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DESIGN & DEVELOPMENT OF A SOLAR POWERED, CCT CHANGING R-B-W LED BASED ARTIFICIAL WINDOW

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ABSTRACT

The concept of Artificial Window is being applied in indoor lighting design since couple of years and is easily available in market, but the main drawback of these artificial windows is their constant CCT (Correlated Colour Temperature) light output. The developed artificial window is a CCT changing system, which follows the preset pattern of daylight CCT throughout the day. It will very effective for those, who stay in a window-less room or a closed room. It is known that light not only has the visual effects but also has photo-biological effects. A dynamic light is very helpful in well being, positive mood, increased concentration, alertness consequently increased productivity. The developed system is solar powered at daytime; this window is powered by the SPV module directly without using battery. A small battery is being charged simultaneously which powers the system at night time. The window is made using two types of coloured LEDs: Red and Blue and Warm White LED. The new concept of dynamic lighting provides a very wide CCT range from 2300 K to 10800 K.

Keywords: artificial window, human centric lighting, CCT changing lighting, solar powered based system, dynamic lighting, dynamic lighting controller

I. INTRODUCTION

Window is a very important part of any building. It has a psychological effect on people. Daylight can enter inside the room through the window; this is the main purpose of a window. Daylight is a natural light source, which varies over time in quantity (illuminance) and quality (colour) [1,2]. A room can be illuminated using daylight and it has several good effects on mankind [3]. Daylight has a great impact on the human circadian system [4], influencing our metabolism and controlling the hormone balance [5,6]. Many modern urban multi-storeyed buildings, even many village huts do not have the windows. People inside those rooms always stay under the artificial light and many of them suffer from seasonal affective disorder (SAD) caused by lack of daylight [7,8].

In such buildings and rooms artificial windows may be used, serving the same purpose, giving the illusion of a natural window. The artificial windows available in Indian market have the constant CCT. Such types of windows do not fulfil the requirement of a real window; they do not give the dynamic light effect of daylight. This designed and developed artificial window produces the dynamic light effect throughout the day. This dynamic light resembles to the daylight, i.e. the window follows the preset pattern of daylight CCT all the day. At night time, it produces a constant CCT (2900 K). The CCT of daylight can varies from 2000 K at sunrise to 5000 K at noon in clear sky conditions. Sometimes it exceeds 10,000 K in overcast conditions [9,10]. Using the combination of Warm White (2840 K) and Cool White (5750 K) LEDs [11] it was not possible to get the CCT of 10,000 K of overcast conditions. Many experiments were done to get the wide range of CCT using red-yellow-green-blue (RYGB) LEDs [9,12,13]. To get that wide range of CCT very easi-

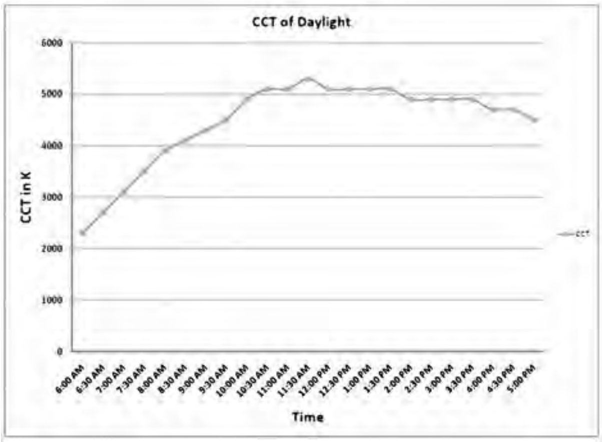

Fig.1. CCT of Daylight in the month of March'2017

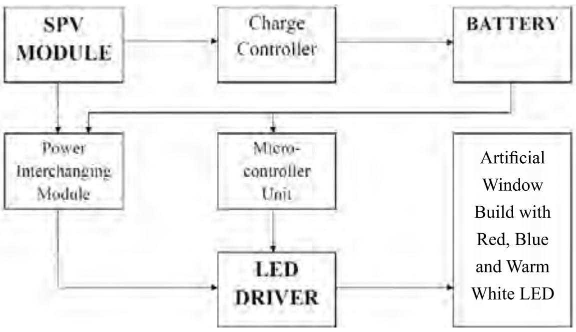

Fig.2. Block diagram of the system

ly, red, blue and warm white LED having CCT 2900 K was used in the window prototype and this combination of LEDs achieved up to 10,800 K CCT.

This window is powered by the solar photo voltaic (SPV) module directly at daytime and at night time it gets power from a battery, which will charged during daytime by the SPV module at daytime simultaneously. When the insolation is less, light level of the artificial window falls down. In the cloudy condition or in the evening time when there is no sunlight, this window provides a constant CCT of 2900 K. The design of the artificial window is described in the following sections.

2. MEASUREMENT OF DAYLIGHT CCT

As daylight is dynamic in quality and quantity, spectral power distribution (SPD) and light level of daylight varies with time [1,2], CCT of daylight cannot be standardized for a particular day or season. For the artificial window a daylight pattern is needed. The measurement of daylight CCT is done in the month of March'2017 on the rooftop of Electrical Engineering Department, Jadavpur University, Kolkata, India, in clear sky condition. This experiment was performed for 15 days. CL200A colorimeter (Konica Minolta Measuring Instrument, Japan) was used to measure the CCT of daylight. It is seen that during sunrise the CCT is around 2300 K, at noon around 5400 K and during sunset it falls to 4500 K. Collecting all the data of 15 days, a CCT pattern is made for the artificial window, which is shown in Fig.1.

3. CONCEPT OF VARIABLE CCT USING LED

In this system, the colour mixing follows the Grassmann's law of colour. According to Grassmann's law, colour mixtures obey the law of addition. If the tristimulus values (*X, Y, Z*) of two colours are known, they can be added to obtain the tristimulus values of the resultant. Usually, a colour can be specified in terms of its chromaticity coordinates (*x*, *y*) and its luminance (*L*), which is proportional to the tristimulus value *Y* [14,16]. Chromaticity of the resultant colour can be obtained using (1):

$$x=\frac{\sum_1^n\left(xk\frac{Yk}{yk}\right)}{\sum_1^n\frac{Yk}{yk}}\ \ and\ \ y=\frac{\sum_1^n\left(yk\frac{Yk}{yk}\right)}{\sum_1^n\frac{Yk}{yk}}. \quad (1)$$

The chromaticity coordinates (*x*, *y*) of this blended colour will be somewhere on the straight line connecting the chromaticity coordinates of two colours on CIE1931 chromaticity diagram. The tristimulus distribution function $\bar{y}(\lambda)$ is exactly similar to the relative spectral luminous efficiency curve V (λ). Hence any photometric parameter like luminous flux (*Φ*), luminance (*L*) or illuminance (*E*) is proportional to tristimulus value *Y* [14]. Therefore, colour can be specified by chromaticity coordinates (*x, y)* and any photometric parameter [11]. In this work, the colour is specified by chromaticity coordinates (*x*, *y*) and the illuminance (*E*). Equation (1) can be rewritten as

$$x=\frac{\sum_1^n\left(xk\frac{Ek}{yk}\right)}{\sum_1^n\frac{Ek}{yk}}\ \ \text{and}\ \ y=\frac{\sum_1^n\left(yk\frac{Ek}{yk}\right)}{\sum_1^n\frac{Ek}{yk}}. \quad (2)$$

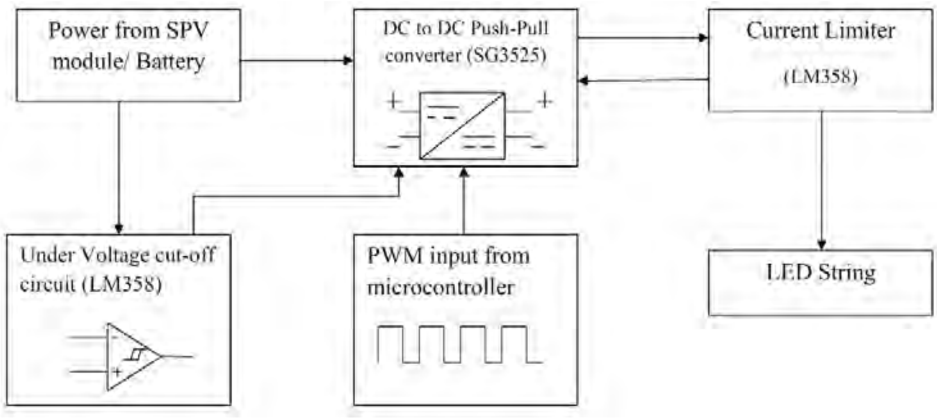

Fig.3. Block diagram of LED driver

4. DESIGN OF THE CONTROLLER CIRCUIT

4.1. Block Diagram of the System

Block diagram of the system is shown in Fig.2.

There are three individual LED drivers for three colours of LED. This driver includes the under voltage cut-off circuit, DC-DC converter circuit and current limit circuit etc. A charge controller charges the battery and consists of a DC- DC converter, under voltage cut-off circuit, current limit circuit, overcharging protection module and deep discharge protection module. Due to low insolation, when SPV module's voltage falls below 10V, whole system gets disconnected from the SPV module and this is done by the under voltage cut-off circuit and the window (at 2900K CCT) is powered by the battery instantly, which is done by the interchanging module. The overcharging protection module protects the battery from excess charging and the deep discharge protection module protects the battery from deep discharging. There is a microcontroller (ATMEGA 32 microcontroller from ATMEL) unit in this system, which generates the PWM signal for three different colours of LEDs for a particular CCT. The CCT changing throughout the day is controlled by this unit.

4.2. Description of LED Driver and the Charge Controller

Three LED drivers are used for three different colours of LED. Design and construction of three drivers are similar. In this section one LED driver is discussed. Block diagram of LED driver is shown in Fig.3.

The LED driver consists of a DC-DC converter, a current limiter, an under voltage cut-off circuit and a push-pull switching circuit for dimming the LED. For any LED driver it is necessary to make it constant current and constant voltage configuration (CC/CV). To make the CV configuration DC to DC Push-Pull converter is designed using SG3525 IC. It is a dual output SMPS IC and it is operated at the frequency of 100 KHz. In current limiter circuit a LM 358 op-amp is used as a comparator, which compares the voltage across current sensing resistor with a reference voltage. When the voltage across the resistor exceeds the reference voltage, a high signal is sent to the IC SG3525 and the output voltage will be reduced, as well as the current will also be reduced. The under voltage cut-off circuit is a comparator too. LM 358 op-amp is used as a comparator, which compares the input voltage with a reference voltage of 10 V. Whenever the input voltage falls below 10 V, it will generate a high signal. The high signal is given to the pin 10 (shut down pin) of SG3525 IC. As long as the pin 10 is in high state, circuit will be shut down completely and output voltage will remain zero. When a low signal is applied to that pin, circuit will be in operating condition. The microcontroller (ATMEGA 32) is programmed in that way, it will give different PWM signal for different CCT. The PWM signal controls the illuminance level of Red LED and Blue LED. The on time and off time of the control signal depends upon the duty cycle of the PWM signal. If the duty cycle of the PWM signal is higher, on time will be high and LED will glow brighter, illuminance will be higher. If the duty cycle is less, on time will be less, LED will be dimmed and the illuminance will be less. The on and off cycle is opera-

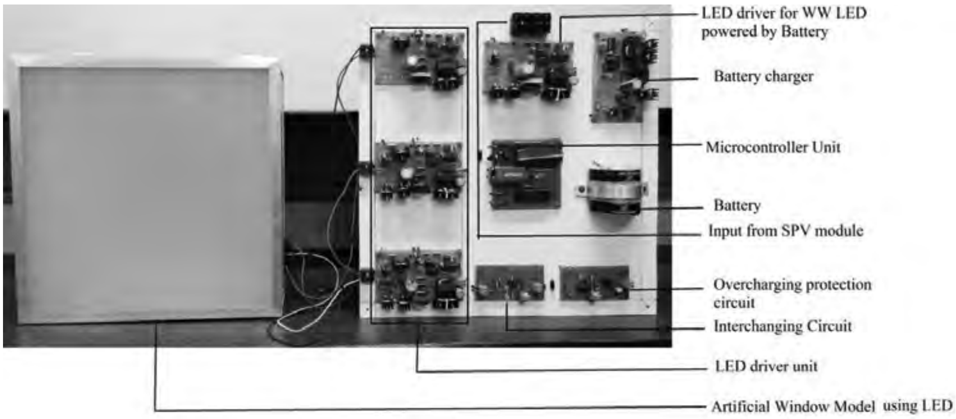

Fig.4. Developed System

ted in very high frequency, so that one cannot see it in bare eye.

The circuit operation of the charge controller is same as the LED driver. It consists of a DC-DC push-pull converter, a current limiter and the under voltage cut off circuit. Beside that an overcharging protection circuit and a deep-discharge protection circuit is also incorporated with the charge controller to protect the battery from damage, which increases the battery life.

5. DEVELOPED SYSTEM

The window has been developed with 24 numbers red LEDs, 24 numbers of blue LEDs and 24 numbers of WW LEDs. When it is covered with a good diffuser and fitted on wall, it resembles opaque glass covered window. The developed system is shown in the Fig.4.

6. COLOUR MIXING EXPERIMENT FOR VARIABLE CCT

To get the variable CCT by mixing the colour, it is necessary to use the suitable light source with appropriate colour. Many works were done in past to get the wide range of CCT using two or more colour sources. By mixing the red-blue-green (RGB) LEDs [15] or red-yellow-green-blue (RYGB) LEDs [9,12,13], variable CCTs were generated, but the mixing algorithm is difficult and the control circuit is costly. Using the mixture of cool white (6000 K) and warm white (2700 K) LEDs [11] wide range of CCT cannot be generated. In this developed system two types of LED, red and blue have been mixed with Warm White LED with 2900 K CCT. WW LED is taken as a reference. Here CCT below 2900 K is achieved by the mixture of WW LEDs and the red LEDs and the CCT above 2900 K is achieved using WW LEDs and blue LEDs. The mixing algorithm is quite easy and a wide range of CCT, starting from 2300K to 10800K has been achieved here.

The resultant CCT is obtained when two or more colours are mixed by changing the input currents of the LEDs and ultimately changing the illuminance (*E*) of the individual light sources (Equation 2).The input current can be changed by the pulse width modulation (PWM) technique. If the width of the current pulse increases, current will increase, as well as the illuminance of the light source also increases.

The colour mixing experiment was performed in the Illumination Engineering Laboratory, Electrical Engineering Department, Jadavpur University, India. A luminaire used in this experiment consists of three WW LEDs, three blue LEDs and three red LEDs (total nine LEDs). A dome shaped P4 type LED of 1watt has been used. Dimension of the luminaire is 6”x6”x3”. Three control circuits are used for each colour of LEDs, the PWM duty cycle is controlled by these control circuit. The WW LED

Fig.5. Experimental setup of the colour mixing experiment

Table 1. Experimental Results of Colour Mixing Experiment

PWM duty cycle, %			Illuminance, E_v, *lx*	Coordinate		CCT, K
Red LED	WW LED	Blue LED		*X*	*y*	
10.2	100	0	27	0.4727	0.3834	2300
2.5	100	0	25.8	0.4122	0.3299	2700
0	100	0	25.6	0.3967	0.3170	2900
0	100	1.9	25.6	0.3736	0.2937	3300
0	100	2.8	25.8	0.3606	0.2838	3700
0	100	4.1	26.1	0.3445	0.2750	4500
0	100	4.5	26.3	0.3369	0.2704	4900
0	100	5.3	26.6	0.3272	0.2630	5700
0	100	5.4	26.6	0.3253	0.2606	6000
0	100	5.8	26.8	0.3204	0.2548	6600
0	100	6.2	27	0.3164	0.2500	7200
0	100	6.5	27.1	0.3132	0.2460	7800
0	100	6.8	27.2	0.3105	0.2429	8400
0	100	7.2	27.2	0.3076	0.2394	9200
0	100	7.5	27.2	0.3058	0.2372	9800
0	100	7.7	27.2	0.3047	0.2359	10200
0	100	8.0	27.3	0.3033	0.2342	10800

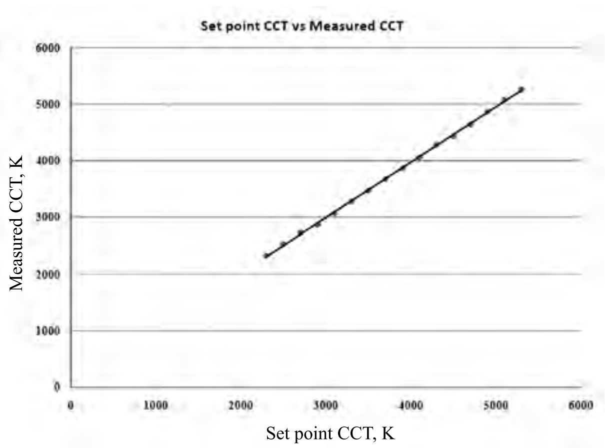

Fig.6. Set point CCT vs Measured CCT

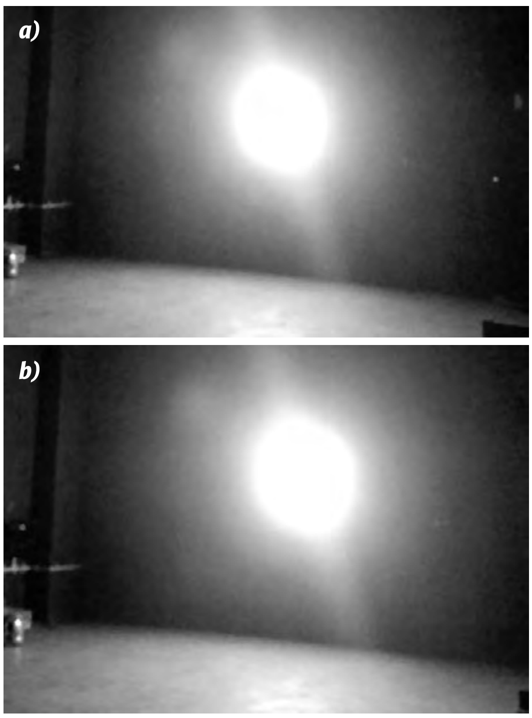

Fig.7. Artificial window model at different CCT: a) CCT 2500 K, b) CCT 5300 K

duty cycle has been kept fixed at 100 %. The colorimeter CL200A is used for measuring the resultant CCT. It is placed vertically at 6 ft distance from the luminaire. The experimental set up is shown in Fig.5.

In this experiment varying PWM duty cycle for red and blue, the data of illuminance at a fixed point,

Table 2. Photometric and Colorimetric Data of the Designed Artificial Window

CCT, K		Illuminance, lx							
		1m		2m		3m		4m	
Set point	Measured	Ver.	Horiz.	Ver.	Horiz	Ver.	Horiz.	Ver.	Horiz
2300	2328	310	106.3	110.4	38	45.6	16.3	27.6	8.5
2500	2530	270	103	106	37.6	45.3	16.2	27.5	8.5
2700	2727	250.2	99	99	37.2	44.2	15	25.9	7.9
2900	2867	225.5	95	97.2	36	43	14.7	25.8	7.9
3100	3069	228.7	95.4	97.3	36.2	43.8	14.7	26.2	8.0
3300	3280	230	95.5	97.7	36.8	44.3	14.7	26.8	8.1
3500	3474	240.6	95.9	97.1	35.8	45.2	14.7	26.3	8.0
3700	3675	255.9	96	97.3	36.1	44.1	15	26.9	8.1
3900	3868	260.2	96.2	99.2	37.5	43.9	14.8	26.9	8.1
4100	4059	262.5	96.9	97.5	36.6	43.6	15	26.9	8.2
4300	4280	255.3	96.2	97.9	37.1	44.1	14.7	26.9	8.2
4500	4436	258.2	97.1	101.2	37.5	45.3	15.5	27	8.2
4700	4639	263.7	97.4	98.2	37	45.4	14.8	27	8.3
4900	4865	265.6	97.4	98	36.8	46	14.6	27.1	8.2
5100	5076	260.3	96.6	98.1	36.7	46.7	14.6	27.3	8.3
5300	5261	267.2	97.5	98.2	36.9	46.6	14.5	27.3	8.4

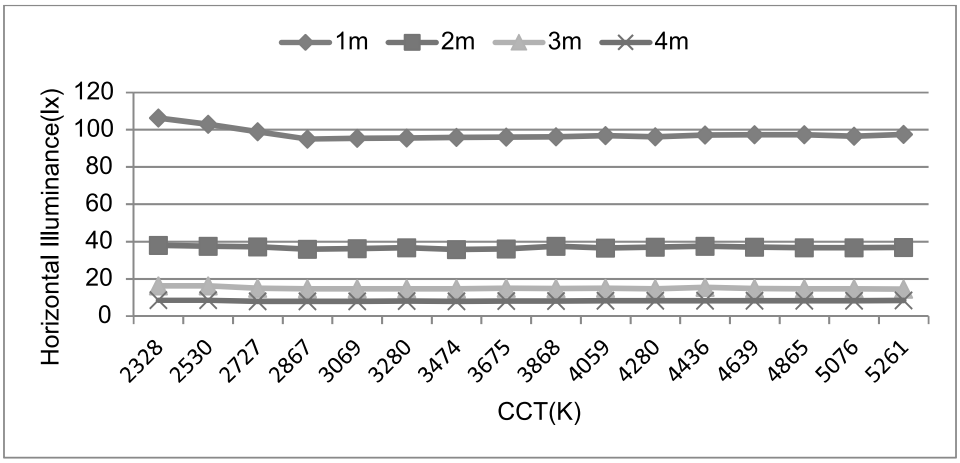

Fig.8. Horizontal illuminance with distance for different CCT of the Source

coordinate (*x*, *y*) and the resultant CCT has been taken. The experimental result of colour mixing experiment to get variable CCT is given in Table 1.

7. PHOTOMETRIC AND COLORIMETRIC PARAMETERS OF THE SYSTEM

The colorimetric and photometric data of the artificial window is taken. For the dynamic lighting, initially the CCT is decided and accordingly the microcontroller is programmed. It is necessary to observe the CCTs of artificial window and compare the observed CCTs with the preset CCTs. CCTs are measured with the colorimeter CL200A with proper experimental set up. Horizontal and vertical illuminance is also measured at 1m, 2m, 3m and 4 m distances from the artificial window. The measured data are given in Table 2.

Set point CCT vs measured CCT is shown in the Fig.6.

It is seen that CCTs of the artificial window are very close to the desired CCTs. Fig.7 shows artificial window at different CCTs.

The measured CCTs vs illuminance graphs are given in Fig.8.

From the graph given in Fig.8, it is seen that when the CCT is 2328 K the horizontal Illuminance is maximum, the red colour is mixed with the warm white colour here. With decreasing value of red content, CCT is increasing and the illuminance is decreasing. When CCT is measured as 2867 K, there is no red or blue colour mixed; only the warm white is present. At that time illuminance is less than any other values. When the CCT is increasing with the increasing value of blue, the illuminance is also increasing. As the change of amount of blue is very less, the illuminance increases very slightly.

8. CONCLUSIONS AND FUTURE SCOPE

Our country India is located close to the equator where sun light with high intensity and long shining hour is available. To meet up the increasing demand of electrical energy, solar energy can play a vital role. Solar energy has some drawbacks, in cloudy days it cannot produce the required energy. This developed system is completely based upon solar energy. In cloudy weather this system will not work properly.

The developed dynamic lighting artificial window follows the preset pattern of day light CCTs for clear sky condition. The system will be more realistic and more practical if the CCT of artificial window varies with the present available daylight CCT instantly considering a feedback system. If the daylight CCT varies, CCT of the artificial will also vary instantly. In that way one may get the exact outer sun conditions (CCT and illuminance) sitting in a closed room where sunlight is not available.

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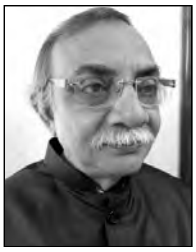

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