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Lux Adjuster Controller for Solitary Ocular Comfort

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This paper presents a precise lighting controller which can concurrently adjust and display the real-time illuminance of a working platform for solitary ocular comfort. It gives the user the provision to select the right amount of lux for a particular task by knowing illumination as endorsed by IES, which is supposed to receive on the desired working plane or area. The above-mentioned controller provides a high degree of certainty for delivering energy savings without compromising ocular comfort. Besides, it can be considered as one of the rationales for the Demand-Side Management lighting technique. This idea is accomplished by integrating a microcontroller prototyping platform with three separate modules namely the controlling module, sensing & displaying module, and power supply module. Appropriate codes for the microcontroller were written, compiled, and uploaded by verifying through simulation. Finally, hardware implementation was done successfully and energy-saving prospects were analyzed.

Keywords: Microcontroller; energy-saving; LACFSOC; lux.

1. Introduction

Probing scientifically shows that the main cause of industrial accidents is due to human error [1][2][3]. An important factor that is responsible for this error arises because of the poorly designed installation of lighting. To be precise, the inability to maintain the right level of illumination for a particular working surface or environment is the root cause of this error. It is a common practice to compromise the quality of lighting to reduce energy consumption. The proposed LACFSOC system will not compromise the right illumination level considering the energy-saving factor. If every family or workplace traded just one incandescent bulb for an efficient LACFSOC-based incandescent bulb, there will be a significant cutting in energy consumption and hence the carbon emissions can be reduced to a greater extent. The analysis regarding the same has been done vividly in Table V of this manuscript.

2. Notation

The following is a list of notations used throughout the paper.

E_v = Illumination received in lux

R_{ldr} = Resistance of LDR

R_{ref} =Reference resistor of 130K ohms

V_{ldr} = LDR voltage

V_{RRV}=Reference resistor voltage i.e. the voltage across the 130 k resistor

V_{mref} = Maximum reference voltage i.e. 5 V DC

MAX_{int} = Maximum integer value for 10-bit analog to digital converter equal to 1023

Raw_{ldr} = LDR raw data that ranges from 0 to 1023

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LACFSOC = Lux Adjuster Controller for Solitary Ocular Comfort

3. Structure and design of lux value adjuster lighting controller for ocular comfort

In this proposed design, Arduino UNO is used as the microcontroller prototyping platform. The whole structure shown in Fig.1 can be categorized as (i) power supply module (ii) sensing &display module (iii) controlling module. All the modules are integrated through Arduino UNO.

3.1. Power Supply module

The power supply module will deal with powering up the Arduino UNO as well as the delivery of power to the load i.e. bulb from the single-phase supply. In Fig.6, 230 V AC mains is stepped down to 9 V AC using a step-down transformer and it is rectified using a full-wave rectifier to get DC output. A capacitor C6 is connected parallel to maintain the output voltage near the maximum voltage. Further, it is followed by a voltage regulator to regulate a constant voltage. Another capacitor C5 is again connected across the output of the voltage regulator to get an almost perfect 9 V DC. Finally, the 9 V DC is ready to power up the Arduino UNO. The circuit is designed in such a way that the bulb is directly connected across AC mains via PWM signal-controlled power from the Arduino UNO.

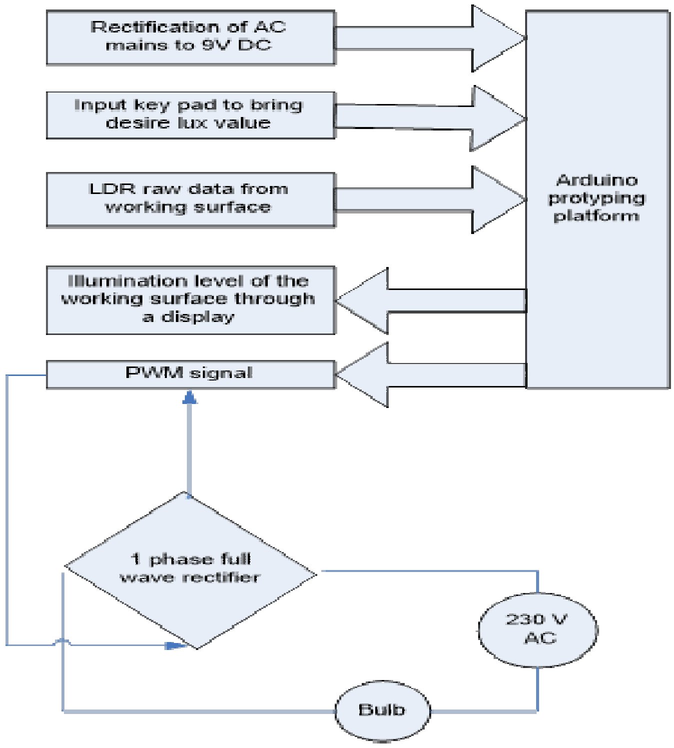

Fig. 1. Structure of working of lux adjuster controller for solitary ocular comfort

3.2. The Sensing and Display Unit

The sensing and display module normally senses the amount of lux received on the working surface and displays the value of the illumination of the working surface where the sensor is located. The module is designed in the following ways. A lux meter, a random LDR, an ohmmeter, a light source, and a variac are arranged initially. The light source of the 60 W incandescent bulb is mounted at a certain height of 0.3 m and a variac is connected across it through a single-phase ac supply. In the meantime, using a breadboard, the two leads of the LDR are allowed to stand parallel to the surface just below the bulb. An ohmmeter is connected across the two leads of LDR. Close to LDR, the sensor of the lux meter is kept. Now varying the knob of the variac, the intensity of light slowly increases, and corresponding readings of ohmmeter and lux meter are noted down as shown in Table I. Using the data, a graph is plotted between Luxmeter reading vs Ohmmeter reading which is non-linear as shown in Fig. 2.

TABLE I. THE CORRESPONDING CHANGE IN RESISTANCE OF LDR AT DIFFERENT VALUES OF LUX LEVE

Sl. No.	The corresponding change in resistance of LDR at different values of lux level	
	Ohmmeter reading, R_{ldr} (Ω)	***Lux level on the working surface, E_v***
1	129000	1
2	59000	3
3	10900	19
4	6600	60
5	4000	110
6	2500	198
7	1990	230
8	1900	290
9	1800	340
10	1600	380
11	1380	495
12	1250	550
13	1190	620
14	1080	695
15	880	930
16	740	1200
17	520	1900
18	320	3300

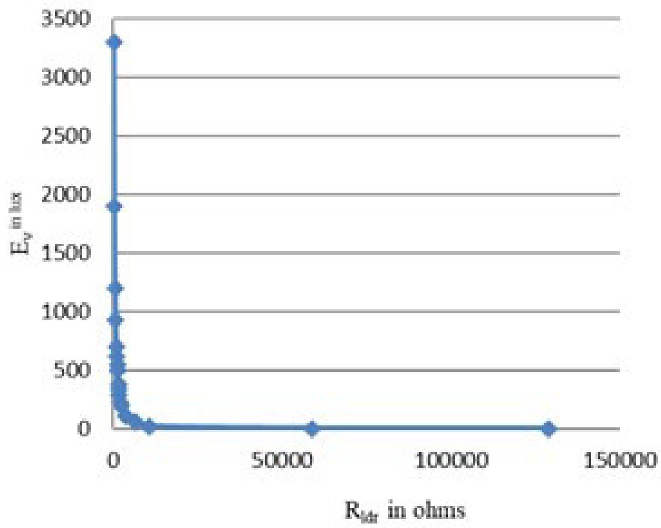

Fig. 2. Plot of Ev vs Rldr

We can see that the characteristic of Fig.2 is non-linear. To have a linear approach, all the data in Table I is taken logarithm of base ten and tabulated as shown in Table II. A graph is again plotted using the data in Table II.

TABLE II. THE CORRESPONDING CHANGE IN RESISTANCE OF LDR AT DIFFERENT VALUES OF LUX LEVEL CONSIDERING THE LINEAR APPROACH

Sl. No.	**The corresponding change in resistance of LDR at different values of lux level considering the linear approach**	
	$log_{10} R_{ldr}$	***$log_{10} E_v$***
1	5.1105	0
2	4.7708	0.47712125472
3	4.0374	1.27875360095
4	3.8195	1.77815125038
5	3.602	2.04139268516
6	3.3979	2.29666519026
7	3.2988	2.36172783602
8	3	2.4623979979
9	1800	2.53147891704
10	1600	2.57978359662
11	1380	2.69460519893
12	1250	2.74036268949
13	1190	2.7923916895
14	1080	2.84198480459
15	880	2.96848294855
16	740	3.07918124605
17	520	3.27875360095
18	320	3.51851393988

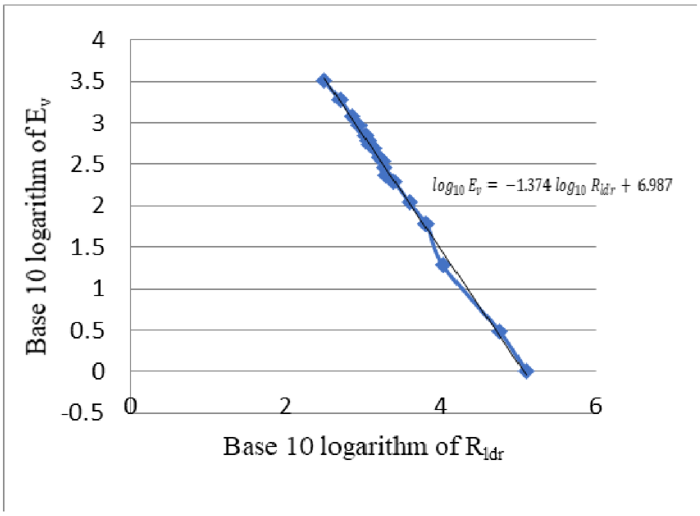

Fig. 3. The plot of log $_{10}$ E_v vs log $_{10}$ R_{ldr} considering the linear approach

The plot in Fig. 3 nearly gives a straight line with an equation furnished below

$$log_{10}\, E_v = -1.374\, log_{10}\, R_{ldr} + 6.987 \tag{1}$$

$$10^{\log_{10} Ev} = 10^{-1.374 \log_{10} Rldr + 6.987} \tag{2}$$

Logarithmic simplification of Equation 2 gives

$$E_v = 9705099\, R_{ldr}^{-1.374} \tag{3}$$

Equation 3 shows that the providing of real-time R_{ldr} information can give the corresponding lux received on the LDR or working surface. The exponents and the constant shown in Equation 3 is used in writing code in the coming steps. The information of Rldr is continuously obtained using a voltage divider to get the real-time lux received on the LDR. Since the maximum resistance obtained in Table 1 is around 129k, we have chosen a resistor of 130k and a voltage divider circuit is set up as shown in Fig.4. Here the input voltage is 5 Volt and the two resistors i.e. LDR and 130k ohms are connected in series as shown in Fig.4. The fraction of 5 Volt DC is continuously measured across 130 k and it is fed to the analog terminal of the prototyping microcontroller. The maximum integer value of 1023 for a 10-bit analog-to-digital converter is considered for multi-channeling. Hence, a relationship is developed between the parameters mentioned above and it is shown in Equation 4 as follows

$$\frac{V_{RRV}}{V_{mref}} = \frac{Raw_{LDR}}{Max_{int}} \tag{4}$$

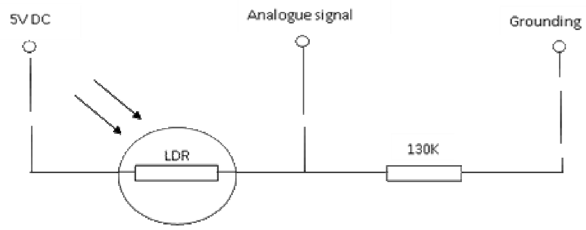

Fig. 4. Voltage divider

The voltage across the reference resistor 130 k ohms, V_{RRV} is given by

$$V_{RRV} = \frac{Raw_{LDR}}{Max_{int}} \times V_{mref} \tag{5}$$

Where,

Max_{int} = Maximum integer value for 10-bit analog to digital converter equal to 1023
Raw_{LDR} = LDR raw data that ranges from 0 to 1023
V_{RRV}=Reference resistor voltage i.e. the voltage across the 130 k resistor
V_{mref} = Maximum reference voltage i.e. 5 V DC

The voltage across LDR, V_{ldr} can be found from the voltage divider circuit Fig.4 as shown below

$$V_{ldr} = V_{mref} - V_{RRV} \tag{6}$$

Where,

V_{ldr} = LDR voltage

Since the voltage across the LDR is known, the resistance across LDR at the varying value of illumination can be obtained by the equation furnished below

$$R_{ldr} = \frac{V_{ldr}}{V_{RRV}} \times R_{ref} \tag{7}$$

Where,

R_{ldr} = Resistance of LDR
V_{ldr} = LDR voltage
V_{RRV}=Reference resistor voltage i.e. the voltage across the 130 k resistor
R_{ref} =Reference resistor of 130K ohms

The information of R_{ldr} from Equation 7 is used to find out Ev, lux received on the working surface in Equation 3 and it will be shown with the help of a basic liquid crystal display. A well-defined specific order of instructions for displaying the lux value is shown in Fig.5. The instructions are based on the equations developed above. The overall circuit diagram for the whole design is shown in Fig.6.The sensor and display module portion can be seen clearly as a part of the whole circuit diagram. The interlink between the pins of 16 X 2 LCD and Arduino UNO is also shown vividly in Fig.6.

3.3. Controlling Module

The controller uses a PWM-controlled IGBT drive circuit and the lamp whose lux value is to be adjusted is connected in series with a bridge rectifier.

ON-OFF AC power control through PWM is utilized in this module. An Arduino UNO which is used as a prototyping platform not only measured the lux level and display but is also used to produce a PWM signal. In this design, Arduino UNO pin 11 is used to produce PWM pulses by controlling the duty cycle of PWM pulses through a 4X4 alphanumeric keypad module as shown in Fig.6. Any duty cycle that ranges from 0 to 100% can be pressed on the keypad and the corresponding AC output will be received at the load i.e. bulb. The PWM hardware timer of Arduino UNO is 8 bit and the largest decimal number that represents eight-bit is 255. Hence, the 100% duty cycle corresponds to 255, and therefore any value between 0 to 100%, say 'K' can be converted from analog to digital as K(255/100). These converted PWM pulses from the Arduino UNO are fed to the input of the optocoupler i.e. LED. The emitted light of the LED is again fed to the base of the phototransistor inside the optocoupler and the voltage across the collector & emitter terminal of this transistor is considered as the output of the optocoupler. Here, the optocoupler is used to isolate the low-voltage Arduino circuit from the higher-voltage lamp circuit which is connected across the 230 V AC supply but the PWM pulses remain the same in both circuits. Now the output of the optocoupler is connected across the DC-biased circuit from the rectifier for quick conduction. A full-wave bridge rectifier is made with the diodes D2, D3, D4, D5, and an AC 230 V, 50 Hz mains is connected across one of the two terminals of the bridge as shown in Fig.6. Further, the ac supply is rectified through diode D6, and the filter network is formed by resistor R5 and capacitor C2. A resistor R1 is connected in series with the optocoupler to safeguard the LED inside it. A resistor R2 is used to minimize the spikes of switching. The input pulse feed to the gate of IGBT is the output of the optocoupler and it is identical to the PWM pulse generated from the Arduino UNO. Here the fast switching ability of the IGBT, which is controlled by the pulse from Arduino will appear the bulb as if it is continuously glowing. It is like connecting a switch between the bulb and AC mains, 50 Hz supply, where the switching process is so quick that it is unable to be sensed by our naked eye.

Putting all the modules together, the actual proposed design is set up as shown in Fig. 7 based on the circuit layout shown in Fig. 6. The descriptions of the components used are listed in Table VI [29] which is under Appendix A. After energizing the proposed design across an AC supply, it can be used in the following steps:-

i. Identify the cognizant illumination level in terms of lux for the solitary working surface according to the suggestion of Illuminating Engineering Society.

ii. Push the button "A" on the alphanumeric 4X4 keypad and enter any arbitrary power cycle between 0 to 100%.

iii. Push the button "#" to log on to the power cycle of the proposed controller. The bulb connected to the controller will shine.

iv. Based on the given power cycle or duty cycle, the liquid crystal display will now show the light intensity in terms of lux. The lux displayed is the illumination received on the solitary or focused working surface.

v. If the illumination is not equal to the approved value given by Illuminating Engineering Society then repeat steps (ii) to (iv) till you find the exact value of lux.

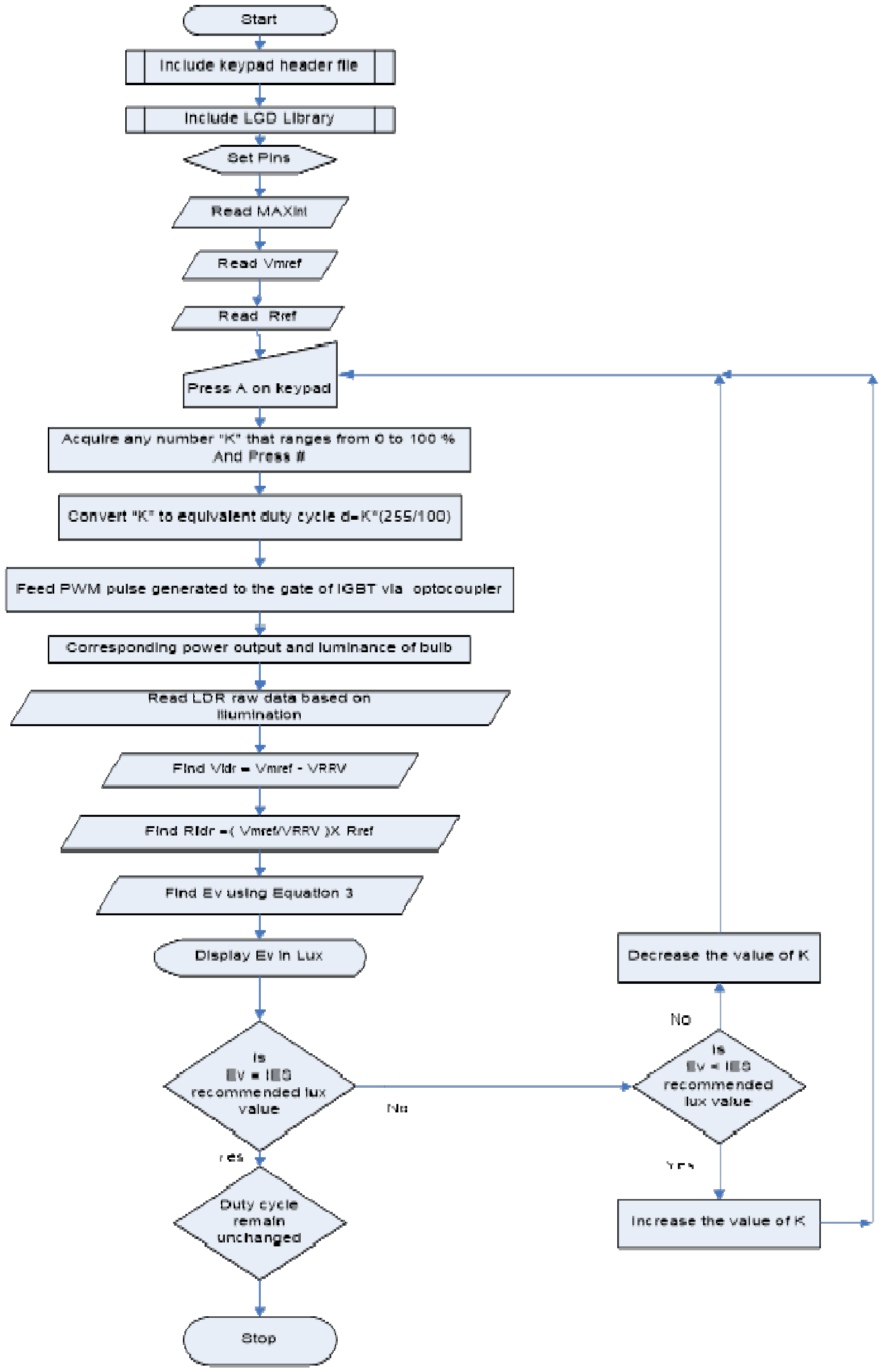

Fig. 5. Flowchart of working of Lux Adjuster Controller for Solitary Ocular Comfort

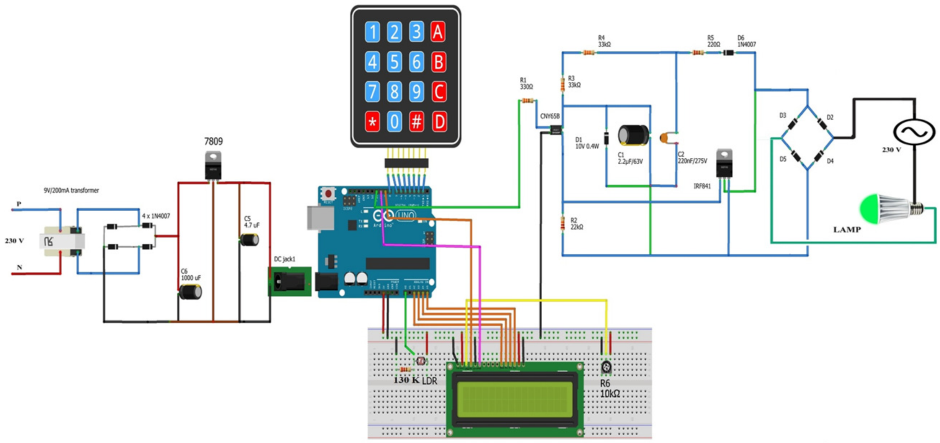

Fig. 6. Circuit layout of Lux Adjuster Controller for Solitary Ocular Comfort

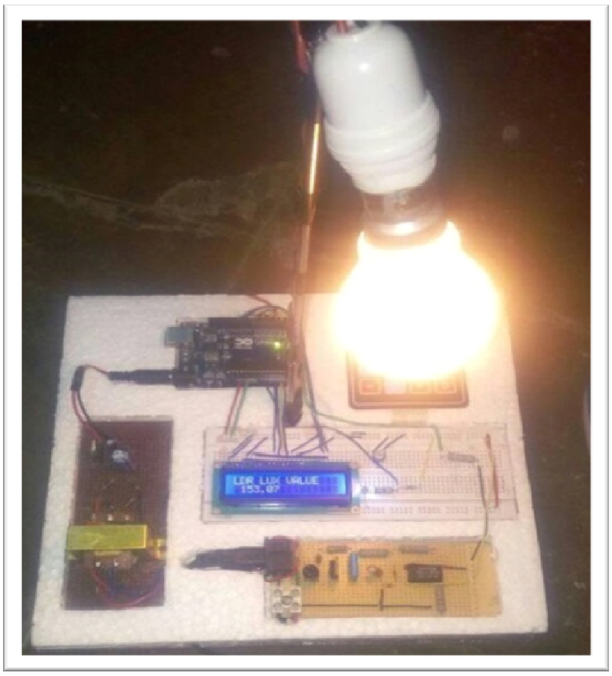

Fig. 7. The actual circuit configuration of the Lux Adjuster Controller for Solitary Ocular Comfort

4. Corroboration of Lux Adjuster Controller for Solitary Ocular Comfort study

Corroboration of the "Lux value adjuster lighting controller for ocular comfort" was performed by installing a bulb that is controlled by LACFSOC with the excitation voltage of 230 V at a mounting height of 11.81 inches and putting the sensors of both the reference lux meter & the proposed controller at the focal point of the working platform as shown in Fig.8. By entering the different values of power cycle %, corresponding values of lux value in both the sensors are recorded as shown in Table III and analyzed. The reading of Sl. No. 7 in Table III is shown in Fig. 9 as proof of the reading taken for analysis. The Assessment in Table III shows that the mean square error (MSE) value of the model was 1.80365. Here MSE represents the quality of the proposed model.

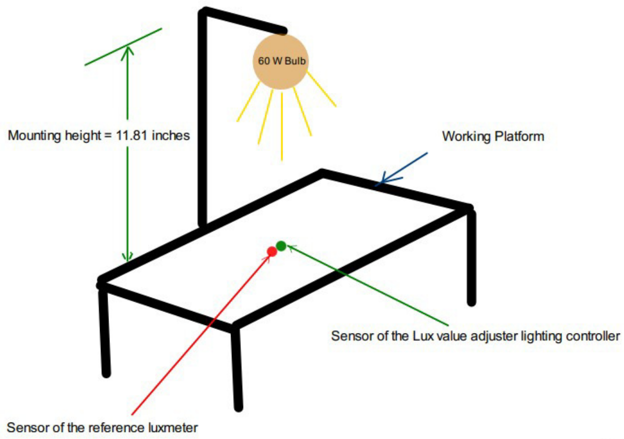

Fig. 8. Representational diagram of setup for corroboration

Fig. 9. Shows the lux value for both the sensors (reference lux meter and LACFSOC) at a 30% power cycle.

TABLE III. MODEL ASSESSMENT ANALYSIS OF *LUX ADJUSTER CONTROLLER FOR SOLITARY OCULAR COMFORT* (LACFSOC) WITH REFERENCE LUX METER AT DIFFERENT VALUES OF POWER CYCLE % WHEN BOTH OF THEM WERE KEPT AT THE FOCAL POINT OF THE WORKING PLATFORM

Sl. No.	**Model assessment analysis of *Lux Adjuster Controller for Solitary Ocular Comfort* (LACFSOC) with reference lux meter at different values of power cycle % when both of them were kept at the focal point of the working platform.**					
	Power cycle % key into the proposed model (LACFSOC)	***Measured value of illumination received on the sensor of LACFSOC***	***The reference value of illumination received on the reference lux meter (lux)***	***Error***	***Error square***	***Mean square Error (MSE)***
1	5	21.55	21.02	0.53	0.2809	
2	10	34.78	34.13	0.65	0.4225	

Sl. No.	Model assessment analysis of *Lux Adjuster Controller for Solitary Ocular Comfort* (LACFSOC) with reference lux meter at different values of power cycle % when both of them were kept at the focal point of the working platform.					
	Power cycle % key into the proposed model (LACFSOC)	*Measured value of illumination received on the sensor of LACFSOC*	*The reference value of illumination received on the reference lux meter (lux)*	*Error*	*Error square*	*Mean square Error (MSE)*
3	15	40.36	40.45	-0.09	0.0081	MSE = (TSE/12) = 1.80365
4	20	50.78	50.25	0.53	0.2809	
5	25	62.12	62.00	0.12	0.0144	
6	30	73.44	69.00	4.44	19.71	
7	40	118.31	119.01	-0.7	0.49	
8	50	132.41	132.53	-0.12	0.0144	
9	60	172.38	172.02	0.36	0.1089	
10	70	228.69	228.38	0.31	0.0961	
11	80	289.61	290.01	-0.4	0.16	
12	90	320.46	320.22	0.24	0.0576	
					Total square error (TSE) = 21.6438	

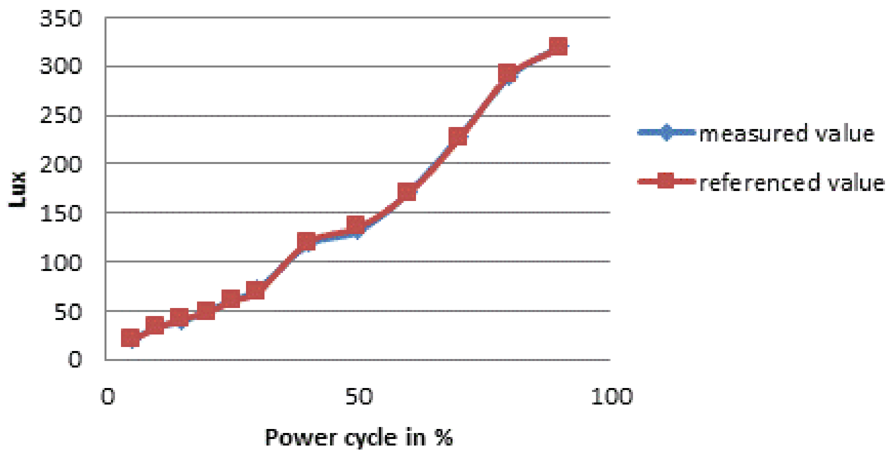

Fig. 10. Comparison of the measured value of LACFSOC lux against the referenced value of lux with different values of power cycle %

5. Guesstimation of Energy Saving Capacity of "Lux Adjuster Controller for Solitary Ocular Comfort "

Experimental data is collected by placing a 60 W bulb at a mounting height of 11.81 inches. By using a wattmeter and with the incorporation of LACFSOC, the power consumption of a 60 W bulb at different power cycle percentages has been tabulated as shown in Table IV.

TABLE IV. POWER CONSUMPTION OF A 60 W BULB AT DIFFERENT POWER CYCLE PERCENTAGE

Sl. No.	Power consumption of a 60 W bulb at different power cycle percentage		
	Power cycle % input via the keypad to the proposed model LACFSOC	*Measured value of illumination received on the sensor of LACFSOC (lux)*	*Power consumption by 60 W bulb with LACFSOC*
1	5	21.55	**3**

Sl. No.	Power consumption of a 60 W bulb at different power cycle percentage		
	Power cycle % input via the keypad to the proposed model LACFSOC	***Measured value of illumination received on the sensor of LACFSOC (lux)***	***Power consumption by 60 W bulb with LACFSOC***
2	10	34.78	**6**
3	15	40.36	**9**
4	20	50.78	**12**
5	25	62.12	**15**
6	30	73.44	**18**
7	40	118.31	**24**
8	50	132.41	**30**
9	60	172.38	**36**
10	70	228.69	**42**
11	80	289.61	**48**
12	90	320.46	**54**

For an illustration, we used a working plane that requires 118 lux from a mounting height of 11.81 inches. By using LACFSOC, 60 Watt bulb was able to maintain 118 lux for the specific task on the working plane and it was continuously used for 6 hours. With this system, we were able to save 0.756 kWh of energy. On the other hand, without LACFSOC, the system won't be able to maintain 118 lux and there will be a lot of energy wastage close to 0.756kWh. Using the data of Sl.No. 7 from Table IV, Table V shows the analysis in detail. It shows that if we used the 60 W bulb for one year with the proposed LACFSOC, it will be saved around 27.594 kWh of energy, which is equivalent to saving 6.4333 kg of CO_2 emission [27]. Figure 11 shows the comparison of the two systems' energy consumption.

TABLE V. OVERALL ENERGY CONSERVED BY LACFSOC

Utilization time in the hour of 60 W bulb	**Overall energy conserved by LACFSOC**				
	Power ingested by 60 W incandescent bulb to maintain 118 lux when LACFSOC was used. (in Watt)	***Power ingested by 60 W incandescent bulb in the absence of LACFSOC and also unable to maintain 118 lux. (in Watt)***	***Energy ingested by 60 W incandescent bulb to maintain 118 lux when LACFSOC was used. (in Watt Hour)***	***Energy ingested by 60 W incandescent bulb in the absence of LACFSOC and also unable to maintain 118 lux. (in Watt Hour)***	***Energy conserved after utilization of LACFSOC (in Watt Hour)***
1	24	60	24	60	36
2	24	60	48	120	72
3	24	60	72	180	108
4	24	60	96	240	144
5	24	60	120	300	180
6	24	60	144	360	216
Overall energy conserved by LACFSOC while maintaining 118 lux on the working plane for 6 hours per day					0.756 kWh

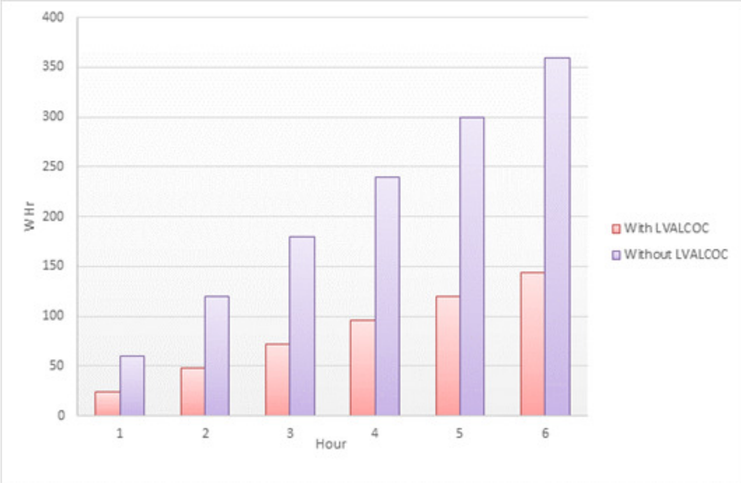

Fig. 11. Comparison of energy consumption of the two systems within a 6-hour time frame

5. Conclusion

The proposed system shows the ability to keep the proper amount of illuminance at the working plane allowing it to use the least amount of electricity possible for a given task or activity, which would otherwise be wasted with traditional lighting. The controller also can take the daylight variation into account. The advantage of using LACFSOC over normal lighting is shown distinctly in Table V and Fig.11 gives the comparison of the two systems within 6 hours time limit for illustration. Considering the usage of 6 hours time limit, the yearly energy consumption of the two systems is found to be 183.96 kWh and 459.9 kWh for the LACFSOC-based system and the normal system respectively. It's been estimated that 275.94 kWh of energy is saved per annum if we utilized the LACFSOC-based system. With proper conversion [27] of this energy unit into equivalent carbon emission, it is observed that 64.33 kg of CO2 emission can be saved from release into the atmosphere if we used the proposed system considering the above criteria. The system is designed for the incandescent bulb and it is suitable for a limited period of hours for effective use where high precision is required. Hence, it can be considered one of the rationales for the Demand-Side Management lighting technique.

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Appendix A [29]

Table VI Electronic components used in this proposed design

Particulars	Descriptions	Number of quantity
Alphanumeric keypad	4 x 4 matrix	1
Condenser	220n F	1
	2.2 μ F	1
	1000 μF	1
	4.7 μ F	1
Resistor	130 k Ω	1
	33 k Ω	2
	330 Ω	1
	22 k Ω	1
	220 Ω	1
16 X 2 character LCD Display	Yellow light	1
Microcontroller platform	Arduino UNO	1
Illumination/lux meter	Company Metravi	1
Ohmmeter	Rishi multi	1
Solderless breadboard and soldering tools [29]		1
LDR	Photoresistor GL75	1
Opto-isolator [29]	CNY65B 832J	1
Universal serial bus cable	A to B type	1
Diode	IN4007	5
Rectifier	GBPC610	1
Insulated gate bipolar transistor	IRGP4063	1
Zener diode	10V/4W	1
Three terminal voltage divider	10 k Ω	1
Jumper	Male to male	30
Step down transformer	230/9 V, 500 mA	1
Positive voltage regulator	7809	1
Power jack	2.1 mm diameter	1