LOW-COST AND SAFE LIGHTING DESIGN FOR CLASSROOMS

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ABSTRACT: *Proper lighting of classrooms has been a problem* ***around*** *the world. Though, daylighting systems could be integrated in classroom buildings to provide proper lighting at reduced cost, ignorance of building designers' cause building of classrooms with poor lighting. This work is on low-cost and safe lighting design for classrooms. Integrated design approach was adopted for this design.The model provides proper lighting through natural light or daylight and artificial light through 15 LED panel lights connected to an AT89C51 microcontroller-based controller.The daylighting design consists of five sets of nearly continuous windows on each of the south- and north- facing walls, ceiling, walls and floor with corresponding reflectance of over 70%, over 50% around 20%, and curtain for shading. Each set of window is made up of daylight section and view section. The façade of this design faces due south.The components of this lighting design bring natural light into classroom in such a way that electric lights can be turned off for most portion of the day, thereby reducing energy costs and preventing students and teachers discomfort associated with regular use of electric lights. The design maintains classroom illuminance around 300lux with negligible glare, thereby preventing excessive variation of illuminance that can reduce visual performance, cause discomfort and hyperactivity. It was urged to adopt this design in order to provide safe and low-cost lighting for classrooms.*

KEYWORDS: *Lighting Design, Low-Cost, Classrooms, Daylight, Artificial Light.*

INTRODUCTION

The classroom is an arena for many activities, such as reading and writing, tests, student or teacher presentations, acting and playing amongst others. So the main part of the learning process is visual and proper lighting is essential for the visual tasks/activities.Proper lighting helps maintain attention levels (Lighting Innovations Africa, 2020) and necessary for establishment of a state of ''flow'' (Dyck, 2002) and improvement of students test score and performance in general.

Upon the importance of proper lighting of classrooms, s**ubstandard lighting conditions are a common problem around the world.According to** Ezetoha and Mmuo (2017) and

Okeoma(2018), classrooms with poorly designed lighting are common in developing countries particularly Nigeria and this is as a result of designer's ignorance of lighting design. Artificial lighting through electricity is therefore inevitable for classrooms with poorly designed lighting. Total use of electricity for lighting classrooms lead to high cost of illumination and increased energy costs. According to EarthTronics (2019), lighting of classrooms through electricity accounts for nearly 25% of energy costs at higher education institutions. In addition, irregular supply of electricity contributes to s**ubstandard or poor lighting of** poorly designed and constructed classrooms.

Moreover, p**oor lightingor l**ow illuminance in classroom **causes eye fatigue to pupils, hinders concentration (Tungsram, 2020),**slows reading, and causes poor posture and long term weakened vision.According to Canadian Centre for Occupational Health and Safety (2017), p**oor lighting** can cause headache, depression and problem such as eyestrain. Depression in turn negatively influence academic progress and encourage under-achievement (IBCCES, 2020). On the other hand, excessive lighting or light with glare interferes significantly with visual tasks and can result in headaches, eyestrain, reduced concentration and poor performance.Classroom lighting also influences students' circadian rhythms that stimulate hormone production, sleep-wake cycle and core body temperature cycles (Lumax Lighting, 2020). These rhythms can be disruptedwhen exposed to p**oor quality light or** artificial light rich in blue wavelengths all day, and this will make students to be more vulnerable to sleep deprivation, mood disorders, poor mental alertness and other health problems (My LED Lighting Guide,2020) which in turn negatively affect their behavior and performance.

Furthermore, classrooms can be designed so as to provide proper lighting through daylight (i.e. daylighting).The outdoor illuminance produced by sun in daytime can be above 500lux after sunrise or before sunset on a clear day (ambient illumination) and 120,000lux for direct sunlight at noon (Wikipedia, 2018) and these can properly illuminate classroom since the intensity of light needed is about 300 lux. Sunlight reveals the true colours of objects because its colour rendering index(CRI)is 100% and therefore best for illuminating classrooms. Besides, incorporating natural light in classroom lighting can provide physical and physiological benefits to students, teachers and administrators. According to Rittner and Robbin(2002), daylight helps students to, retain and learn information. Natural light helps pupils concentrate and to have higher test scores (HMG, 2003; INNOVA, 2014).

In contrast, outdoor illuminance level on an extreme of thickest storm clouds at midday is less than 200lux and at sunrise/set is less than 1lux(Bunning & Moser, 1969; Schlyter, 2006) and therefore not enough to illuminate classroom.In addition, outdoor may be darker under unusual circumstances like a solar eclipse or very high level of atmospheric particulates, which include smokes *(Ross, 2008),* dust (Cox, 2017) and volcanic ash.In this condition, artificial lighting is needed for lighting of classrooms. Thus, an effective classroom lighting scheme will make use of any natural light that is available, with the addition of artificial light where it is necessary.

The aim of this work is to design a low-cost and safe lighting system for classrooms.

Classroom Lighting Design

The low-cost and safe lighting design for classrooms comprises of daylighting and artificial lighting. The lighting design makes use of natural light that is available and artificial light in addition when classrooms illuminance is less than 300 lux. Integrated design approach was adopted for this design. This approach involves decisions about the building form, site, climate, building components (such as windows), lighting controls, and lighting design criteria.

The design requires that classroom has illuminance of 300 lux (ambient light), standard unified glare rating (UGR) value of 19, colour rendering index (CRI) of at least 80%, illumination at any point is 300 lux (uniform brightness) and the lighting should be controllable and these requirements are based on indoor lighting standard (ENSTO, 2011)

Daylighting Design

Daylighting or natural lighting design requires that window size and spacing, glass selection, the reflectance of interior finishes, and the location of any interior partitions must all be evaluated. It carefully considers the use of shading devices to reduce glare and excess contrast in the classroom.

Building Form. The prototype is an I-building, a bungalow containing one classroom. The length of the classroom is 11m; width is 7.6m and height is 3m. The front view of the classroom is shown in figures 1.

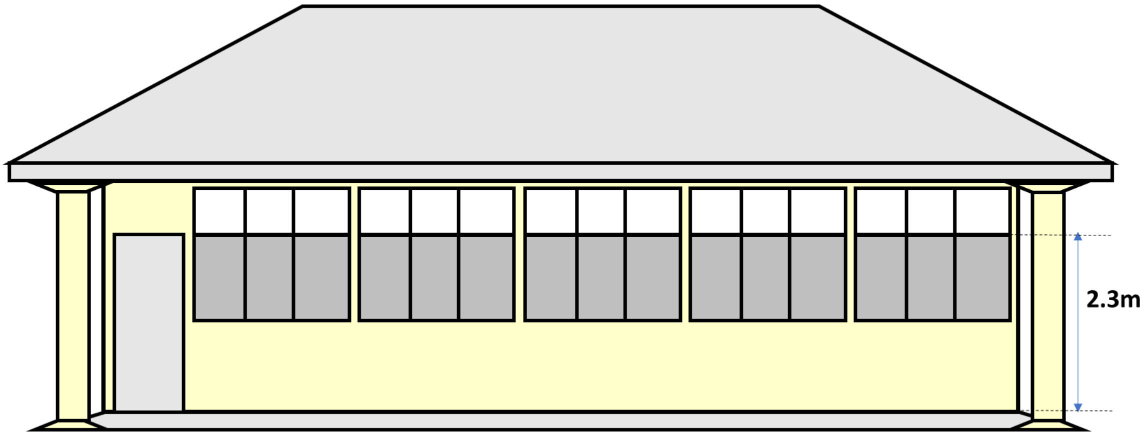

Fig. 1 Front view of the classroom

Front Approach. The front approach (façade) of this design faces due south and contains corridor as shown in figures 1. The location of the facade (due south) was chosen because in the northern hemisphere, day-lighting requires that façade and more and larger windows face due south for proper day-lighting of building and in the southern hemisphere façade and more windows face due north. A maximum façade facing due south is the optimal orientation because south-facing window would get direct sunlight

Window Design. The window system is a nearly continuous strip window comprising of five, 1.8m by 1.8m windows on each of the north- and south-facing walls. It has no window on east- and west-facing wall. Each window; a three-in-one window, is made up of upper daylight window and lower view window and aluminum frame. A sliding system allows maximum of two windows of each type (daylight or view window) to be opened at a time. Nearly continuous strip window was chosen for this design because it provides adequate and more uniform daylight. In addition, use of two sets of glasses-for daylighting and viewing is justified because good daylighting fenestration practice dictates that the window should ideally be composed of two discrete components: a daylight window for daylight delivery or admittance and a view window for provision of view to the students and teacher. Aluminum window frame was used in this design because it decreases the insulation value of the glazing unit and its great impact on the thermal performance of windows (Lyons, 2002).

Aluminum window with 3mm thick single glaze clear glass was used for the daylight window while 3mm single glaze tinted glass was used for view window. The daylight window has visible light transmittance or visible transmittance VT of 0.88 and solar heat gain coefficient (SHGC) of 0.77 while that of view window has VT of 0.53. The selection of glazing and window area is appropriate because the effective aperture (EA) is 0.254 (approximately 0.30) and this is in line with the thumb rule (Robinson and Selkowitz, 2013) that specifies that EA should be around 0.30 on a daylit side of a room.

The value of EA was calculated using the equation: $EA = VT \times WWR$

Where VT is visible transmittance of the glazing

WWR is window area to wall area ratio

VT of the glazing is combination of VT of daylight and view windows based on the ratio used. $VT = 0.88 + (2 \times 0.53)/3 = 0.647$

WWR=net glazing area/gross interior wall area

Where net glazing area is window area minus mullions and framing or 80% of rough opening.

So $WWR = \frac{9.0 \times 1.8 \times 0.8}{3 \times 11} = 0.3927$

Therefore, $EA = 0.647 \times 0.3927 = 0.254$

The daylight window starts at 2.3m above the finished floor while the view window is placed lower. As a general rule, the higher the window head height, the deeper into the space the daylight can penetrate. The use of high-transmission, clearer glazing in daylight windows and lower transmission glazing in view windows helps to control glare.

A thermal break; a low conductivity component (typically urethane or other low conductivity polymer) was used to separate the exterior and interior pieces of the frame and this reduces the heat conduction through aluminum frames. The window-sills are large and light colored to project light into the room and inner sides of window openings are slanted so that they are larger than the outer openings and these improve the amount of light available from a window (Gregg, 2016).

A high-performance glazing system of this kind will generally admit more light and less heat than a typical window thereby allowing for day-lighting without negatively impacting the building cooling load in summer.

Fenestration Design: The design is meant for use in the Northern Hemisphere. The classroom has five larger windows (1.8 by 1.8m windows) on the equatorial-side (south-facing wall). It also contains five larger windows on north-facing wall and none on east- and west-facing walls. Equatorial-side windows receive at least some direct sunlight on any sunny day of the year (except in the tropics in summertime). So they are effective at daylighting areas of the room adjacent to the windows (*Spellman &Beiber, 2011).Again,* maximizing the amount of daylight in south- and north-facing facade area and minimizing east and especially west exposureallows for the easiest controllable daylight fenestration. Each window in classroom is positioned at 1.1m above finished floor and at 0.15m from one another except the last-the one close to door that is placed at 0.2m from the door. The north- and south-facing windows nearest to the board side (first window from the right side) start at the same line with the board. The windows are placed close to light colored walls.This window system provides adequate and uniform daylighting, serves to facilitate ventilation and prevents passersby from seeing the classroom interior.

Interior Design. Reflectance values from classroom surfaces significantly impact daylight performance and should be kept as high as possible. It is desirable to keep ceiling reflectance's over 70%, walls over 50%, and floors around 20%. The classroom interiors were designed to be painted with reflective colors. Pure white color was used for ceilings, sunbeam yellowcolor for walls and grey color for floor ties. Since the light reflectance value (LRV) of pure white surface is about 85%; sunbeam yellow color is above 70% (above 50%) and grey color is less around 20% (Sawaya&Sawaya, 2005), the choice of surface colors is appropriate.The walls and ceilings are highly reflective, so they help "bounce" and distribute the redirected daylight more fully while floor reflectance has the least impact on day-lighting penetration and this is why low-reflectance color was chosen for the floor.

The *ceiling* is made of polyvinyl chloride (PVC). It is of pure white color and has height of 3m on fenestration area (0.1m higher than window head height) and sloped away from it. PVC ceiling has its smooth surface as part of the room interior surface and sloping it away from the fenestration area helps in increasing the surface brightness of the ceiling further into a space and its reflectance..

Work surfaces such as desks and tables are positioned at a distance from the south façade and this makes solar control to be easier with smaller solar shading materials such as curtain than if they are placed directly against the south facade.

Simple shading (orange colored curtains) were used specifically for reducing high illuminance of the classroom caused by direct sunlight at noon when windows are open. The curtains prevent direct beam daylight on critical visual tasks and poor visibility and discomfort that will result if excessive brightness differences occur in the vicinity of critical visual tasks (HMG, 2003).

Artificial Lighting Design

The artificial lighting design requires that the light should be controlled and glare that disturbs concentration should be avoided. Electric lighting system-an advanced lighting with controls was used in the artificial lighting design because it can adjust the level of electric light to make up for insufficient daylight in classroom.The artificial lighting design consists of LED panel lights and controller.

LED Panel Lights. Fifteen 600x600mm, 40W LED ceiling panel lights were used in this design. LED panel light was chosen because it is **energy efficient, eco-friendly, adjustable,** have long lifespan, **provide optimal results in terms of light distribution, glare and colour accuracy and therefore, suitable for academic tasks.**The40W LED panel light requires input voltage of 240v a.c, and only uses 40W of power and outputs a maximum of 3400 lumens (lm).The 40W LED panel light has color rendering index of over 80, beam angle of 120^o,a lifespan of up to 50,000 hours (beyond 15 years when used on an average of 8 hours a day) andmaintenance factor MF of 0.8.The color temperature of each panel light chosen for this design is daylight 4000K. The number of LED panel lights required for this design and their arrangement was calculated based on guidelines by CharlstonLights (2016) and Parmar(2014) and is as follows:

The required number of luminaires (LED panel lights) $N = \frac{E \times A}{MF \times UF \times F \times n}$

Where E is the general level of illumination on work surface (uniform brightness)in lux

Ais total floor area in m^2

MF is the maintenance factor

UF is the utilization factor

F is lighting design lumens per lamp and

n is the number of lamps in each luminaire

Theutilization factor UFfrom reference table using reflectance code for classroom (752) is 0.66.

Substituting the values from the specification above, $N = \frac{300 \times (11 \times 7.6)}{0.8 \times 0.66 \times 3400 \times 1} = 13.97 \cong 14$

The space to height ratio $SHR = \frac{1}{H_{WC}}\sqrt{\frac{A}{N}} = \frac{1}{2}\sqrt{\frac{83.6}{14}} = 1.2218$

Where H_{WC} is ceiling to work surface height

The minimum spacing between luminaires along the width of the classroom $= H_{WC} \times SHR = 2 \times 1.2218 = 2.4456$

The required number of rows between luminaires along the width of the classroom is width of the classroom divided by minimum spacing between luminaires.$= \frac{7.6}{2.4436} = 3.11 \sim 3$

15 LED panel lights were used for this design because the calculated number of rows is three and 14 LED panel lights cannot be uniformly arranged in the rows. In addition, the extra LED panel light adds very little to the classroom illuminance (with it uniform brightness is 322lux) and has no negative effect since lluminance from 300lux to 500lux is acceptable.

Number of LED panel lights in each row is total number of required lights divided by number of rows $= \frac{15}{3} = 5$

Axial spacing between each LED panel light is length of classroom divided by LED panel lights in each row$= \frac{11}{5} = 2.2m$

Transverse spacing between each LED panel light is width of classroom divided by number of LED panel lights in each row$= \frac{7.6}{3} = 2.533m$

The connection and arrangement of the 15 LED panel lights on the ceiling is shown in figure 2. The 15 lights are connected in parallel and to 230v a.cpower supplyat connection point **A,**via switch S1 automatically operated by the controller. The 15 LED panel lights will be ON when the classroom illuminace is less than 100lux.

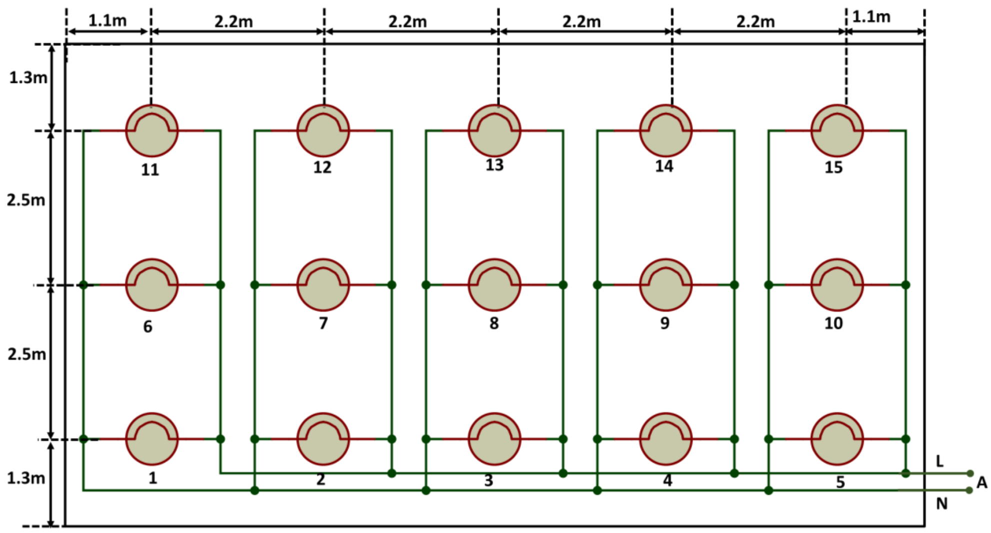

Fig. 2 Arrangement and connection of 15 LED panel lights on the ceiling

Ten LED panel lights (LED panel lights 1, 3, 5, 7, 8, 9, 11, 12, 13, 15) out of the 15 are connected in parallel and to 230v a.cpower supplyat connection point **B,** via switch S2 and will be ON when the classroom illuminace ranges from 100lux to 199lux. Six LED panel lights (LED panel lights 1, 3, 5, 11, 13, 15) out of the 15 are connected in parallel and to 230v a.cpower supplyat connection point **C,** via switch S3 and will be ON when illuminace ranges from 200lux to 299lux.

Controller. The controller is a microcontroller-based systemconsisting of power supply unit, sensing unit, control unit, switching unit, display unit (LCD) and alarm unit as shown in bloc diagram of figure 3.

Power supply unit provides uninterruptable, regulated 5v DCpower source needed by the controller. The input power of 230v is supplied to the controller either by public power supply or inverter through the help of automatic change-over circuit.

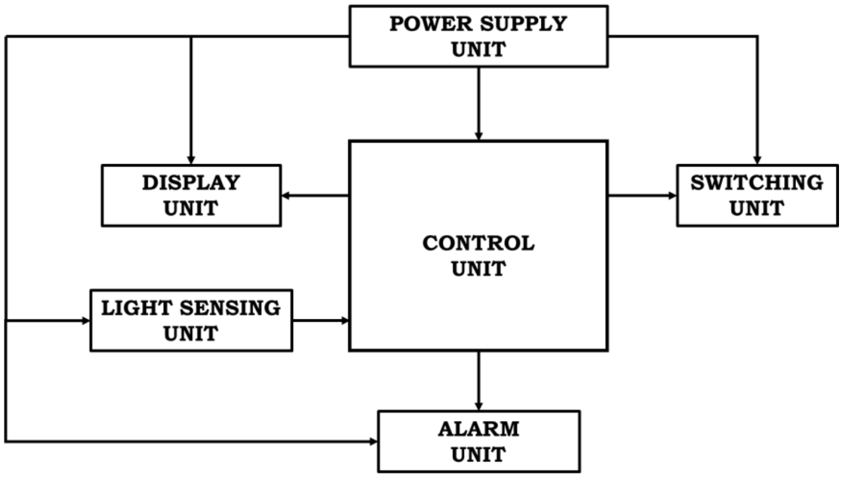

Fig. 3 Block diagram of controller

Sensing unitconsists of circuit having two LM393 4pin optical sensitive resistance light detection photosensitive sensor modules (light sensors) L1 and L2 and an analog to digital converter (ADC) 0808 as main components.L1 is used indoors for sensing classroom illuminance while L2 is used outdoors for sensing daylight.The light detection module was chosen for this design because of its low operating voltage (3.5v-5v), ability to detect ambient brightness and light intensity, its adjustable sensitivity, advancement cost, availability, and efficiency.Only one light detection module was used indoors because the windows and fixtures are well located and evenly distributed and illuminance at any point in the classroom is the same. L2 was used outdoors to sense when outdoor daylight is enough (up to 500lux) to properly illuminate classroom. The VT of each window is 0.647 and it can transmit 323.5lux (0.647×500) of daylight.

Control unitis AT89C51 microcontroller and was used for coordinating the entire activities in the controller. Binary outputs from the ADC connected to light sensor circuitsare interfaced with a port of the microcontroller. The microcontroller takes decision depending on the value it receives from the ADC. Interfacing of microcontroller with other units is made based on microcontroller-based systems development guidelines (Ezetoha, Nwokeke&Onyemaobim, 2019; Milan, 2009).

Switching unitconsists of three relay circuits. Each relay circuit consists of a 12v dc relay, anIN4007 diode connected across it, a BC337/547 transistor and a 1KΩ resistor connected to the base of the transistor. Each of the three LED panel lighting arrangement is connected to 12v d.c relays in a normally open mode. When a relay is energized, the set of lights connected to the particular switch is switched*on*.

Display unitis a 20×4liquid crystal display (LCD) module. This unit displays the illuminance level in classroom and instruction on what to do when illuminance is greater than 500lux. The module is interfaced with the microcontroller and connected to output terminal of the regulated power supply. The module was chosen because of its low power requirement and that it can display up to 20 characters

Alarm unitis a 5v buzzer. Whenever classroom illuminanceis above 500lux, the microcontroller sends signal to the 5v buzzer to flash alarm.

.**Circuit diagram** of the controller is shown in figure 4. When the controller is switched *on,* light sensor L1 senses classroom illuminance. If illuminance is 300lux or greater but not more than 500lux, no set of LED panel light is switched *on*. If classroom illuminace ranges from 200lux to 299lux, the microcontroller sends signal to the connected relay circuit S1 to switch *on* the six LED lights connected via **C**.If classroom illuminace ranges from 100lux to 199lux, the microcontroller sends signal to the connected relay circuit S2 to switch the 10 LED lights connected via **B.** If classroom illuminace ranges from 0lux to 99lux, the microcontroller sends signal to the connected relay circuit S1 to switch *on* the 15 LED lights connected via **A.** On the other hand, when any set of light is *on,* L2 starts sensing daylight outdoor. When it is up to 500lux it switches off artificial light, but when it is less than 500lux, it keeps sensing. If L1 senses classroom illuminance greater than 500lux, the microcontroller sends signal to the 5v buzzer to flash alarm while the LCD displays instruction to cover windows with curtain.

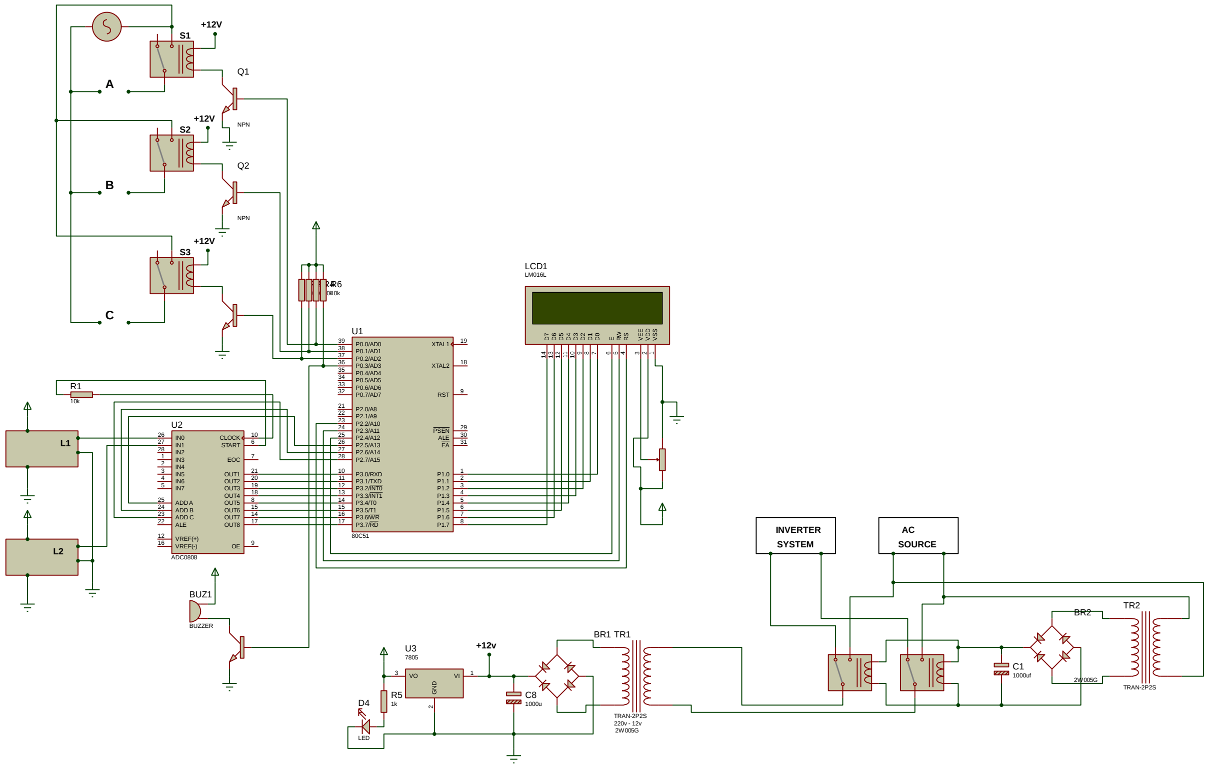

Fig. 4 Circuit diagram of the controller

CONCLUSION

In this design, both qualitative and quantitative aspects were taken into consideration. The components of this lighting system were designed to bring natural light into classroom in such a way that electric lights can be turned off for most portion of the day, thereby reducing energy costs and preventing students and teachers discomfort associated with regular use of electric lights.

The design maintains classroom illuminance around 300lux thereby preventing excessive variation of illuminance that can reduce visual performance, cause discomfort and hyperactivity.

It is recommended that this design be adopted in order to provide safe and low-cost lighting for classrooms.

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