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SOLID STATE LIGHT CONVERSION

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Advisor: Dr. Steve Durbin

ELECTRICAL and COMPUTER ENGINEERING 4820

April 27, 2018

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ABSTRACT

Demand for innovative and energy-efficient technology has increased as an environmentally sustainable society has become priority. Technological development of solid-state light plays a part in meeting that demand. Our research has revealed that LED (Light Emitting Diode) lighting uses less energy and is a more cost effective and environmentally responsible choice than incandescent and fluorescent lighting. Converting from incandescent and fluorescent dominated lighting to LED lighting may be cumbersome but can result in a classroom milieu that is attractive, cost/energy effective, easy to manipulate as well as facilitative to learning. For this project, a small-scale mockup of the light fixtures was built complete with all wiring to demonstrate the install of the LED lights. The prototype was designed to represent how the lighting would work in a real-world environment. For the project, the existing wall switch dimming controller was upgraded to a uniquely created application run on an Android operating system to act as a wireless controller for remote dimming and off/on capabilities. The application gives the operator the ability to manipulate lighting for different sections of the classroom to optimize the teaching and learning experience in which we will refer to as “zone control”. A projection screen feature was added to dim the lights automatically whenever the projector button is selected by the operator. For the classroom implementation, the old fluorescent lights will be replaced with LEDs that are connected to the new user interface. The initial cost of the material for the mockup did not exceed \$500. The findings were presented at Western Michigan University Senior Design event and if implemented, the solid-state light conversion will produce increased lifespan, decreased maintenance cost and greater functionality along with an attractive milieu that will benefit students and faculty for years to come.

INTRODUCTION

Senior electrical engineering students researched the efficacy of updating university classroom lighting systems. The Solid-State Lighting Conversion project focuses on updating lighting for classrooms in Floyd Hall at Western Michigan University. Solid-state lighting is a form of lighting that uses semiconductors to produce light. Light Emitting Diodes (LED) are a type of solid-state lighting. When LEDs were first introduced, the initial cost did not justify the eventual cost savings related to manufacturing costs. In time, manufacturing costs have decreased allowing LED's to have potential cost savings up to 40% versus fluorescent. The existing lighting in the classrooms is fluorescent which produces adequate light yet consumes more power than solid-state lighting. Fluorescent lighting has an increased cost/energy savings compared to incandescent lighting however solid-state lighting creates an even greater efficiency. One goal of this project is to discover if the difference in efficiency creates significant cost/energy savings. The students considered variables including material, labor and maintenance cost along with lux distribution, usability and other functional changes the proposed lighting plan would incur.

DISCUSSION

1. Safety

1.1 Connecting to Alternating Current (A.C.) Power

The team chose to connect to a 3-prong power cord into a wall outlet to demonstrate how the prototype should work in a real-world environment. Before applying power to our LED panel, the team had to follow a few safety precautions. The panels supplied are designed to be hard-wired into a A.C. power line, but for mobility and safety decided to add the 3-prong plug. The specifications for the LED Driver for input voltage ranges from 100-277 VAC. The wall outlet that supplied power to our panel measured at 120V.

The 3-prong cord shows a green, white, and black spliced in a coaxial cable. The green cord is for Ground, the white cord is for Neutral, and the black cord is for Live. Connection for Live is represented by a 'L' on LED Driver Panel and 'N' for Neutral. Ground wire should be connected to the yellow and green wire from LED panel. When securing the wires to the 'L' "N" and Ground use the clamp connector to limit the movement of the power cord with-in the junction box. Use a wire nut to secure connection for ground wire and screw on cover before applying power.



Dimmable LED Driver



3-prong cord spliced



Clamp Connector

Figure.1 Wire Securing

1.2 Securing wire connections

There are seven wire connections the inside the junction box on the LED panel. Reading from bottom to the top, the labeling is L, N, LED (-) a, LED +, LED (-) b, Dim +, and Dim -.

Power Supply Lines

L- Live

N- Neutral

The power supply lines used for A.C. voltage is as described in the A.C. Power connection section.

Driver to LED panel connections

LED (-) a

LED +

LED (-) b

The Driver to LED panel connections were used for the 8-channel relay switch. The relay switch is connected to the LED +. The wires from LED + to relay should go through the same clamp connector as the power cord to limit movement. The team also recommends that the relay is secured in a separate ROHS (Restriction of Hazardous Materials) approved junction box. The size the design team used was 7.9"x 6.1" x 3.1" and this was the housing for the circuit that control the dimmer and the 8-channel relay switch.

Dimming Controls for 0-10V dimming

Dim +

Dim -

Dimming controls are connected to the microcontroller for user interface. Since, the wiring was smaller for the dimming the team used the plastic clamp connector (figure. 2) to secure wires.



Figure.2

Lighting Calculations

Inverse Square Law Method

Inverse Square Law Method is used to calculate the distance between panels. The distance travel and the lumens produced will help calculate the required lux for the classroom. Depending on the area of a room and the required lux the placement of the light panels will vary from room to room. The lux requirement for classroom setting is 300-500 lux. [2] The goal of our project was to have a lux standard of 400 in all areas of the classroom. Attached to the report will be a worksheet with calculations configured for the user to help aid with the panel placement. The figure below demonstrates how the light intensity weakens as the light travels further away from the light source. This figure below is the inverse light law. The 'intensity' represents the lux required and 'd' representing the distance measured.

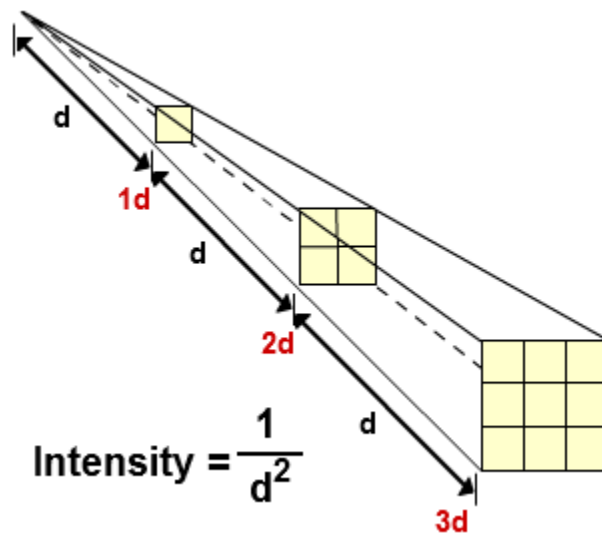


Figure.3

Retrieved from: <https://www.nde-ed.org/EducationResources/CommunityCollege/Radiography/Physics/inversesquare.htm>

This figure shows the lux calculated for a 2ft. X 4 ft. Lumegen panel after the distance 'a' (in our case) is measured for classroom C-136. The distance 'a' measured is in meters and 'a' equals 2.438 meters. The Lumegen LED panel produces 5500 lumens and has a maximum output of 50 watts. The lumens and the distance measured were used to calculate the lux.

Equations are shown in Figure 4.b:

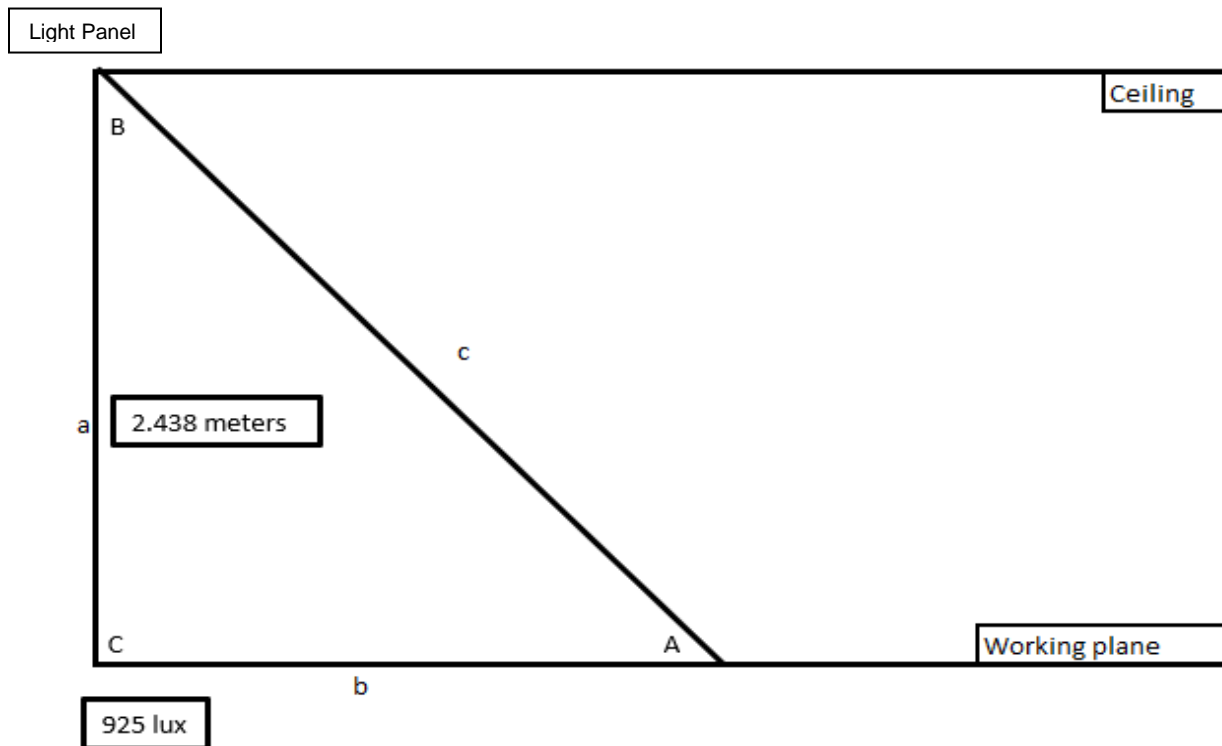


Figure. 4.a

$$E = \frac{I}{d^2}$$

E= light intensity
a = distance
Light intensity = lux

$$E = \frac{I}{d^2} = \frac{5500 \text{ lumens}}{2.438^2 \text{ meters}} = 925 \text{ lux}$$

Distance 'a' measured = 2.438 meters

Lux at point C = 925 lux

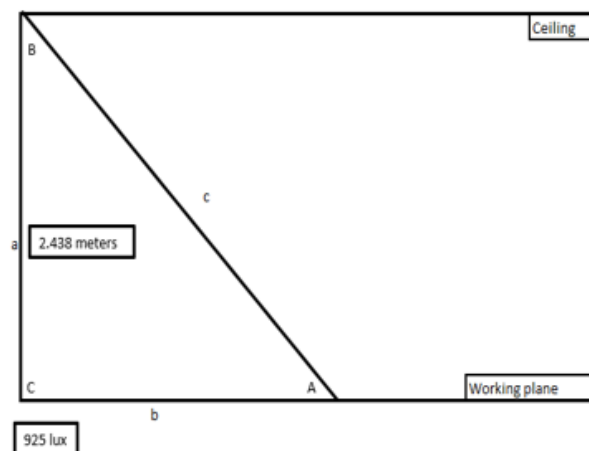


Figure. 4.b

This figure shows how to calculate the angle at the light source. The angle is needed to calculate how far apart the next panel will be when the required lux is known on the surface plane. The required lux used in this diagram is 500 lux.

Equations are shown in Figure 4.c:

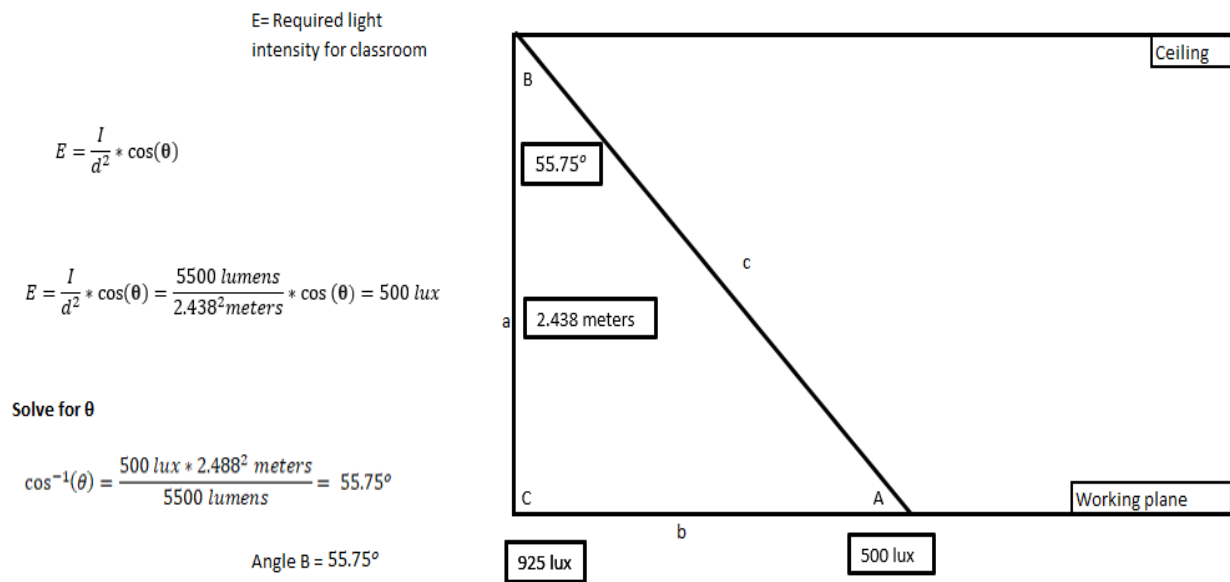


Figure. 4.c

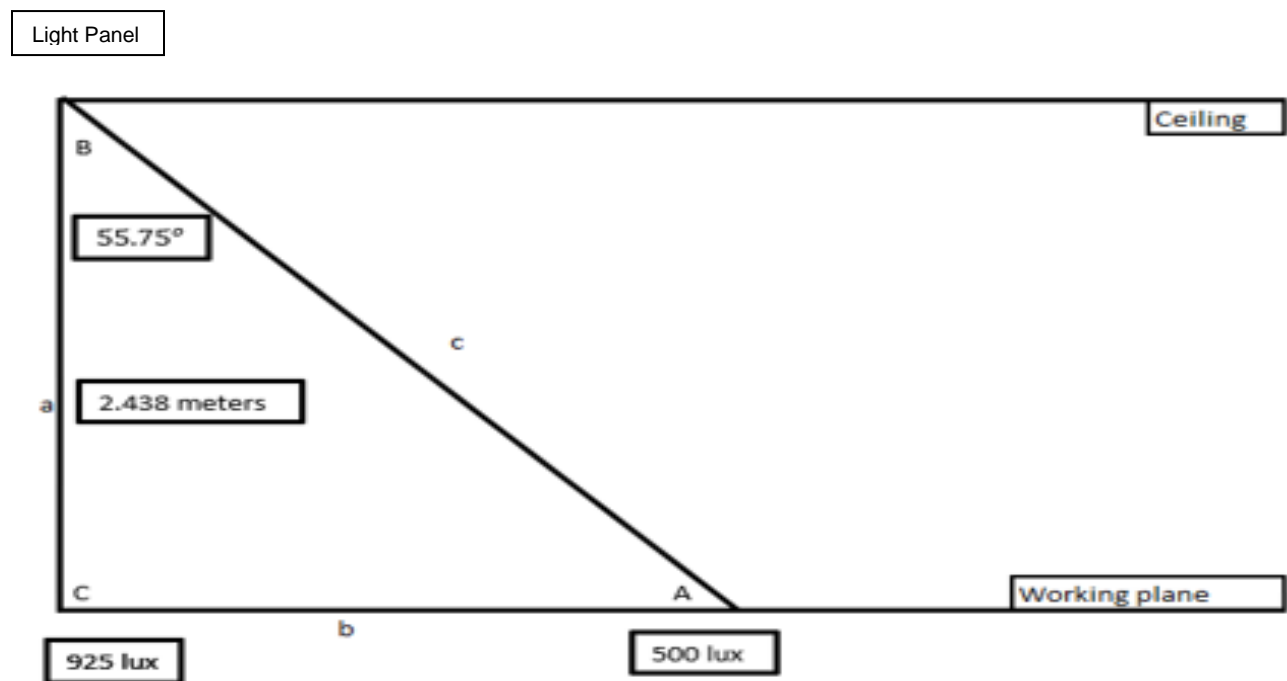


Figure. 4.d

This figure below shows the calculated value for side ‘b’ and side ‘c’. Side ‘b’ is the surface plane and gives the max distance for obtaining 500 lux. The next light panel should be placed 7.162 meters from point C, twice the 3.581 distance. Placing the light panel at 7.162 meters will give the maximum amount of required coverage at the most minimum distance

Equations are listed in Figure 4.e.

$$\tan(\theta) = \frac{\text{opposite}}{\text{adjacent}}$$

$$\tan(55.75^\circ) = \frac{b}{2.438 \text{ meters}}$$

$$b = \tan(55.75^\circ) * 2.438 \text{ meters}$$

$$b = 3.581 \text{ meters}$$

$$\sqrt{c^2} = \sqrt{a^2 + b^2}$$

$$c = \sqrt{2.438^2 + 3.581^2}$$

$$c = 4.332 \text{ meters}$$

Distance calculated from point C to point A for the required 500 lux.

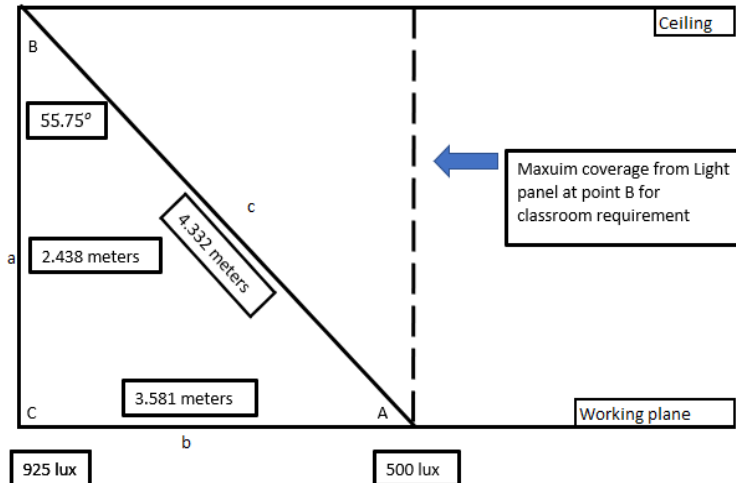


Figure. 4.e

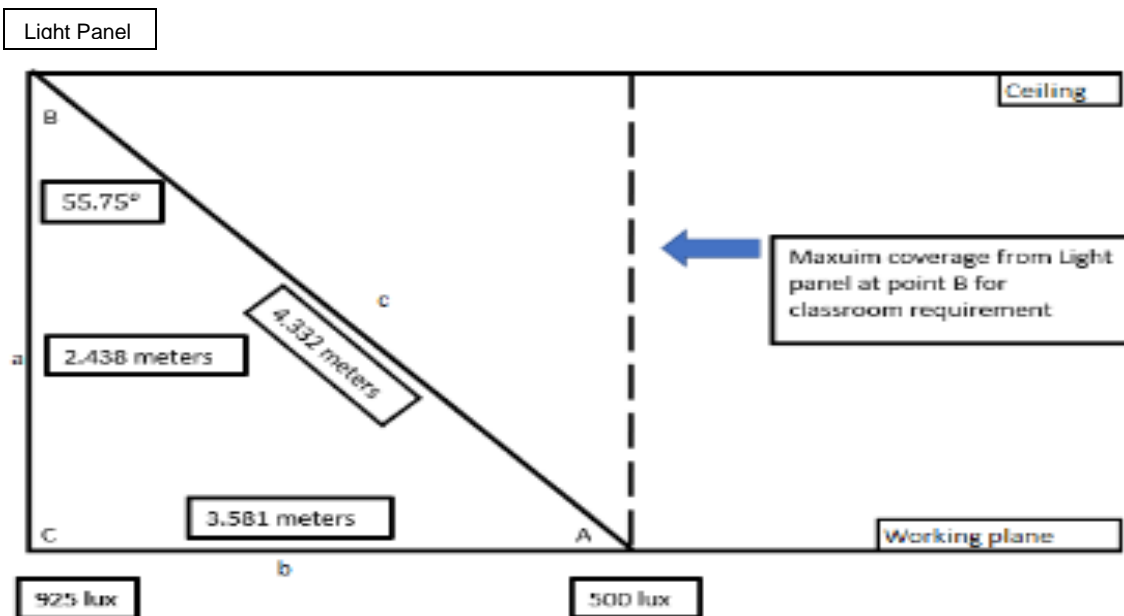


Figure. 4.f

Zonal Cavity Method

Zonal cavity method also known as the lumen method is used to perform lighting calculations to determine the required quantity of light fixtures needed for a specified illuminance level. This hand method provides a high degree of accuracy for indoor applications such as classrooms because “it takes into account the effect the reflectance has on the level of illuminance” [1]. Figure 1 shows the basic cavity divisions of a room used in this method of computation. The height from a luminaire to the ceiling is known as the ceiling cavity (h_{cc}). The distance from a luminaire to the work plane is known as the room cavity (h_{rc}) whereas the distance between the work plane to the floor is known as the floor cavity (h_{fc}).

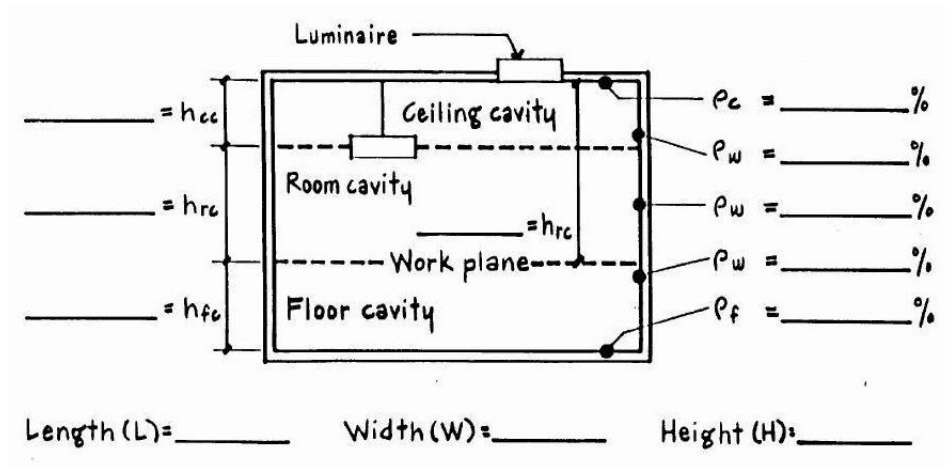


Figure 5. Zonal cavity basic division of space

Retrieved from: http://www.electrical-knowhow.com/2012/12/lighting-design-basics-and-terminology_22.html

For each of these three cavity divisions, the cavity ratios were determined using the following equations:

$$\text{Ceiling cavity ratio (CCR)} = \frac{5 h_{cc} (L + W)}{L \times W} = 0$$

$$\text{Room cavity ratio (RCR)} = \frac{5 h_{rc} (L + W)}{L \times W} = 2.863$$

$$\text{Floor cavity ratio (FCR)} = \frac{5 h_{fc} (L + W)}{L \times W} = 0.895$$

where,

L = length of classroom

W = width of classroom

C-136 classroom is 35' long and 23' wide with a 10' ceiling height with capacity of 35 students. The wall and ceiling are light colored whereas the floor is dark colored. From the IES lighting handbook the reflectance factors were determined to be 70% for ceiling, 50% for wall, and 20% for floor. Since the lumen method considers what happens only inside the room cavity, the ceiling and floor reflection factors are replaced with their effective reflectance factors effective ceiling reflectance factor and effective floor reflectance factor. These reflectance were found to be = 116 and = 100 respectively.

Having the reflectance factors and knowing the cavity ratios, the CU coefficient of utilization was then found using the CU table prepared by the manufacturer and it was found to be 0.8. LLF light loss factor was found to be 0.86. The required level of illuminance was found using the IES lighting handbook. Where they recommended illuminance level for classrooms to be between 300 to 500 lux. The number of panels were then found using the following:

$$\text{Number of panels} = \frac{E \times A}{L \times UF \times M} = \frac{500 \times (10.668 \times 7.0866)}{5500 \times 0.86 \times 0.8} = 10 \text{ panels}$$

where,

E = desired illuminance

A = area of classroom

L = lumen output per panel

UF = coefficient of utilization

M = light loss factor

DIALux Software

Lighting calculations were done manually. With a more effective approach a lighting design software DIALux was used to design different distributions of panels in C-136. DIALux is a simple, effective and professional design tool. This software is free and takes into consideration daylight effect coming through windows. Architects, electrical engineers and interior designers can use this lighting design software. The user can import the IES extension files or the photometric files from the manufacturers website to the software and do different panel layouts. Figure 2a shows the distribution of 13 fluorescent panels with 11 panels that are 2x4ft. and 2 panels that are 2x2ft. For the new design only 10 panels (2x4ft.) are needed to meet the required illuminance in a classroom shown in Figure 6b.

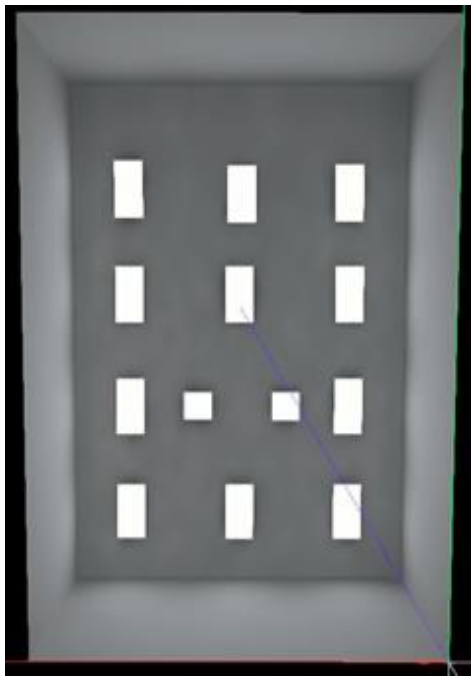


Figure 6a. C-136 old layout (Fluorescent)

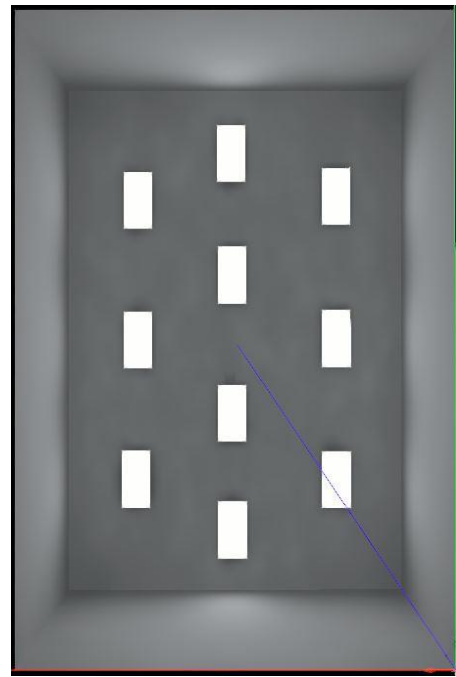


Figure 6b. C-136 new layout (LED)

With reflection factors: ceiling 70%, wall 50%, floor 20% and classroom measurements, the software was able to verify the calculations and show that with this layout, Figure 3b, the illuminance level is suitable for C-136 classroom. The average perpendicular illuminance on the work plane is 420 lux with minimum of 165 lux in the corners of the classroom and maximum of 572 lux in the center of the classroom as shown in Figure 7c.

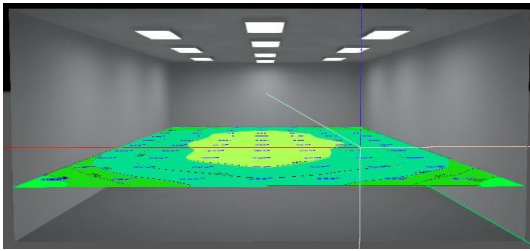


Figure 7a. C-136 view

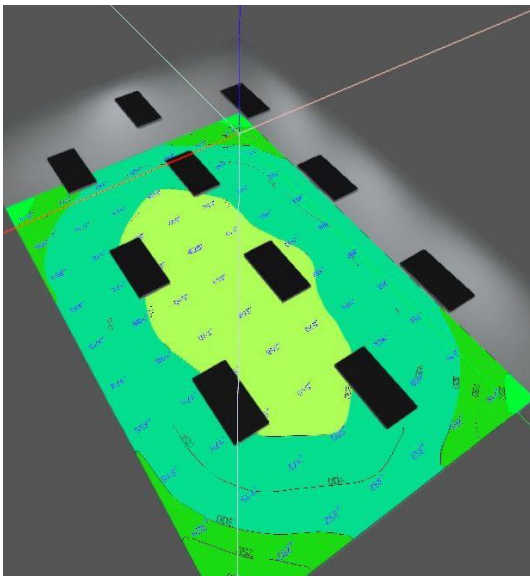


Figure 7b. Panel layout

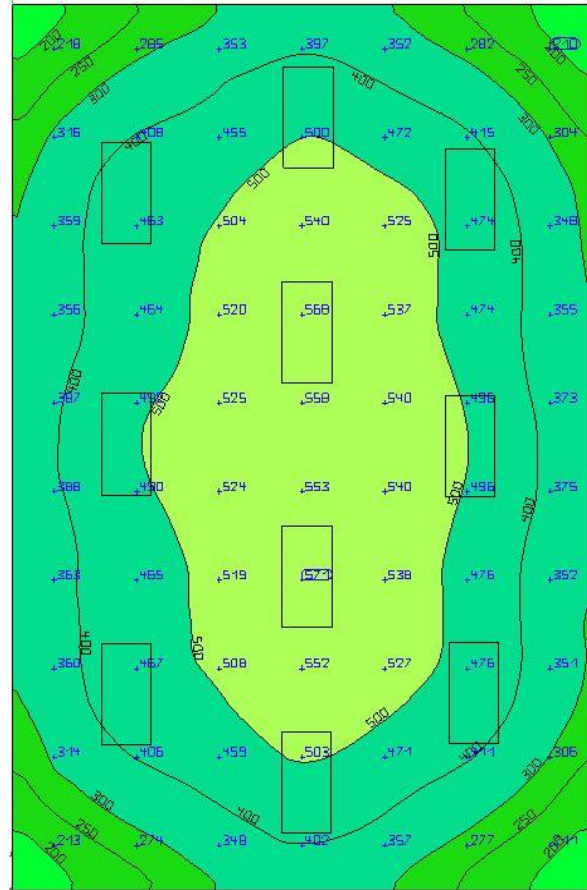


Figure 7c. Illuminance levels

Ambient light sensing

Ambient light sensing is the functionality with which the sensor is able to sense the natural light present in the room and adjust the light of the panels based on the light present in the room. If there is excess amount of natural light present in the room, the sensor keeps the panel lights low and if there is low natural light in the room, the sensor keeps the panels light high.

For this functionality, a photoresistor was used. A photoresistor is a variable resistor which has a functionality of changing resistance depending on the amount of light it is exposed to. It is semiconductor with very high dark resistance. When light falls on it, photons from light is absorbed by it and energy is transferred to electrons which break up and results in lower resistance and higher conductivity [10].

For the circuitry, the main parts used are photoresistor, 100k ohm resistor, 1k ohm resistor and a NPN transistor. One side of the photoresistor is connected to the ground and another side is connected to the 100k ohm resistor. One side of 1k ohm resistor is connected to 3.3V pin on Arduino and another side is connected to the base of the transistor. The collector of the transistor is connected to the dim+ of the panel and emitter of the transistor is connected to the dim- of the panel. The side of photoresistor and 100k resistor connected together is also connected to the analog pin 1 which sends the analog signal to the Arduino from photoresistor. And then the Arduino dims the light high or low. With this functionality there is a long-term cost saving as it uses less energy when the natural light is present in the room. Figure 9 shows complete circuit with ambient light sensing functionality.

Motion Sensor

Motion sensor helps save energy by turning off the lights when the room is not occupied. For the prototype, a passive infrared sensor (PIR) sensor was used. The term passive means that it doesn't use any energy to detect the energy. It measures infrared(IR) radiation from the object. Any object with a temperature above absolute zero emit heat energy in a form of radiation. This radiation is not visible to human eyes because it radiates at infrared wavelength but it can be detected by electronic devices designed for such purposes [7].

For the circuitry, the out pin of PIR sensor is connected to pin 7, VCC pin was connected to 5V and GND pin was connected to ground. Then there is a relay connect to Arduino PIN 13. Motion sensors senses motion and it sends the signal to Arduino, then Arduino sends signal to relay to close the circuit to turn power on. When it senses no motion, it sends signal to Arduino and Arduino sends signal to relay to open the circuit to turn the power off. Figure 9 shows the complete circuit with motion sensor.

System Design

The following section describes the methods and procedures used to conduct this project. The system block diagram of the design is shown in Figure 4. The circuit design of the system is shown in

Figure 5.

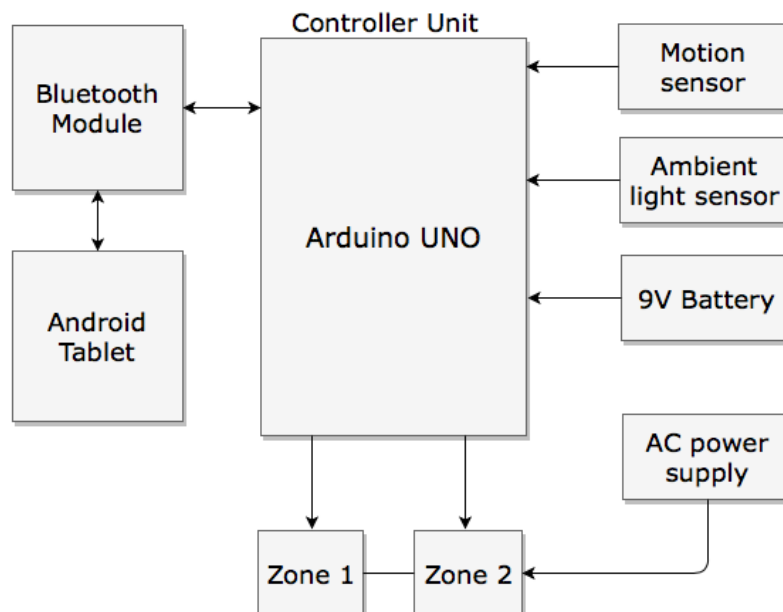


Figure 8. Block diagram

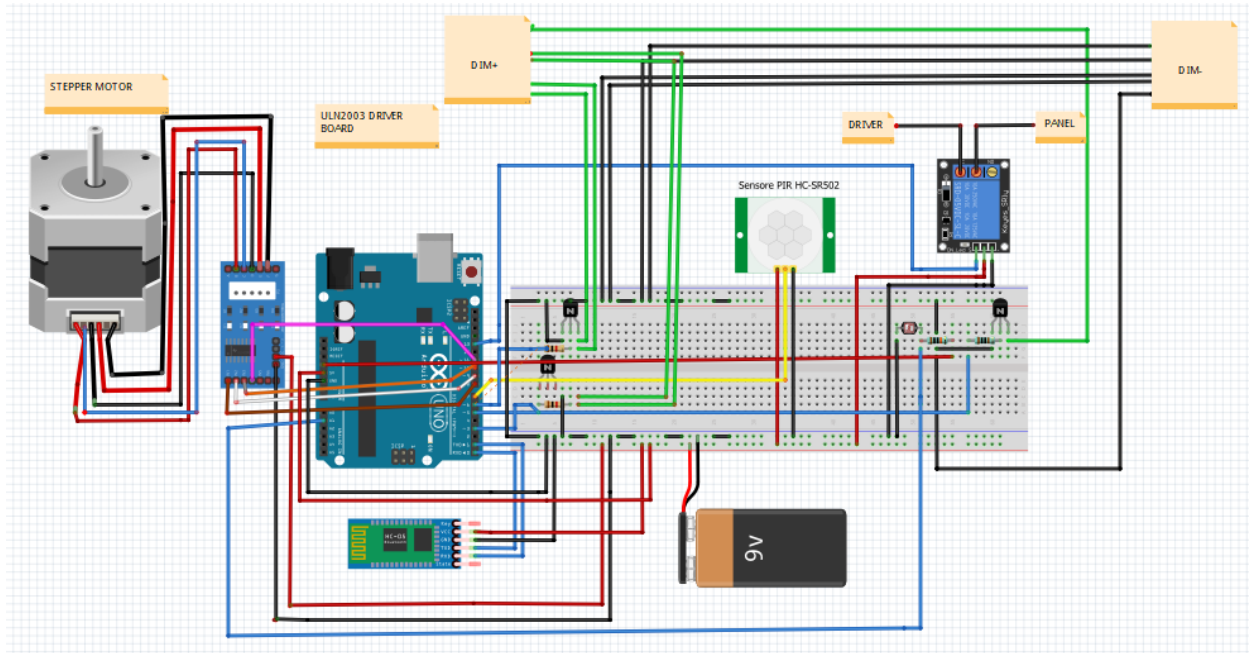


Figure 9. Circuit design

Arduino UNO-R3

Arduino Uno is a widely used open-source microcontroller. In 2003 the original platform was created by Hernando Barragan in Italy. In 2005, two computer developers (Massimo Banzi and David Cuartielles) introduced Arduino Uno-R1 which based on the ATmega168 microprocessor. Since its introduction, the Arduino use and application has grown rapidly. Arduino Uno-R3 is based on ATmega328P microprocessor [2].

The reason Arduino Uno-R3 was chosen for this project is because it's an open source platform microcontroller that can run on Windows, Mac, and Linux systems. The hardware/software is accessible and can be easily customized. It is inexpensive when compared to other microcontrollers. The genuine version is less than \$25.00 while the clone version can be found for less than \$5.00. Arduino is supported by many individuals, groups of people, and communities. There are hundreds of YouTube videos, online free courses, documents, and

websites that teach basic to advanced and more complex levels of building and programming Arduino.

Arduino Uno-R3 version is equipped with the following [3]:

- 14 digital input/output pins (of which 6 can be used as PWM outputs, pins 3, 5, 6, 9, 10, and 11)
- 6 analog inputs
- Serial In/Out- TX/RX (For wireless communication, used receive and transmit serial data)
- Reset button (Used when the microprocessor hangs up)
- USB connector (Used for uploading program to the board from any computer)
- External power jack to provide power to Arduino (9-12 VDC)
- Power pins
 - Vin input voltage to Arduino as an alternative to the external power jack.
 - 3.3V supply regulated 3.3V with maximum current of 50mA.
 - 5V supply regulated 5V with maximum current of 50mA. This voltage power the microcontroller and other components connected to Arduino.
 - GND is the ground pin.

Bluetooth Module

The Bluetooth technology is a short distance wireless communication between mobile phones, computers, tablets, and other devices using band from 2.4 to 2.485 GHz. The range of communication is approximately 10 meters (30 Feet). In this project the Bluetooth HC-06 module is used because its low power consumption, low cost, and most important it works well with Arduino and other microprocessors.

HC-06 Module Specifications [6]:

- Small in size (About 3 cm long).
- It runs only on 3.3VDC and 50 mA.
- Operating frequency 2.4 GHz.
- High transmission speed, can reach 2.1 Mbps max.

It has four pins and can be easily connected to the Arduino. These pins are:

- VCC: Connects to positive terminal of the power source.
- GNG: Ground connection.
- TXD: Transmitting terminal (Must connected to receiving terminal of the other device).
- RXD: Receiving terminal (Must connected to transmitting terminal of the other device).

The HC06 has small LED that indicates the connection status. It blinks once the power is connected and keep blinking till it pairs with other devices. Once both devices are paired and know each other, the blinking stops and the LED lit.

Battery

A 9V battery was connected to input jack of the Arduino. This voltage can supply the necessary power needed to run the Arduino and the components attached to it. Arduino and most parts connected need 5VDC.

AC Power Supply

Outlet 110VAC is connected to the all four LED panels. Panels run on 100-277 VAC, 0.6 Amp, 50/60 Hz, and output 27-42 VDC, 1.2 Amp. The dimming option from 0-10 V/PWM/RX/RF.

Zone Configuration

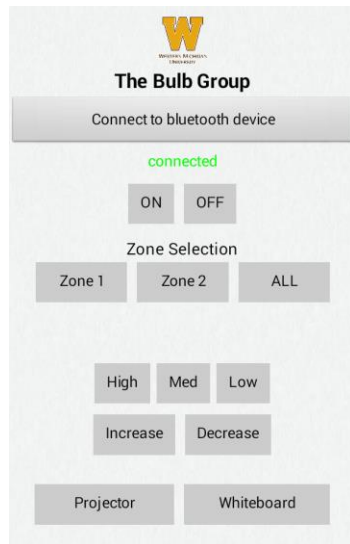
A consistency in light zone configuration for each separate classroom will increase usability of the lighting system for the operators. Proposed ideal light zoning for projector mode is dimming lights to 25 percent power in the row of lights parallel and most proximal to the front of the room (zone 1) and allowing 50 percent to the row of lights distal to the front of the room (zone 2). The proposed ideal light zoning for whiteboard mode consists of zone 1 and 2 having 75 percent power to enlighten the whiteboard.

MIT App Inventor

One of the requirements for this project is to use a touch screen panel that is user friendly. The current panel used in all classrooms in Floyd Hall is shown in Figure 5. An app was created using MIT App Inventor. MIT App Inventor is an open source web application; the programming environment is very simple and easy to learn. There is no need for any prior coding or programming skills. The user can easily drag and drop the graphical blocks and attach them together to build a fully functional app that can run on a smartphone or a tablet [4]. Figure 6 shows the layout of the app created. The user will first connect to the Bluetooth module. When the connection is successful “connected” will be colored in green, and if the connection fails “disconnected” will be colored in red. Appendix A. shows the code for the connection setup between the Bluetooth module and the tablet.

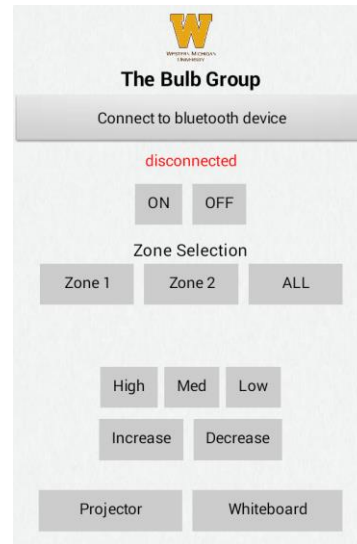


Figure 10. Existing panel



*Figure 11a. App
Layout
layout*

(Disconnected)



*Figure 11b. App
(connected)*

After successfully connecting to the Bluetooth, the user will be able to turn ON or OFF all the panels. Referring to Appendix B., when ON is clicked character “6” will be sent to the Arduino through the Bluetooth. As the Arduino receives character “6”, it will set the output pin to HIGH. Same as when OFF is being clicked, character “7” will be sent and Arduino will set the output pin to LOW. This is done using digitalWrite with only two arguments: high or low.

The app includes a zone selection option where the user selects the zone they desire to control. In this design, there are two zones as shown in Figure 7, where Zone 1 is near the front of the classroom (near the whiteboard). Zone 2 will come after Zone1 and more zones can be added. The user will select Zone 1, Zone 2 or all zones to control in the classroom. Appendix C. shows the code for zone selection where characters a, b and c represent Zone 1, Zone 2, and all zones respectively.

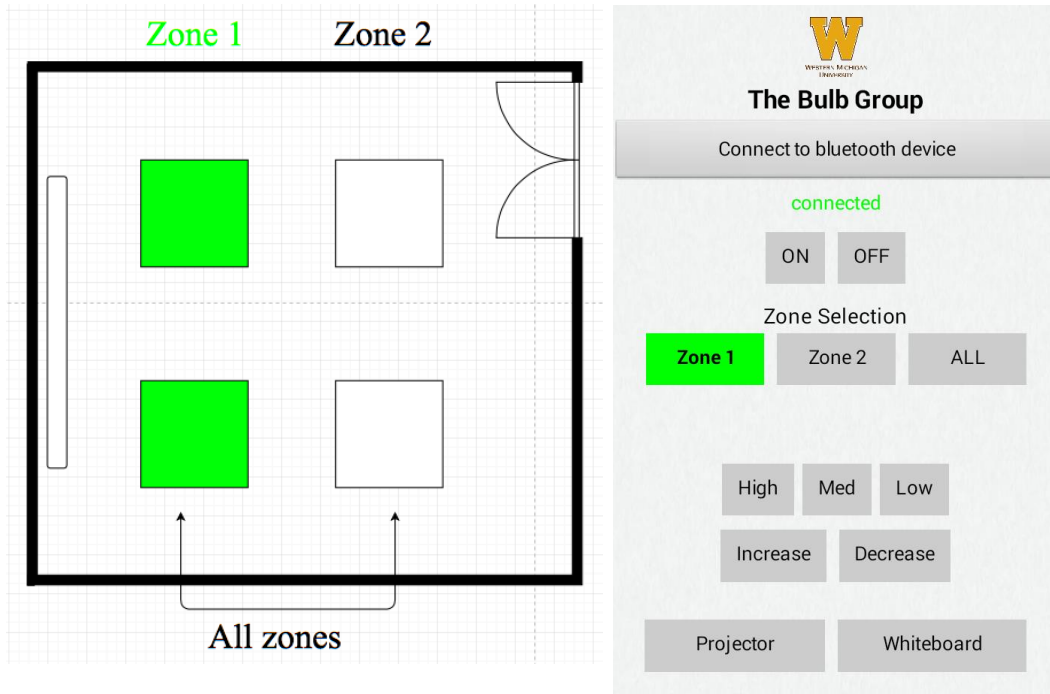


Figure 12. Zone configuration

There are 3 default settings for brightness level (high, med, and low) with the ability to increment or decrement the brightness in between these default modes. As shown in Appendix D., after the zone has been selected High, Med, Low, decrement and increment option will be available. Using analogWrite, the output can be set between 0 – 255 where 0 is off and 255 is full on. High having a value of 191 (75% duty cycle), Med having a value 127 (50% duty cycle), and Low having a value 64 (25% duty cycle). By this, the panels brightness is being controlled using PWM which is a good way to achieve much more linear control of brightness. The increment and decrement option which increases or decreases the brightness by 5% as shown in Appendix E. In addition, the user has the option to select a projector or whiteboard mode. Appendix F shows the code for all the project.

Dimming

In this project the dimming was achieved by using the PWM option. As mentioned earlier, Arduino and all connected components run on 5V DC. It can only deliver 20mA of current and a maximum 50mA when the chip is stressed to its limit. This PWM current is not enough to switch the dimming circuit and cannot control the brightness of the panels. PWM pins are meant to send control signals, not to act as a power supply. To provide the adequate current needed by the dimmer, the Arduino signal need to be amplified. NPN 2N3904 transistor was used to overcome this obstacle. This transistor is rated to a continuous 650 mA which satisfy the current needed for the panels [5]. The transistor is used to control the flow of the power to the dimming part of the circuit.

As shown in Figure 8 the base of the transistor is connected to a PWM pin of the Arduino through a 1k resistor. The collector is connected to the load DIM+ of the panel and the emitter is connected to a ground. This configuration is called low-side switch, meaning the control input flows into the base, the output is connected to the collector and the emitter is connected to ground.

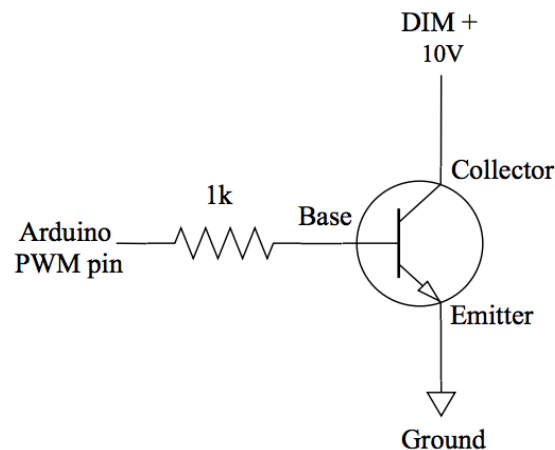


Figure 13. NPN transistor

The 1k series resistor that connects the base to the Arduino PWM acts as current limiter and protects the transistor from extra power that could damage it. When the base voltage reaches 0.7V or greater, the transistor turns on and the current flows from base to emitter. The larger this current is, the larger the current flows from collector to emitter. This is called the gain of the transistor and can be defined as: $\text{Gain} = I_{CE}/I_{BE}$.

PWM (Digital Dimming)

The Panels are turned on and off at a rate of 490Hz frequency. The human eye cannot recognize blinking LED with any frequency higher than 100Hz. The Arduino PWM pins are used to perform the on/off switching (Dimming) digitally at high rate of 490Hz.

The advantages of digital dimming over analog dimming are:

- Low power consumption
- Requires simple circuitry
- Accurate color control

Looking at Figure 9, Zone 1 is being High level of brightness where its on for 75% of the duty cycle time and off 25% until the start of the next cycle.

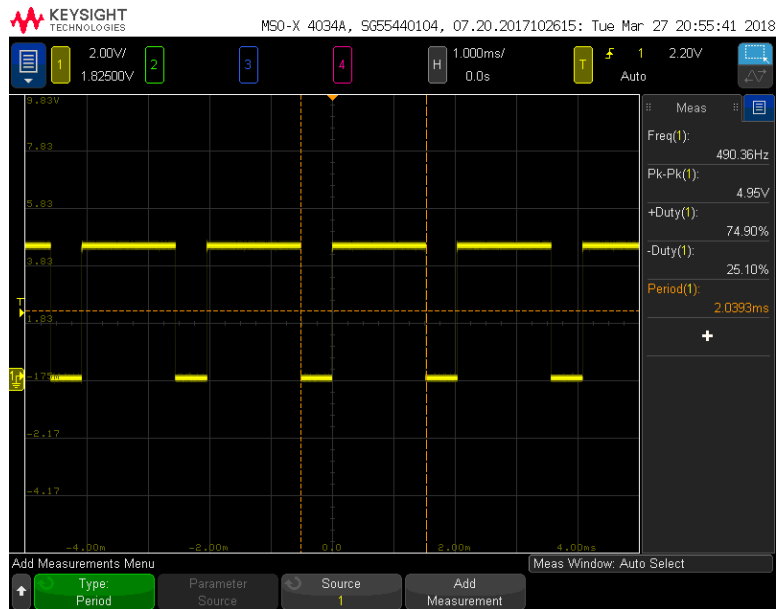


Figure 14. High brightness

Figure 10 shows a Med level of brightness where its on for 50% of the duty cycle time and off 50% until the start of the next cycle.

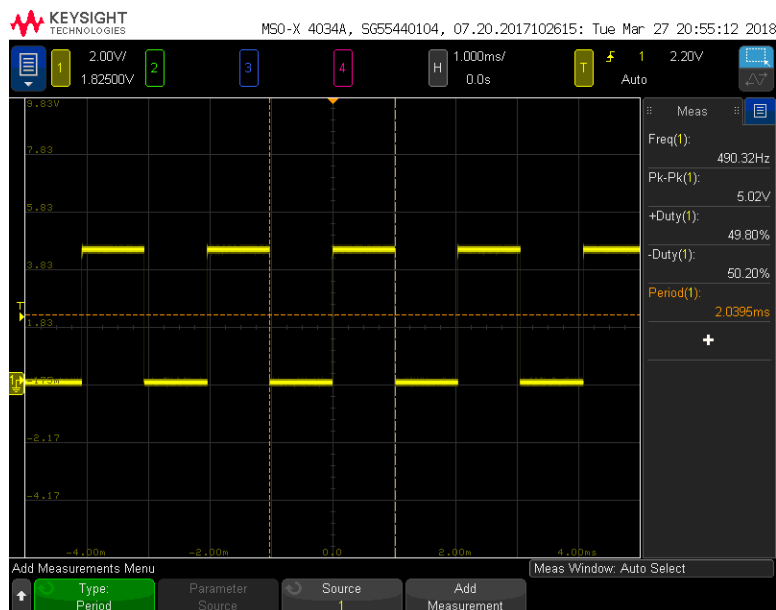


Figure 15. Medium brightness

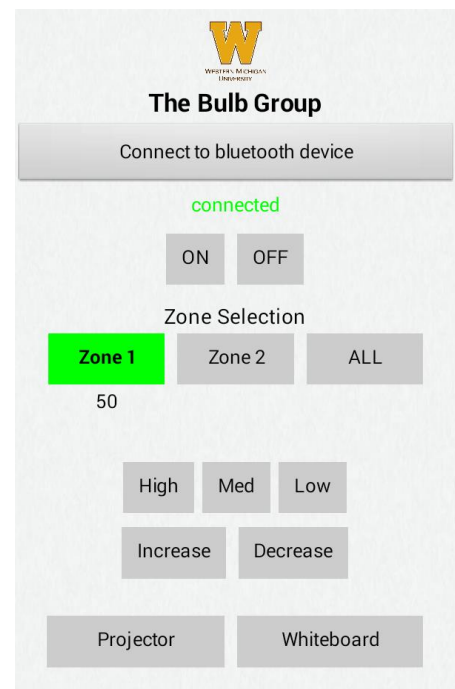
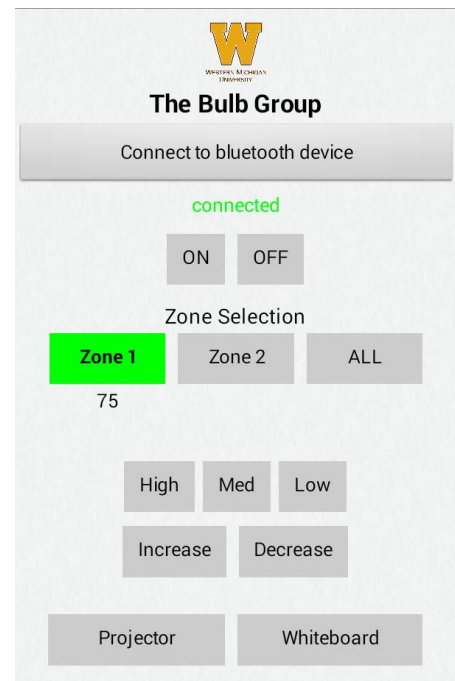


Figure 11 shows a Low level of brightness where it's on for 25% of the duty cycle time and off 75% until the start of the next cycle.

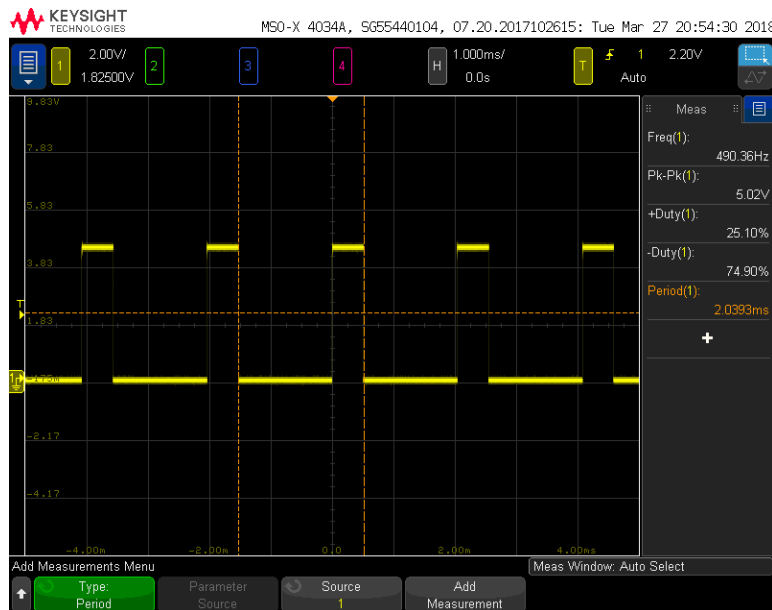
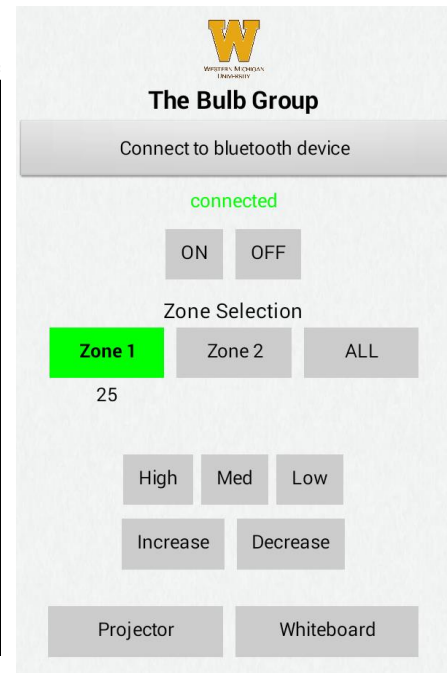


Figure 16. Low brightness



Cost Analysis

LED lightings are good quality, lasts longer and saves money overtime. With the functionality like dimming, ambient light sensing, motion sensing; it saves more energy and money. Initial cost of LED panels is higher as it costs more than fluorescent tubes but the long term saving pays off for its high initial cost.

Cost comparison between LED and fluorescent lighting is shown in Figure 17.

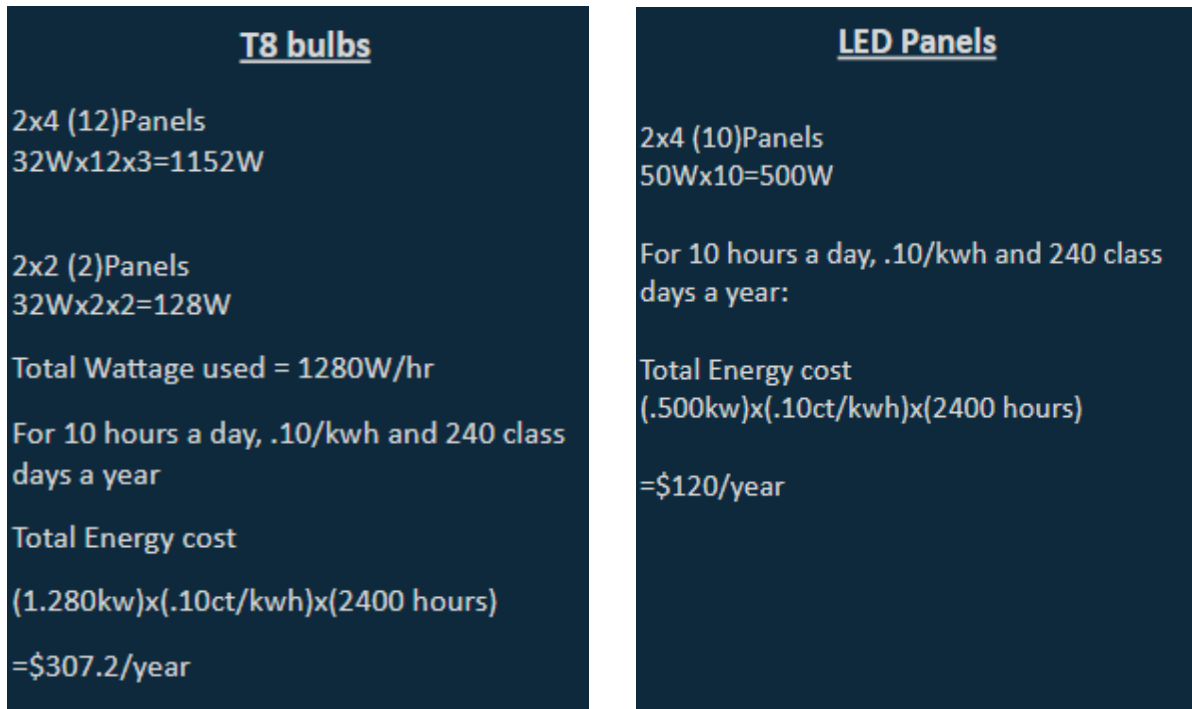


Figure 17. Cost Comparison between T8 and LED

The cost analysis for the room C-136 is shown in Figure 18:

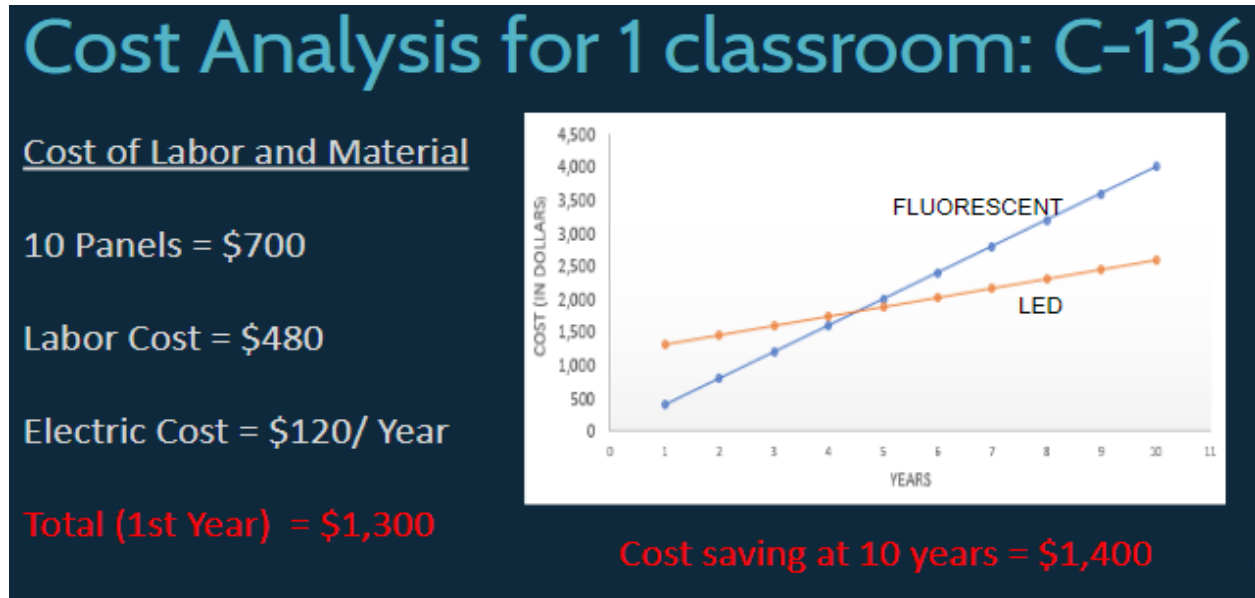


Figure 18. Cost Analysis for C-136

Figure 18, shows LED starts higher than fluorescent because it includes the cost of labor and material which is \$1300. Between 4 and 5 years there is a breakeven point. The cost of fluorescent keeps going up and the LED cost goes down which gives us 10 years saving of \$1400 for one classroom.

In Floyd hall there is 15 classrooms. All classrooms have fluorescent lighting which if replaced with LED panels would save lot of energy as well as money. The cost analysis for 15 classrooms shown in figure 19 shows that the cost of LED panels for all classrooms are \$10,500 and labor cost to replace it would be \$7,200 and the electric cost for first year comes to be \$1,800 which makes the total cost for first year to be \$19,500. The total cost saving over 10 years would be \$20,964.

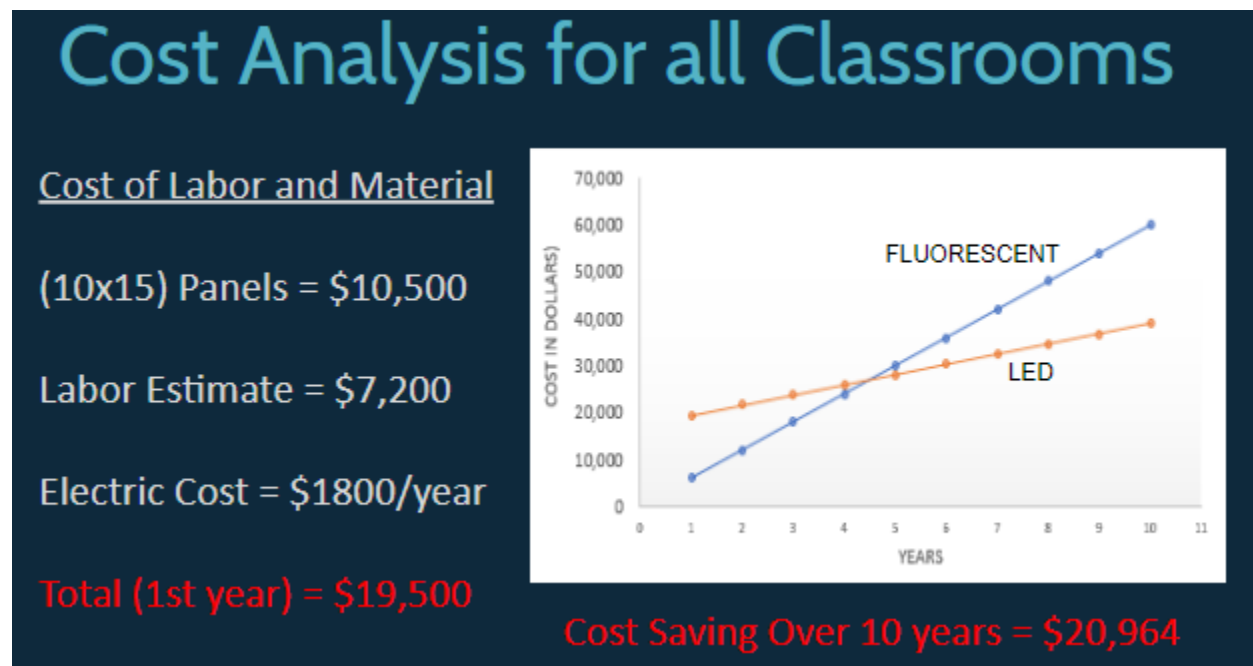


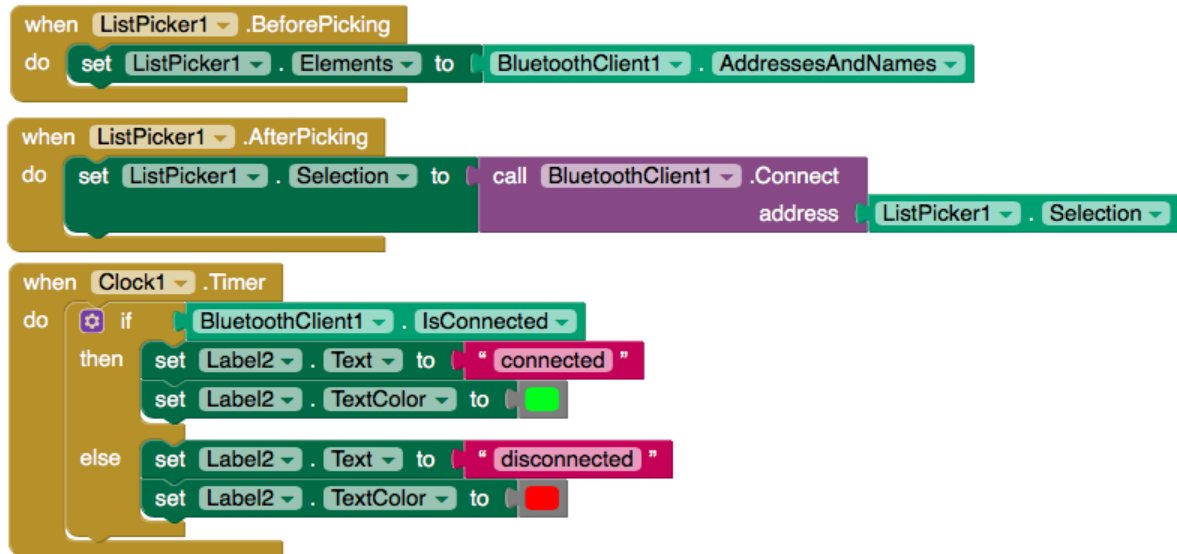
Figure 19. Cost Analysis for all classroom

Conclusion

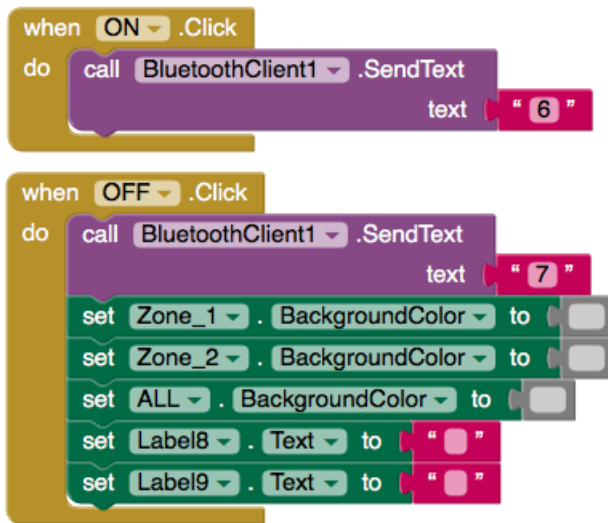
The senior engineering student group at Western Michigan University provided a wealth of insight regarding solid-state lighting and the feasibility of its implementation in the classroom environment. The primary purpose of the project was to research, plan, design, create a cost benefit analysis and present findings of the feasibility of implementing a certain lighting system. The proposed lighting system needed to meet the requirements of the university, the patrons thereof and present a cost and energy savings. The students applied for and received grant endowment from the university and used personal income to fund the research project. The engineering students researched a variety of lighting options with regard to capability, type, initial and maintenance cost, installation cost and needs of university patrons and faculty. The students designed a lighting system with functionality including zone control, ambient light sensing and adequate lux distribution. The students successfully created a functional and intuitive Android application to command the lighting system via Bluetooth. The students exemplified the projected light distribution using complex computer simulations and mathematical calculations and then presented the findings at the Western Michigan University Senior Design Project event. The students accomplished the creation of a prototype of the proposed lighting system in its entirety. The findings of the research were that upon implementation of the proposed lighting system in university classrooms that the lighting environment could be quickly and easily be manipulated to facilitate excellent teaching/learning environment while generating a cost and energy savings over time.

APPENDICES

A. Bluetooth connection



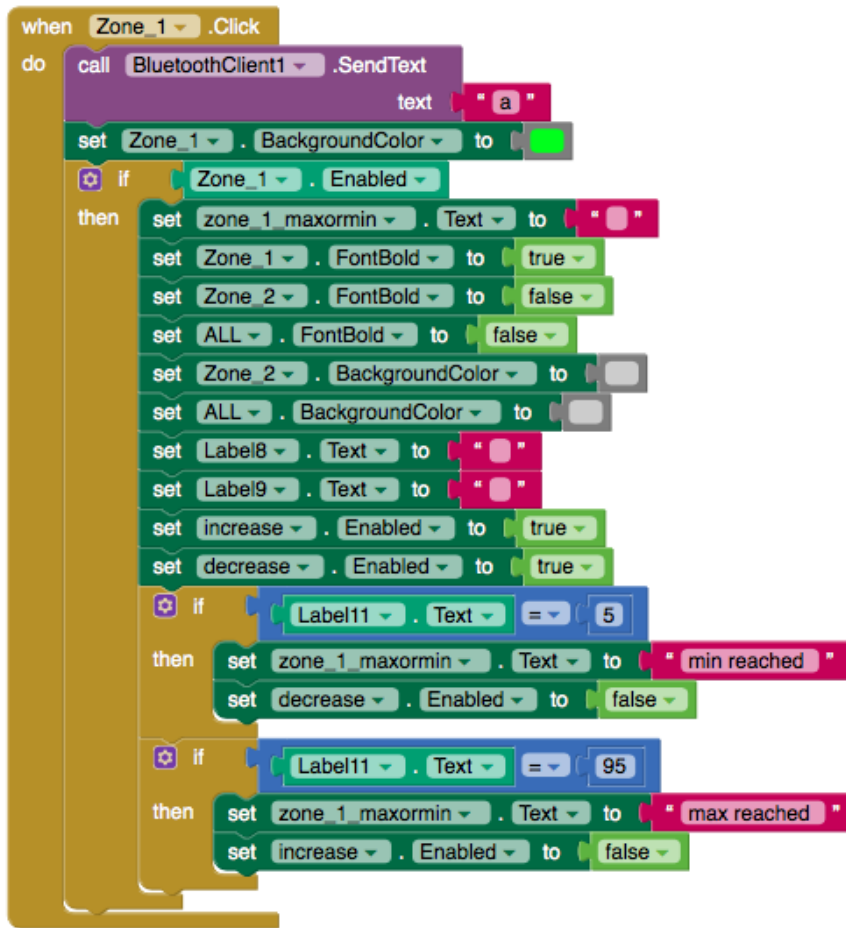
B. ON/OFF



```
else if (received == '6')           // ON
{
    digitalWrite(panel, HIGH);
}

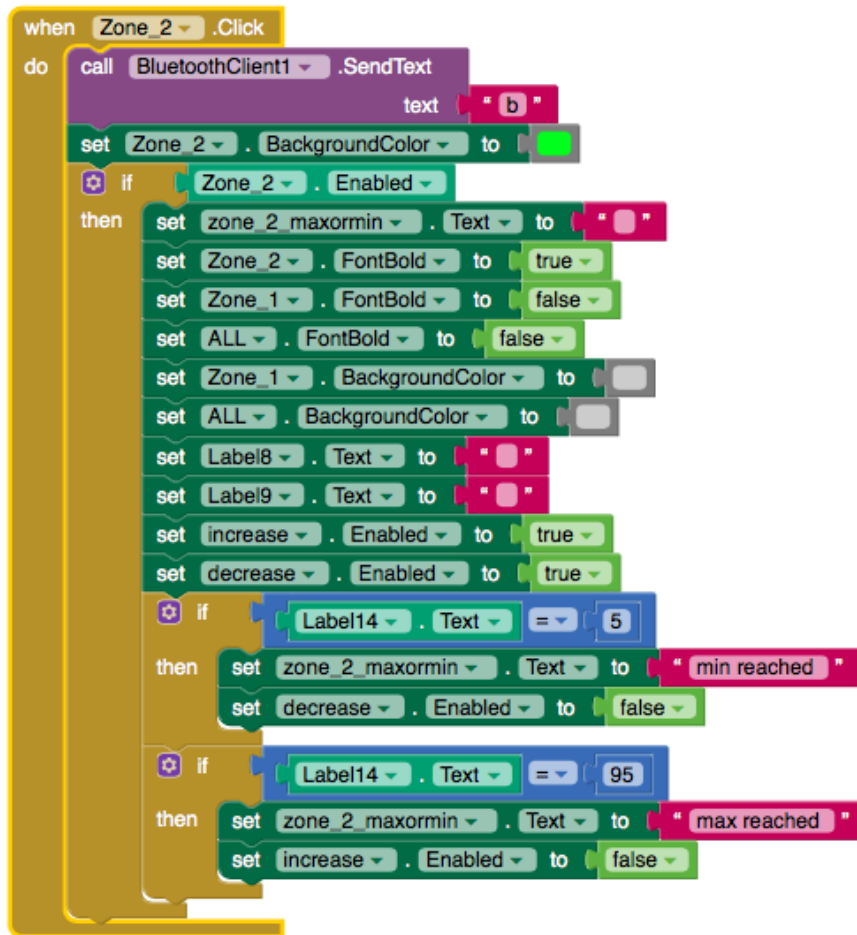
else if (received == '7')           // OFF
{
    digitalWrite(panel, LOW);
}
```

C. Zone selection
(Zone 1)



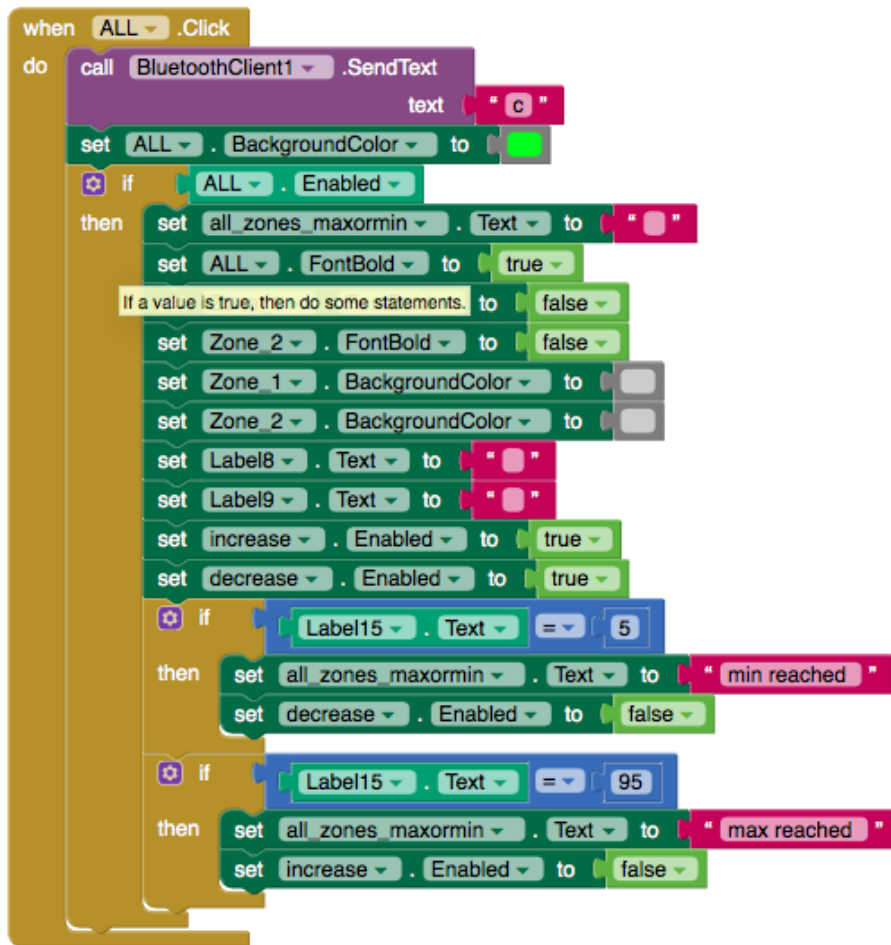
```
if (received == 'a')      // ZONE 1 control
{
    y = 2;
}
```

(Zone 2)



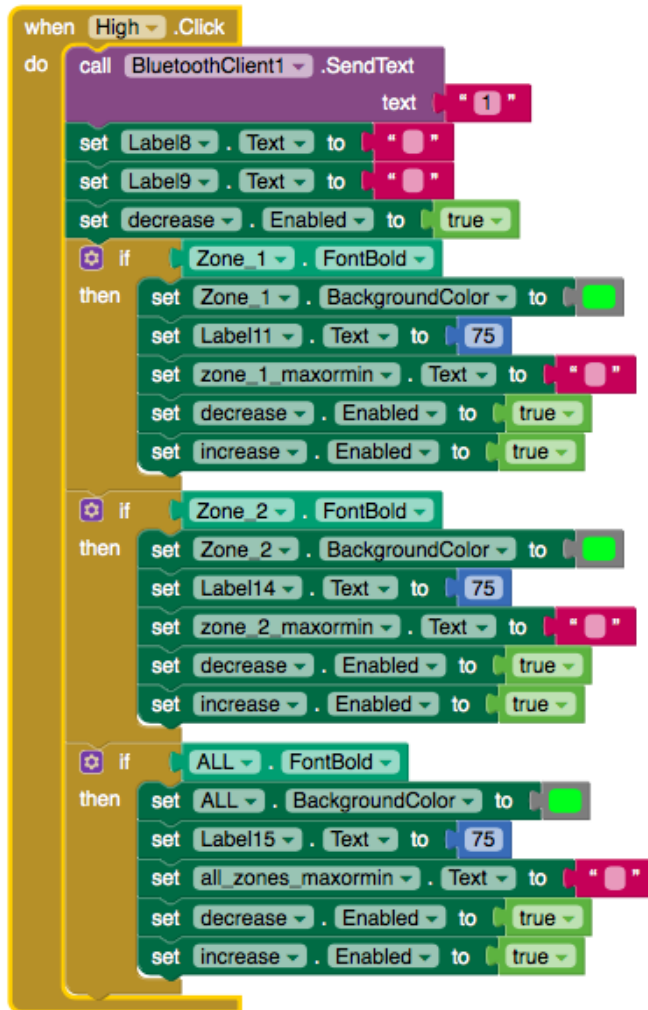
```
if (received == 'b')           // ZONE 2 control
{
    y = 3;
}
```

(All zones)



```
if (received == 'c')          // All zones
{
  y = 4;
}
```

D. Brightness modes (High)

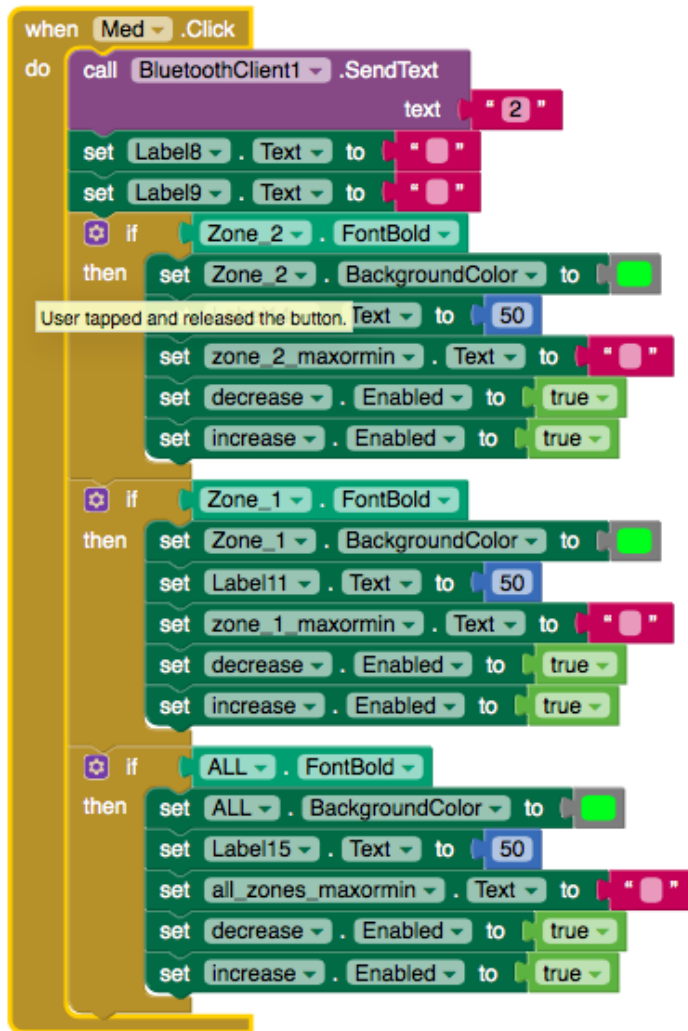


```

if (y == 2 && received == '1') // HIGH
{
  analogWrite(zone1, 191); // 75% duty cycle
  x = 191;
}

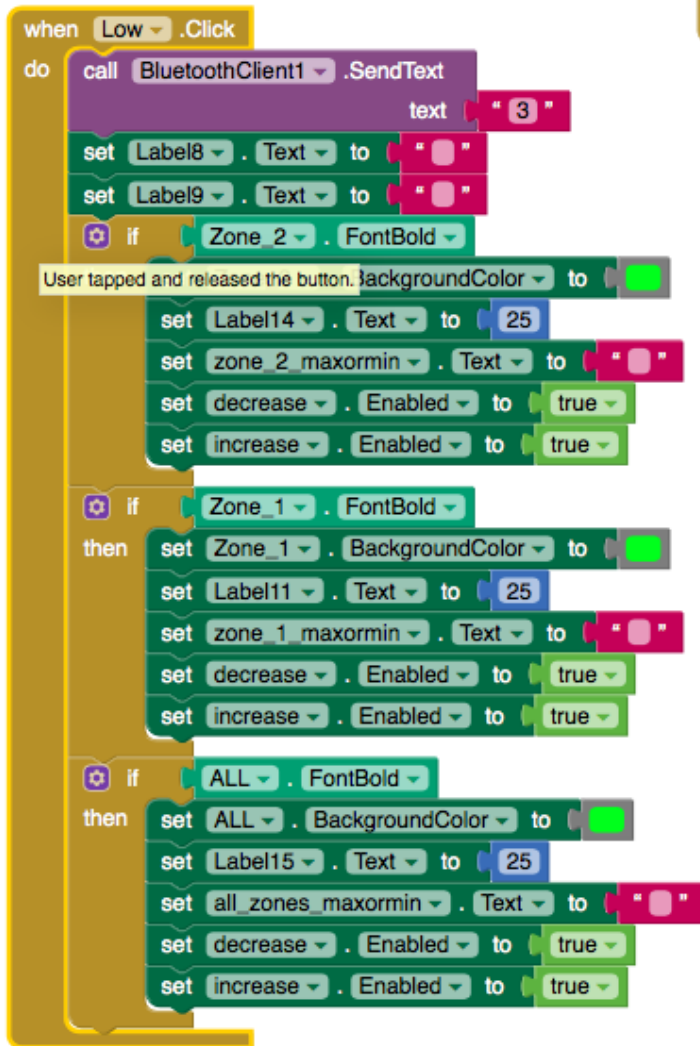
```

(Medium)



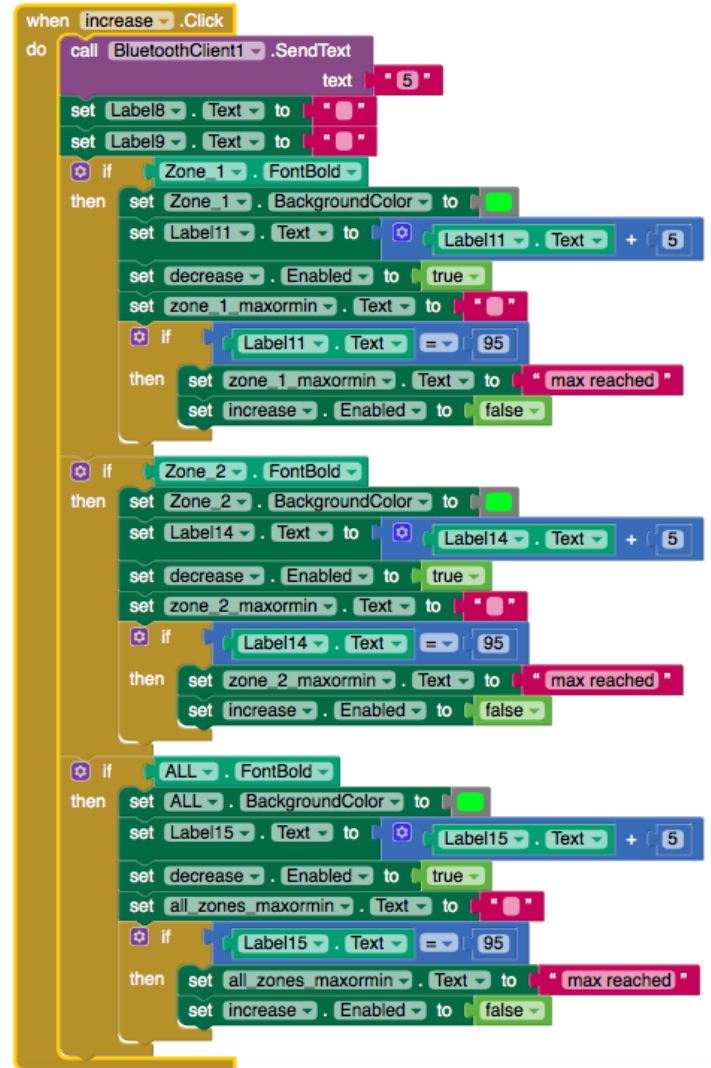
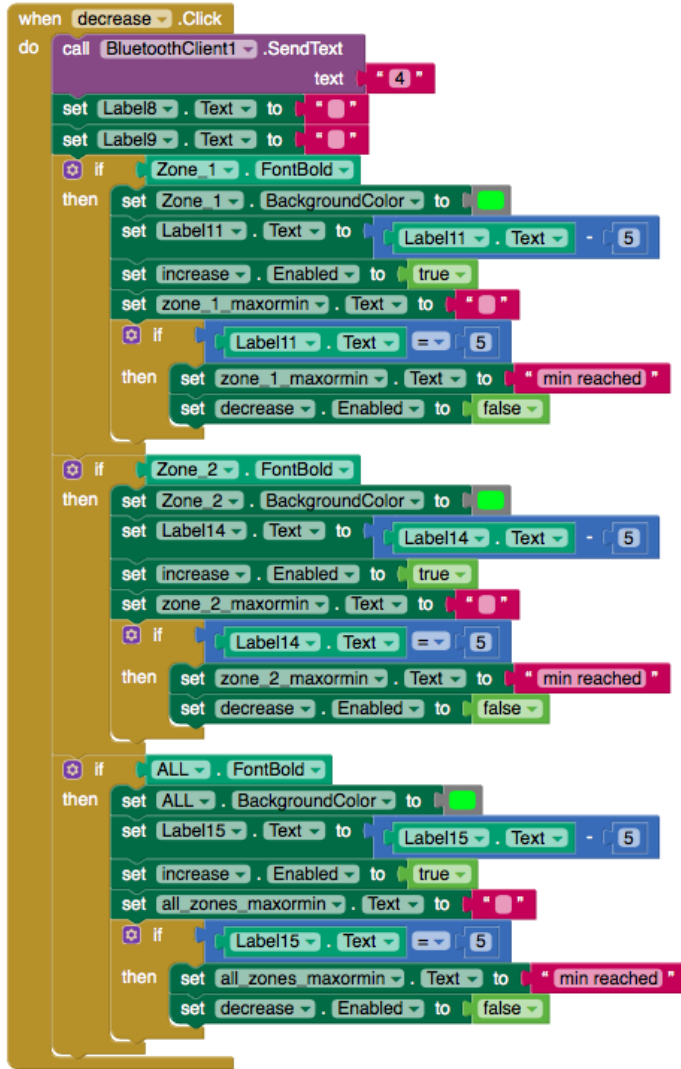
```
else if (y == 2 && received == '2') // MED
{
    analogWrite(zone1, 127);          // 50% duty cycle
    x = 127;
}
```

(Low)



```
else if (y == 2 && received == '3')    // LOW
{
    analogWrite(zone1, 64);              // 25% duty cycle
    x = 64;
}
```

E. Increase/decrease



```

else if (y == 2 && received == '4') // decrease
{
  if (x > 15) // if min isn't reached
  {
    int newx = x - 13; // decrement by 5%
    analogWrite(zone1, newx);
    x = newx;
  }
  else if (x <= 15) // if min reached
  {
    x = x; // stop decrementing
  }
}

```

```

else if (y == 2 && received == '5') // increase
{
  if (x < 243) // if max isn't reached
  {
    int newx = x + 13; // increment by 5%
    analogWrite(zone1, newx);
    x = newx;
  }
  else if (x >= 243) // if max reached
  {
    x = x; // stop incrementing
  }
}

```


F. All System

Arduino Code:

```
#include <Stepper.h>
const int stepsPerRevolution = 1500;
Stepper myStepper(stepsPerRevolution, 8, 10, 9, 11);

int zone1 = 3;
int zone2 = 6;
int panel = 2;
int x = 0;
int y = 0;

void setup() {

    Serial.begin(9600);
    myStepper.setSpeed(15);
    pinMode(zone1, OUTPUT);
    pinMode(zone2, OUTPUT);
    pinMode(panel, OUTPUT);

}

void loop() {

    if(Serial.available() > 0)
    {
        int received = Serial.read();
        Serial.println (received);

        if (received == 'a')    // ZONE 1 control
        {
            y = 2;
        }

        if (y == 2 && received == '1')    // HIGH
        {
            analogWrite(zone1, 191);      // 75% duty cycle
            x = 191;
        }

        else if (y == 2 && received == '2') // MED
```

```

{
    analogWrite(zone1, 127);          // 50% duty cycle
    x = 127;
}

else if (y == 2 && received == '3') // LOW
{
    analogWrite(zone1, 64);          // 25% duty cycle
    x = 64;
}

else if (y == 2 && received == '4') // decrease
{
    if (x > 15)                      // if min isn't reached
    {
        int newx = x - 13;          // decrement by 5%
        analogWrite(zone1, newx);
        x = newx;
    }
    else if (x <= 15)                // if min reached
    {
        x = x;                      // stop decrementing
    }
}

else if (y == 2 && received == '5') // increase
{
    if ( x < 243)                    // if max isn't reached
    {
        int newx = x + 13;          // increment by 5%
        analogWrite(zone1, newx);
        x = newx;
    }
    else if ( x >= 243)              // if max reached
    {
        x = x;                      // stop incrementing
    }
}

if (received == 'b')                // ZONE 2 control
{
    y = 3;
}

```

```

if (y == 3 && received == '1') // HIGH
{
    analogWrite(zone2, 191);    // 75% duty cycle
    x = 191;
}

else if (y == 3 && received == '2') // MED
{
    analogWrite(zone2, 127);    // 50% duty cycle
    x = 127;
}

else if (y == 3 && received == '3') // LOW
{
    analogWrite(zone2, 64);     // 25% duty cycle
    x = 64;
}

else if (y == 3 && received == '4') // decrease
{
    if (x > 15)                  // if min isn't reached
    {
        int newx = x - 13;      // decrement by 5%
        analogWrite(zone2, newx);
        x = newx;
    }
    else if (x <= 15)            // if min reached
    {
        x = x;                  // stop decrementing
    }
}

else if (y == 3 && received == '5') // increase
{
    if ( x < 243)                // if max isn't reached
    {
        int newx = x + 13;      // increment by 5%
        analogWrite(zone2, newx);
        x = newx;
    }
    else if ( x >= 243)          // if max reached
    {
        x = x;                  // stop incrementing
    }
}

```

```

    }
}

if (received == 'c')    // All zones
{
    y = 4;
}

if (y == 4 && received == '1')  // HIGH
{
    analogWrite(zone2, 191);    // 75% duty cycle
    analogWrite(zone1, 191);
    x = 191;
}

else if (y == 4 && received == '2')  // MED
{
    analogWrite(zone2, 127);      // 50% duty cycle
    analogWrite(zone1, 127);
    x = 127;
}

else if (y == 4 && received == '3')  // LOW
{
    analogWrite(zone2, 64);        // 25% duty cycle
    analogWrite(zone1, 64);
    x = 64;
}

else if (y == 4 && received == '4')  // decrease
{
    if (x > 15)                    // if min isn't reached
    {
        int newx = x - 13;        // decrement by 5%
        analogWrite(zone2, newx);
        analogWrite(zone1, newx);
        x = newx;
    }
    else if (x <= 15)              // if min reached
    {
        x = x;                    // stop decrementing
    }
}

```

```

    }

    else if (y == 4 && received == '5')    // increase
    {
        if ( x < 243)                      // if max isn't reached
        {
            int newX = x + 13;              // increment by 5%
            analogWrite(zone2, newX);
            analogWrite(zone1, newX);
            x = newX;
        }
        else if ( x >= 243)                // if max reached
        {
            x = x;                          // stop incrementing
        }
    }

    else if (received == '6')              // ON
    {
        digitalWrite(panel, HIGH);
    }

    else if (received == '7')              // OFF
    {
        digitalWrite(panel, LOW);
    }

    else if (received == '8')              // Projector mode
    {
        Serial.println("clockwise");
        myStepper.step(stepsPerRevolution);
        myStepper.step(stepsPerRevolution);
        myStepper.step(stepsPerRevolution);
        analogWrite(zone1, 64);            // 25%
        analogWrite(zone2, 127);           // 50%
    }

    else if (received == '9')              // Whiteboard mode
    {
        Serial.println("counterclockwise");
        myStepper.step(-stepsPerRevolution);
        myStepper.step(-stepsPerRevolution);
        myStepper.step(-stepsPerRevolution);
        analogWrite(zone1, 191);           // 75%
    }

```

```

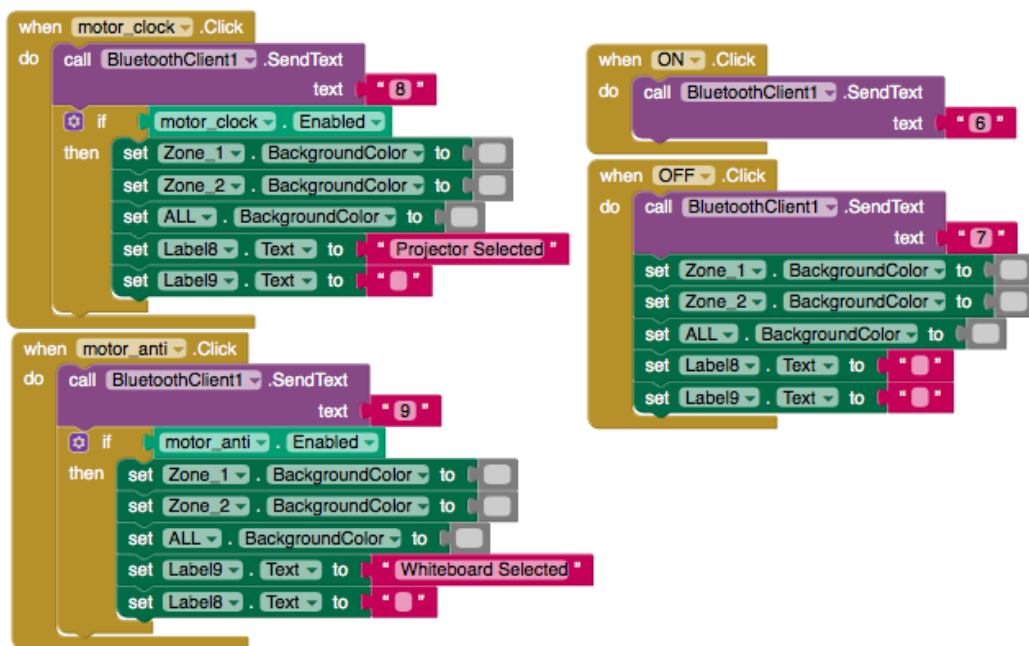
        analogWrite(zone2, 191);          // 75%
    }

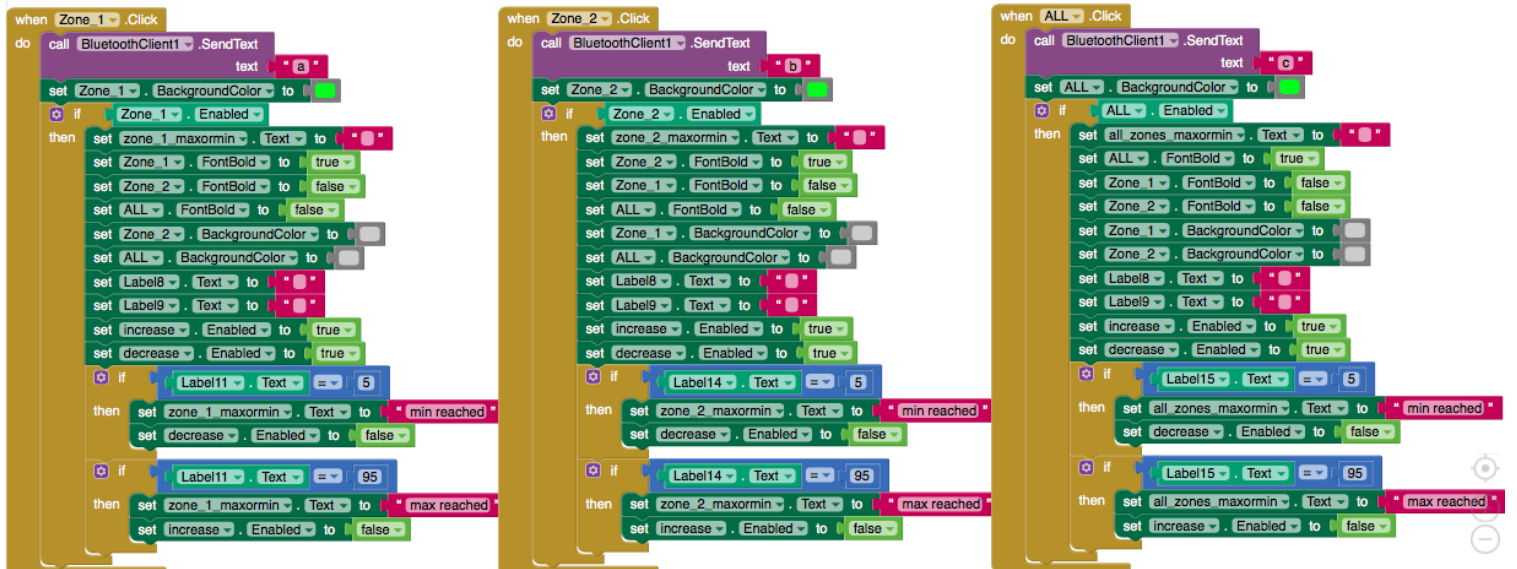
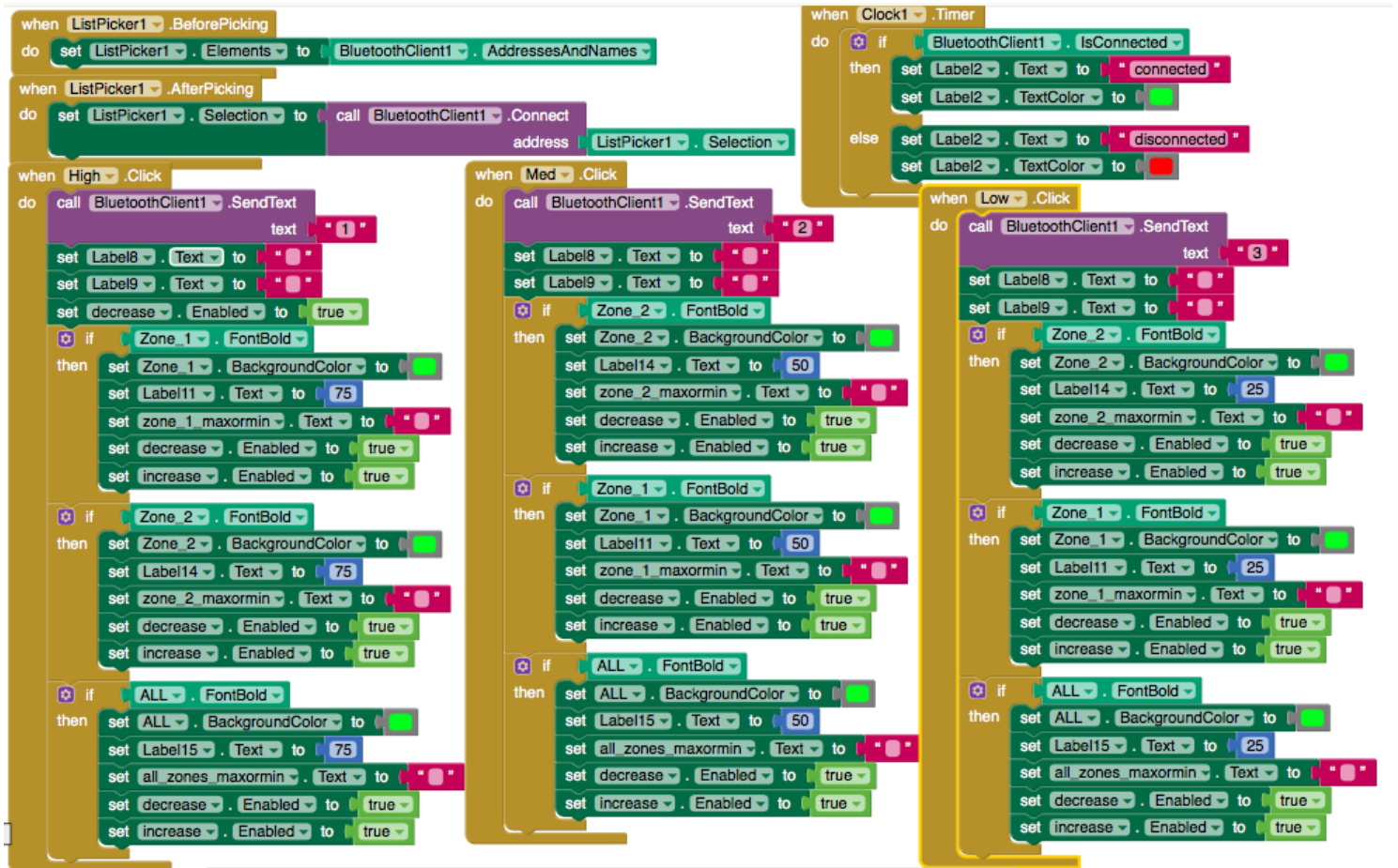
}

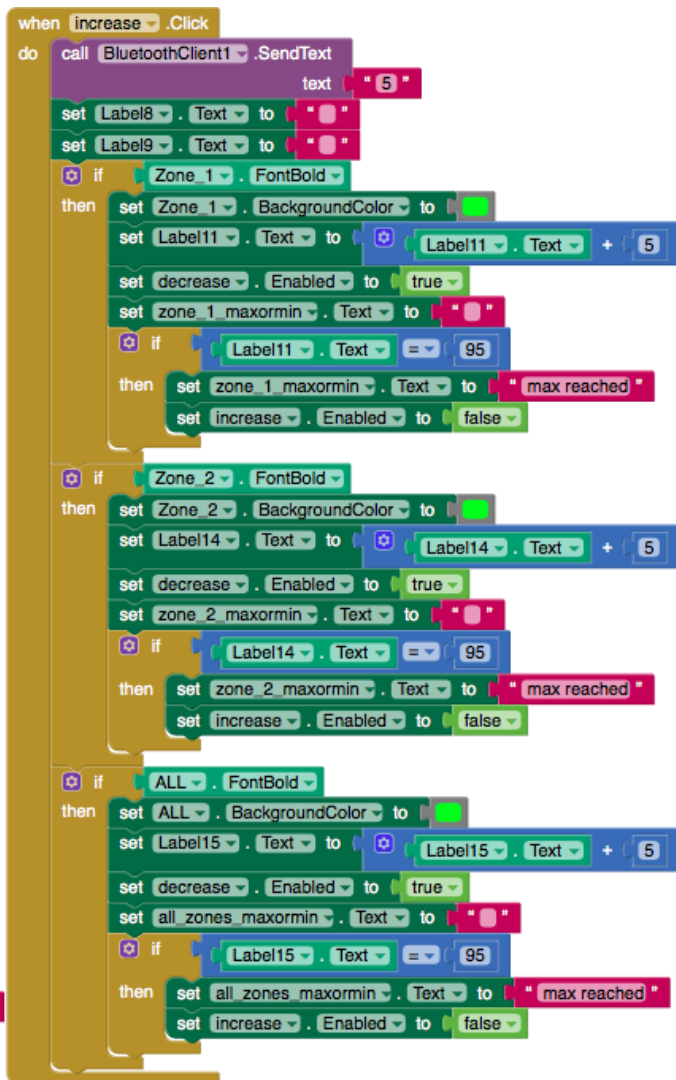
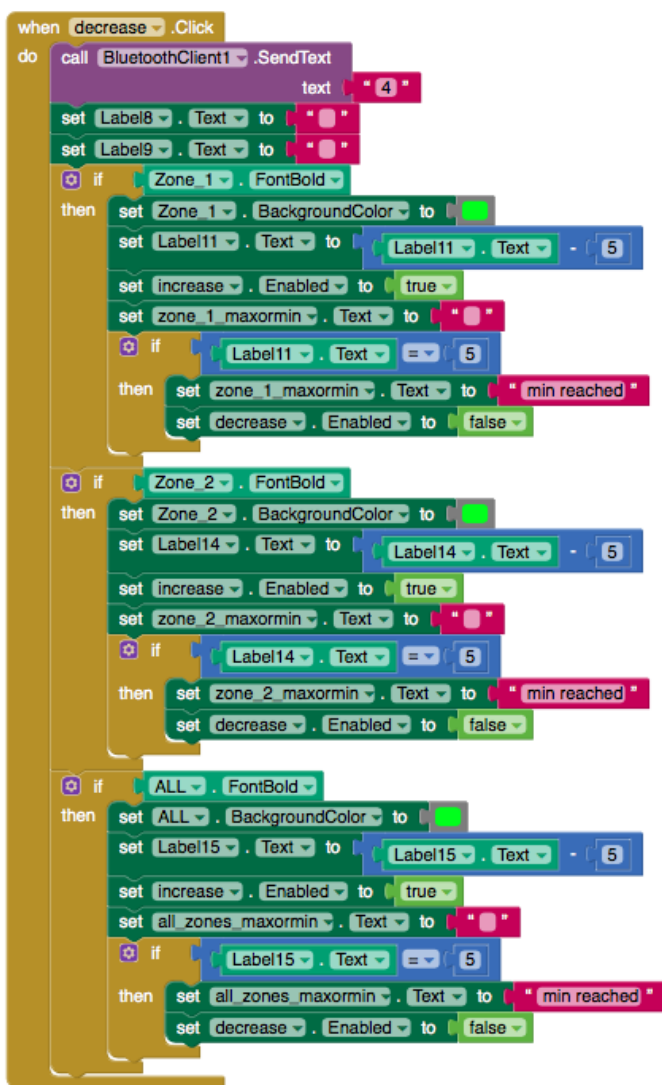
}

```

MIT App Inventor code:







Ambient Light code.

```

const int sensorPin = A1; //Photoresistor sensor
const int ledPin = 5; //PWM pin for LEDs (connected in parallel)

void setup () {
  pinMode(ledPin, OUTPUT);
  Serial.begin (9600);
}

void loop () {
  int value = analogRead (sensorPin); //Get the brightness value as determined by the sensor
  //Serial.println (value, DEC);
  value = map(value, 0, 1023, 0, 255); //map the low and the high
  Serial.println(value);
  analogWrite(ledPin, value);
  delay (50);
}

```


Motion sensor code:

```
int PIR = 7; // Pin of PIR Sensor
int relay = 13; // Pin of Relay

void setup(){
  Serial.begin(9600);
  pinMode(relay, OUTPUT); // Set Pin connected to Relay as an OUTPUT
  digitalWrite(relay, LOW); // Set Pin to LOW to turn Relay OFF
}

void loop(){

  while (digitalRead(PIR) == HIGH) { // If Motion detected
    digitalWrite(relay, HIGH); // Turn Relay ON
    Serial.println("Relay is ON");
    delay(500);
  }

  digitalWrite(relay, LOW); // Turn Relay OFF
  Serial.println("Relay is OFF");
  delay(500);
}
```

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