
# The Smart Window

## Group 4

## Final Presentation

## SD2 - Spring 2021

# Project Team Members

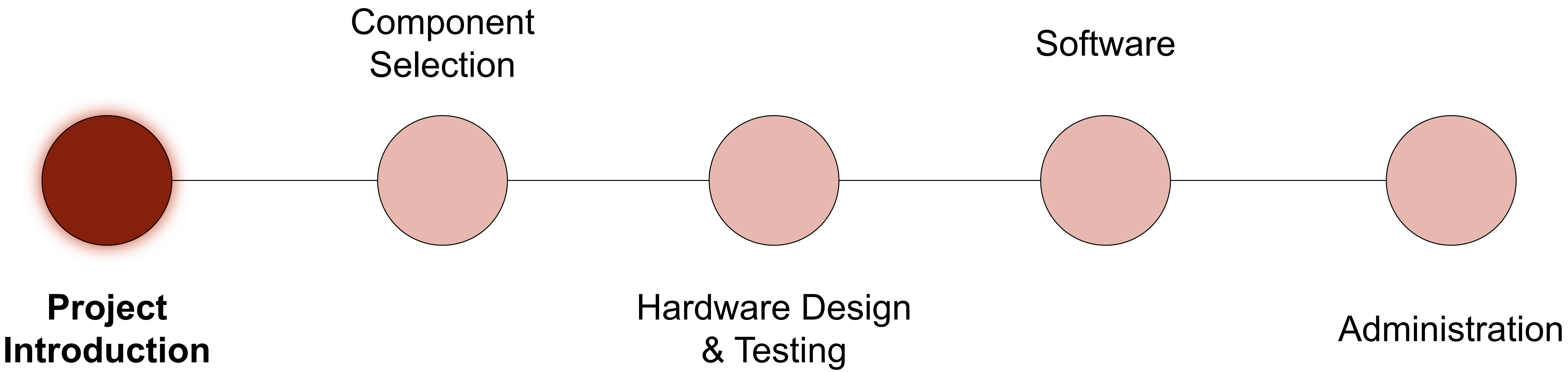
**Jake Pivnik - Pablo Calzada**

Photonic Science & Engineering

**Shaneal Findley - James Brunner**

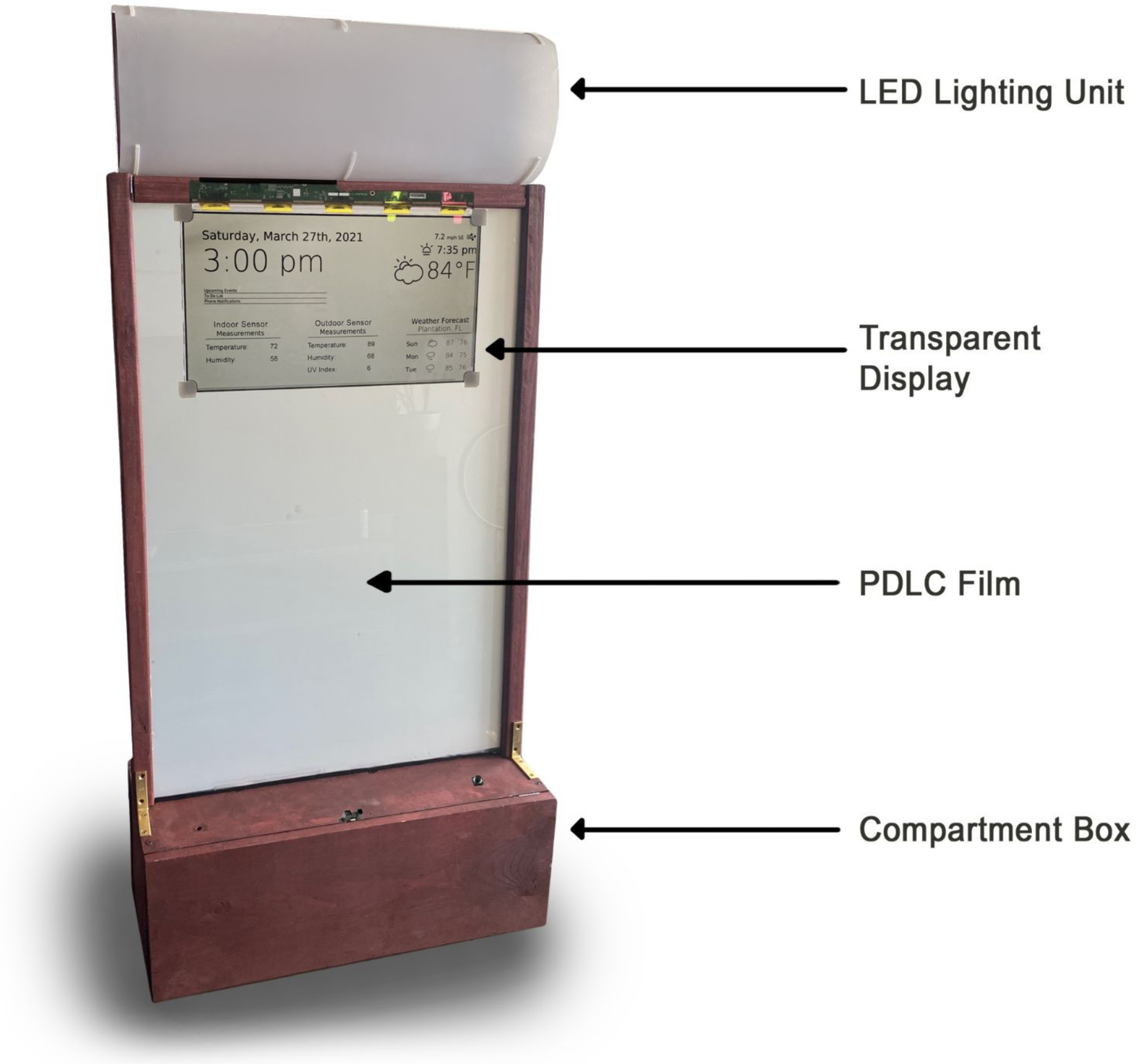
Computer Eng. | Electrical Eng.

# Presentation Timeline



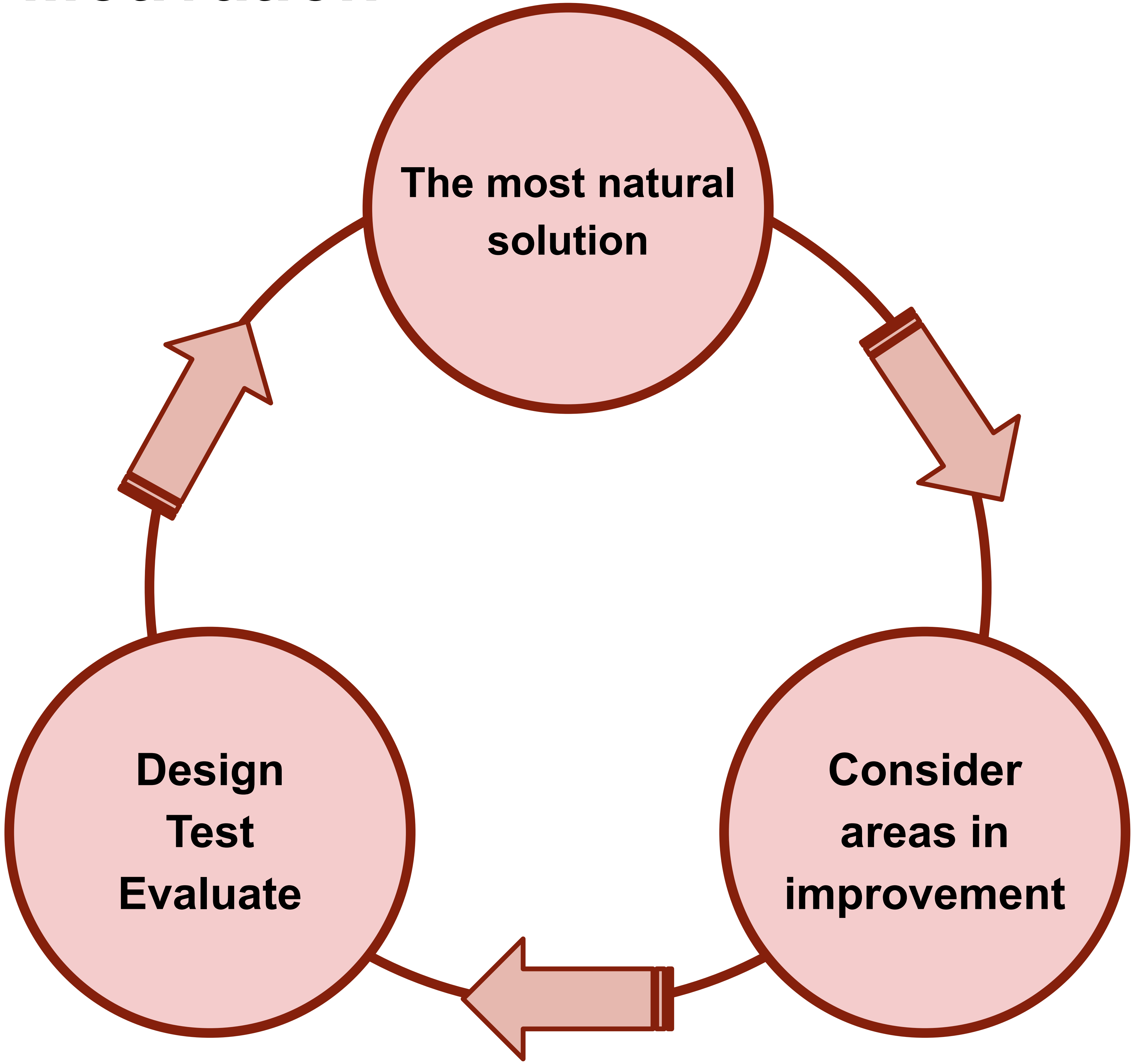
# Project Goals and Objectives

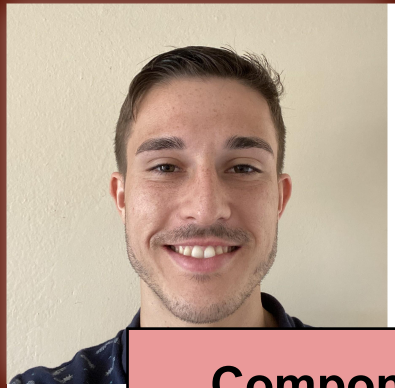
- Build a user-friendly Smart Window
- Display real time weather information collected by onboard sensors
- Supports end user's privacy via switchable smart film
- Add room-lighting with a color adjustable LED light bar
- Create a user interface displayed on a translucent monitor when triggered by a proximity sensor
- Maintain a lower cost without compromising features



# Design Motivation

- We noticed a widespread problem with how people receive weather data
- Too many sources giving different information
- Data may be inaccurate depending on user location
- Apps feel impersonal, and aren't very user accessible
- Team seeks to solve these problems using local data and ease of access





# Requirements and Specifications

| Component | Engineering Requirement | Justification | Achieved? |
|---|---|---|---|
| Transparent Display | 1600x900px Resolution. ≥50% light transmission in visible spectrum. | A large conventional LCD could be made translucent by backlight disassembly, perfect for showing the desktop GUI without removing the outside view. | ✓* |
| Smart Film | ≤ 60V \| 2 ft x 3 ft | Smart film offers privacy and reduces glare | ✓ |
| Window Housing | Custom built window pane, wood | Be aesthetically pleasing and able to house sensors | ✓ |
| LED Lighting | Multiple lighting modes / 24 W<br>3000K / 6000K Light Temperatures | Using two lighting modes offers color mixing,, and 1200 lumens should provide adequate lighting in any environment | ✓ |
| Lighting Control | LED control between 0-1 amp | Two knobs control current to offer variable lighting for color and power | ✓ |
| Proximity Sensor | 3ft Range, in all lighting conditions | Proximity Sensor for the window to only display information when a user is nearby | ✕ |
| Outdoor Weather Sensor | +/- 2% Relative Humidity / +/- 0.5 C | Outdoor sensors to reliably determine the weather conditions | ✓ |
| Indoor Weather Sensor | +/- 5% Relative Humidity / +/- 2.0 C | Indoor Sensors determine the house conditions | ✓ |
| Desktop Application | Maintains a GUI that displays:<br>The weather forecast in Farenheit<br>Human readable sensor measurements | The desktop application serves as the primary user interface for reading sensor measurements and weather conditions from the window. | ✓ |
| Mobile Application | The mobile application uses WiFi to connect to the remote database shared by by the desktop app. | The mobile application allows the user to update the UI's to-do list items, sync phone notifications and calendar events. | ✓ |

# Criteria 1: PDLC Smart Film

Original Specification:

Smart Film that uses ≤ 60V | 2 ft x 3 ft area

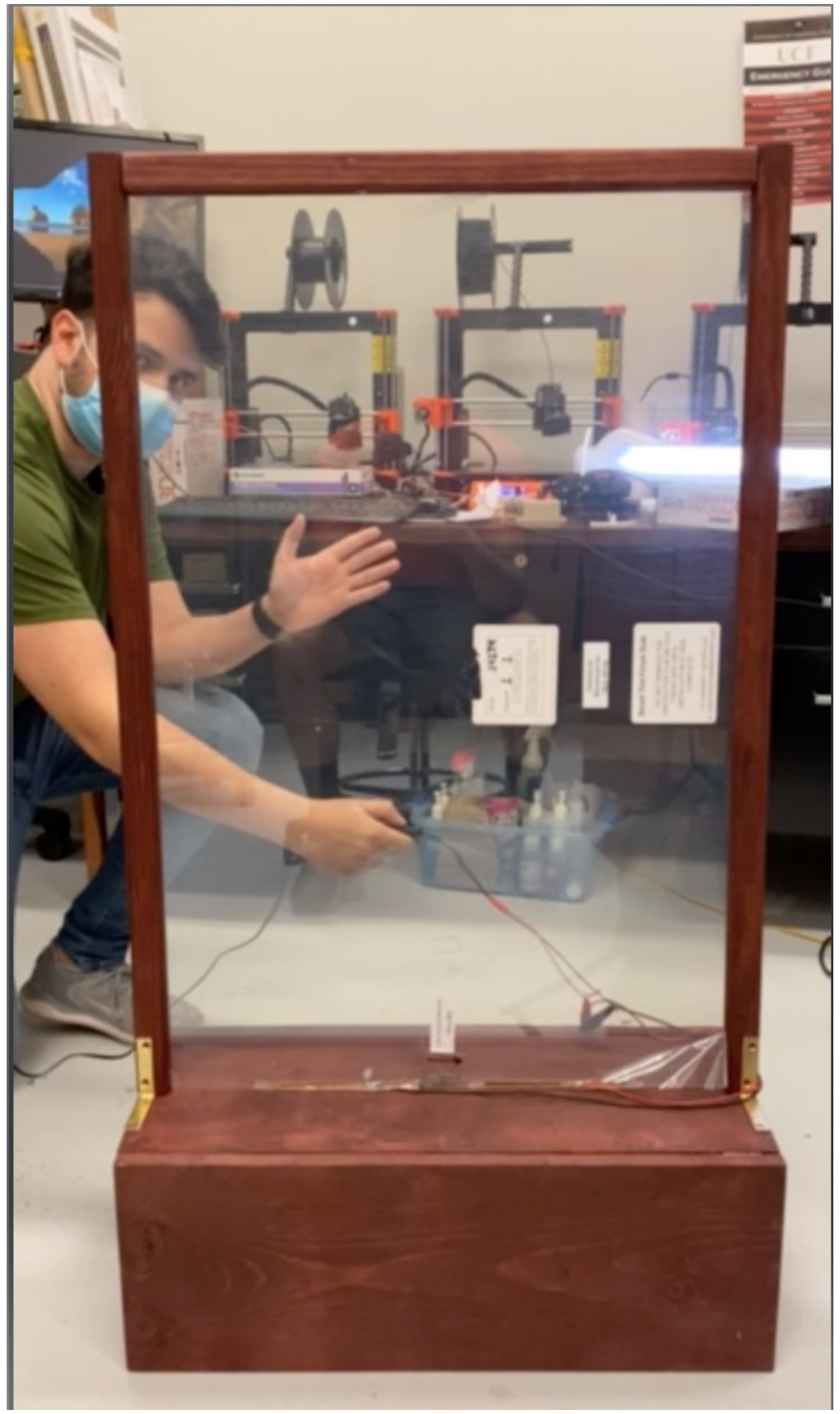
Achieved Specification:

PDLC which runs at 60V

2 ft x 3 ft area

3 million switches

Estimated 10 year lifetime

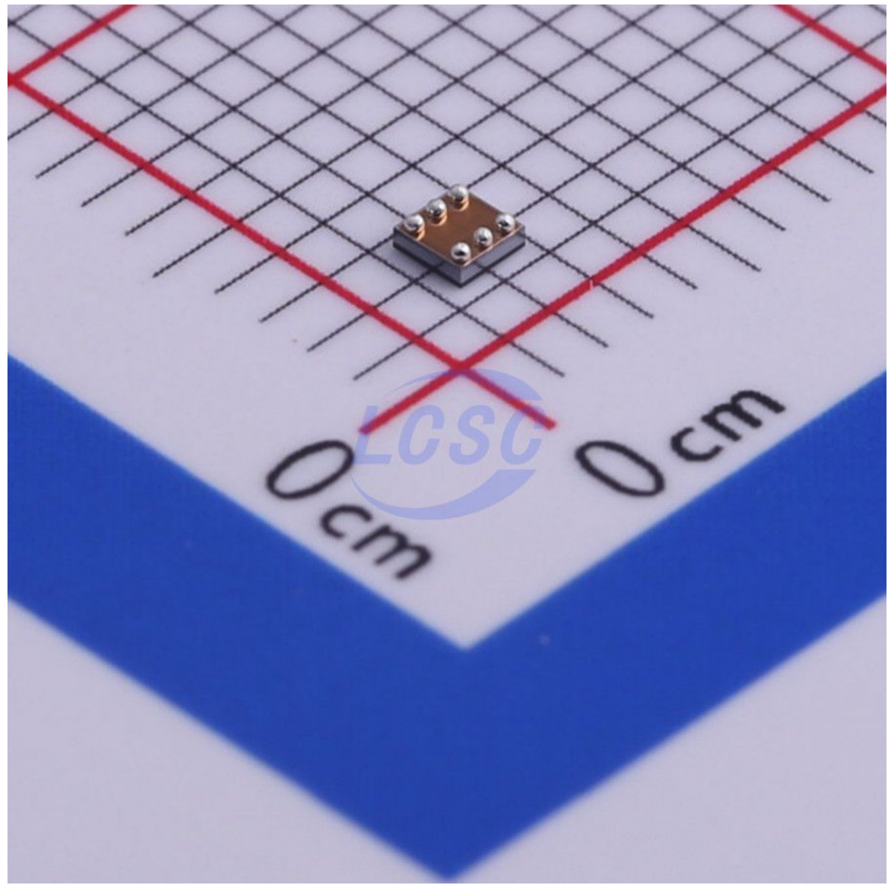


# Criteria 2: Indoor / Outdoor Weather Sensors

Original Specification:

Indoor - ±5 % relative humidity & ±2.0 ℃

Outdoor - ±2 % relative humidity & ±0.5 ℃

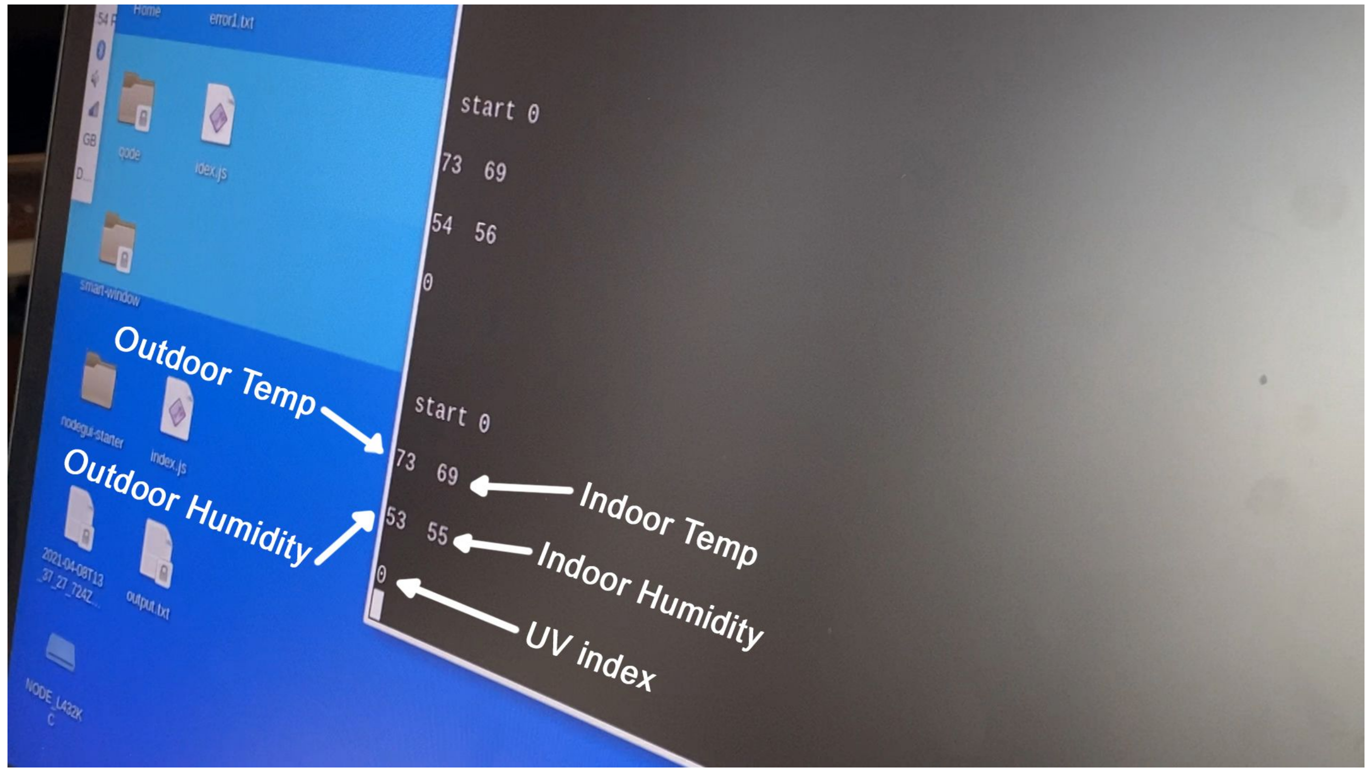


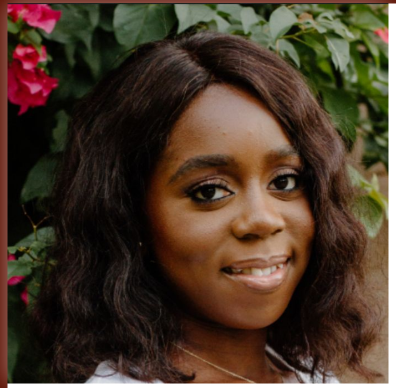

Achieved Specification:

Indoor - ±2 % relative humidity & ±0.5 ℃

Outdoor - ±2 % relative humidity & ±0.5 ℃

Both sensor PCB's using HDC2010YPAR





# Criteria 3: Desktop / Mobile Application

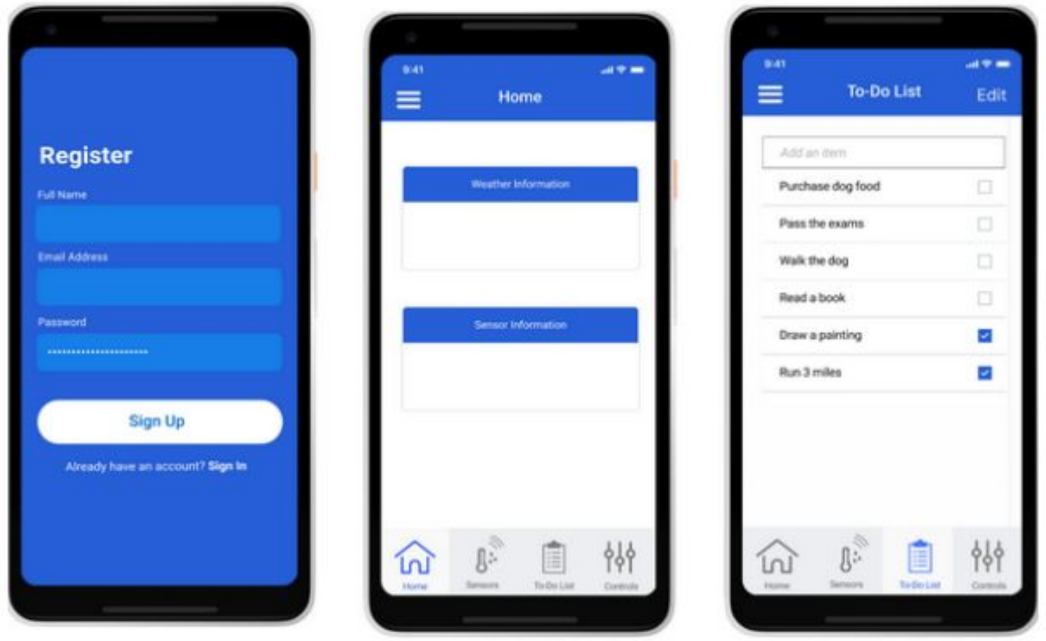

## Original Specification:

D: Maintains a GUI that displays:
The weather forecast in Farenheit
Human readable sensor measurements

M: The mobile application uses WiFi to connect to the remote database shared by by the desktop app.

## Achieved Specification:

D: Live Desktop GUI to update with average sensor values every 30s
Also provides 3-day forecast, Sunset time, local wind speed, clock, and updates from mobile app.

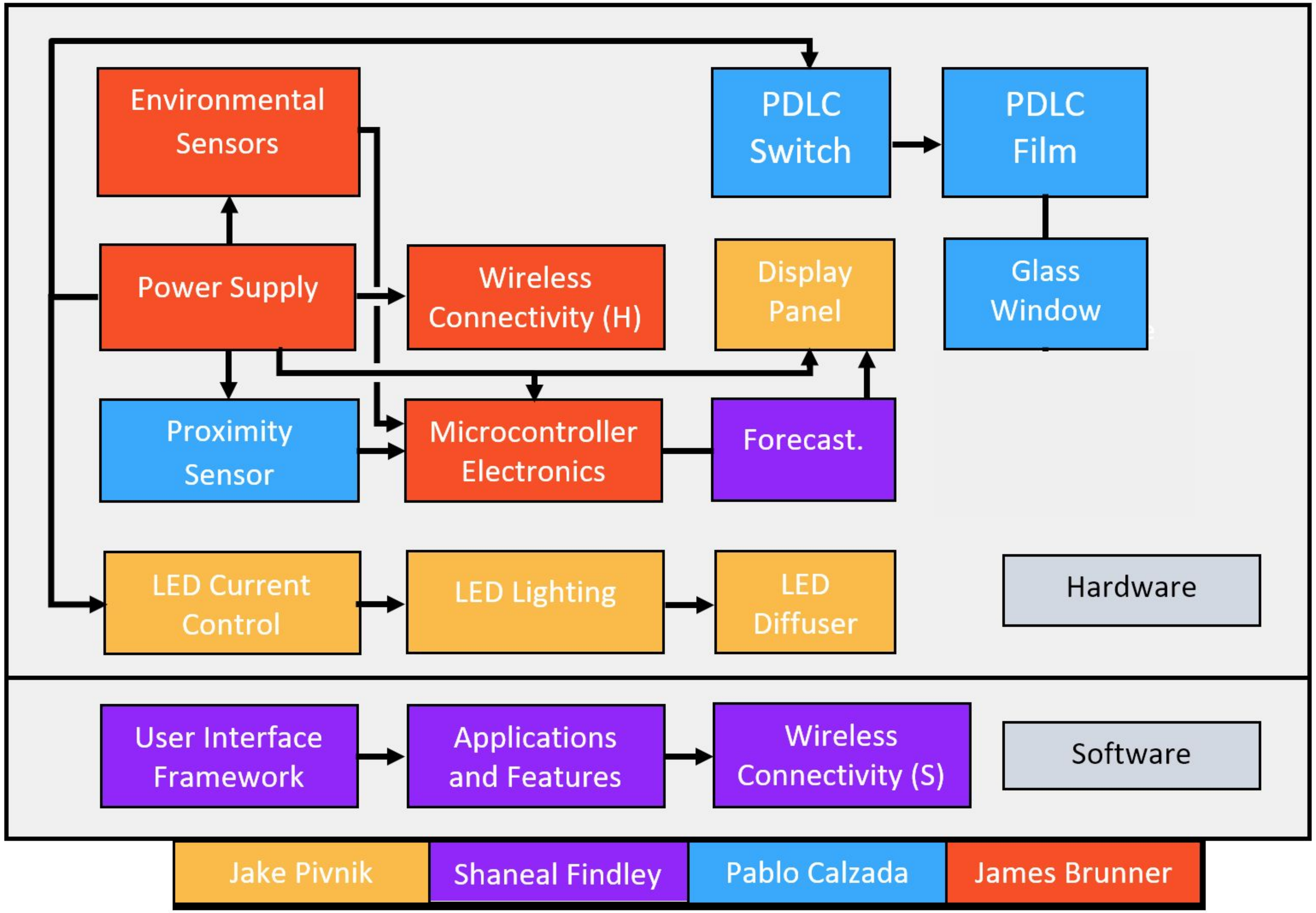



M: Mobile app connects to database over WiFi for viewing sensor readings, and adding items to the To-Do list

# Project Block Diagram

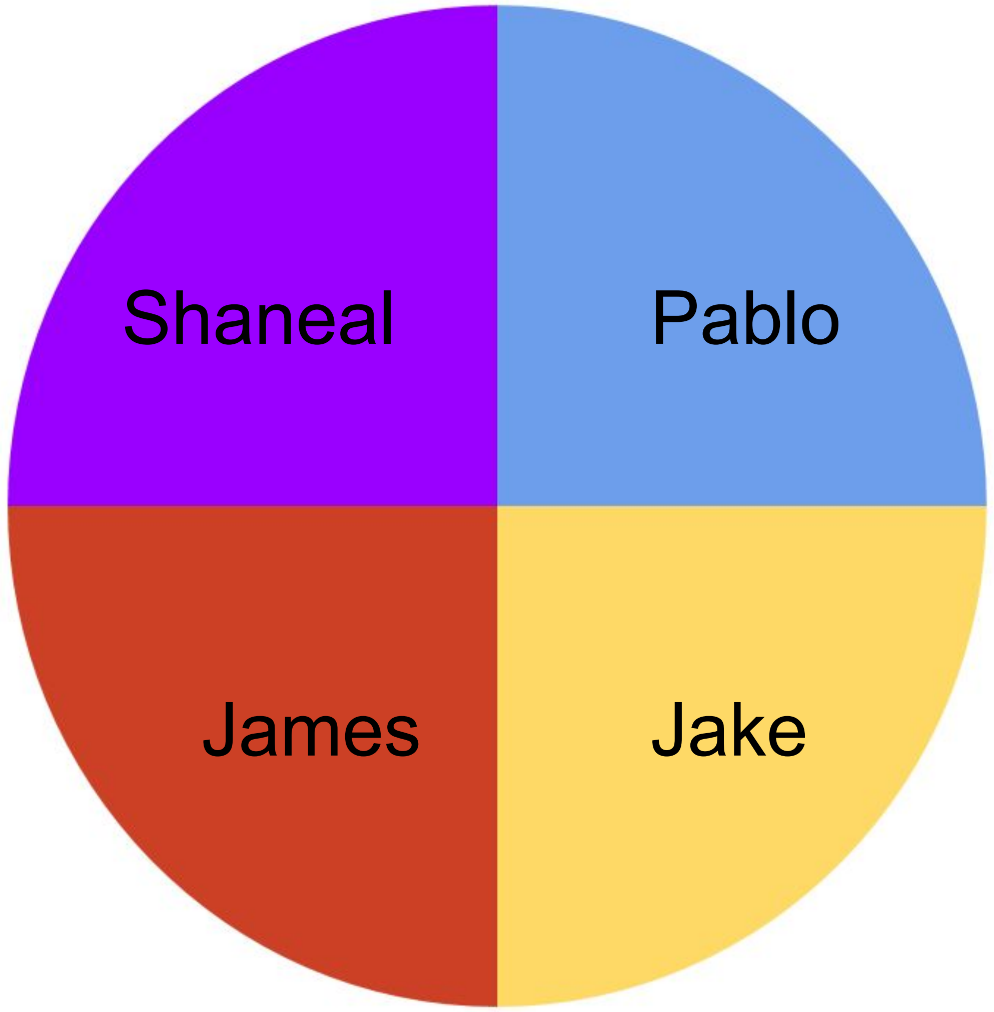
Blocks are colored according to team member in charge of subsystem

Arrows show flow of data / power between subsystems



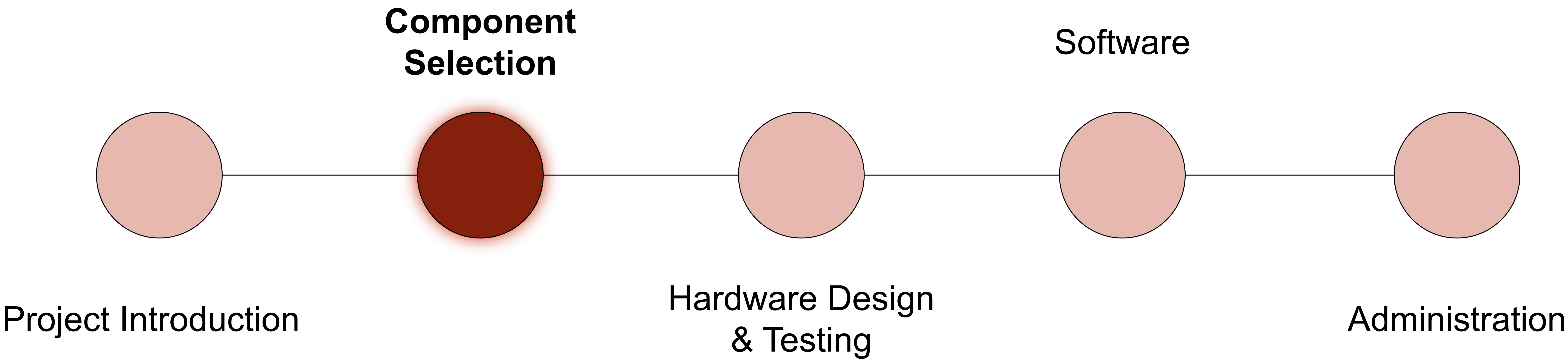
# Work Distribution

| Group member | Display and Lighting | Glass Layer and Films | Power and Electronics | Software | Administrative |
|---|---|---|---|---|---|
| **Jake** | **Primary** | Secondary | | | **Primary** |
| **Pablo** | Secondary | **Primary** | | | Secondary |
| **James** | | | **Primary** | Secondary | Secondary |
| **Shaneal** | | | Secondary | **Primary** | Secondary |

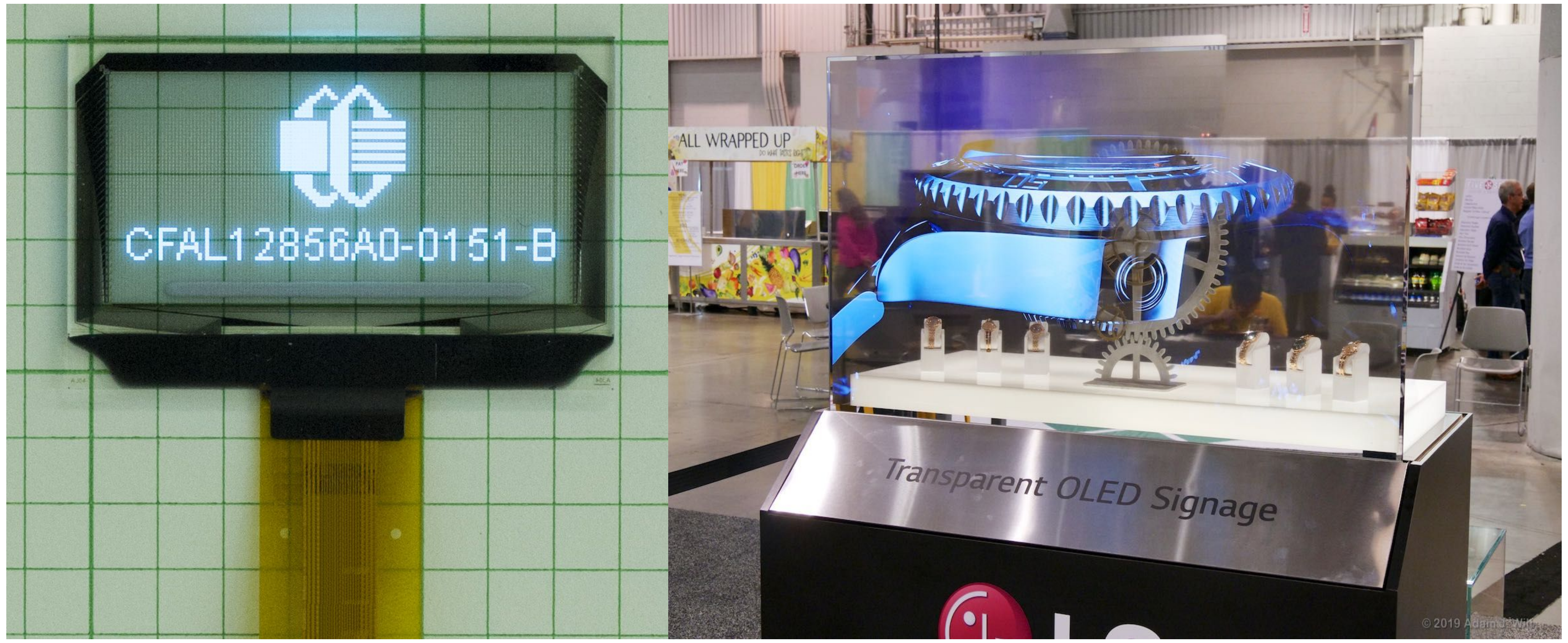



*Project subsystems have been assigned to group members with the skill-set most equipped to tackle them. Splitting the workload up evenly prevents burnout and frustration, while ensuring progress is being made in each section evenly.*

# Presentation Timeline



# Display Selection





**Transparent OLED Display**

- Prohibitively expensive large displays
- Cheaper displays too small for application
- Self-emissive, bright, wide color gamut

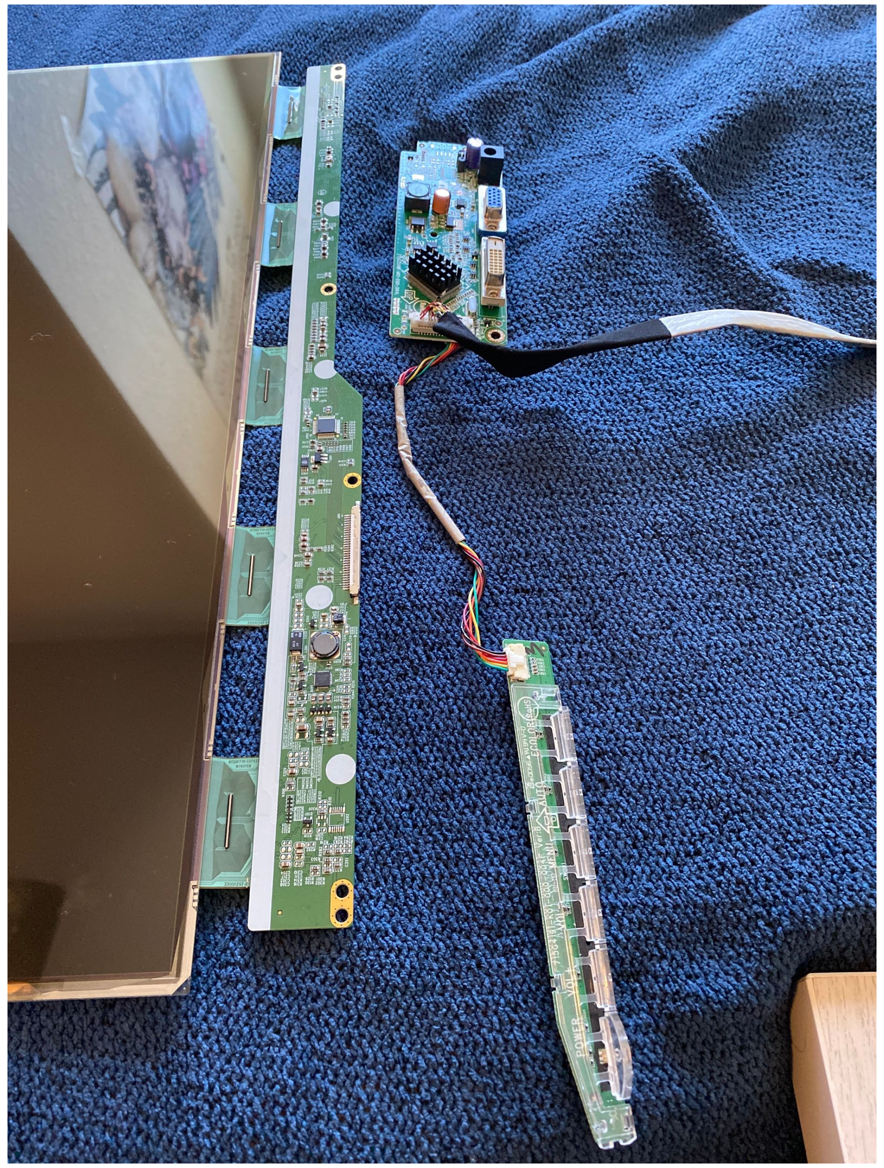
**See-Through LCD**

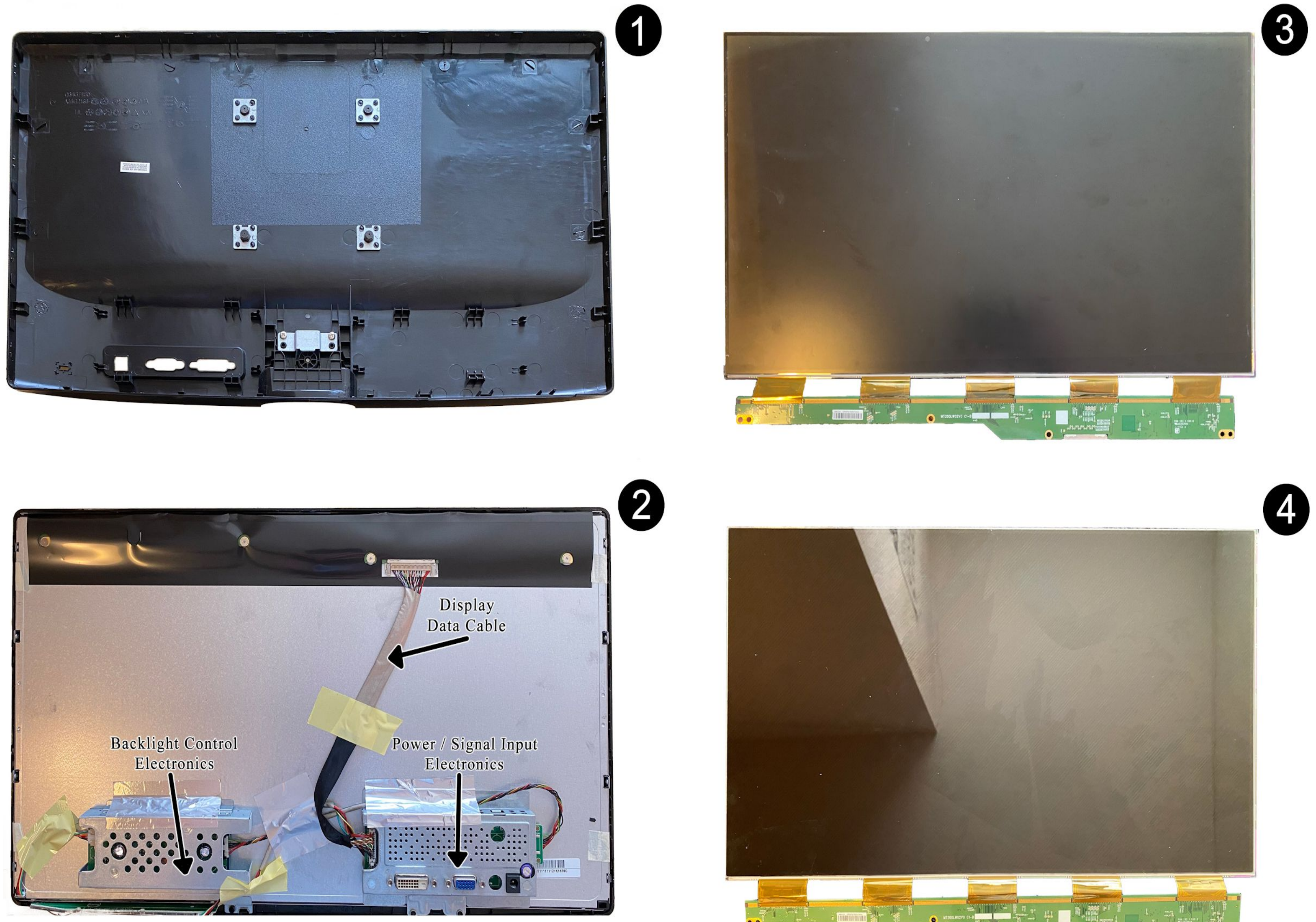
- ~500x less expensive than OLED
- Displays available in a range of sizes
- Physical limitations to 50% Transparency

*Our group decided to investigate See-through LCD first, planning to use ambient sunlight as the display backlight. Our tests have shown that full sun to partial shade offers adequate contrast for the display.*
*We plan to use see-through LCD for the completion of the project.*

# Display Selection

- Acer S201HL 20” LCD Display (TN)
- 1600 x 900 pixel resolution
- 0.276mm pixel pitch
- Backlight / Frame disassembled
- Anti-Glare filter removed to increase transparency





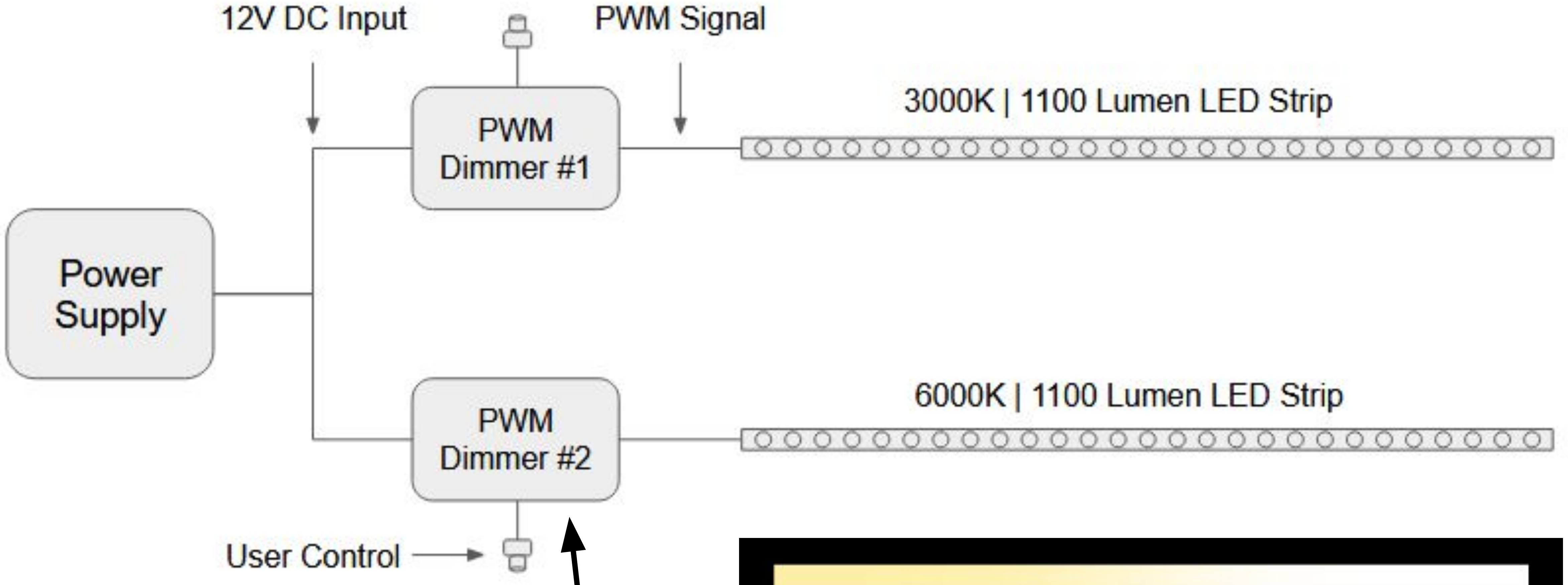
# LED Strips and Control Selection

**LED Strips: LEDSupply**

- HD 60LED/M LED Strip
- 12V DC | 14.4 W
- 1080 Lumen / Meter
- 3000K and 6000K Color range

**LED Control: Hiletgo**

- 0% - 100% Power
- DC12-24V 8A Max
- PWM Control

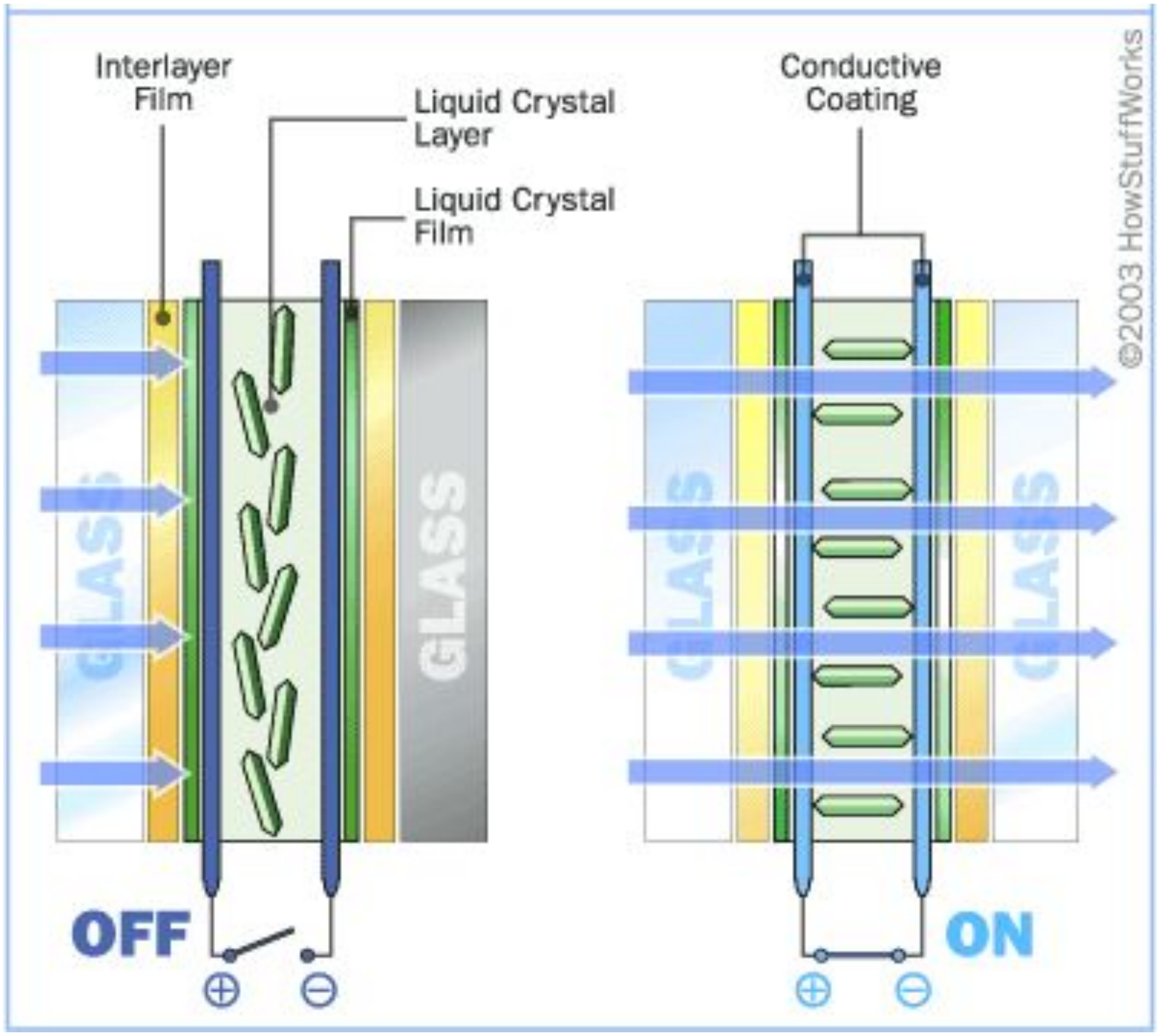




# Smart Film Selection

- **Passive Smart Films**
  - Thermochromic and photochromic materials
  - Uses non-electric stimuli
  - No user input

- **Active Smart Films**
  - Electrochromic, suspended particle devices (SPDs), Microblinds, PDLC film
  - Uses electricity to transition between states
  - PDLC is the most affordable and widely used




PDLC Working Principles

# PDLC Film Selection

- Considerations when selecting a vendor
  - Maximize visible light transmittance
  - Solar gain coefficient and power consumption
  - Price- individual suppliers were asked for quotes on custom 2x3 ft film
  - Avoid international vendors due to possible shipping delays
- Smart Tint was selected

| Parameters | Impelwell | Magic-Film | EB Glass | Smart Tint |
|---|---|---|---|---|
| Haze Coefficient *(transparent, opaque)* | <3%, >92.5% | <6%, >90% | <6%, >90% | **5%, 93%** |
| Visible Light Transmittance *(transparent, opaque)* | >83%, <70% | ≥80%, <4% | ≥80%, <4% | **90%, 4%** |
| IR Light Transmittance *(transparent, opaque)* | 10%, 5% | >80%, >20% | >80%, >20% | **>20%, 5%** |
| UV Light Transmittance *(transparent, opaque)* | 1%, 1% | 1%, 1% | 1%, 1% | **1%, 1%** |
| Viewing Angle | 160° | 145° | 150° | **150°** |
| Maximum Switching Speed | 45 ms | 60 ms | 200 ms | **<40ms** |
| Solar Gain Coefficient *(transparent, opaque)* | 0.8, 0.2 | 0.79, 0.06 | 0.79, 0.06 | **0.71, 0.1** |
| Power Consumption | <3 $W/m^2$ | 3.6 $W/m^2$ | <5 $W/m^2$ | **3 $W/m^2$** |

# Proximity Sensor Selection

- Use in this project
  - Detect when the user is standing in front of the window
  - If user is under a certain distance, it will initialize the displays graphical interface
- IR sensors
  - Chosen for small size, high resolution and range
  - Both active and passive IR sensors were taken into consideration
- Final component selection: Sharp GP2Y0A02YK0F Long Range Sensor
  - Measuring distance of 20 to 150 cm (8 in - 5 ft)
  - Distances are output as an analog voltage between 0-3 V

*Sharp GP2Y0A02YK0F*

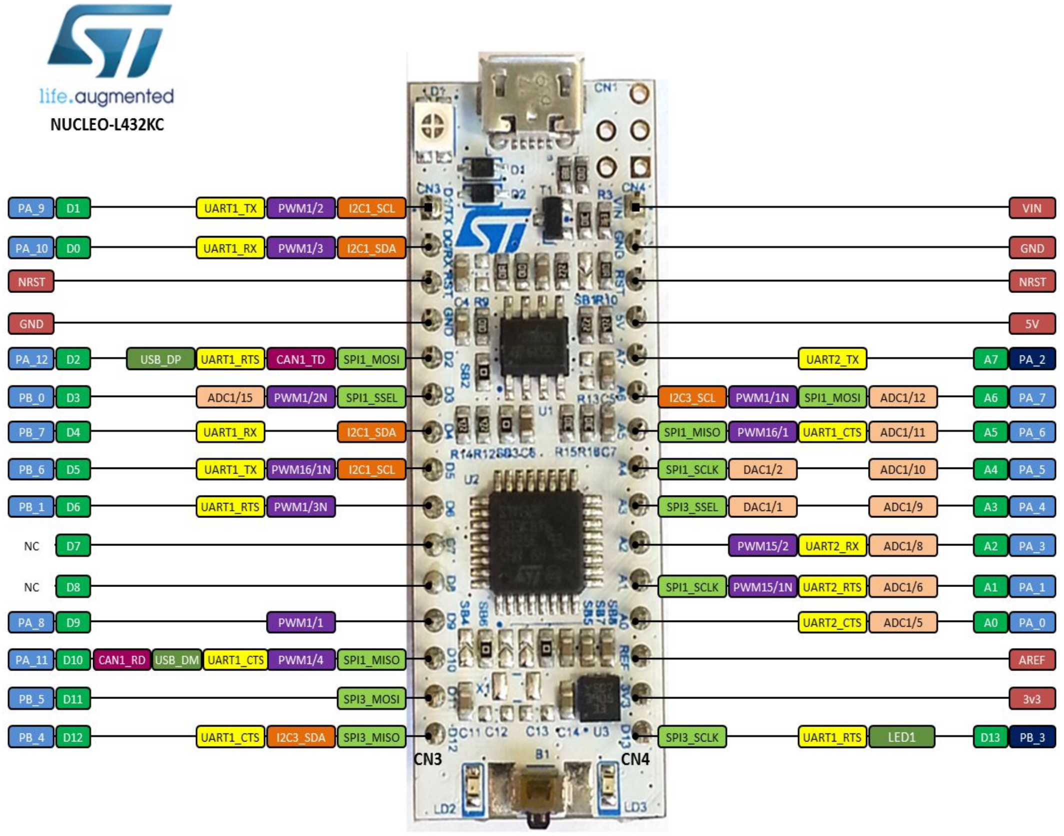
# Glass Selection

- **Materials Considered**
  - Glass pane
  - Hardened plastic screen

- **Factors Taken into account**
  - Price
  - Thickness/Weight
  - Durability and Performance

- 24 x 36 x 0.125 in. Clear Glass pane from Home Depot was selected

# Microcontroller Selection


The MCU should be able to perform I2C, SMBus, UART, and/or SPI communications as well as utilize GPIO pins.

Using the MSP430 series would be familiar as it was used in previous courses and has thorough documentation.

The Atmega328P used with the Arduino IDE would make programming very user friendly.

STM32 has a useful graphical initialization tool for setting up code as well as detailed documentation and powerful chipsets.

In the end, the STM32L432KC was chosen for its low power consumption, graphical code initialization tool, extensive documentation, relative popularity, and low price range.

# Temperature/Humidity & UV Sensor Selection

The engineering requirements we specified for the weather sensing portion of our project include ±2% humidity accuracy and ±0.5℃ temperature accuracy. This data must also be live so that it can update on the GUI in real time. Here we have a sample of the datasheet for the selected sensor which specifies values that meet these requirements.

## HDC2010 Low-Power Humid

### 1 Features

- Relative humidity range: 0% to 100%
- Humidity accuracy: ±2%
- Sleep current: 50 nA
- Average supply current (1 measurement per second)
  - RH only (11 bit): 300 nA
  - RH (11 bit) + temperature (11 bit): 550 nA
- Temperature range:
  - Operating: –40°C to 85°C
  - Functional: –40°C to 125°C
- Temperature accuracy: ±0.2°C typical
- Supply voltage: 1.62 V to 3.6 V
- Programmable sampling rate (5 Hz, 2 Hz, 1 Hz, 0.2 Hz, 0.1 Hz, 1/60 Hz, 1/120 Hz) or trigger on demand
- $I^2C$ interface

# Temperature/Humidity & UV Sensor Selection

Selecting a temperature and humidity sensor was fairly straightforward as semiconductor ICs for this application are very cheap and accurate. The HDC2010YPAR was chosen for its dual packaging of humidity and temperature sensing with high accuracy and low power draw for a very low price.

The UV sensor (SI1143-A10-GMR) was selected based on the limited number of sensors available for a cheap price combined with its output of UV index as opposed to UV light intensity.

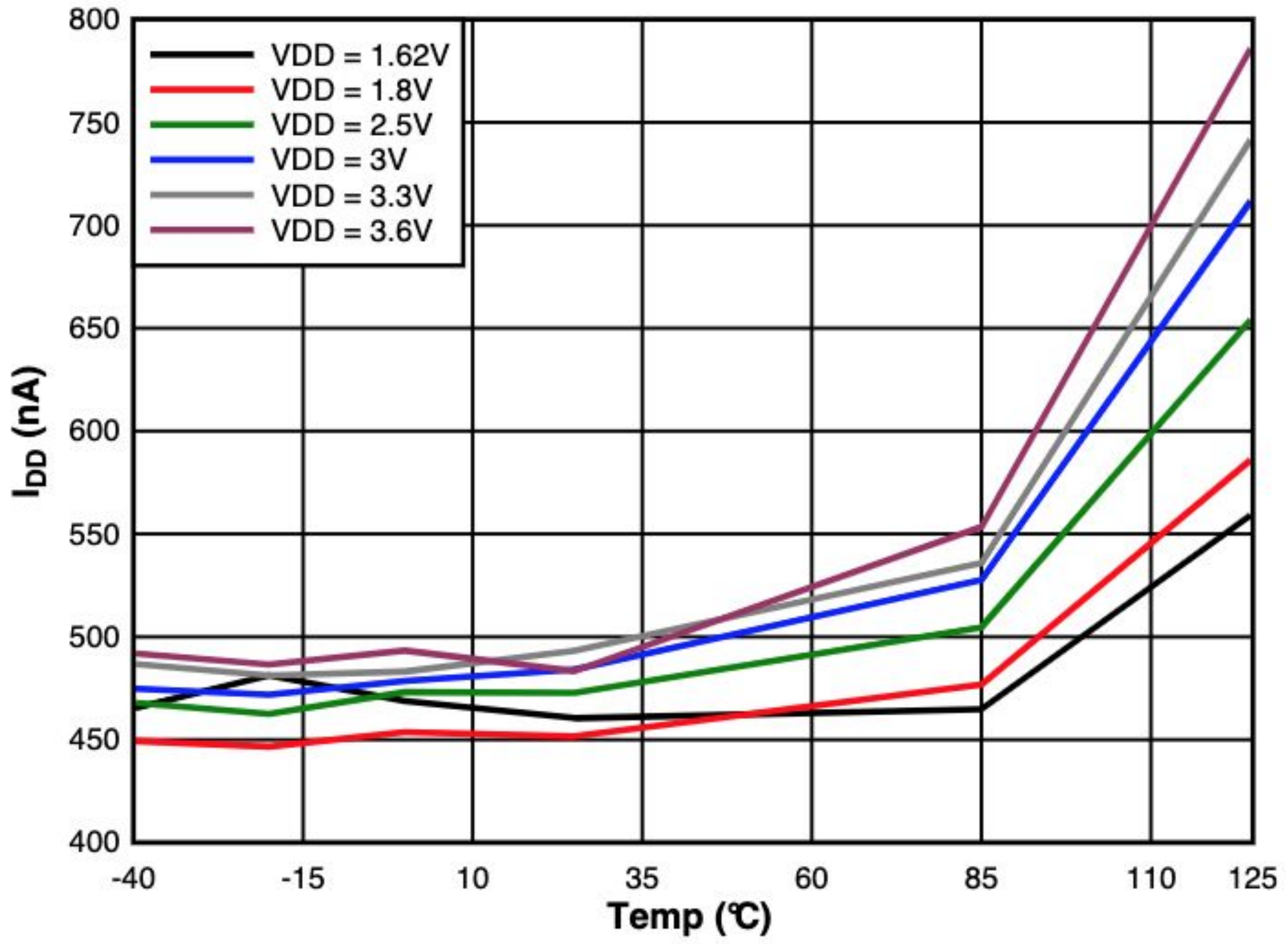
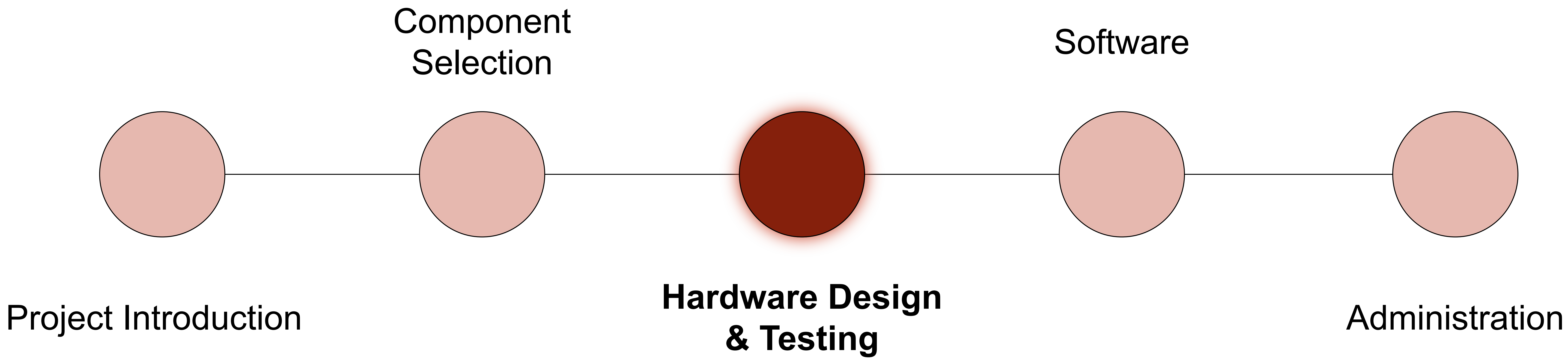



**Figure 5. Supply Current vs. Temperature, Average at 1 Measurement/Second, RH (11 Bit) + Temperature (11 Bit)**

# Component Selection Summary

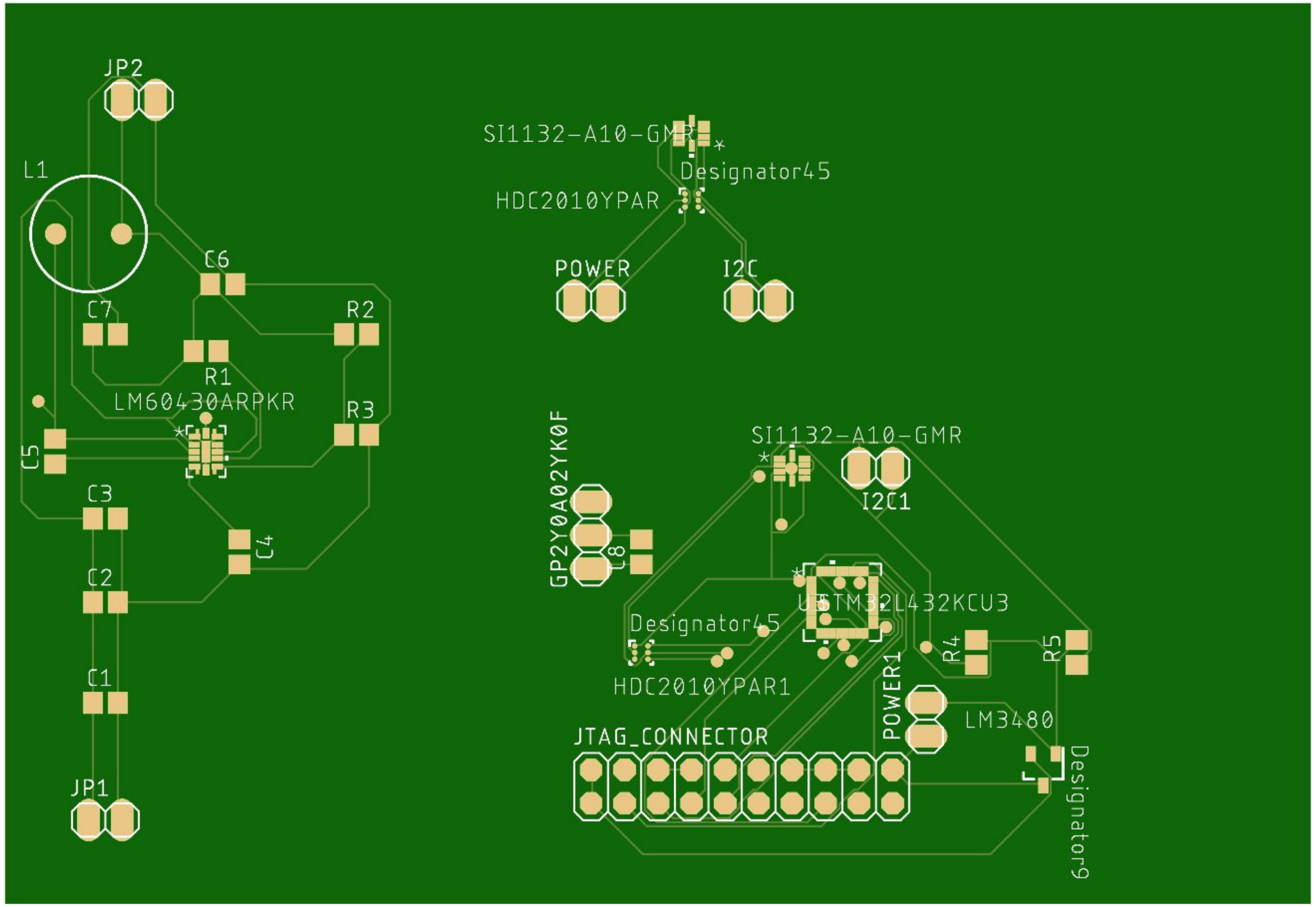
| Part | Model Selected |
| --- | --- |
| Display | Acer S201HL 20” LCD Display |
| Glass Window | Home Depot Model #92436 Clear Glass |
| Smart Film | Smart Tint ® PDLC Film |
| LED Strips | LEDSupply IP20 HD 3ft Strips |
| LED PWM Control | Hiletgo B073R7H52B |
| Microcontroller | STMicroelectronics STM32L432KC |
| HDMI Output, Runtime Environment | Raspberry Pi 3 Model B+ |
| Battery Charger IC | Texas Instruments BQ24765 |
| Temperature Sensors | Texas Instruments HDC2010YPAR |
| Humidity Sensors | Texas Instruments HDC2010YPAR |
| UV Sensor | DigiKey SI1132-A10-GMR |
| Proximity Sensor | Sharp GP2Y0A02YK0F Long Range Sensor |

# Presentation Timeline



# PCB Design

The first PCB designed was to test the sensors' capabilities as well as program the MCU and test the voltage regulation circuit for the display. The sensors could be read via I2C on the development board but programming the MCU on the PCB was not accomplished due to connectivity errors between the MCU and programmer. Lastly the voltage regulation circuit was not providing adequate voltage for the display so the display was connected to a surge protector hidden inside the Window's base compartment.



# PCB Testing

Sensors

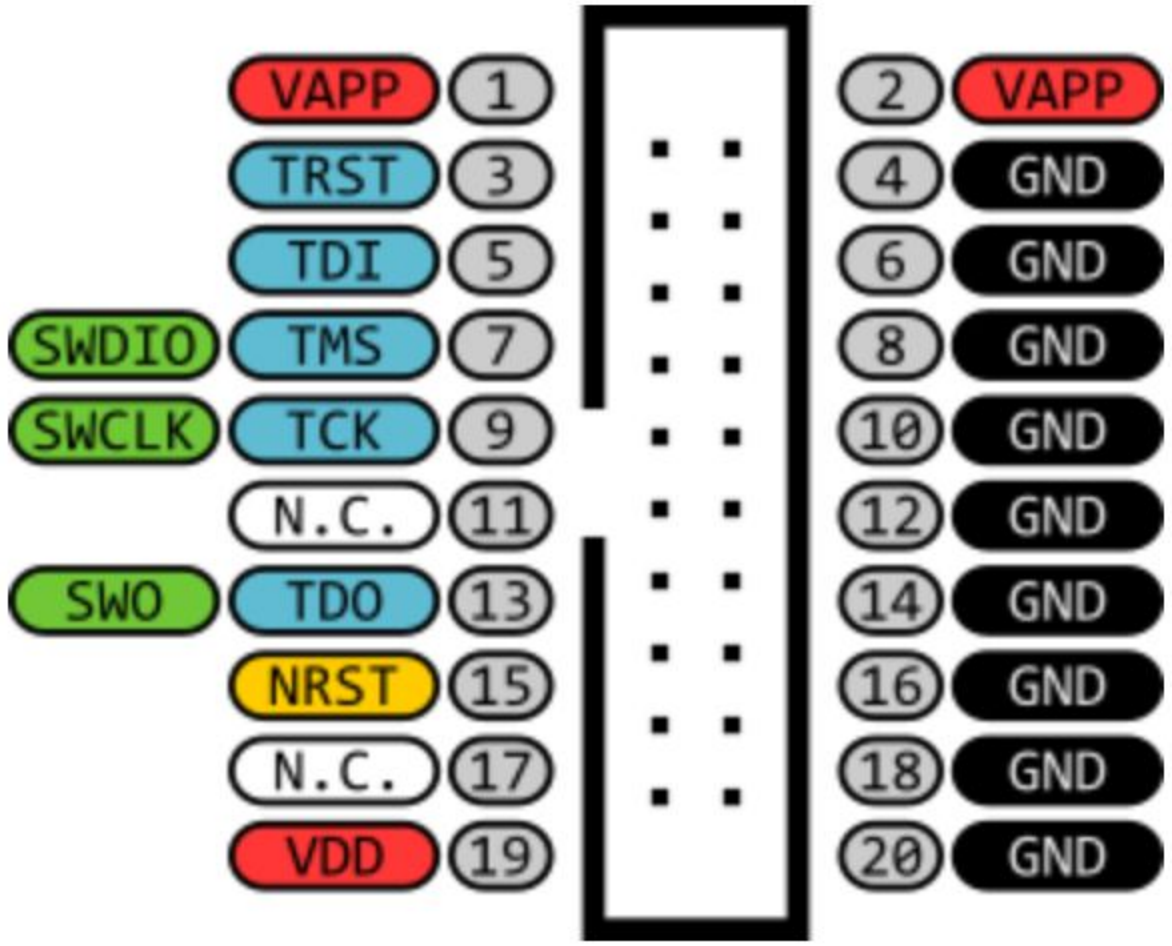
- The proximity sensor was connected to the ADC pin of the MCU
- Upon passing a threshold for the ADC set in the code, a GPIO is set high which is connected to an LED to indicate something is in proximity which was successfully tested
- The temperature, humidity, and UV sensor could all be read over I2C displaying accurate results when compared to local weather conditions

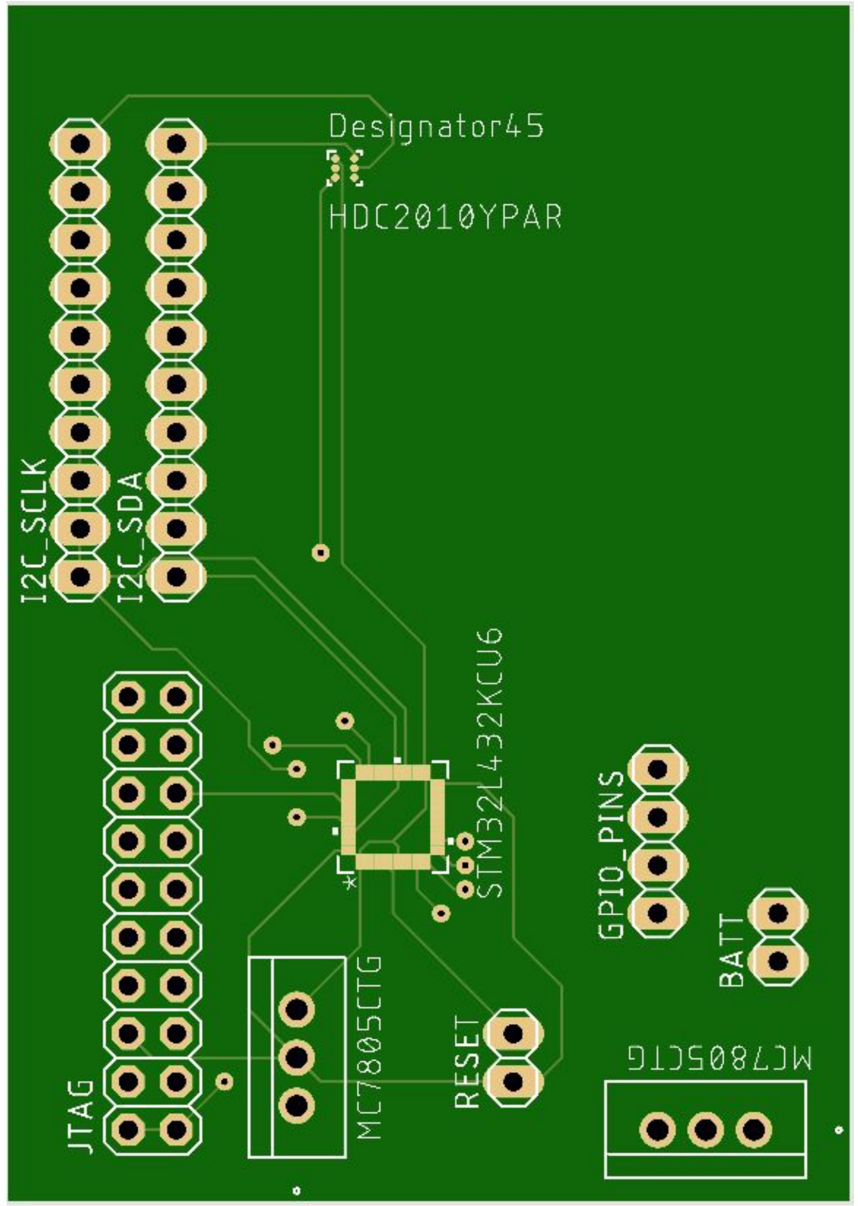
Battery Charger / Voltage Regulators

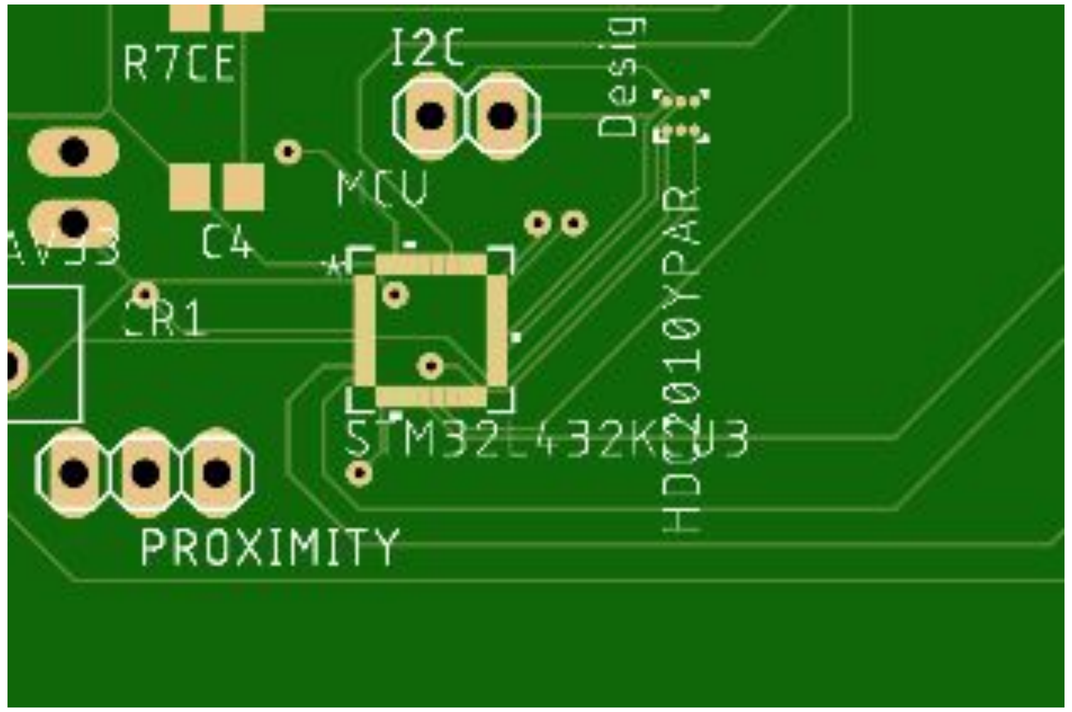
- The battery charging IC must be programmed through MCU communication on SMBus
- Since the MCU could not be programmed on the PCB the battery charging and voltage regulation portions of the Smart Window design were scrapped to focus on core functionalities

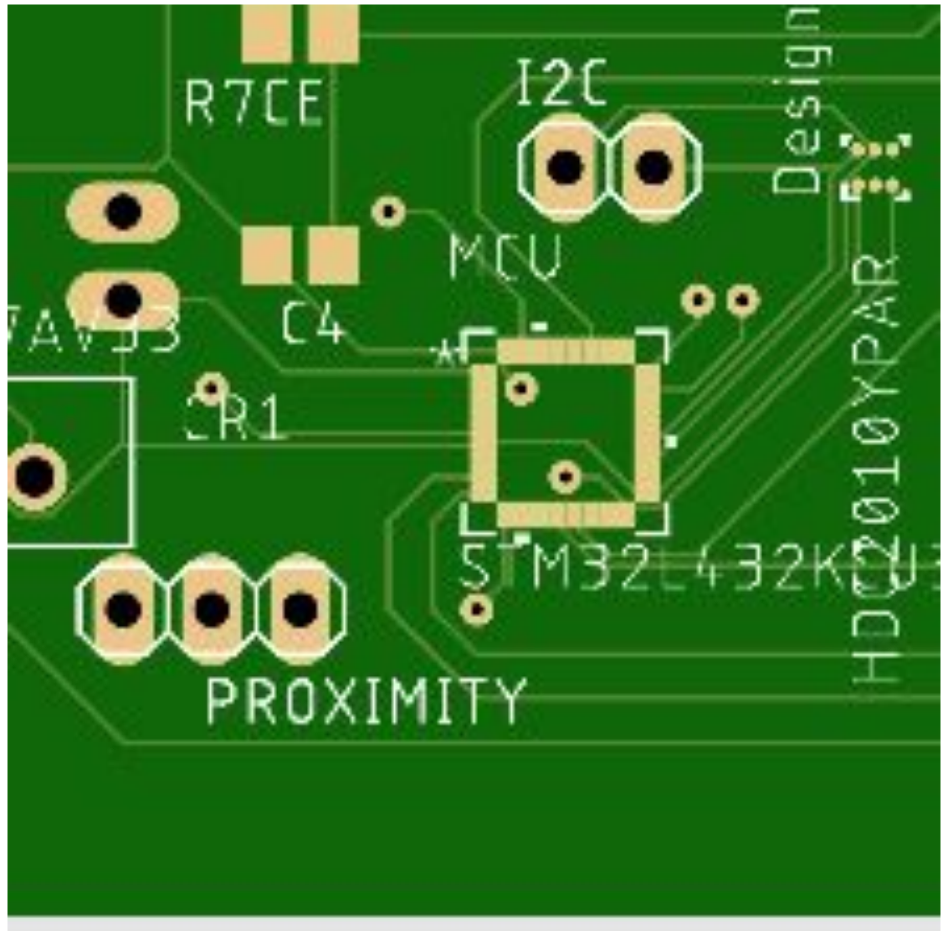
# JTAG Connectivity Issues

After many attempts, we were unable to program the MCU on a PCB through JTAG. Every time the ST-Link/V2 was connected an error message stating that an unknown target is detected was the result.



# Voltage Regulation

Different components of the Smart Window require different voltage levels to operate so there must be some sort of regulation to meet these requirements.

Due to difficulty programming the MCU on board, 3.3V and 5V were found from pins on the Raspberry Pi

12V and 19V were found through the power adapters originally intended for the LEDs and Display

| Part | Voltage Requirement |
|---|---|
| MCU & sensors | 3.3V |
| Proximity Sensor & Raspberry Pi | 5V |
| LEDs | 12V |
| Display | 19V |

# Display Testing

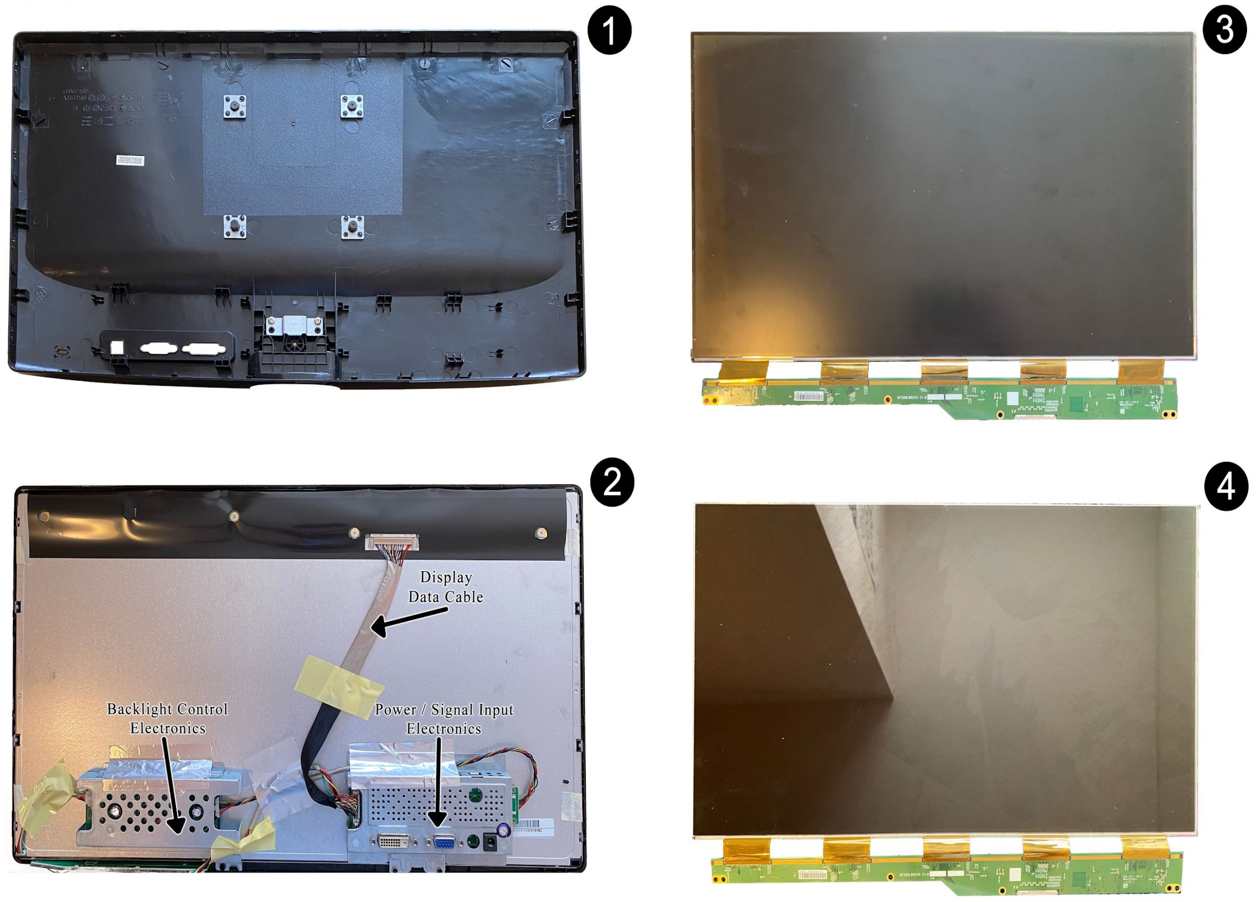
| | Position 1 | Position 2 | Position 3 | Position 4 | Position 5 | **Average** |
|---|---|---|---|---|---|---|
| Backlight | 5770 | 5780 | 5950 | 6210 | 6960 | 6134 |
| Display | 2810 | 2790 | 2890 | 2960 | 3270 | 2944 |

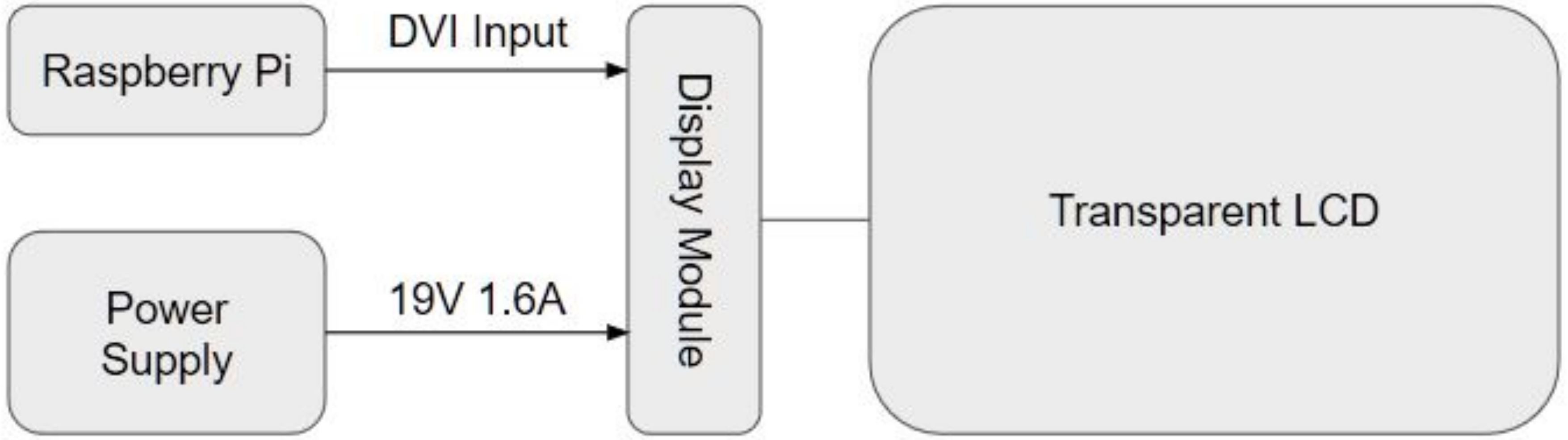
Positives: Display disassembly went smoothly, and the screen has thin bezels which will looks nice attached to the edge of the window frame. Transmissivity was very high.

Negatives: Display electronics use short cables, which will pose a small challenge to make the electronics fit nicely in the final package. Solar backlighting means the feature will be inaccessible at night.

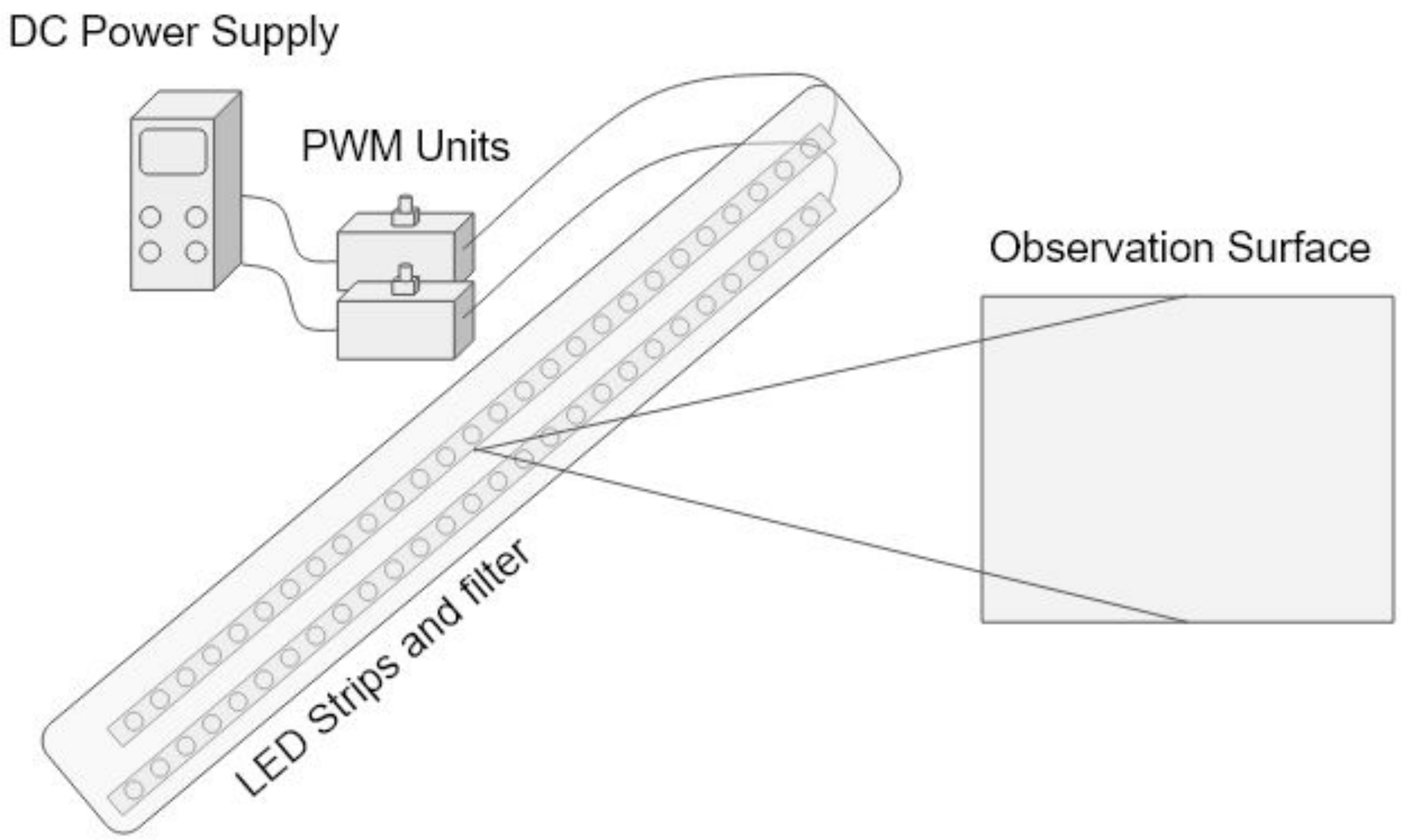
Average light transmitted through the display was almost exactly **48%**.

Although the transparency did not reach the spec'd 50%, it was close enough that the group decided to continue its use for the project.



# LED Testing




The width of the lighting unit shown above is 24 inches, to match that of the width of the window frame. However, the LED strips both have a length of 36”. Therefore the LED strips were cut to fit inside of this shortened form factor. The 18” strips were then re-wired using standard LED 2-pin cable extensions.

They were then wired to the PWM controllers, and connected to the power supply in the compartment box.

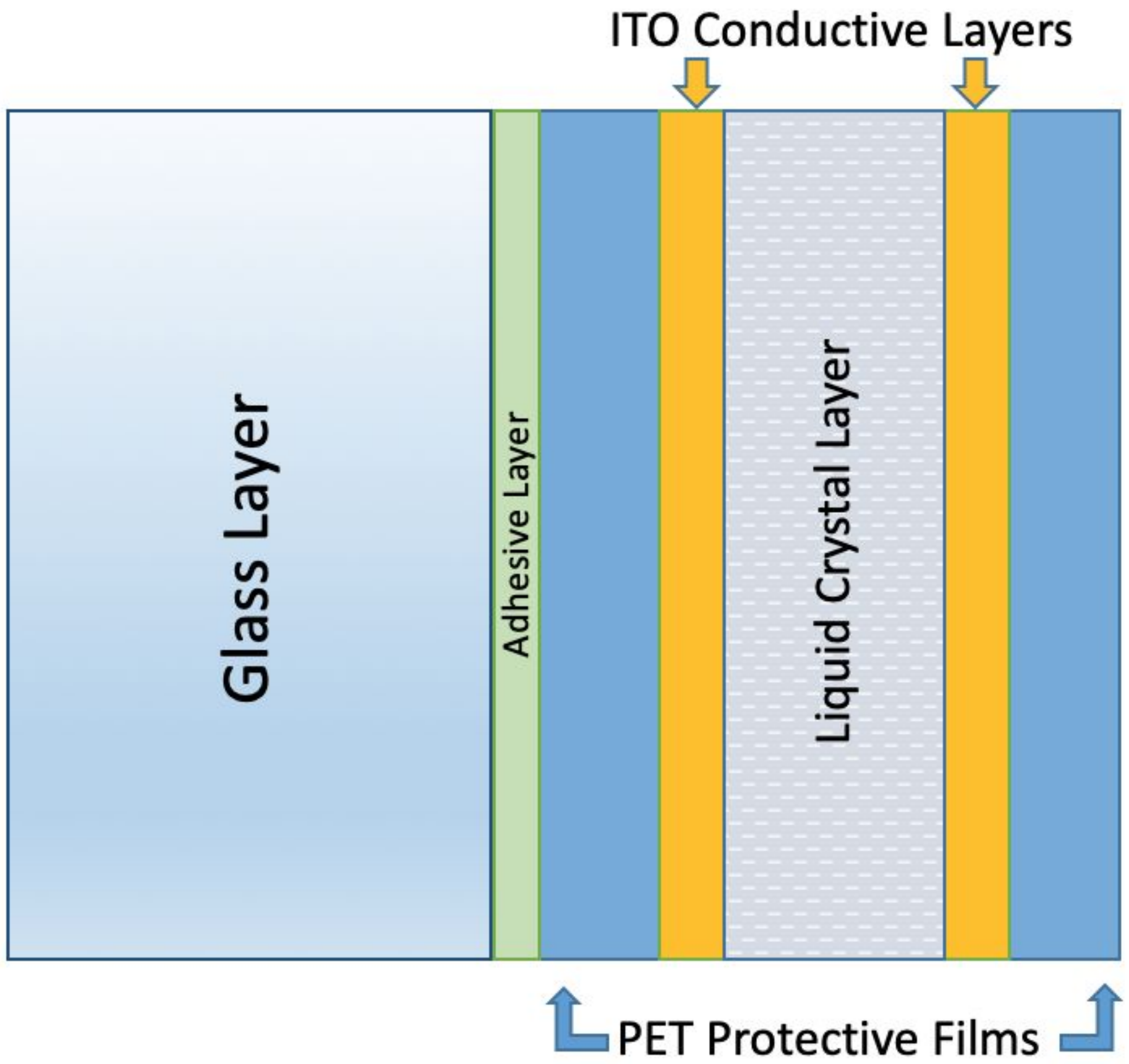
Varying each PWM unit independently showed no signs of detectable flickering, and a complete range of 0 to 100 percent of the maximum light output was reached

*All three testing criteria, the light output, color mixing, and temperature tests returned positive, passable results.*

# Glass Subsystem

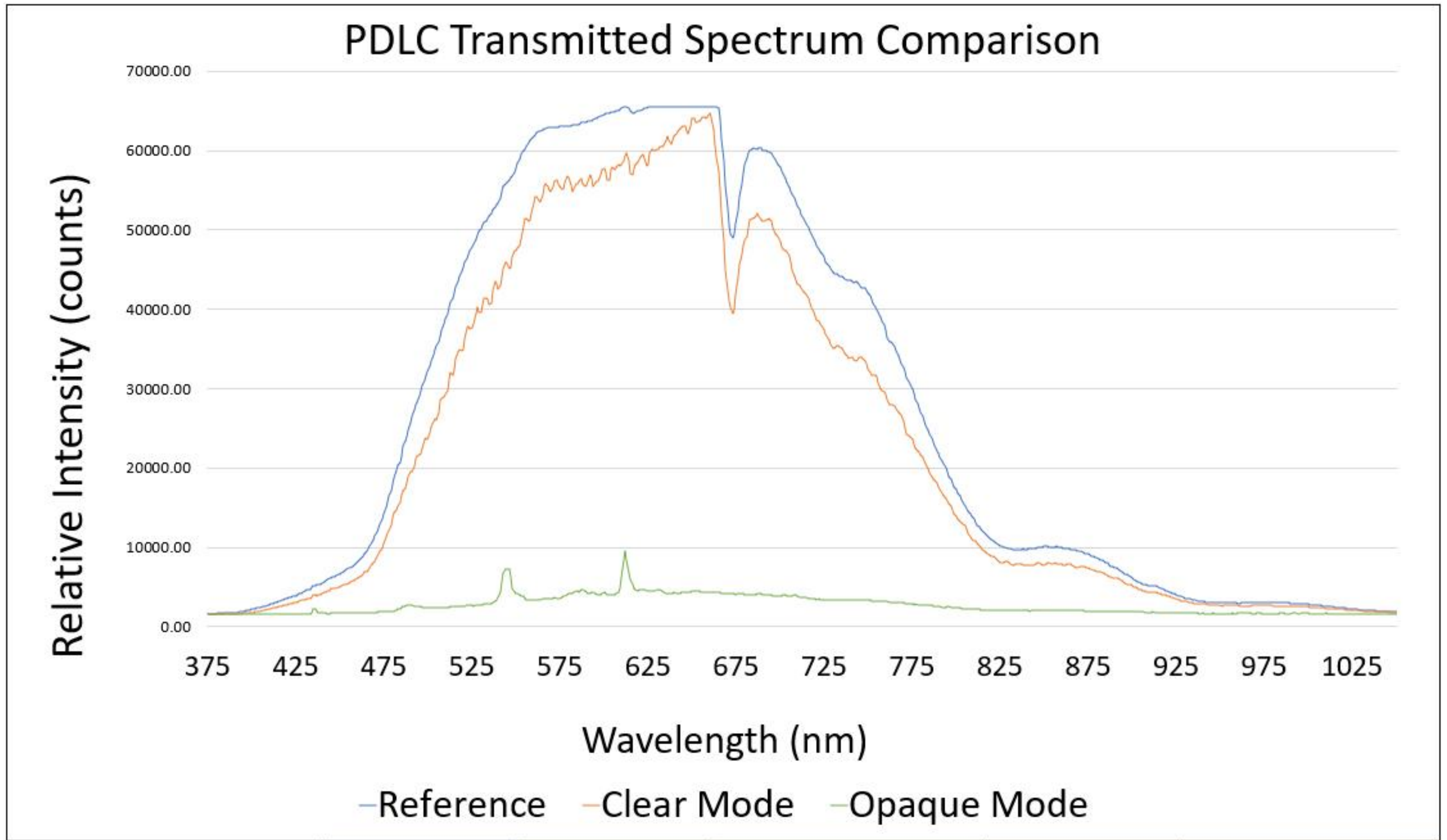
| Component | Engineering Requirement | Justification |
| --- | --- | --- |
| **Smart Film** | ≤ 60V \| 2 ft x 3 ft | Smart film offers privacy, and reduces glare |

- PDLC applied to glass pane using adhesive backing
- Wires ran into the compartment box where the power supply adapter is located
- Wooden frame notched to fit glass subsystem, holes were drilled for wiring PDLC and button




# PDLC Film Testing

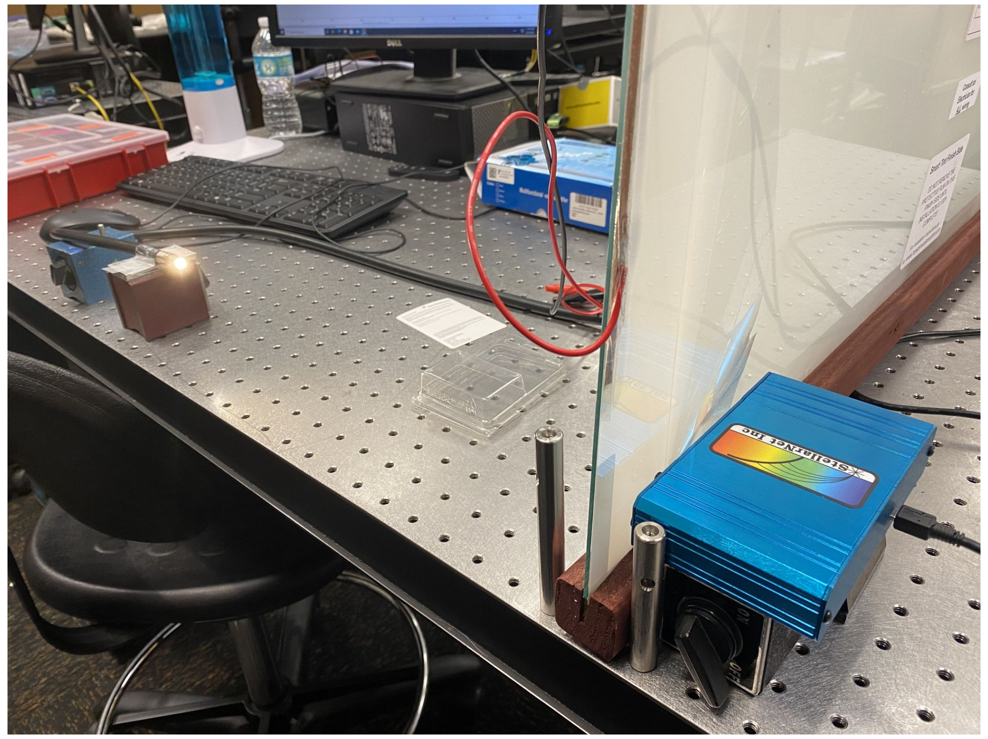
1. Basic functionality testing
2. Ran spectrometer tests using broadband fiber light source
3. Photometric tests of transmitted light

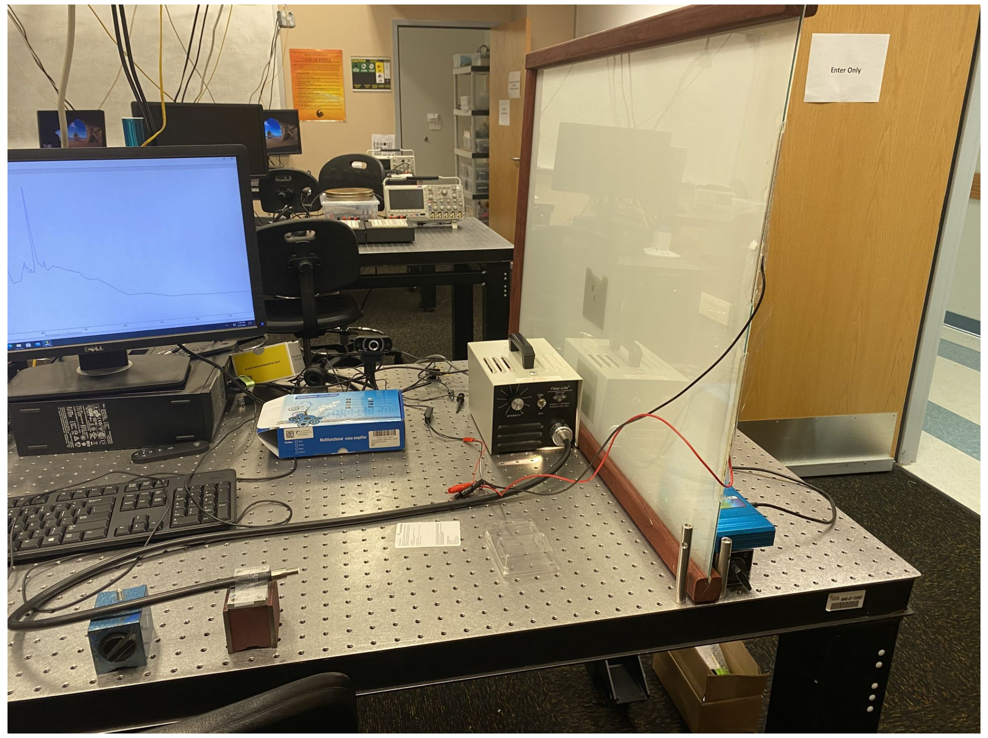



| Wavelength | Reference | Opaque | % Red. of Ref. | Clear | % Red. of Ref. |
|---|---|---|---|---|---|
| Long UV-A (400 nm) | 2196.20 | 1544.60 | 29.7 | 1780.60 | 18.9 |
| F Line (486.1 nm) | 22846.00 | 2556.80 | 88.8 | 17194.00 | 24.7 |
| D Line (589.3 nm) | 63508.00 | 4585.00 | 92.8 | 55462.00 | 12.7 |
| C Line (656.3 nm) | 65535.00 | 4399.50 | 93.3 | 64179.00 | 2.1 |
| Near IR-A (890 nm) | 7418.30 | 1918.90 | 74.1 | 6160.60 | 17 |

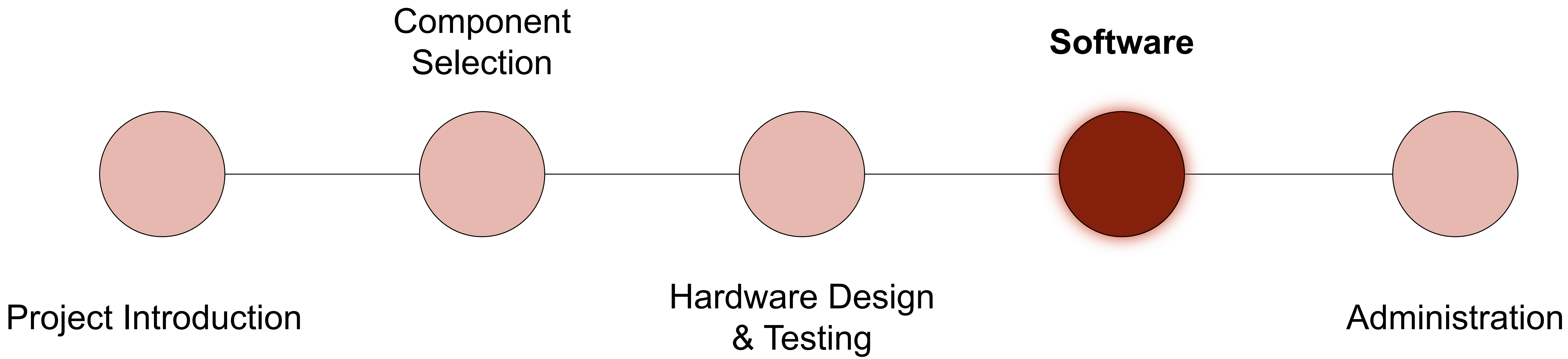
| | Opaque | Clear |
|---|---|---|
| Switching Speed | 40ms | 200ms |
| Solar Gain | 0.1 | 0.71 |
| Haze | 98% | 3% |

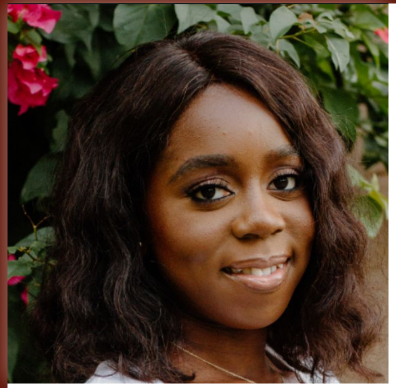
| | Reference | Clear | Opaque |
|---|---|---|---|
| Top | 1475 | 1225 | 965 |
| Middle | 1450 | 1250 | 1025 |
| Bottom | 1425 | 1202 | 957 |
| **Average** | **1450** | **1226** | **982** |



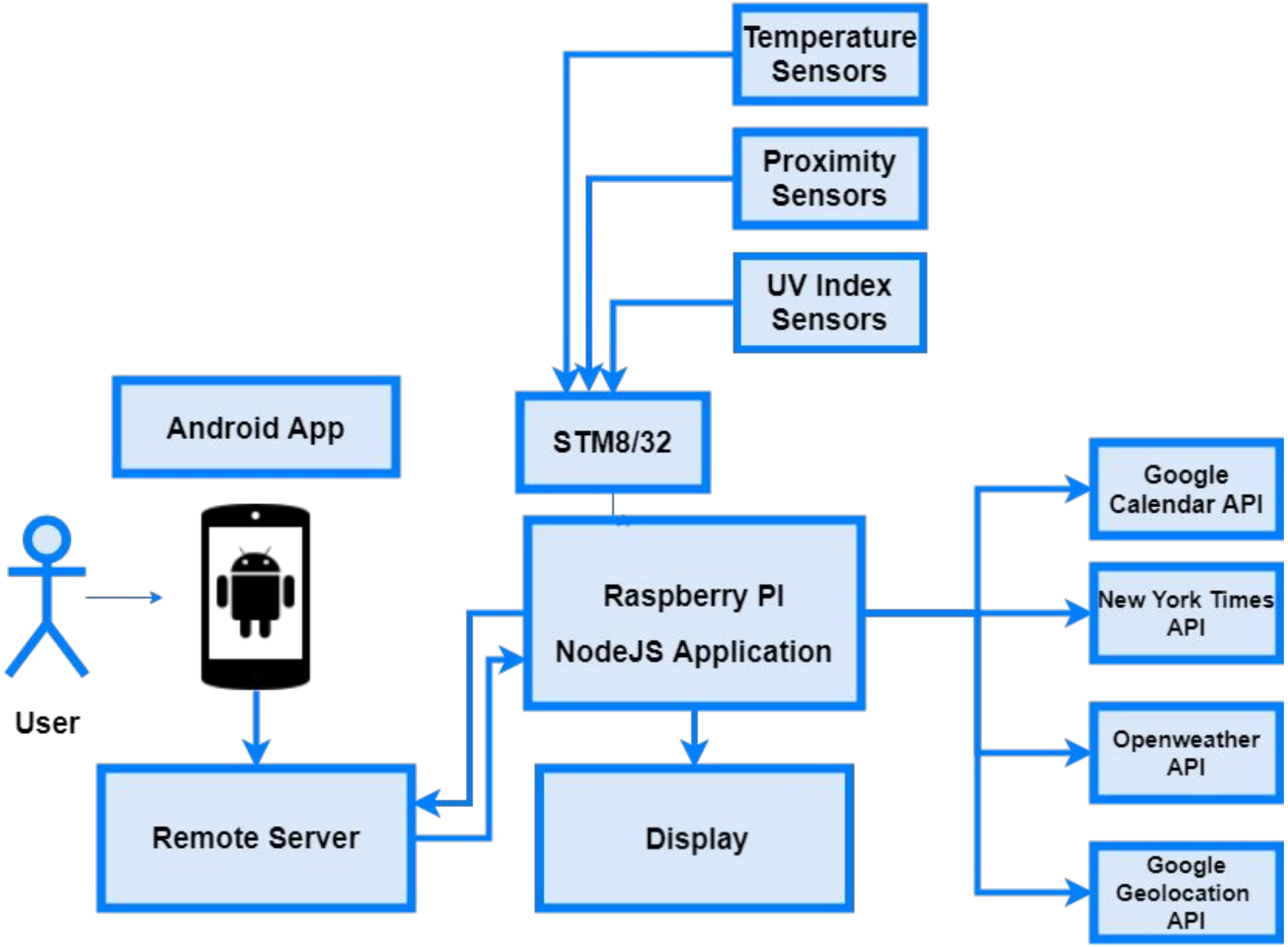


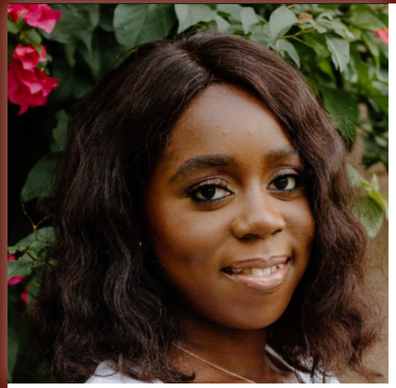
# Presentation Timeline





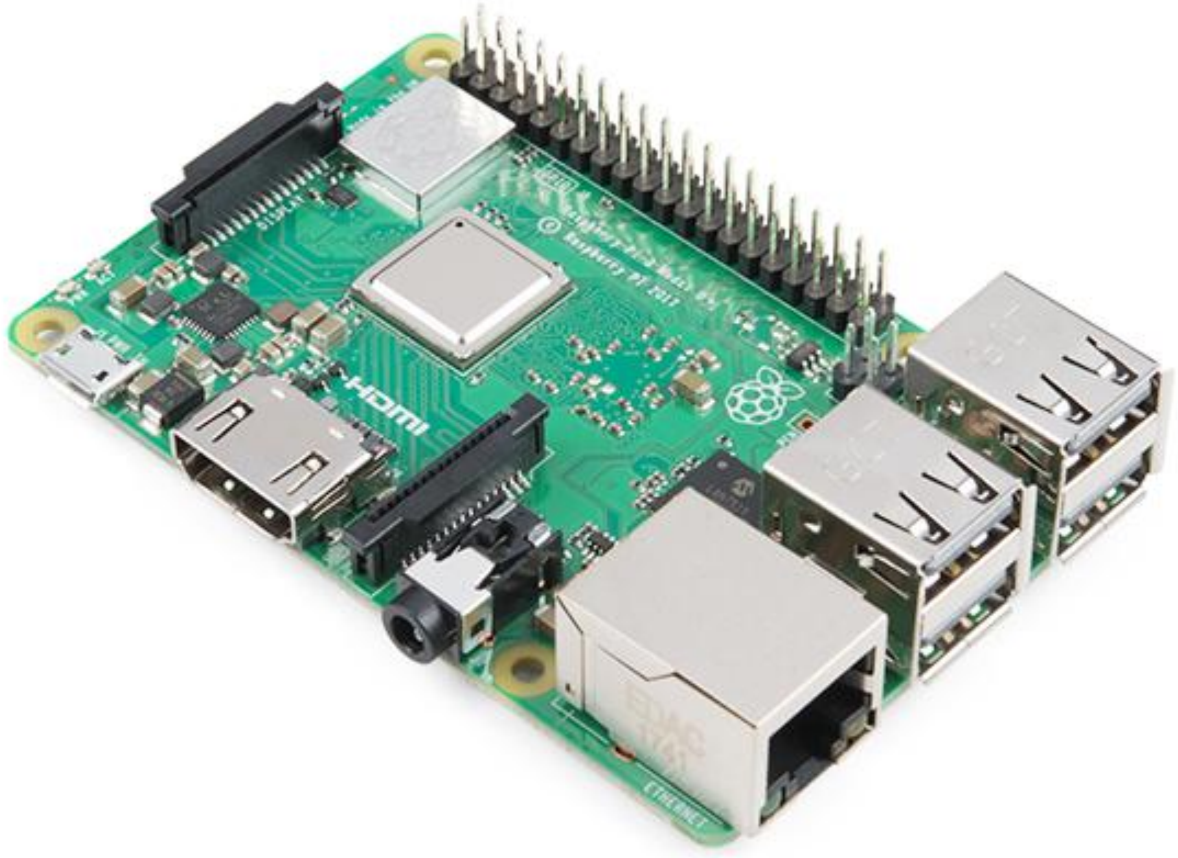
# Software Block Diagram





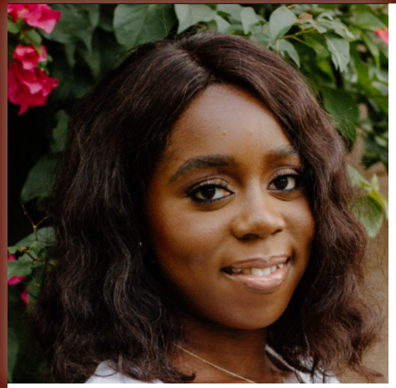
# Raspberry Pi 3 B+

- Memory: 1 GB RAM
- Operating System: Gentoo Linux
- Processor: arm64, 1.4 GHz



**Used to:**

- Drive HDMI output to LCD display
- Communicate with STM32 microcontroller
- Support Node.js runtime environment and
  Qt event loop



# Sensor Algorithms

- Desktop Application poll sensors for 3500 ms every 30 seconds

**Temperature:**

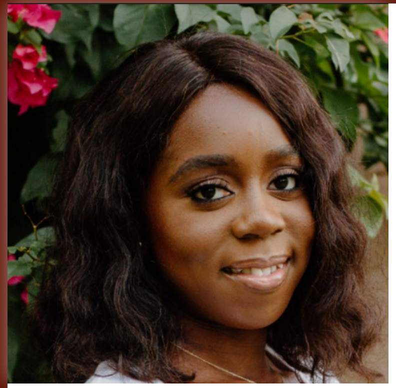
- Measures three different temperatures to calculate average
- Measured in Celsius then converted to Fahrenheit

**Humidity:**

- Measures three different humidity measurements to calculate average
- Measured in Relative Humidity

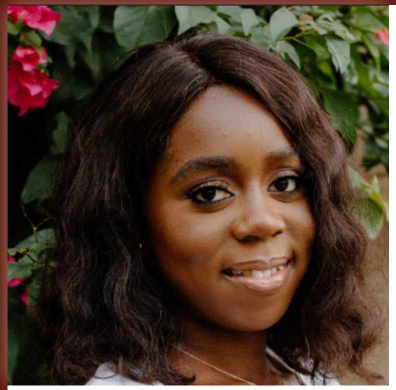
**Light Sensor:**

- Measures three different UV Indexes  to calculate average
- Measured in UV Index (25 $mW/m^2$)



# Mobile Application

- React Native for Android
- **Capabilities:**
  - Turn on/off Display
  - Toggle objects displayed in window
  - Show weather notifications on mobile device
  - Read push notifications based on app permissions
  - Access sensor measurements collected by window

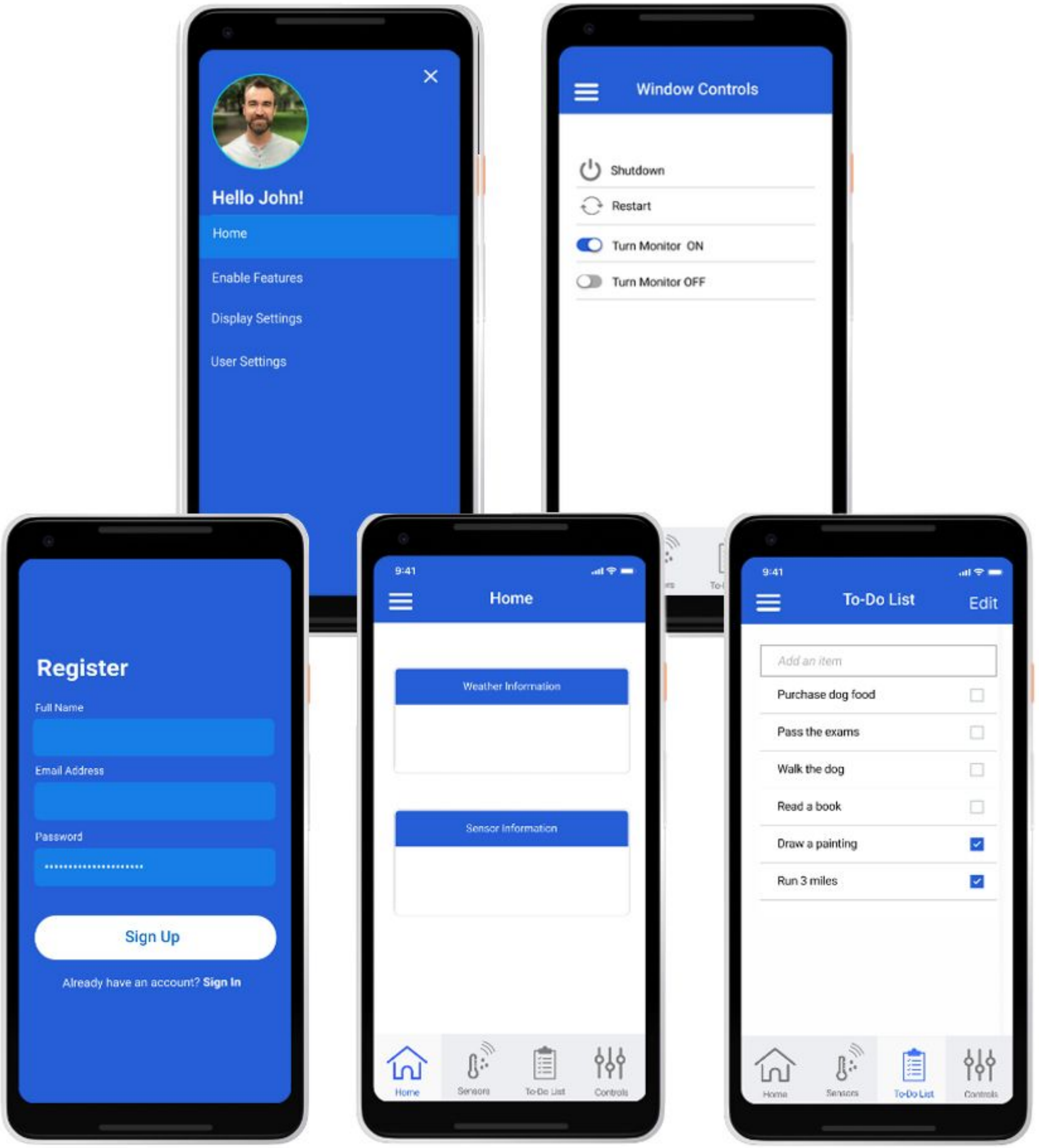


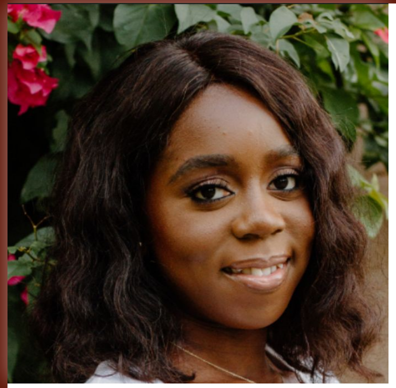
# Mobile Application

The application opens with a login screen. Authentication then redirects the user to a tab based interface with a hamburger menu.

## Views:

- Login
- Create Account
- Display Settings
- Home Screen (Read Sensor Measurements)
- To-Do List (View and edit list)



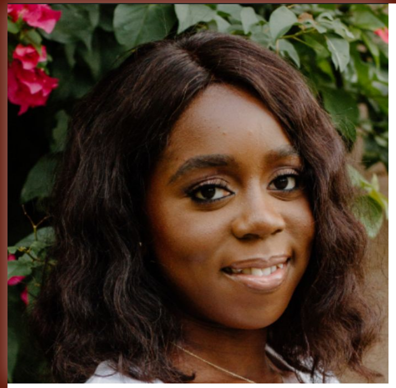


# Desktop Application

- **Qt** - Widget toolkit used for creating native graphical user interfaces
- **NodeGUI** - Library that uses Javascript wrappers around Qt's through a C++ Addon
- **Qode** - Forked version of Node.js (Javascript Runtime Environment)
  - Uses message injection to merge Node's event loop and Qt's event loop
- Used to create desktop application for Raspberry Pi

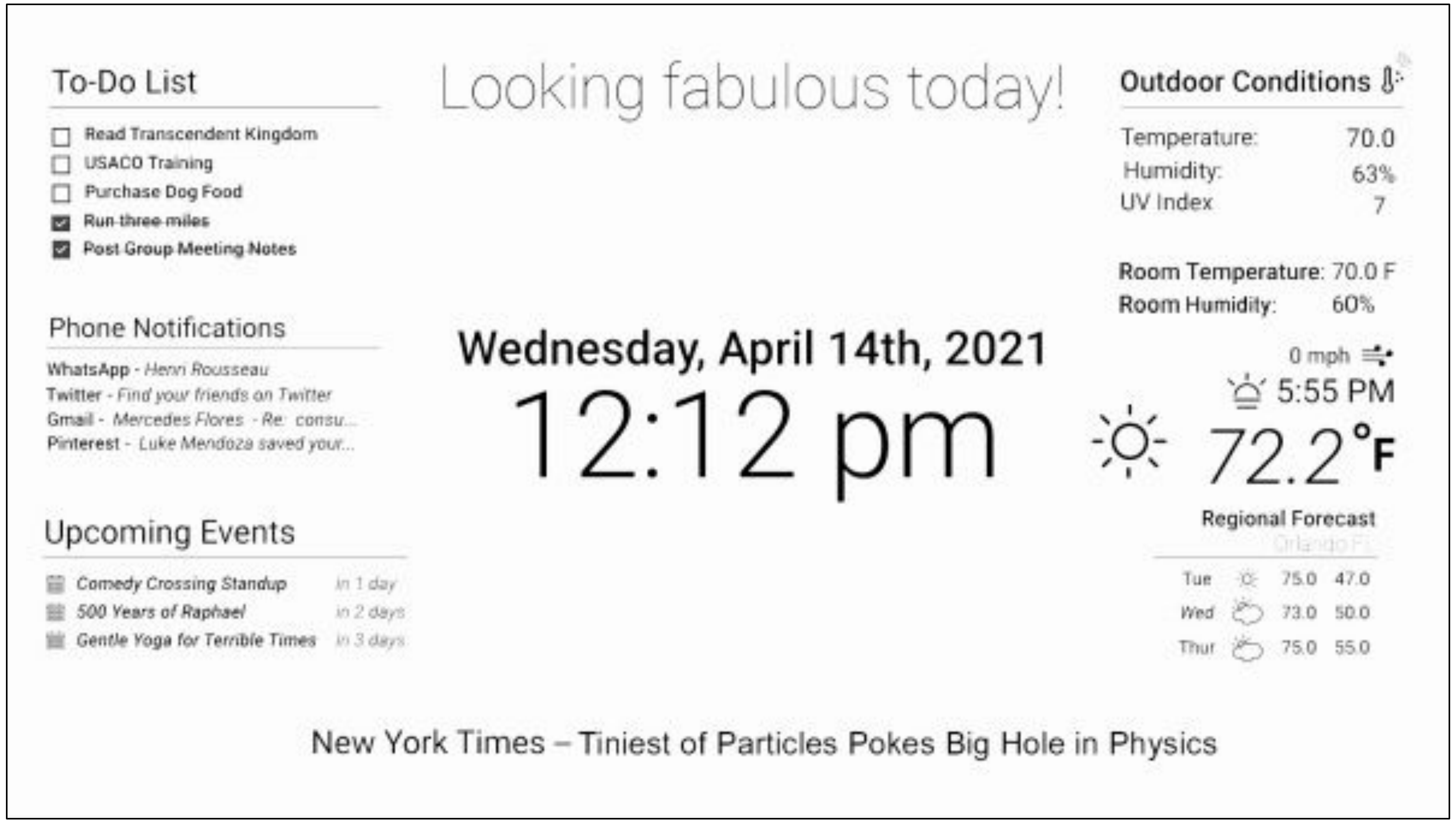
**UI Elements Include:**

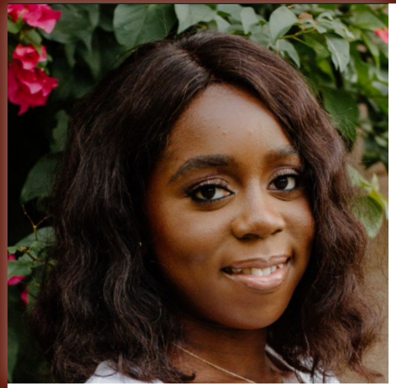
- To Do List
- Sensor Measurements
- Regional Forecast
- Welcome Message & New York Times Headline



# Desktop Application GUI

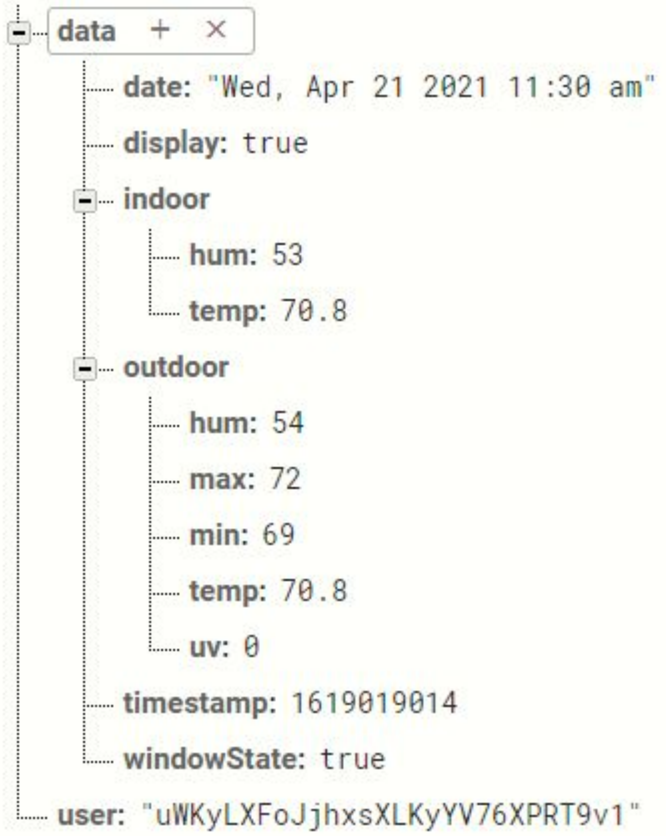
- **Sensor Measurements** - Polls the microcontroller for sensor data and converts them into their respective units
- **Regional Forecast** - Polls a remote database for the weather condition for the metropolitan area the device is located in
- **To Do List** - Allows user to maintain a To-Do List on their phone to be displayed in window
- **Phone Notifications** - Allows the mobile application to read a user's cell phone notifications for each individual app when given permission to display in the window
- **Welcome Message**
- **New York Times headline**

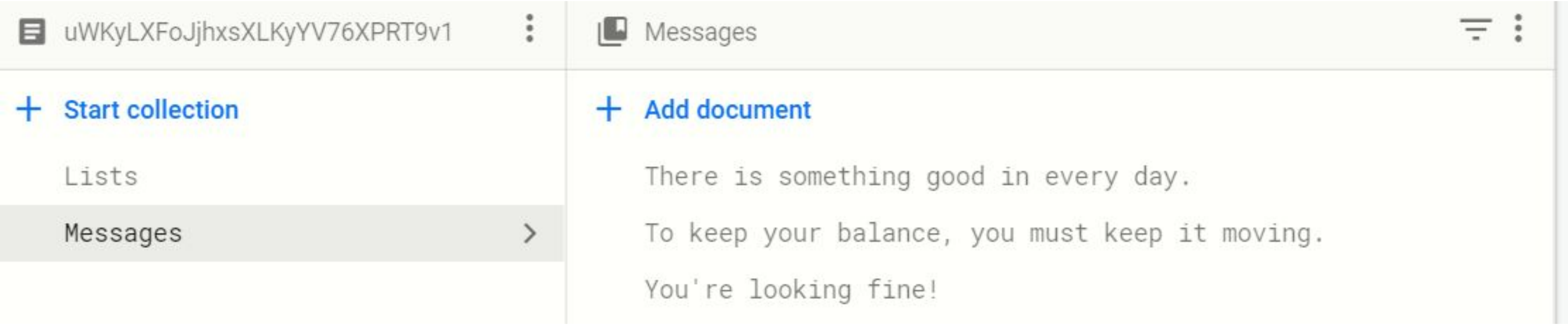


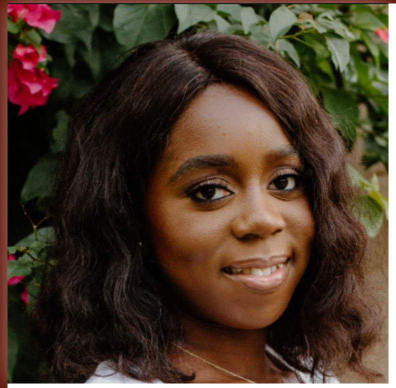


# Database

- Google's Firestore and Realtime Database
  - NoSQL database that represents data in JSON pairs
- Email/Password and Google Identity based authentication
- Used store user info, to-do list and collected measurements
- **Collections:**
  - Users
    - Messages
    - To-Do List
    - Sensor Readings
    - Window State



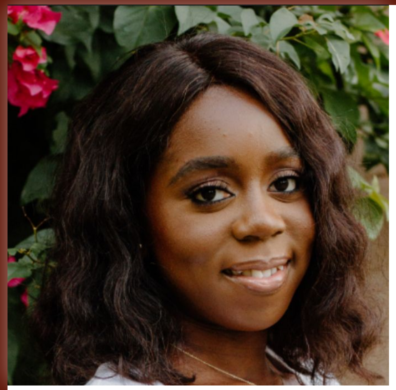





# Weather Forecasting API

OpenWeather

- Weather API is polled to read regional weather conditions
- Required data from API: 3-day Temperature Forecast, Sunset Time, Wind Speed, Weather Condition
- **Openweather API**
  - Free plan offers 60 calls/min
  - Polling of the API will take place in both the desktop and mobile application
- **Google Geolocation API**
  - Used to return latitude and longitude coordinates to approximate metropolitan area



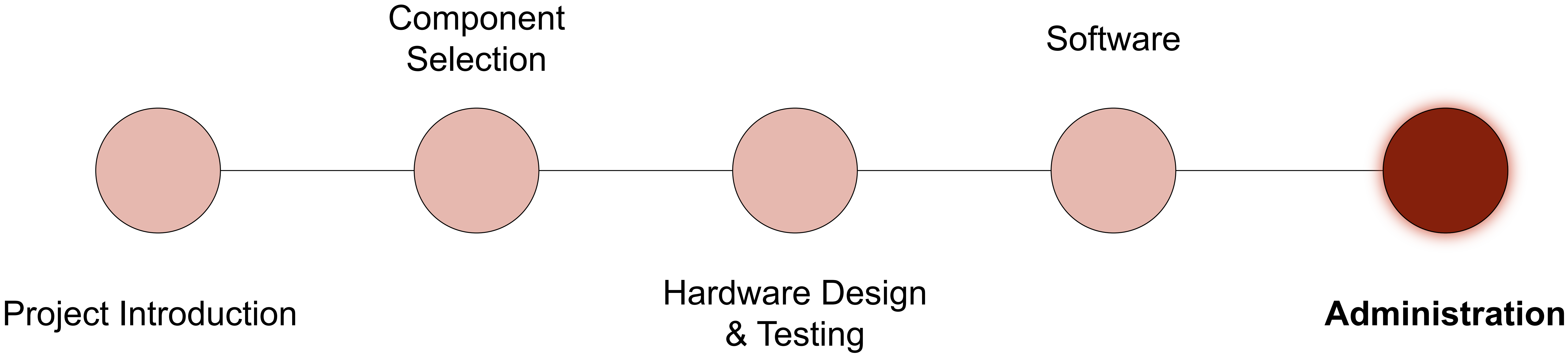
# Software Issues Encountered

Proximity Sensor

Long times to compile the Pi environments impacted other areas of software development

etc...

# Presentation Timeline



# Design Constraints

| Constraint | Specification |
| --- | --- |
| Size | Window Area: 3 ft x 2 ft |
| Power Consumption | Energy efficient components (LED strips, PDLC…) |
| Health and Safety | Electrocution or possible fires when handling electronic equipment and use of power tools to build frame |
| Ethical, Social & Political | Online Privacy, PDLC Film Privacy |
| Economics and Time | ~$500 budget, 2 semester timeline |

*All constraints worked together to help the project group to outline the scope of the design, and also keep it within the bounds of what the Smart Window became. The price of PDLC film grows very rapidly as the area increases so making a balance between size and price is necessary, which is why the team initially decided on a 3ft by 2ft window area. To minimize tool related injury and potential hazards like dust inhalation, or eye injury, proper safety equipment and laboratory standards were adhered to.*

# Standards

| | |
|---|---|
| Display Standards | HD+, DVI, HDMI |
| LED Standards | IEEE PAR1789, IEC62031:2018 |
| PDLC Film Standards | CEN EN 674, DIN EN 410 |
| Communication Standards | Serial RS232, RS422, RS385, SPI, I2C, IEEE 802.11, IEEE 802.15.1 |
| Power Standards | U.S. 120VAC 60HZ Type A |
| PCB Standards | IPC-2581 |
| Programming Language Standards | ANSI C |

# Display and LED Standards

## Display Standards

Digital Visual Interface (**DVI**.) DVI is compatible with both analog and digital signals. DVI is an important interface because of it's compatibility between older standards such as VGA, a serial connection, and newer digital interfaces like **HDMI** and DisplayPort. When the DVI interface connects both the signal source and the display, the display characteristics are read by the EDID block over an I2C Link. Cable has a maximum length of 15ft.

The relevant standards for the display used in the Smart Window relate to the screen's display resolution, aspect ratio, color depth, and refresh rate. The display used in our project follows the **HD+** standard. The HD+ Standard defines a 1600x900 pixel resolution with a 24bpp color depth. The aspect ratio of the display is 16x9, and supports refresh rates up to 60Hz.

## LED Standards

**IEC 62031:2018** specifies the safety requirements of non-integrated LED modules and semi integrated LED modules for operation under constant voltage, constant current or constant power. Integrated LED modules for use on DC supplies up to 250 V or AC supplies up to 1000 V at 50 Hz or 60 Hz.

**IEEE PAR1789** outlines the recommended practice for minimizing flicker as follows: The frequency of the modulation is multiplied by either 0.025 for frequencies under 90Hz, or by 0.08 for frequencies above 90Hz. The human visual system is less sensitive to flicker at higher frequencies, and therefore more flicker is deemed safe in high frequency systems.

# PDLC Film Standards

**CEN EN 674**

This standard outlines a measurement method to determine the thermal transmittance of glazing in buildings. Certain surfaces such as patterned glass and PDLC film are included.

The procedure specified in this Standard determines the thermal transmittance (U-factor) in the central area of the glazing. The edge effects, due to the thermal bridge differences on an insulating glass unit or through the window frame are not included.

**DIN EN 410**

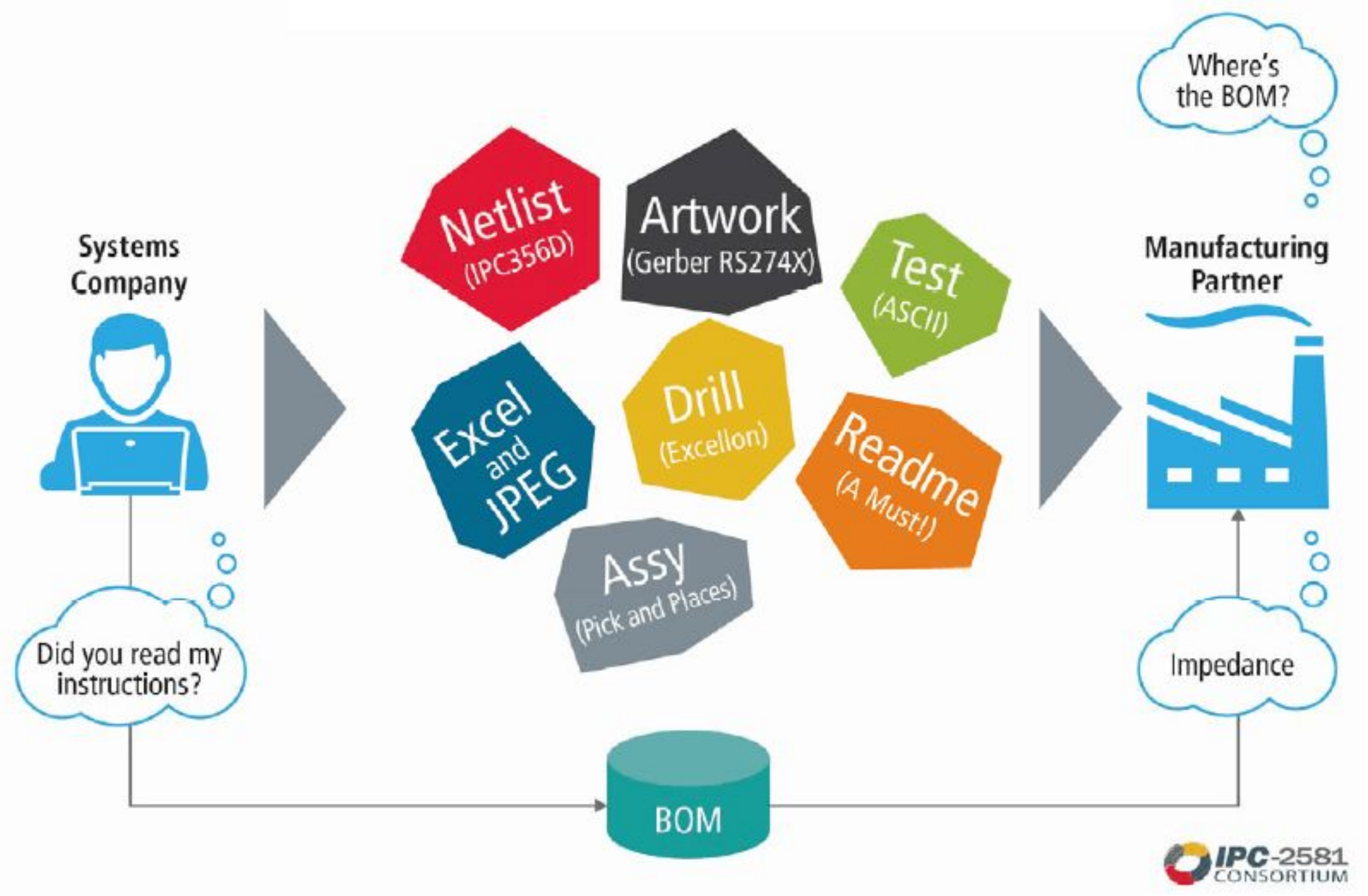
This standard specifies methods of determining the luminous and solar characteristics of glazing in buildings.

These characteristics can serve as a basis for lighting, heating and cooling calculations of rooms and permit comparison between different types of glazing.

# PCB Standards

**IPC - 2581**

Standard file format for information exchange between designer and manufacturer including files such as copper imaging for etching, board layer stack information, netlist, bill of materials, and fabrication/assembly notes.

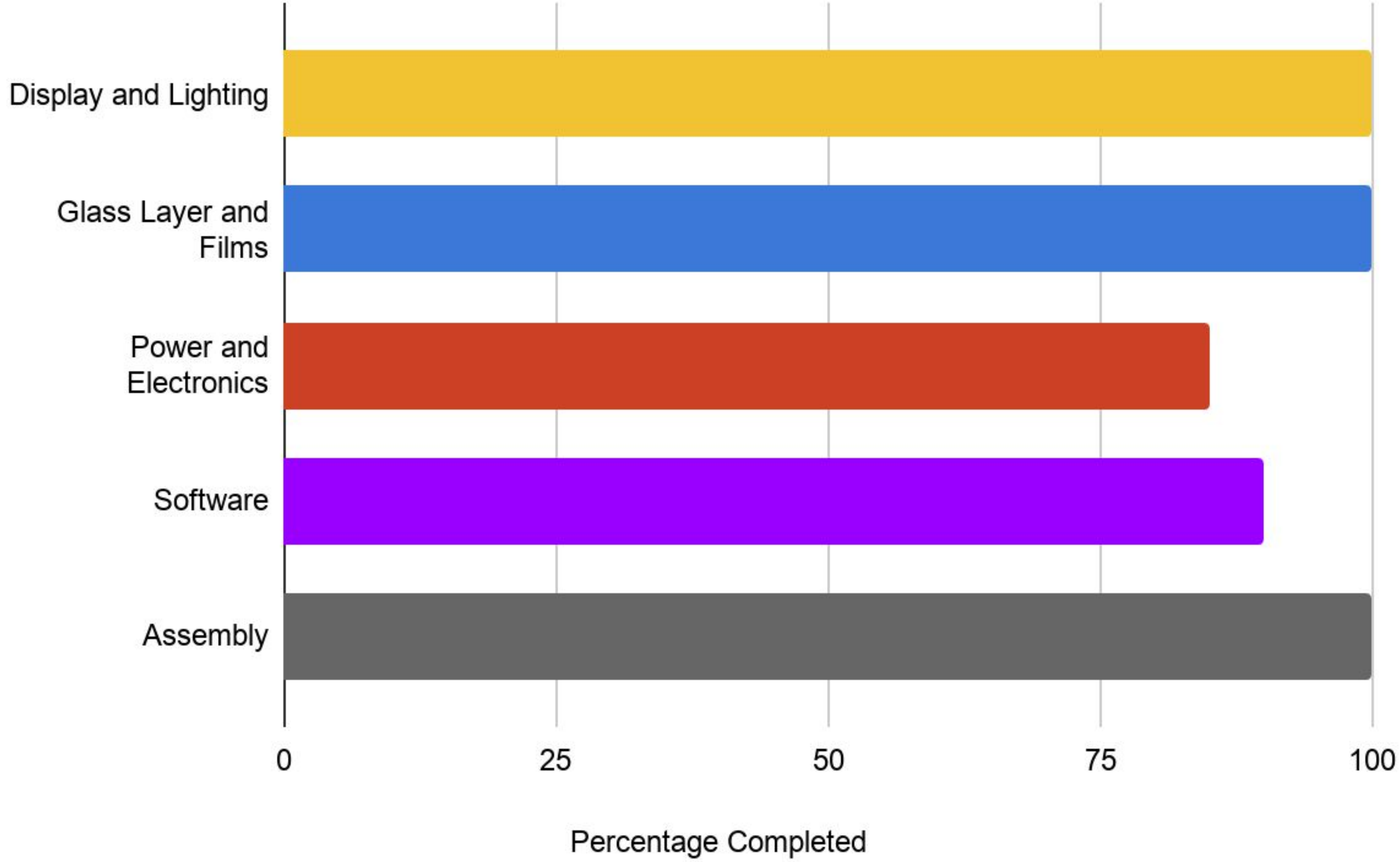


# Budget and Financing

- No corporate sponsors
- Project was fully self-funded by team members
- Expected total contributions: $500 (flexible)
- Group went $31.13 over budget

| Expected Bill of Materials | Expected Cost | Actual Cost |
|---|---|---|
| Window frame | <$30 | $18 |
| Glass Pane | <$15 | $15 |
| 18650 Lithium ion batteries (x8) | <$40 | $40 |
| Temperature/Humidity sensor (outdoor) | <$5 | $4.81 |
| Temperature/Humidity sensor (indoor) | <$5 | $4.81 |
| UV sensor | <$7 | $5.04 |
| LED strips | <$25 | $22 |
| LED Peripherals | <$25 | $9.99 |
| PDLC Film | $225 | $214.99 |
| Testing Products | <$50 | $37.99 |
| Other Electrical Components | $30 | $43.50 |
| Shipping | <$50 | $115 |
| Total | **$497** | **$531.13** |

# Smart Window Progress



*Thank you for watching!* - Smart Window Team