW-hr at 3.3 ($)	Saving/ Year ($)	Without Control (kW-hr/Yr)	With Control (kW-hr/Yr)	Savings (kW-hr/Yr)	Payback Years[a]
Indianapolis	157	208	388.72	28.14	16.00	852.8	367.81	484.99	24.3
Los Angeles	108	257	388.72	28.14	19.79	852.8	253.01	599.79	19.6
Miami	134	231	388.72	28.14	17.78	852.8	313.92	538.88	21.8
Minneapolis	150	215	388.72	28.14	16.14	852.8	351.41	501.39	24.0
Washington, D. C.	147	218	388.72	28.14	16.78	852.8	344.40	508.40	23.2

[a]Simple amortization.

Table 6. Hypothetical Economical Analysis of CEL Constant Illumination Lighting System Consisting of 100 Luminaires, Each Containing Two 40-Watt Fluorescent Lamps.

City	Days On	Days Off	Installation Cost ($)	Cost/Year Without Control kW-hr at 3.3 ($)	Saving/ Year ($)	Without Control (kW-hr/Yr)	With Control (kW-hr/Yr)	Savings (kW-hr/Yr)	Payback Years[a]
Indianapolis	157	208	5,490.00	686.40	396.36	20,800	8,971	11,200	14.0
Los Angeles	108	257	5,490.00	686.40	482.76	20,800	6,171	13,829	11.4
Miami	134	231	5,490.00	686.40	435.20	20,800	7,656	12,344	12.6
Minneapolis	150	215	5,490.00	686.40	403.56	20,800	8,571	11,429	13.6
Washington, D. C.	147	218	5,490.00	686.40	409.20	20,800	8,400	11,600	13.4

[a]Simple amortization.

Appendix A

INDUSTRY SURVEY

Literature in the form of brochures, catalogs, and manuals were received from the following companies:

1. General Electric
2. Westinghouse
3. Sylvania
4. Philips (Netherlands)
5. Wide-Lite Corporation
6. Verd-A-Ray Corporation
7. Appleton Electric Company
8. Quality Outdoor Lighting
9. American Electric (ITT)
10. World Lighting Products
11. Lutron Electronics Company, Inc.
12. Roxter Corporation
13. Columbia Lighting, Inc.
14. Munro Lighting, Inc.
15. Perma Division Munro Lighting, Inc.
16. Polrized Corporation of America
17. Claude Neon Industries, Ltd.
18. Thorn Lighting Limited (England)
19. Swivelier Company, Inc.
20. Alkro Manufacturing Company (Lighting Division)
21. Welshbach Lighting Products Company, Inc.
22. Hubbell Lighting Division
23. Kingston Industries Corporation
24. Dual-Lite Company
25. Holophane Division, Johns-Mansville Corporation
26. Duro-Test Corporation
27. Universal Manufacturing Corporation
28. Magnaray International

29. ASCO Control, Automatic Switch Company
30. Tensor Corporation
31. Benjamin Electric Manufacturing Company
32. Spectrolab
33. Westron Corporation
34. Spaulding
35. Crouse-Hinds Company

Appendix B

WIDE-LITE SENSING AND CONTROL SYSTEM

The Wide-Lite Corporation light sensing and control system can only operate high intensity discharge lamps (HID) with associated dimming ballasts. The system consists of a photocell sensor and a calibrated monitor which interact with master control panels and dimming ballasts to provide constant level illumination from HID lamps. With this system a photocell senses the average room illumination level, then transmits this level to the monitor which compares this level with a pre-set level. The monitor signals the master controller, which in turn increases or decreases lamp lumen output to maintain the pre-set lighting level.

The Wide-Lite light sensing and control system is an ideal system because it maintains a constant lighting level. Persons working in areas where the lighting is controlled at a near-constant level would not be distracted by lighting changes. The main disadvantage of the system is that it cannot be used with most existing lighting systems. The cost of completely changing the lighting system in existing facilities to the Wide-Lite system would be prohibitive. On new construction, the energy savings of such a lighting system will, in all probability, prove cost-effective. Because HID light is not generally used for office and work area lighting, the Wide-Lite system was not evaluated by CEL.

Appendix C

GENERAL ELECTRIC OPERATIONAL DESCRIPTION

In operation, the remote-control interface receives a maintained signal (on or off) from the photocell relay and converts it into a momentary pulse to three relay control channels and one motor master channel (see Figures C-1 and C-2). The three relay channels operate independently; an override momentary switch can be used to activate the relays on one channel without affecting relays on the remaining channels. The RCI-1 can be used to pulse an on or off motor master. The RCI-1 motor master and relay channels are not independent. Activating the motor master channel with an override switch will also activate the three relay channels. The system can control either incandescent or fluorescent light fixtures. The RCI-1 can control a total of six relays but no more than three per channel. If more relays are required to control a large lighting system, the RCI-1 can be used to pulse an on or off motor master, which has 25 independent contacts. The photorelay can be adjusted by opening and closing the aperture and rotating the aperture relative to the sensing cell. This allows adjustment to the point where the lights are turned off. The photorelay must monitor only the natural light level. Otherwise, the switching of the lighting being controlled will cause an oscillating on-off cycle.

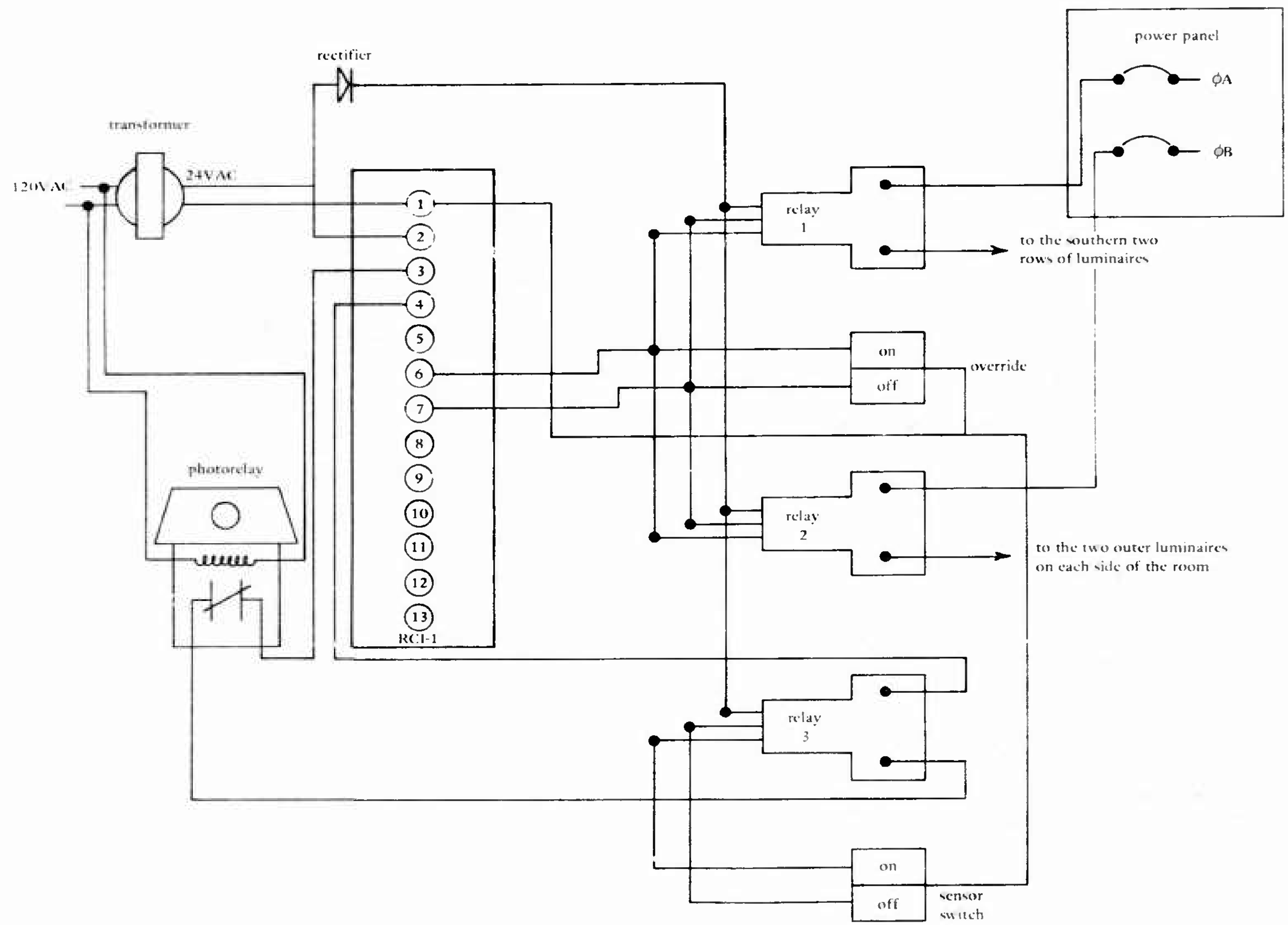


Figure C-1. Wiring diagram of GE light sensing and control system for room 242 of CEL building 560.

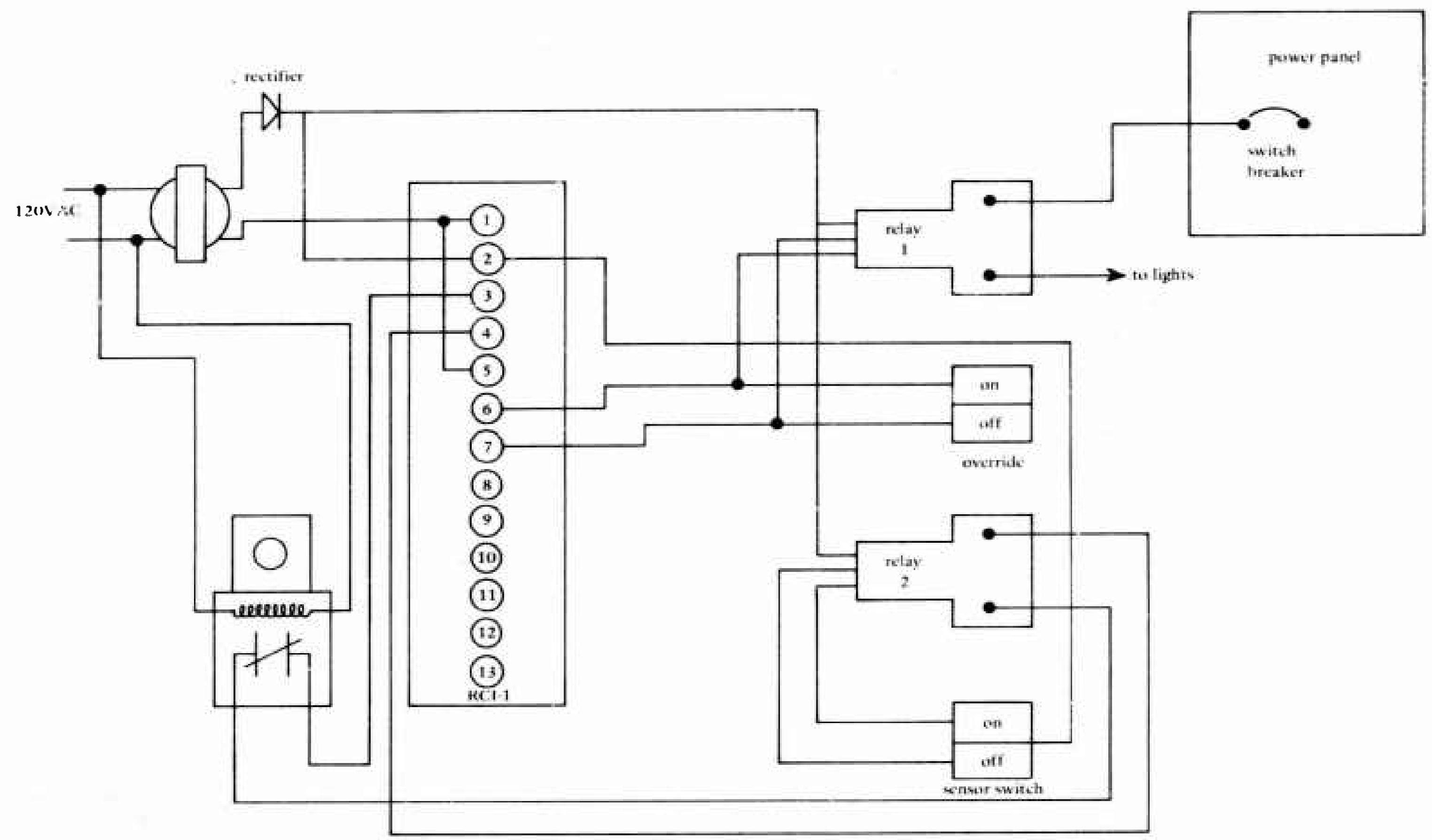


Figure C-2. Wiring diagram of GE light sensing and control system for hallway in building 560.

Appendix D

THEORY OF OPERATION OF CEL TWO-LEVEL LIGHTING SYSTEM

When the on-off switch of Figure D-1 is positioned to the ON position, power is furnished to the power supply. This enables the initial instant-on circuit to supply power to the switch driver that gates the solid-state switch to turn on the lights. After all lights are lighted and stabilized, the initial instant-on circuit is inhibited from further operation. Power to the switch driver is then supplied from the automatic on-off delay circuit. If the light in the area of the controlled lighting is below the foot-candle setting of the threshold level control, the automatic on-off delay circuit will continue to supply power to the switch driver, and the lights will remain on. When the light in the area of the controlled lighting goes above the threshold level control setting, the threshold level control circuit will stop supplying power to the automatic delay circuit. After the programmed delay time has elapsed, power will be removed from the switch driver, stopping the gate pulses to the solid-state switch and thus turning off the lights. If the light in the controlled lighting area drops below the threshold level control setting, the threshold level control circuit supplies power to the automatic on-off delay circuit. After the programmed turn-on time delay has elapsed, the automatic on-off delay circuit supplies power to the switch driver which gates the solid state switch, thus turning on the lights. The on-off delay is required to prevent the lights from blinking on and off if a cloud should pass by or if a person or object should momentarily pass in front of the sensor. Any number of lights can be controlled with this circuit. The limiting factor is the current capacity of the solid-state switch. A bypass is provided so the lights can remain on, if desired. Additional levels of lighting may be had by adding additional control circuitry, using the same sensor.

Operation

When the lighting system on-off switch is positioned to the ON position, 120-VAC power is supplied to the primary of transformer T1 and one side of each solid-state switch, as shown on schematic circuit diagram of Figure D-1. The voltage that appears on the secondary of transformer T1 is rectified by the half-wave rectifier CR1 and is filtered by C8, R35, and C9. Zener diode CR10 is used as a regulator, holding the power supply DC output voltage at 12 VDC. At initial turn-on, there is an almost instant voltage rise across C8; this instant rise of voltage charges C1; the combination of C1 and R36 with this instant voltage rise causes a positive pulse on the gate of SCR1, turning it on. This allows the DC power supply output voltage to fully charge C2. When C2 is fully charged, current flow through SCR1 stops, causing it to turn off. SCR1 remains in an OFF state until the next initial turn-on of the lighting system. The full charge voltage of C2 appears across resistor R3 on the base of Q2. Q2 and Q3 and associated components form a modified Schmitt trigger circuit. The voltage that appears on the gate of Q2 exceeds the turn-on threshold (5.5 VDC) of the Schmitt trigger circuit which is determined by the value of R7. The Schmitt trigger circuit goes from a quiescent to an ON state in a very sharp transition. The voltage on the collector of Q3 in a quiescent state is 2.5 volts, and in an ON state it is 7.5 volts. This causes the reverse-biased zener diode CR5 to allow a positive voltage to appear on the base of Q5, causing it to turn on to full conduction. This puts the collector of Q5 to essentially ground potential. This grounds pin 1 of integrated circuit IC1 (NE555) (which is configured as an astable multivibrator), turning it on.

The output of IC1 is a pulse train of approximately 100 kHz. These appear on the base of Q6 which drive pulse transformer T2 that supplies positive pulses to the gate of the solid state switch (triac) turning it on, supplying power to the lighting system. Simultaneously, the same sequence of operation occurs in the other section of the two-level lighting control. If the lighting level from both natural and artifical light is below the threshold setting of each section of the two-level automatic lighting system, all lights will remain on. If the lighting level goes above the threshold setting of one or both levels of the control, the following will occur (only level one's operation will be described because the operation of both sections is identical). The photocell, which is the sensor, acts as a variable resistor: when the lighting level increases, the photocell resistance decreases and vice versa. The combination of the photocell resistance and R1 control the bias voltage on the base of Q1. When the desired lighting level in the area of the controlled lighting is reached (without the lights being on and with the control system energized), R1 is adjusted so that Q1 is just at the threshold of turning on. Then with just a slight increase in the lighting level, Q1 will turn completely on, preventing C2 from charging. If the light output drops below the desired level, the resistance of the photocell will increase, and in turn decrease the bias on the base of Q1 to a smaller positive voltage which causes Q1 to turn off and allows C2 to start charging. The RC time constant of the combination of R2 and C2 determine the time required for C2 to charge to a value equal to or greater than the trigger level of the Schmitt trigger. When this level of voltage is reached or exceeded, the same sequence of operation occurs as in initial turn-on, thus turning on the lights. If the lighting level increases above the threshold setting, the resistance of the photocell decreases, increasing the bias voltage on the base of Q1, causing it to turn on and stopping C2 from charging.

With Q1 remaining on, C2 will discharge through resistor R4. The RC time constant of the combination of C2 and R4 determines the time required for C2 to discharge below the trigger level of the Schmitt trigger circuit. When C2 discharges below the triggering level, the

Schmitt trigger goes back to its quiescent state. Again, this is a very sharp transition. The voltage on the collector of Q3, which was at 7.5 volts, instantaneously drops to 2.5 volts. Because of the combination of C3, R9, and R10 (during this sudden voltage drop), a negative pulse appears on the base of Q4. This causes a positive pulse to appear on the collector of Q4 and the gate of SCR2, turning on SCR2. This causes C2 to fully discharge, and with C2 fully discharged, current stops flowing through SCR2, shutting it off. This operation allows for the full delay time to turn the lights on again. Q1 through Q5 and Q7 through Q11 are two 14-pin dip transitor arrays which allow for small packaging of the circuitry.

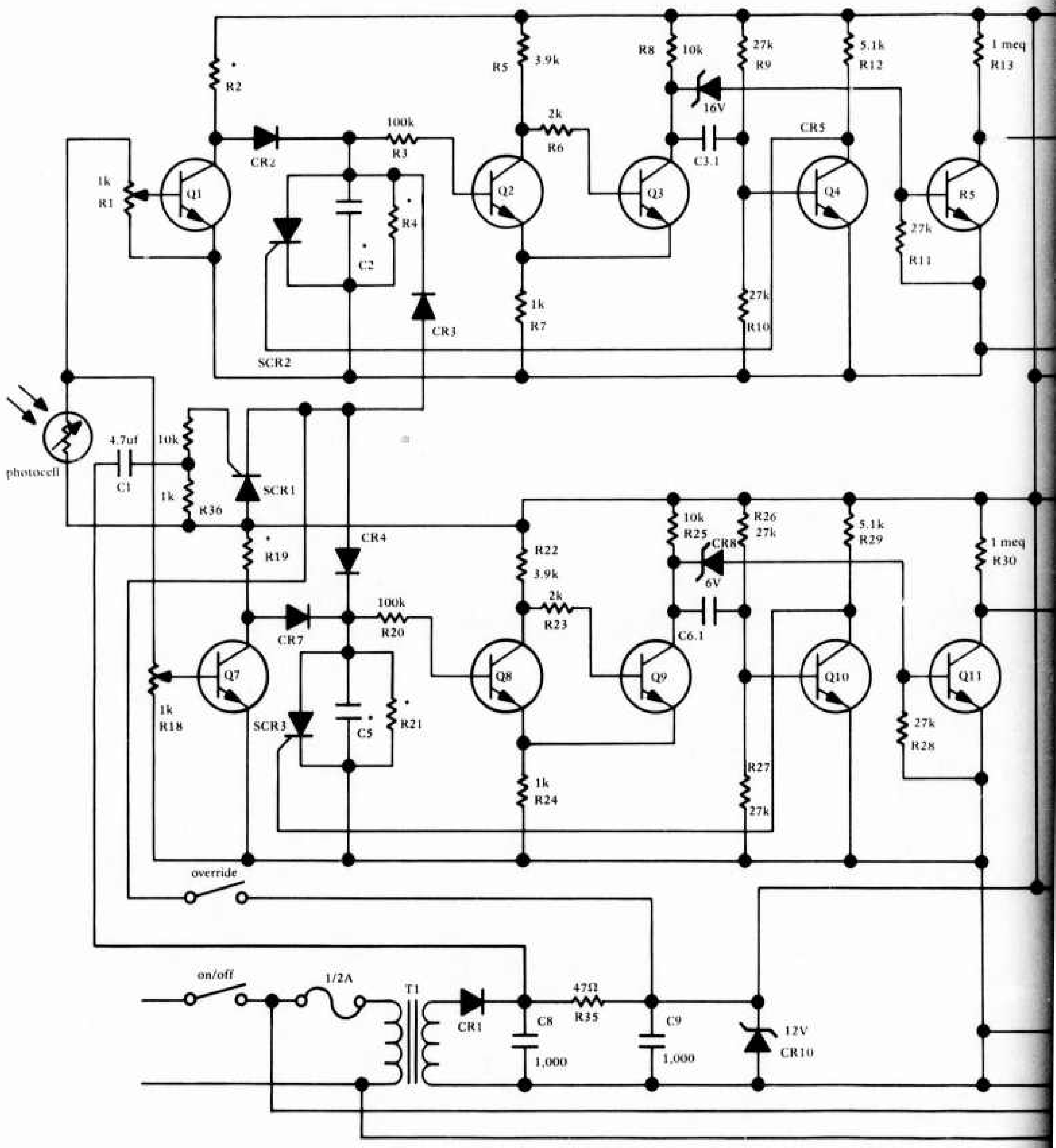
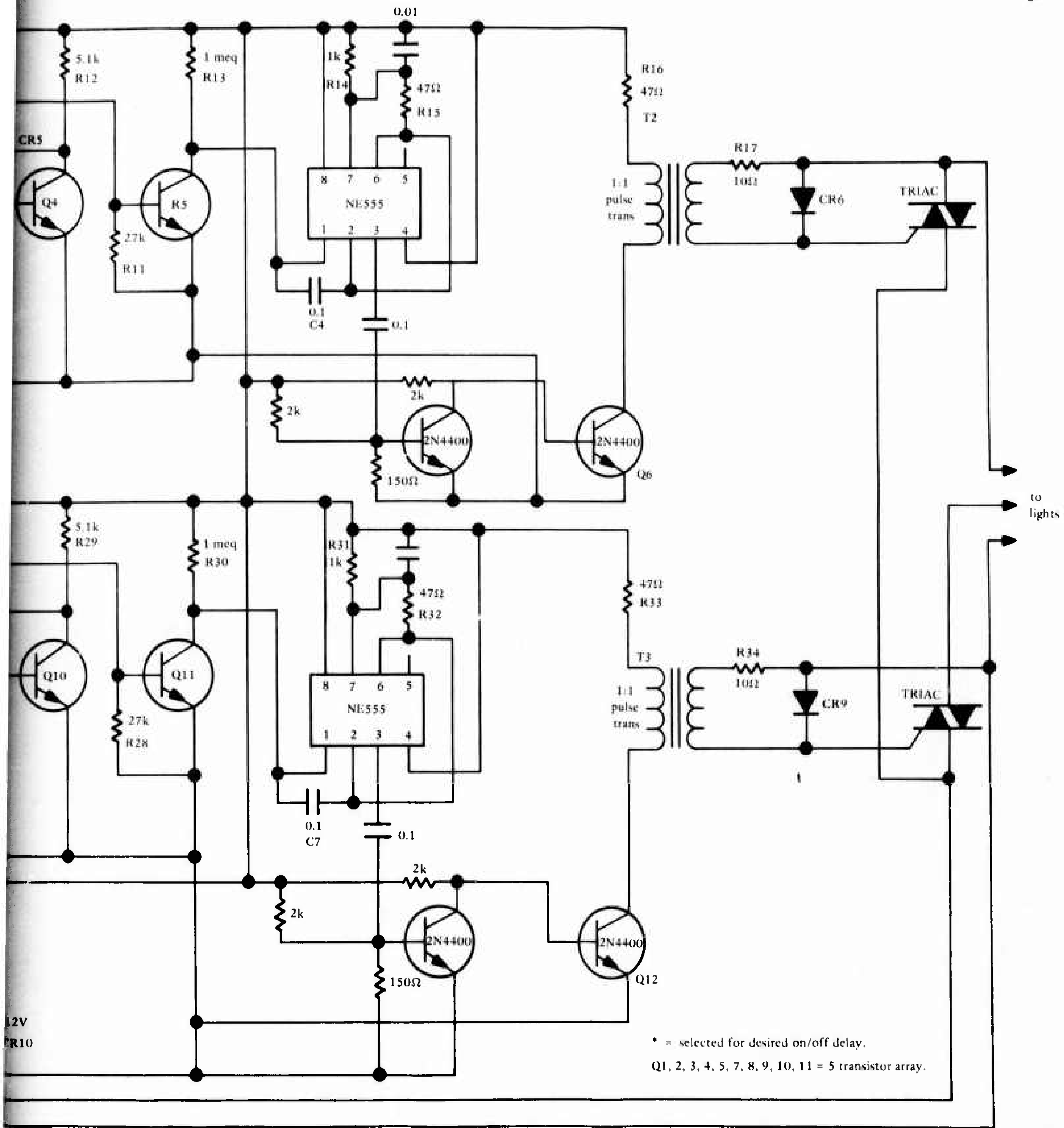


Figure D-1. Two-level automated li



Two-level automated light sensing and control.

Appendix E

THEORY OF OPERATION OF CONSTANT ILLUMINATION CONTROL

To adjust for the desired illumination level upon installation, the control unit is turned on and the automatic-set switch is positioned to the set position. The bright or dim button is depressed until the lighting system provides the desired illumination level. Then the null potentiometer is adjusted until a null is indicated on the null indicator, and the automatic-set switch is moved to the automatic position. If the light level in the area of the controlled lighting system increases above the desired level setting, the sensor sends a signal to the input amplifier. The output voltage of the input amplifier is then compared by the comparator with the reference voltage established by the null potentiometer. The comparator signals the electromechanical drive to drive the dimmer in the dimming direction. As the lighting system is dimming, the signal from the sensor causes the output voltage of the input amplifier to change. When the input amplifier's output voltage equals the reference voltage, the comparator's output goes to zero, thus stopping the electromechanical drive. The illumination level in the controlled lighting area will be at the desired level. If the illumination level in the controlled lighting area decreases, the same sequence will occur except the dimmer will be driven in the bright direction.

CIRCUIT OPERATION CONSTANT ILLUMINATION CONTROL

When the on/off switch, with the automatic-set switch in automatic position, is positioned to the ON position the lighting system will automatically adjust to the preset level as described in the theory of operation. Figure E-1 is a schematic diagram of the control circuitry. The photocell sensor acts as a variable resistor and, in combination with potentiometer R1, supplies the input voltage to the noninverting operational amplifier A1. R1 is initially adjusted when the control is installed, so the photocell will have control over the full range of natural light in the controlled lighting area. The output voltage of A1 (determined by the light level in the controlled area, setting of R1, and gain of A1) will be between 0 and 10 volts. A2 is used as a comparator: it is configured so that when the input voltage on pin 2 is equal to the reference voltage (determined by the setting of R8) on pin 3 the output on pin 6 will be 0. If the voltage on pin 2 is lower than the reference voltage on pin 3 the output on pin 6 will be of some positive value. This positive voltage will appear on the base of Q2 through CR7. Q2 will turn on, energizing normally open relay 2. When the contacts of relay 2 are closed, power is supplied to the input of the dimmer driver motor that will turn the dimmer in the brighten direction. As the lights brighten, the resistance of the photocell will be decreasing, causing the input at pin 3 of A1 to increase. As the input and output of

A1 continue to increase, the voltage on pin 2 of A2 will increase until it is equal to the reference voltage on pin 3. When it is equal to the reference voltage on pin 3, the output at pin 6 will be 0; the base of Q2 will be at 0 potential, shutting off Q2 and causing relay 2 to de-energize, thus stopping the motor. If the voltage on pin 2 of A2 goes above the reference voltage on pin 3 the output voltage on pin 6 will be of some negative value. This negative voltage will appear on the base of Q1 causing it to turn on. This will energize relay 1 which is normally open. With the contacts of relay 1 closed, power will be supplied to the input of the dimmer drive motor that turns the dimmer in the lower direction. The lights will dim until the voltage on pin 2 of A2 is equal to the reference voltage on pin 3, causing the output on pin 6 to be 0. This will turn off Q1, thus causing the motor to stop.

If the lighting system is desired to remain on at a fixed level of illumination the automatic-set switch should remain in the set position. Then by adjusting the light level to the desired illumination with the bright or dim button it will remain at this setting regardless of a change in the natural lighting.

The dimmer used in the system is GE model DF61U dimmer, a 600-watt solid-state dimmer that can control twelve 40-watt fluorescent lamps. Solid state dimmers that can control up to forty 40-watt fluorescent lamps are commercially available. To control more lamps, the dimmers can be ganged and controlled with one controlling system. Also by ganging the dimmer, the phase loads on a power distribution system can be balanced.

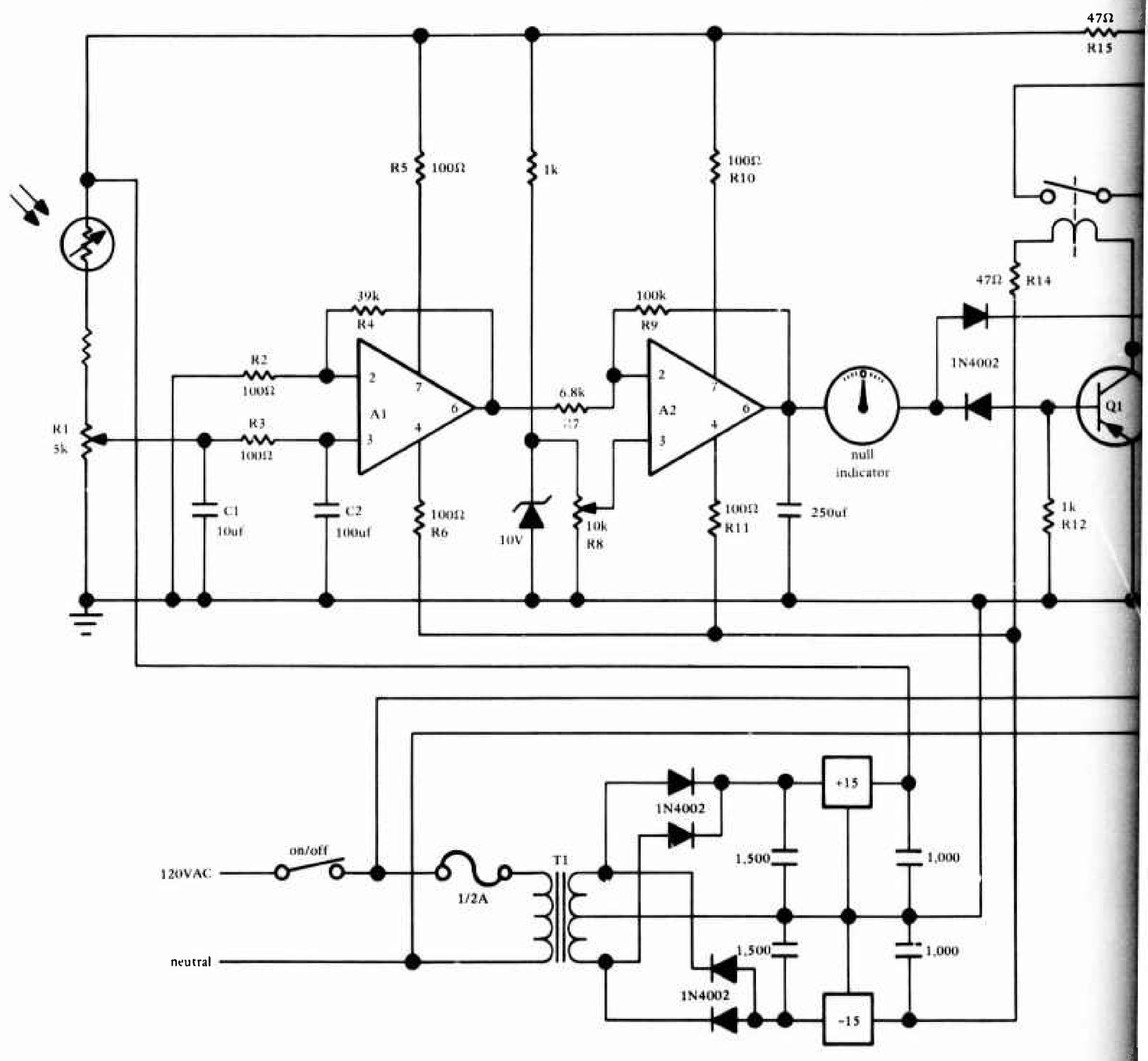
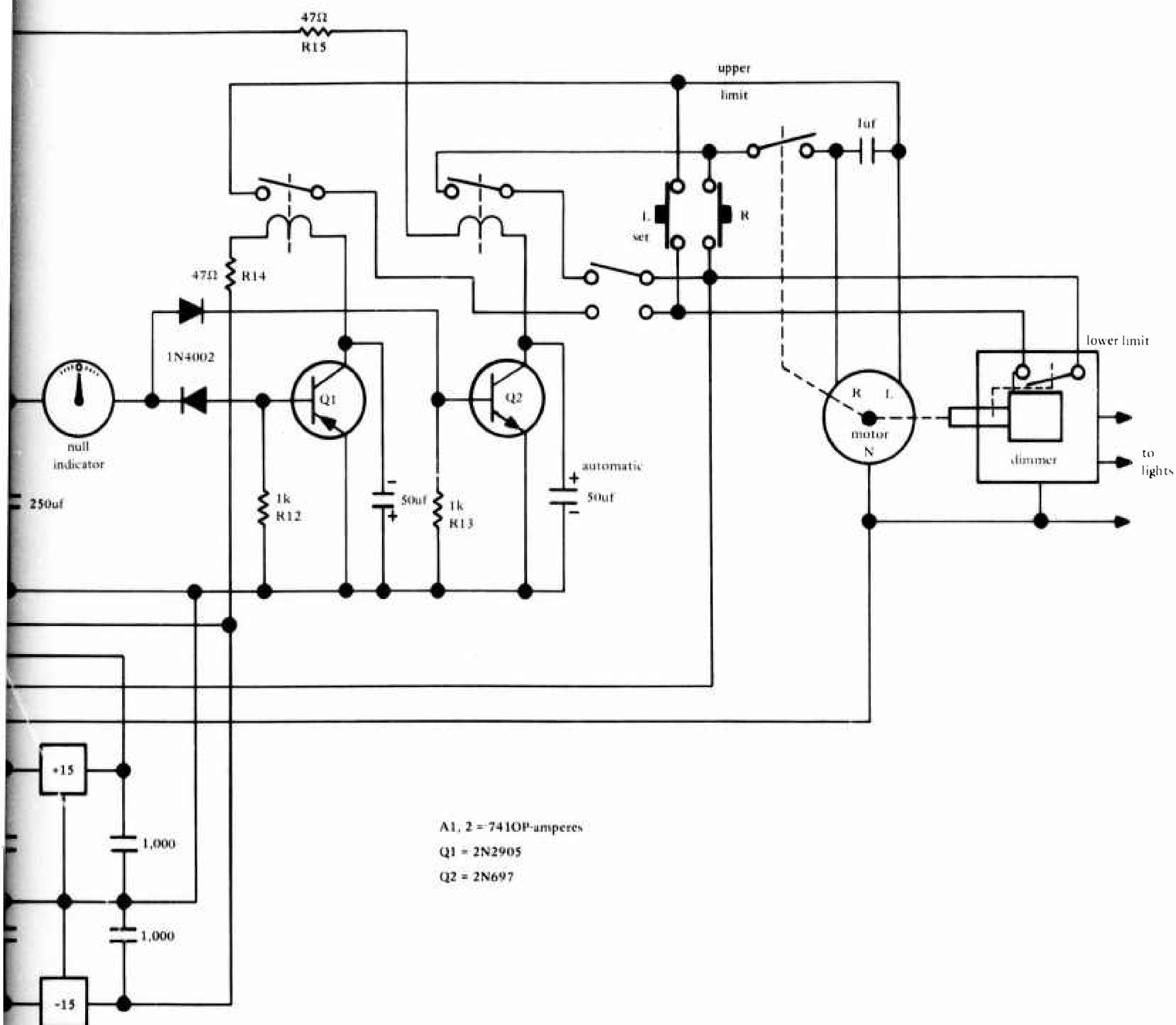


Figure E-1. Constant illumination lighting



nstant illumination lighting control.

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Subj: Errata Sheet for Technical Note N-1486, "Automatic Light Sensing and Control of Lighting Systems for Energy Conservation," by M. N. Smith

Encl: (1) Replacement page for Table 6, page 30

1. Please replace Table 6, page 30 of subject document with enclosed page.

Pete D Triem
PETER D. TRIEM
By direction

Table 4. Economic Analysis for CEL Two-Level System Used for Small Office Lighting

City	Days On	Days Off	Installation Cost ($)	Cost/Year Without Control kW-hr at 3.3 ($)	Saving/ Year ($)	Without Control (kW-hr/Yr)	With Control (kW-hr/Yr)	Savings (kW-hr/Yr)	Payback Years[a]
Indianapolis	204	162	130.00	48.04	21.24	1,456	812	644	6.1
Los Angeles	131	234	130.00	48.04	30.49	1,456	532	924	4.2
Miami	157	207	130.00	48.04	27.72	1,456	616	840	4.7
Minneapolis	196	174	130.00	48.04	23.09	1,456	756	700	5.6
Washington, D.C.	186	179	130.00	48.04	23.49	1,456	744	712	5.5

[a]Simple amortization.

Table 5. Economic Analysis for CEL Constant Illumination Lighting System Installed in Building 1195

City	Days On	Days Off	Installation Cost ($)	Cost/Year Without Control kW-hr at 3.3 ($)	Saving/ Year ($)	Without Control (kW-hr/Yr)	With Control (kW-hr/Yr)	Savings (kW-hr/Yr)	Payback Years[a]
Indianapolis	157	208	388.72	28.14	16.00	852.8	367.81	484.99	24.3
Los Angeles	108	257	388.72	28.14	19.79	852.8	253.01	599.79	19.6
Miami	134	231	388.72	28.14	17.78	852.8	313.92	538.88	21.8
Minneapolis	150	215	388.72	28.14	16.14	852.8	351.41	501.39	24.0
Washington, D. C.	147	218	388.72	28.14	16.78	852.8	344.40	508.40	23.2

[a]Simple amortization.

Table 6. Hypothetical Economical Analysis of Cost Difference of CEL Constant Illumination Lighting System and Standard Fluorescent Lighting System Each Consisting of 100 Luminaires, Each Containing Two 40-Watt Fluorescent Lamps

City	Days On	Days Off	Installation Cost ($)			Savings/ Year at 3.3¢/ kW-hr ($)	Without Control (kW-hr/yr)	With Control (kW-hr/yr)	Savings/ Year (kW-hr/yr)	Payback Years[a] of Constant Illumination
			Standard	Constant Illumination	Difference					
Indianapolis	157	208	3,525.00	5,490.00	1,965.00	390.36	20,800	8,971	11,829	5.0
Los Angeles	108	257	3,525.00	5,490.00	1,965.00	482.76	20,800	6,171	14,629	4.1
Miami	134	231	3,525.00	5,490.00	1,965.00	433.75	20,800	7,656	13,144	4.5
Minneapolis	150	215	3,525.00	5,490.00	1,965.00	403.56	20,800	8,571	12,229	4.9
Washington, DC	147	218	3,525.00	5,490.00	1,965.00	409.20	20,800	8,400	12,400	4.8

[a] Simple amortization.