Indian Journal of Engineering, Vol. 13, No. 33, July 1, 2016 RESEARCH

ISSN 2319–7757 EISSN 2319–7765

Indian Journal of Engineering

Design and Implementation of a Programmable Logic Controller Based Day Lighting Control System

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Publication History
Received: 16 May 2016
Accepted: 24 May 2016
Published: 1 July 2016

Citation
Aldi BI, Kadadevarmath JS, Bannibagi NP. Design and Implementation of a Programmable Logic Controller Based Day Lighting Control System. *Indian Journal of Engineering*, 2016, 13(33), 477-486

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ABSTRACT

Automatic lighting in building automation is a technology mainly designed for energy efficiency and uniformity of illumination during working hours. In this paper design and implementation of automatic lighting controller, consists of low cost and simple approach of electric lighting interface module with Programmable Logic Controller (PLC) is presented. The electric lamps were controlled inside the building in order to achieve illumination according to bureau of National Building Code of India (NBCI). To achieve illumination standard, the number of lamps were accordingly determined and their illumination levels were maintained automatically with the use of PLC. In order to quantify the results obtained by the PLC as a controller, the results were also obtained for without the use of controller. It is observed that, illumination levels were found to be 300-310 lux and 120-160 lux for with and

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without controllers respectively. Further, uniformity ratio and power consumption were also estimated. It is observed that, the uniformity ratios were found to be 0.9 - 0.95 and 0.1 - 0.15 for with and without controller respectively. Thus, illumination level of luminaries and uniformity ratio with controllers are in close agreement with the values of NBCI. Also the power consumptions of the lamps used in the system with and without controllers were found to be 100 W and 400 W respectively. Therefore, it may be inferred that the proposed model is said to be efficient in saving power. That is the power saving of nearly 75% is said to be achieved in a system of lighting control using PLC.

Keywords: Day lighting system, Ladder logic program, Lighting control interface module.

Abbreviations: PLC - Programmable Logic Controller, SCADA - Supervisory control and Data Acquisition

1. INTRODUCTION

The need for electrical energy is essential in all the fields such as residential, commercial, industrial, institutions and agriculture. The maximum usage of electrical energy is in residential and commercial buildings for lighting and operating electrical appliances. There are many improvements in utilizing these devices for reducing the usage of energy and cost. Energy control technologies used in Building Automation System (BAS) provide design strategies to enable energy efficiency and to reduce the cost. Energy efficiency refers to permanent changes to electricity usage by replacing more efficient end-use devices for reducing the quantity of energy needed to perform a desired function or service [1]. In energy efficient buildings, control of lighting is considered to be as one of the primary requirements. It is known that, commercial buildings utilize 26% of energy for lighting [2].The fluorescent lights and light emitting diode (LED) technologies used in lighting of lamps are more efficient than traditional incandescent lights [3]. The illumination levels inside the buildings depend upon the type of the interior usage or the activity under the given area. The NBCI group specifies the Illuminance levels in libraries, music rooms, sports halls, and workshops ranging from 200-500 lux and in seminar rooms, laboratories, demonstration benches ranging from 300-750 lux. Thus the recommended illumination level for a typical room is 300 lux. [National building code of India-SP 7: Group 4 (2005)]. Further, according to NBCI, the uniformity ratio should not be less than 0.7.

Keeping the above mentioned facts in view the objective of the paper is to carry out a design strategy in controlling electric lighting system within the buildings using PLC for the management of lighting luminary control operations. The proposed model may also prove to be efficient in power consumption. Apart from the introduction, the paper has the following sections: The second section discusses the day light control. The third section presents the adopted methodology for the hard ware design. The fourth section is devoted to the development of the model for lighting control system which includes prototype interface module, light dimmer circuit and their implementation with the use of Allen Bradley MicroLogix 1100, 1763-L16BBB PLC. The fifth section presents the software design for the day lighting control, the sixth section discusses the results and performance analysis of a developed system and finally seventh section gives the conclusions.

2. DAY LIGHT CONTROL

The primary source of energy for day lighting is the sun. The lighting received by the earth from the sun consists of two parts namely, direct solar luminance and sky luminance. For the purpose of day lighting design, direct solar luminance shall not be considered. Only sky luminance shall be taken as illumination levels in building interiors during the day. The relative amount of sky luminance depends on the position of the sun defined by its altitude, which in turn, varies with the latitude of the locality, the day of the year and time of the day.

Lighting control is divided into building management system, automated control system with ability/without the ability to switch off the light. An important criterion of the control design is the efficient use of the day light to control the illumination levels of lighting systems which serves to consume less power [4]. There are different types of day lighting controls. They include ON and OFF or dimming of lights based on signals from the light sensors. The installation of illumination detector, namely light dependent resistor (LDR) and the use of PLC, make it possible to adjust the illumination levels of lighting systems at a predefined level. LDRs detect the light levels based on the amount of available light inside and the surrounding buildings [5-7].

3. RESEARCH METHOD

The research method involves PLC based automatic artificial interior day lighting system, particularly the determination of number of lamps in accordance with the room activity or usage and variations in day lighting. Recommended illumination levels have to be maintained for artificial day lighting control. Generally, for the given working area of the room total luminous flux Φ of the light is given by Equation (1)

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$$\Phi = \frac{E_{av}A}{\mu m_f} \quad (1)$$

E_{av} = Required illuminance (lux); A = area to be lit (m^2); m_f = maintenance factor; μ = utilization factor.

Utilization factor μ indicates how much of the luminous flux produced by the lamps enter the work plane (the plane at which the work is to be taken place) and it depends on the factors of light efficiency and distribution of luminaires and reflectance of ceiling, walls and geometry of the space. This may be determined by Lumen method and is based on Room Cavity Ratio (RCR), wall and ceiling reflectance of the room. Maintenance factor m_f depends on the depreciation of lamps and reflective surfaces over a period of time. This value accounts for the reduction in light output from a lighting system due to ageing of the lamps and the accumulation of dirt and dust on the light fittings and room surfaces, etc., [8] Luminous flux produced at a work plane is measured using a digital illuminance meter of make Equinox EQ-802 with light measuring levels range from 0.1 to 200,000 Lux. This has high accuracy and rapid response.

Efficiency of electric lighting is determined by the uniformity ratio and power consumption of the system. Uniformity ratio of a given lighting area is the ratio of minimum illumination to the average illumination of the day measured at work plane as given in Equation (2).

$$\text{Uniformity ratio} = \frac{\text{Minimum illumination}}{\text{Average illumination}} \quad (2)$$

Power consumption of the lamps is determined by the analog dynamometer type MECO make watt meter of voltage rating 125/250/500 V, current rating 5/10 A and accuracy of full scale value within 1.0%. Lamps consume maximum power while the controller is not in use since the lamps remains ON continuously. Thus power saving in a system with controller is given by Equation (3). P^1 is the power consumption of the lamps by implementing the controller and P is the power consumption without using the controller over a period of time.

$$\text{Power saving} = 1 - \frac{p^1}{P} \quad (3)$$

3.1 Hardware design

The proposed schematic hardware design of PLC based lighting control system (LCS) is shown in Figure 1. It consists of LDR as a light sensor, lighting control interface module, light dimmer (LD) circuit and direct current electrical gear motor (DCEGM). LDR senses the luminance of the surrounding light which in turn adjusts the light output of LCS. LCIM consists of opto isolators and relay drivers and is interfaced with LD through DCEGM. The DCEGM controls the intensity of lamps based on the control signals from the PLC.

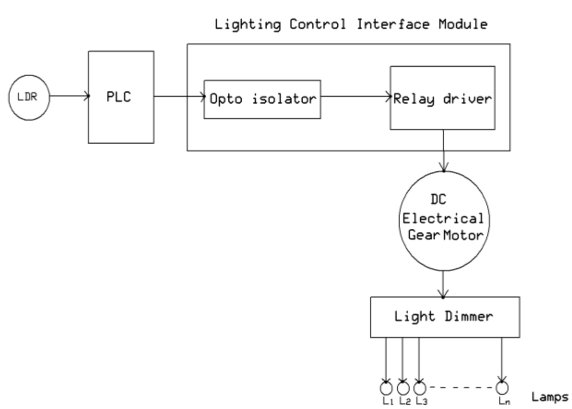

Figure 1 Schematic diagram of LCS

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3.2 PLC as a system controller

A suitable micro-controller or programmable logic controller techniques can be designed for the automation process. The control program is entered into the memory. This program solves control logic and generates control signals to output modules. The wide variety of sizes and window based programming tools give the flexibility to solve problems related to automation in buildings and industrial process control instruments [9-11]. These are categorized based on functionality, number of inputs and outputs, cost and physical size. For LCS, modular type of PLC can be used because they include fault indicators displayed on the programmer screen.

Specially developed and relatively simple ladder diagram programming language makes the electrician and technician to develop and control program without any difficulty. These controllers use built in opto-couplers or opto-isolators for driving input and output interface devices and operated by a fixed ac/dc power supply. Thus the PLC is a complete computer with a built-in microprocessor [12-15].

4. MODEL DEVELOPMENT

4.1 Lighting Control Interface Module

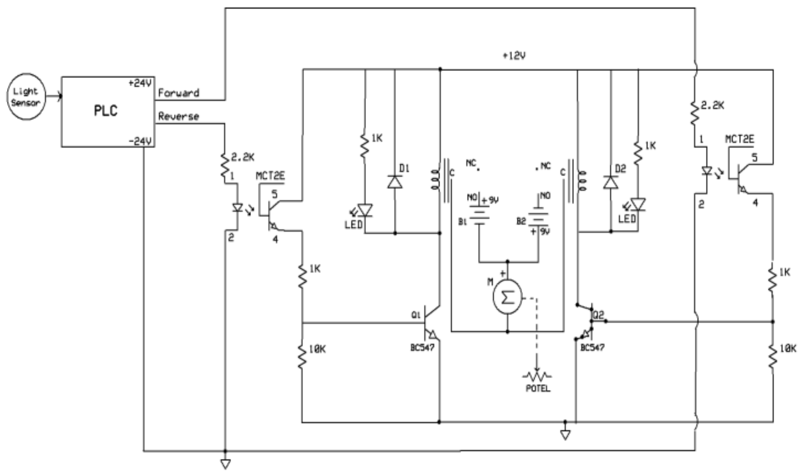

Figure 2 Circuit diagram of LCIM

The circuit diagram of low cost lighting control protocol implemented with the hardware tool named as lighting control interface module (LCIM) is shown in Figure 2. This module communicates between PLC and the load of LD circuit for automatic controlling of the electric lighting. Opto-couplers MCT2E made up of gallium arsenide infrared LED and silicon NPN photo transistors, enable when the control electrical signals from the PLC appear at the inputs of MCT2E. Opto-couplers are mainly used to protect the controller and LCIM from the effects of electrical noise and harmonics, there by smooth functioning of the controller can be achieved.

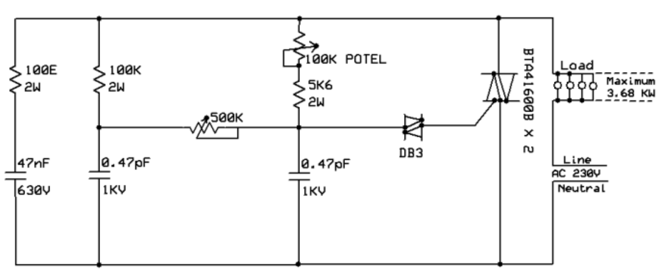

Figure 3 LD circuit

The switching is established by the control relays through BC 547 NPN transistors. This allows direct current electrical gear motor (DCEGM) to rotate in either forward (F)/reverse(R) direction to increase/decrease the intensity of the luminaries by varying the 100KΩ potentiometer (POTEL) of LD circuit. The gearing mechanism is used between the DCEGM of LCIM and the POTEL for the automatic action of the controller. LD circuit consists of TRIAC BTA41600B and DIAC DB3 as shown in Figure 3.This circuit is having

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the power handling capacity of up to 3.68 KW loads of the lamps.

4.2 Implementation of LCIM

Figure 4 Testing of lighting controller

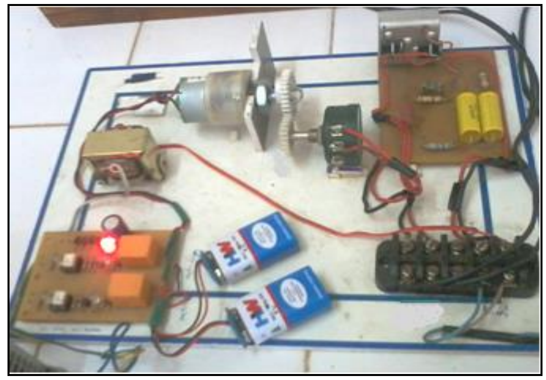

Figure 5 Hardware of LCIM and LD circuit

The need of control system in a small building is to provide required illumination in a given room to use the day light effectively for reducing energy and also glaring at the workplace can be avoided [16]. Based on these needs, lighting controller system is designed and implemented with use of a versatile Allen Bradley MicroLogix 1100, 1763-L16BBB PLC. This supports built-in RS 232/DH 485 port for serial and networked communication. [17-19]

The controller has both digital and analog input/output (I/O) terminals for connecting devices and can be expanded using I/O expansion modules 1762-IF20F2-A. The light detector LDR GL20-2AP01, analog input module for the PLC, made up of cadmium sulphide (CdS) photoconductive material having spectral peak of 560 nm is used to detect the illumination levels. Digital signals from the output modules actuate either forward or reverse rotation of the DCEGM for varying the illumination of lamps. The digital I/O modules work at 24V DC and analog input modules work at voltages ranges from 0 to 10V DC. Real time testing and programming of PLC for automatic control of lighting through LCIM along with personal computer is shown in Figure 4, and Figure 5 shows the interface between DCEGM of LCIM and POTEL of LD circuit.

4.3 Determination of number of lamps

While designing controlling action of electric lighting of lamps, a control room as shown in Figure 6 is considered. LDR is placed near the window for sensing the illumination. The numbers of lamps N required were determined based on the need of illumination [20-21], given by Equation (4).

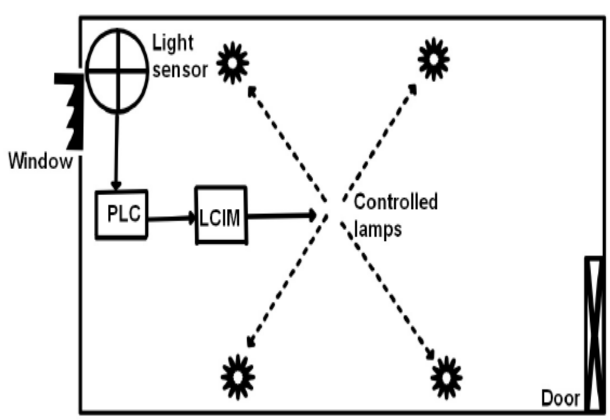

Figure 6 Control room

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$$N = \frac{E_{av}A}{\mu m_f \Phi} \qquad (4)$$

For standard illumination E_{av} = 300 lux, control room of Area A= 3 x 4.4 = 13.2 m^2, maintenance factor m_f = 0.99, and utilization factor μ = 0.5, number N of incandescent lamps with = 2000 lumens is found to be 4, as given in Equation (5). Thus four lamps of 100W each were used for lighting the room.

$$N = \frac{300x13.2}{0.5x0.99x2000} = 4 \qquad (5)$$

5. SOFTWARE DESIGN

Initially, analog signals of varying illumination from the LDR are converted to digital values by built-in Analog-Digital converter. The digital values increase linearly with increase of analog voltages. The PLC is programmed by using ladder logic (LL) programming method [22].

LCIM and light dimmer circuits are tested before implementing controller program. The program written in the personal computer (PC) is converted to binary object code and is downloaded to the PLC's microprocessor via the serial communication RS 232 port. The ladder logic program for controlling illumination is tested. The PLC program in the control mode uses a cyclic scan of the whole program. The execution of the program starts by scanning the inputs to the system and storing their states in fixed memory locations called input image memory I. The ladder program is then executed rung by rung. The updated output states are stored in fixed memory locations called output image memory O. The output values held in these locations are used to update (set and reset) the physical outputs of the PLC. At the end of the program, the same process continues till the PLC is in the control mode.

The flow chart of illumination control software is shown in Figure 7. Illumination level set point (ISP) is set to the standard reference value of 300 lux. This ISP is compared with the light sensor signal (LS) (i.e. from LDR). When both LS and ISP are at the same levels the controller is set to control mode to scan inputs and the same is stored. When LS is less than ISP, the control signal, switches a relay to rotate the motor in forward direction for increasing illumination levels of lamps. When LS is more than ISP, the

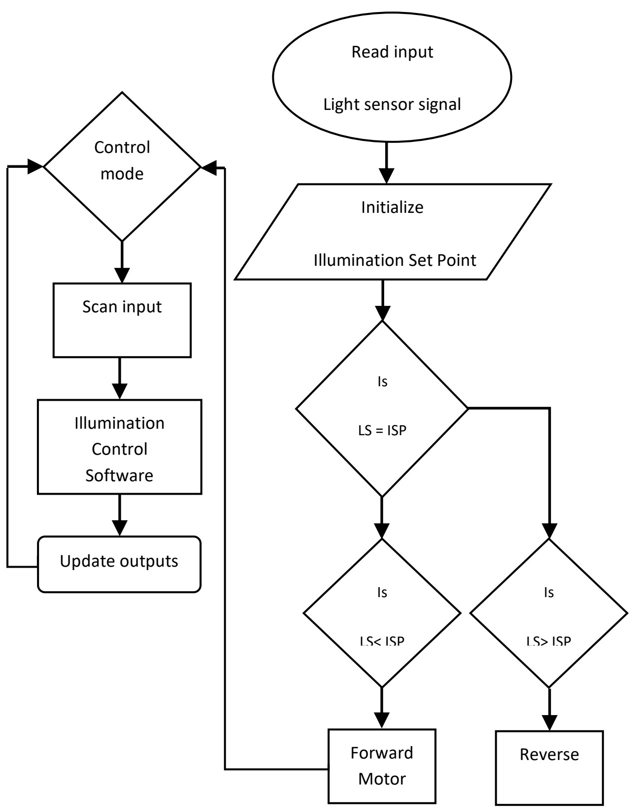

Figure 7 Flow chart of illumination control software

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control signal, switches another relay to rotate the motor in reverse direction for decreasing illumination levels of lamps.

The instructions used in the program include move, digital and analog input/output instructions, less than (LES), greater than (GRT), less than or equal to (LEQ) and scale with parameter (SCP) etc. The proposed program is monitored through Supervisory Control and Data Acquisition (SCADA) software. The implementation of SCADA system may be used to integrate different types of information coming from the several technologies present in modern buildings such as ventilation and temperature control systems, computer networks, lightning control systems, etc [23-25].

6. RESULTS AND DISCUSSION

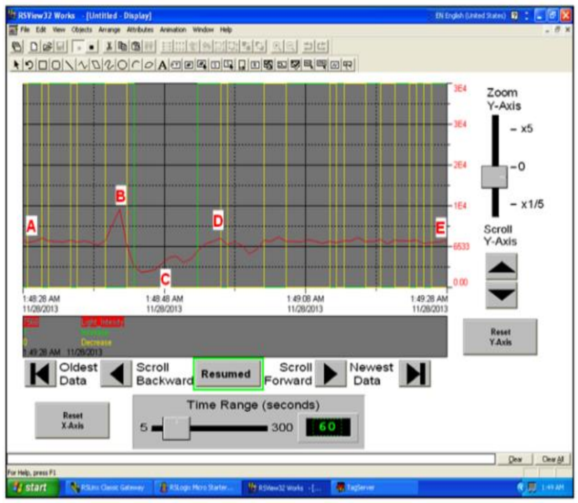

Figure 8 Monitoring of controller

Figure 8 shows an overview of the implemented lighting controller, running in the RS View 32 Works SCADA software. The status of the illumination levels within the room (line A-E) can be supervised at any instant of time by linking this software to the controller. The curved line B-D indicates decrease in the illumination levels during which the controller senses this loss of light illumination and increases the illumination levels of the lamps at work plane to 300 lux automatically. During the lines A-B and D-E, the controller maintains the illumination levels accordingly.

Four lamps of 100W each were inserted on the ceiling control room. The observation of illumination levels of a controlled room is obtained for seven days from 7am to 7 pm in each day, with and without using the controller. Illumination levels were measured using lux meter and power consumption of the lamps corresponding to these illumination levels were measured using watt meter.

Uniformity ratio and power saving with and without the use of controller were then determined according to Equations 2 and 3 respectively and are shown in Table 1. Plots of illumination levels versus days are shown in Figure 9. It is observed from the plot that with controller illumination level remains almost constant (approximately 300 lux), whereas without controller illumination level shows larger variations and less illumination level (around 150 lux). Figure 10 shows uniformity ratios as a function of days for both the systems. It is observed that uniformity ratio for with controller is varying within 0.9 to 0.95 where as for without controller is varying within 0.1 to 0.15. It may be inferred that uniformity ratio is well above the limit of 0.7 set by NBCI standard with controller. The plot of power consumption versus days is shown in Figure 11. It is observed that power consumption of the lamps with controller is less than that without controller and power saving of nearly 75% is said to be achieved in this system of lighting control using PLC.

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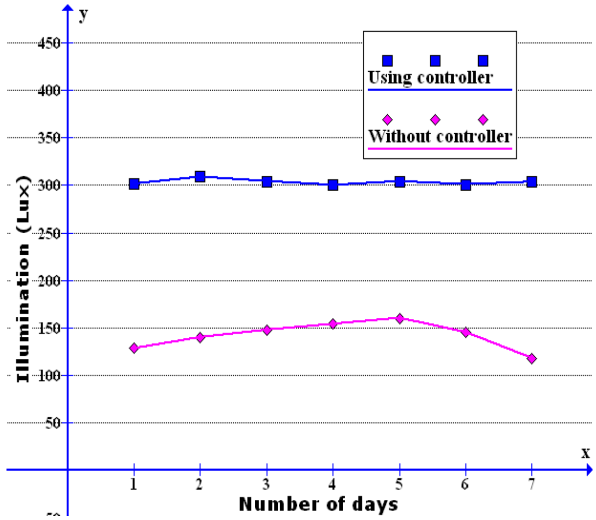

Figure 9 Illumination – With and without controller

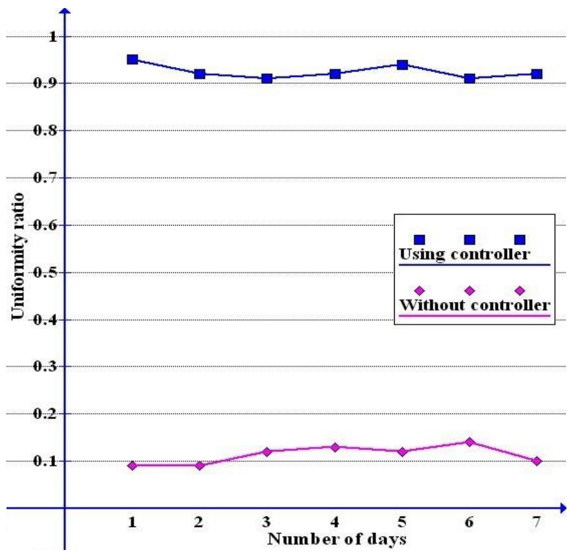

Figure 10 Uniformity ratio: With and without controller

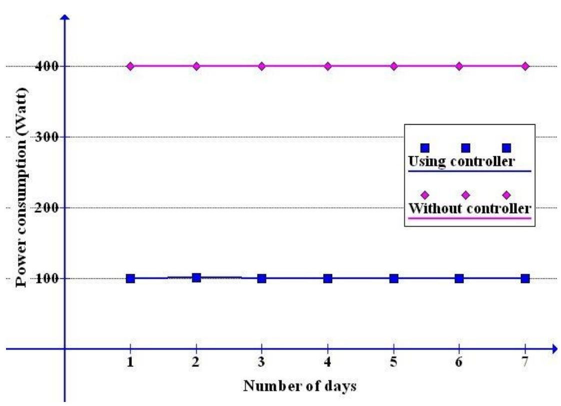

Figure 11 Power consumption: With and without controller

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7. CONCLUSION

Table 1 Illumination level, power consumption and uniformity ratio comparison

	Days	1	2	3	4	5	6	7
Without Controller	Illumination level (Lux)	128.46	140.15	147.85	154.08	160.39	145.46	118.31
	Power consumption (P) (Watt)	400	400	400	400	400	400	400
	Uniformity ratio	0.09	0.09	0.12	0.13	0.12	0.14	0.10

In this paper, design and implementation of a low cost electric lighting interface module and new logical approach of automatic day lighting control of electric lighting system using Allen Bradley MicroLogix 1100, 1763-L16BBB PLC as a lighting controller is designed and implemented. The numbers of lamps were determined and controller in a control room for the automatic variation of illumination during day time and achieved average illumination level of 300 lux and average uniformity ratio nearer to 0.9. These values met the requirement of NBCI of the typical building. Power consumption of the lamps was also estimated and the results shows that during day lighting control, lamps consumes very less power and saved the 75% energy usage of the control room. Same system can be used in day lighting control of building automation for better energy efficiency using LED lamps and also, the large power handing capacity of the light dimmer can also be implemented.

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