Smart Window

Group 4

SD2 - Spring 2021

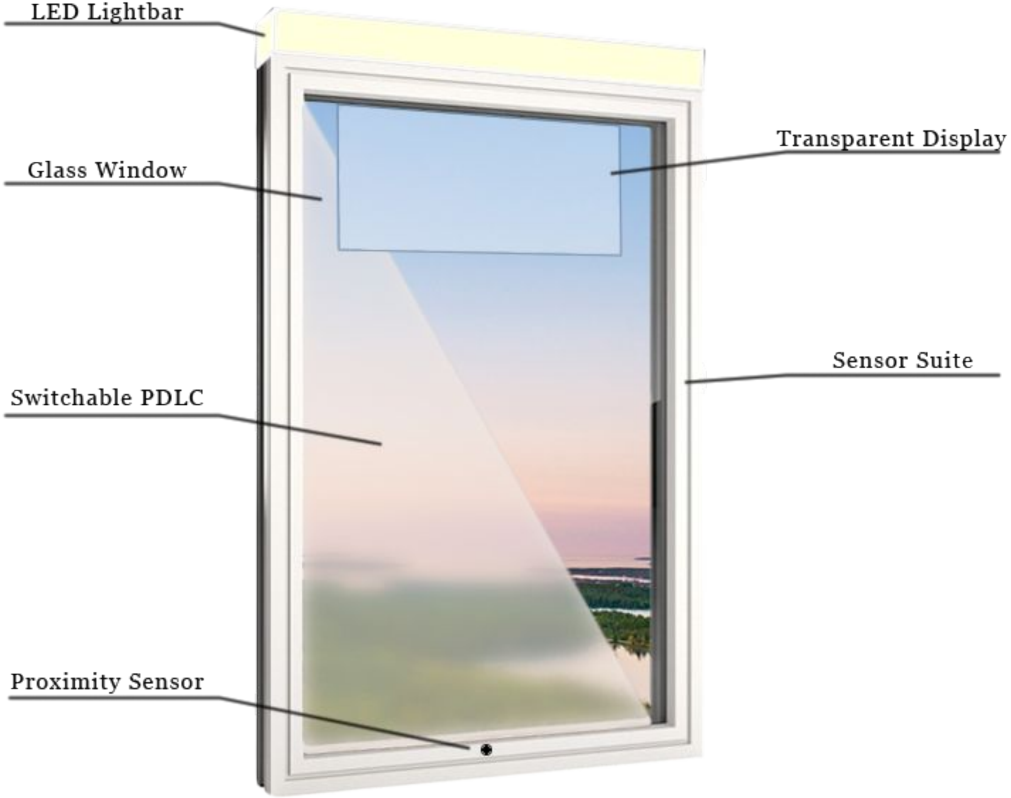
Smart Window Team Members

Jake Pivnik - Pablo Calzada
Photonic Science & Engineering

Shaneal Findley - James Brunner
Computer Eng. | Electrical Eng.

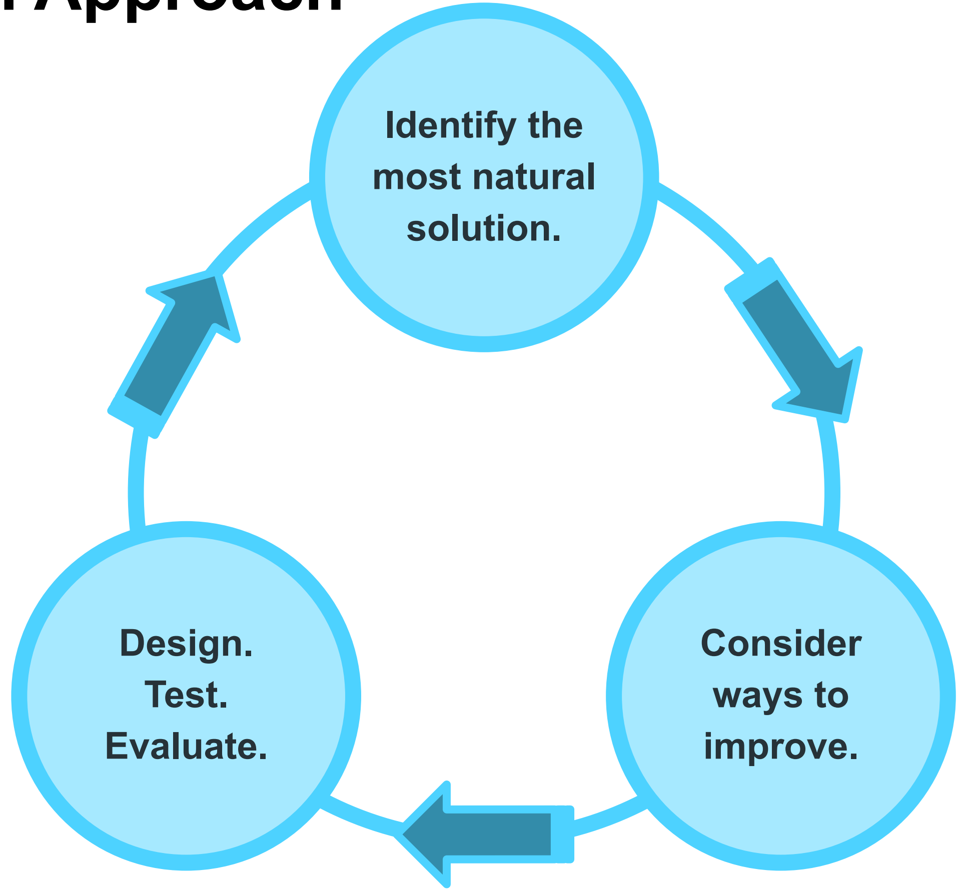
Project Goals and Objectives

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



Design Approach

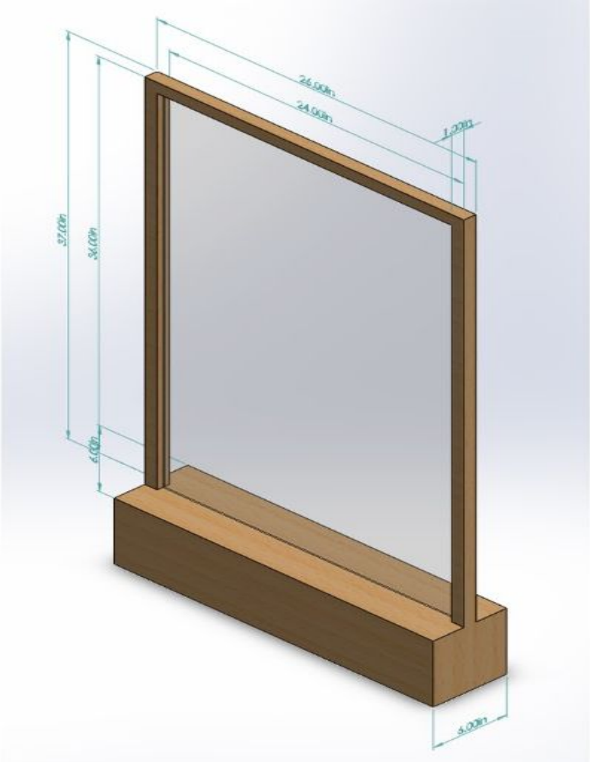
- We noticed a widespread problem with how people receive weather data
- Too many sources giving different information
- Data may be inaccurate depending on user location
- Apps feel impersonal, and aren't very user accessible
- Team seeks to solve these problems using local data and ease of access



Proposed Implementation

- Because our design is an improvement over existing technology, established methods of window installations can serve as a guide for implementing the Smart Window.

- Further iterations of the project could easily accommodate windows of different sizes thanks to flexibility of PDLC sheet sizes and the large amount of available consumer displays.

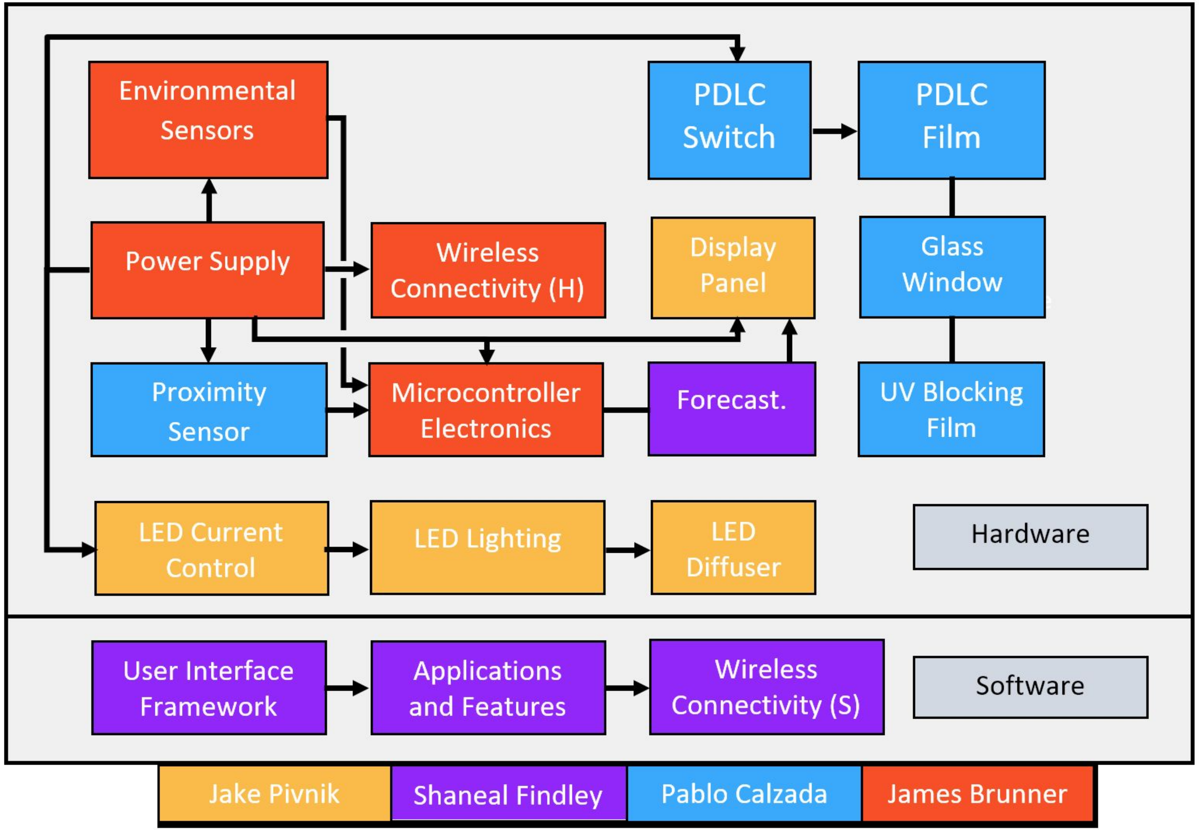


Our current design aims to show a cohesive product demonstration, and electronics will be contained safely inside the support structure housing the glass subsystem.

Project Block Diagram

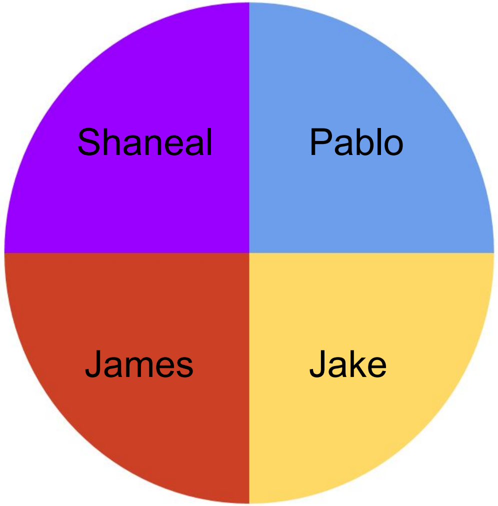
Blocks are colored according to team member in charge of subsystem

Arrows show flow of data / power between subsystems

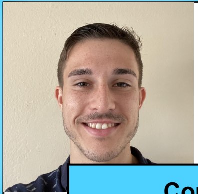


Work Distribution

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

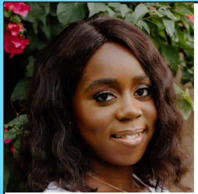


Project subsystems have been assigned to group members with the skill-set most equipped to tackle them. Splitting the workload up evenly prevents burnout and frustration, while ensuring progress is being made in each section evenly.



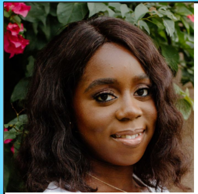
Requirements and Specifications

Component	Engineering Requirement	Justification
Transparent Display	1600x900px Resolution. Allows >40% light transmission in visible spectrum.	A large conventional LCD could be made translucent by backlight disassembly, yet offers a high quality image.
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 (12W Max power draw per color) 2700K / 6700K Light Temperatures	Using two lighting modes offers color mixing,, and 1200 lumens should provide adequate lighting in any environment
Lighting Control	LED Power control between 0-1 amp	Two knobs control current to offer variable lighting between 2700-6000K and between 0-2400 Lumen
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
Indoor Weather Sensor	+/- 5% Relative Humidity / +/- 2.0 C	Indoor Sensors determine the house conditions
Desktop Application	Maintains a GUI that displays: The weather forecast in Farenheit 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 is the primary way the user is able to change the display state of the smart window and read its sensor measurements.



Window Application Requirements

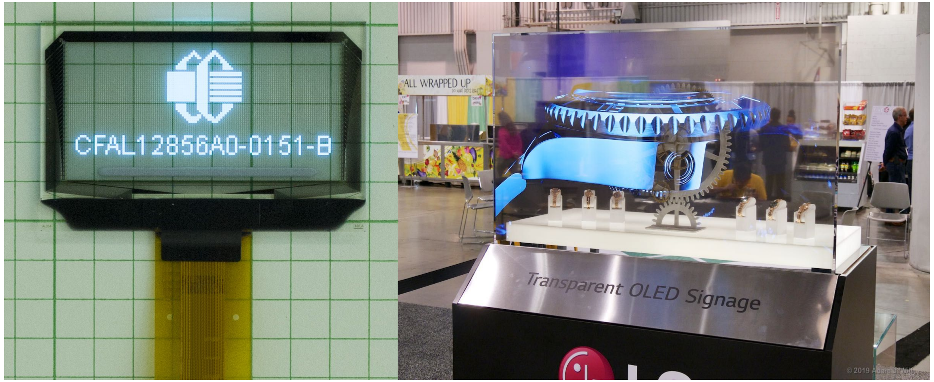
Engineering Requirement
The desktop application will store a UID to identify each Raspberry Pi in a remote database.
The desktop application will be a single-instance application.
The desktop application will display a 1600x900 px browser window.
The desktop application will use a GUI to display the current date and time.
The desktop application will poll the microcontroller every 60 seconds for sensor information.
The desktop application will display sensor data decoded from the microcontroller in human readable format.
The desktop application poll a remote database for the current weather forecast for the metropolitan region the device is located in every 60 seconds.
The desktop application will display an accurate image that corresponds to every weather condition polled from the weather API.
The desktop application will store the sensor measurements in a remote database every 60 seconds.
The desktop application will reload the browser window everytime the database is updated.
The desktop application will use JSON to communicate to the remote database.



Mobile Application Requirements

Engineering Requirement
The mobile application will poll the remote database to read the latest sensor data sent by the desktop application.
The mobile application will follow standard security protocol for storing user’s email address and password information.
The mobile application will allow a user to sign in using their Google Account credentials.
The mobile application will support an Android operating system.
The mobile application will support Android 10 (Q) and above.
The mobile application will store the users display settings in a remote database to determine the UI elements showed in the desktop application.
The mobile application will use JSON to communicate to the remote database.
The mobile application will allow a user to maintain a To-Do list that will be stored in system memory and displayed in the desktop application’s GUI.

Display Selection



Transparent OLED Display

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

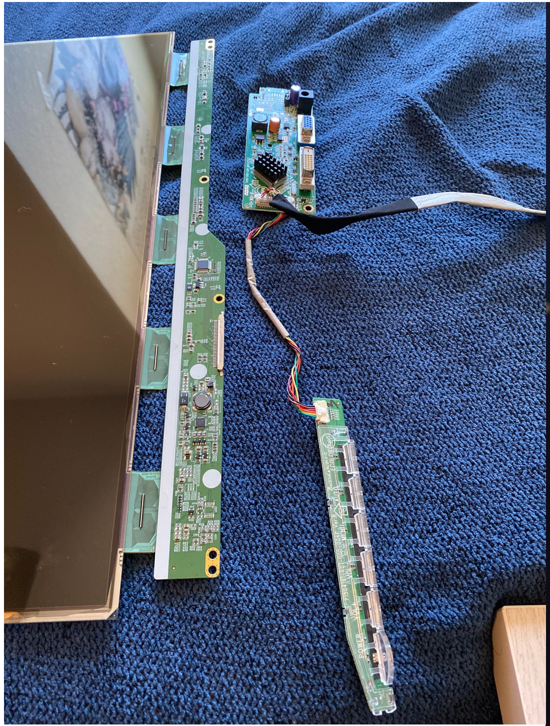
See-Through LCD

- ~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



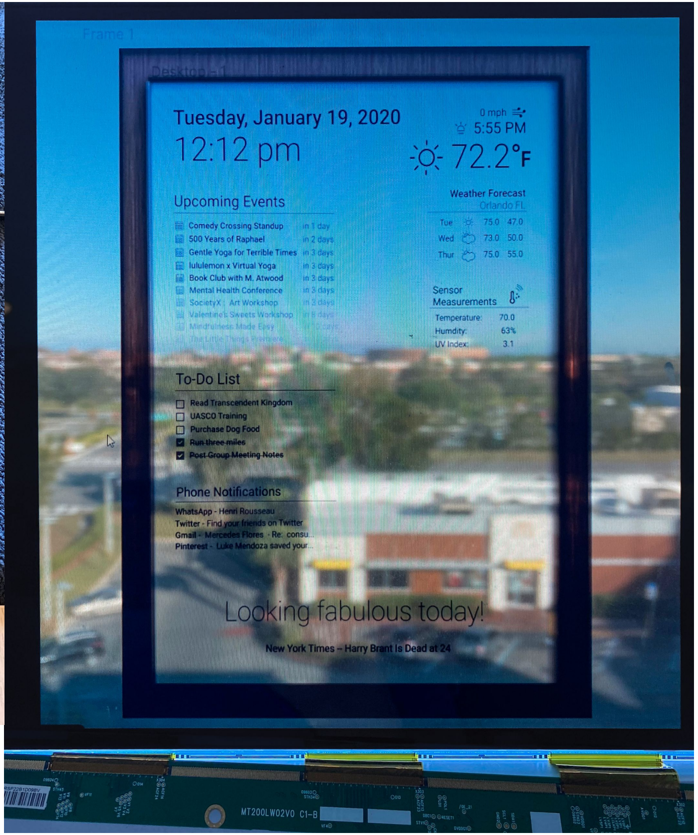


Photo taken at 4pm 1/28/2021 in indirect sunlight on an east-facing window.

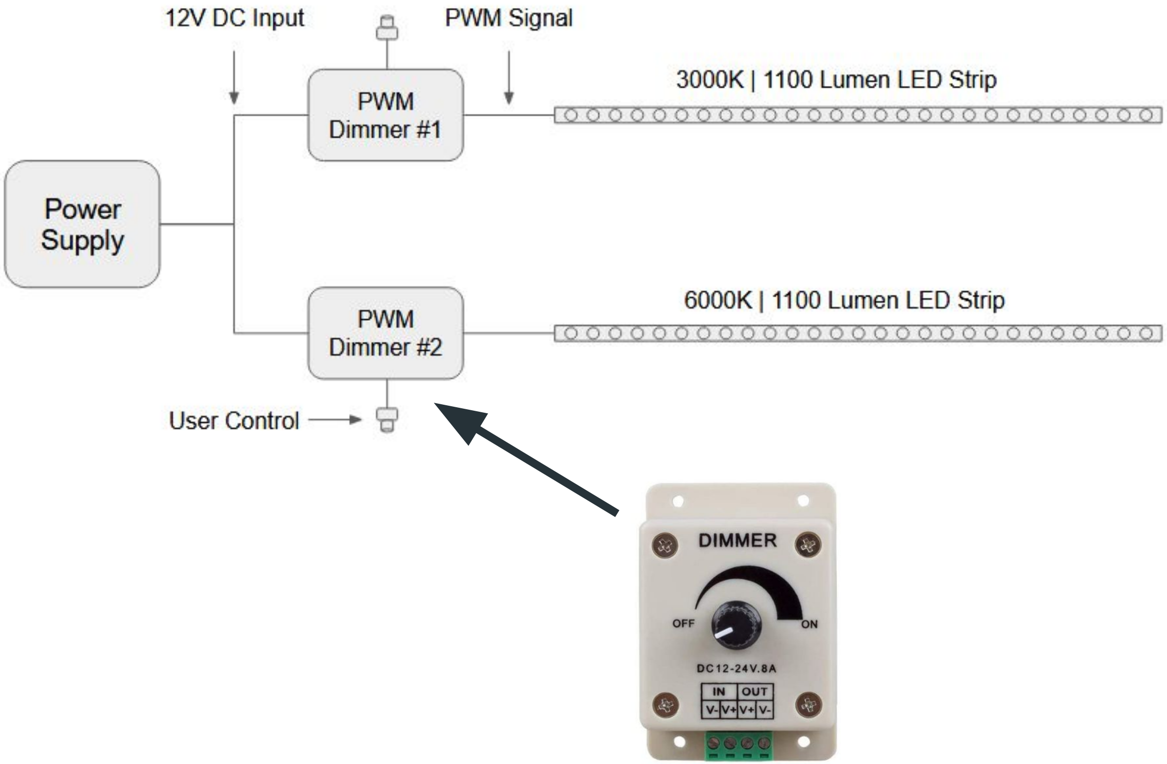
LED Strips and Control Selection

LED Strips: LEDSupply

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

LED Control: Hiletgo

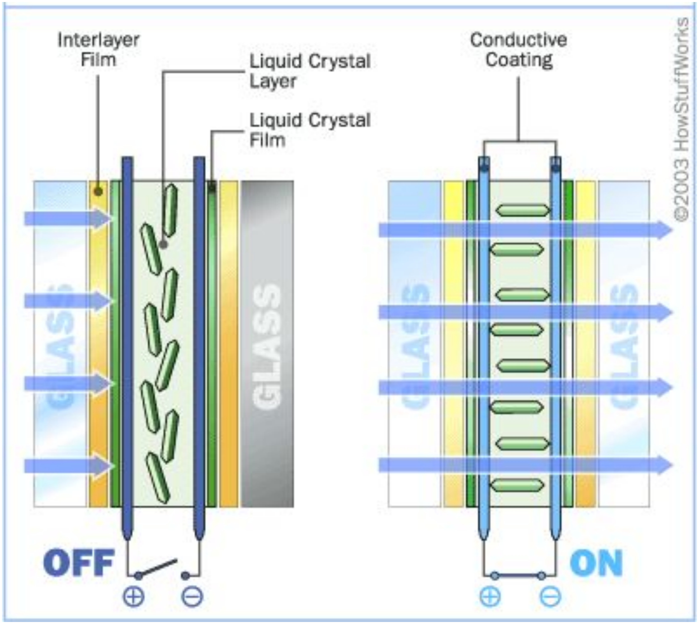
- 0% - 100% Power
- DC12-24V 8A Max
- PWM Control



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

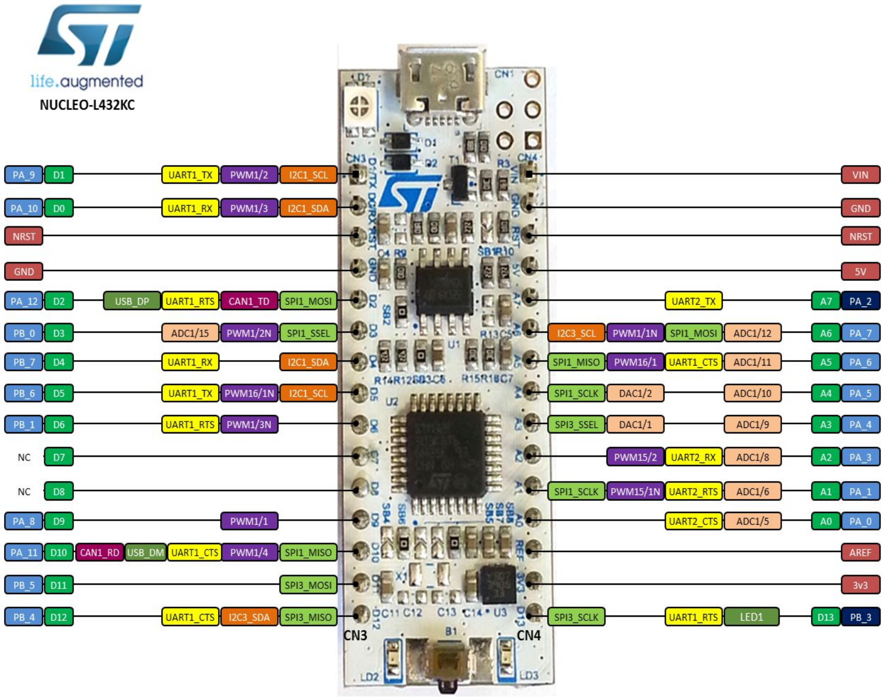
- Use in this project
  - Detect when the user is standing in front of the window
  - If user is under a certain distance, it will initialize the displays graphical interface
- IR sensors
  - Chosen for small size, high resolution and distance
  - Both active and passive IR sensors were taken into consideration
- 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

Microcontroller Selection

The MCU should be able to perform I2C, SMBus, UART, and SPI communications as well as have multiple GPIO pins to enable/disable MOSFETs.

Selecting a cheap MCU with thorough documentation is a must and with the easy initialization of peripherals CubeMX IDE offers, the STM32L432KC was chosen.



Battery Selection

The batteries should optimize power density, cost, and package size. They also need to supply enough power for Raspberry Pi, LEDs, PDLC film, and the rest of the electronics.

18650 Li-Ion Rechargeable batteries meet these requirements at a low cost. Our plan is to assemble them into an battery bank to meet the voltage requirements of components.

	Samsung 25R	Samsung 26J	**LG MH1**	LG HE4
mAh	2500	2600	**3200**	2500
Voltage	3.7V	3.7V	**3.67V**	3.6V
Discharge	20A	5.2A	**10A**	20A
Unit cost	3.85$	3.95$	**4.25$**	3.95$

We decided to use the LG MH1 Battery cell because of its high capacity, low cost, and ability to support a high discharge current.

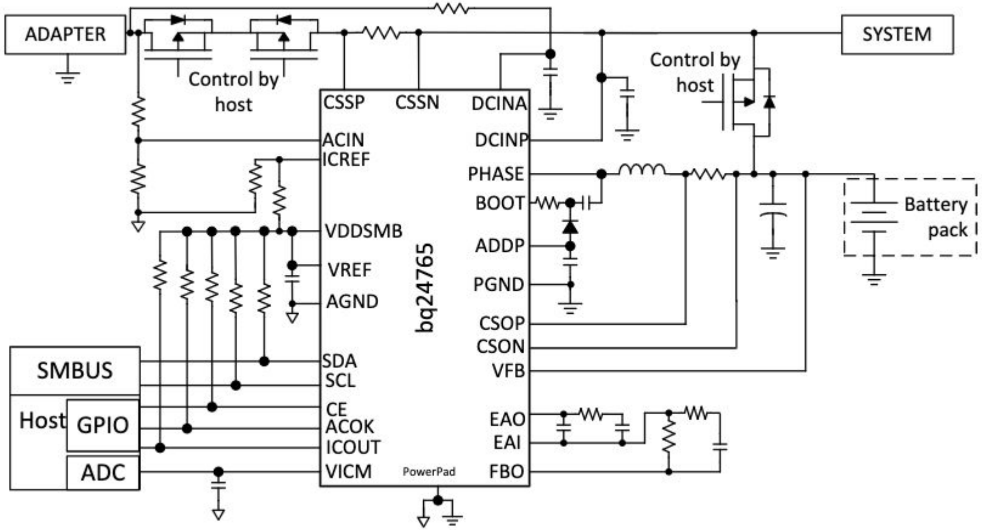
Battery Charger IC

Charging the batteries precisely is required to ensure the lifetime of the Smart Window lasts beyond one charge.

It is therefore necessary to select a battery charging IC which can support the chemistry of the batteries chosen, perform with a high efficiency, and support multiple cells in series.

The IC chosen for this application is the BQ24765.

Simplified Schematic



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.

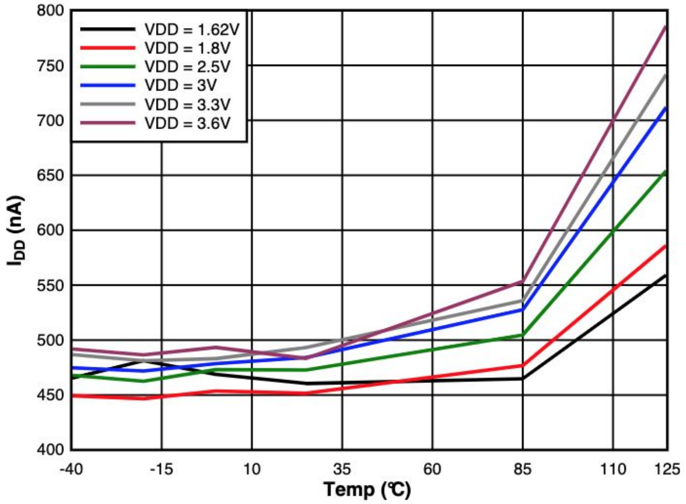


Figure 5. Supply Current vs. Temperature, Average at 1 Measurement/Second, RH (11 Bit) + Temperature (11 Bit)

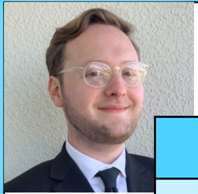
Voltage Regulators

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

Linear voltage regulators provide a simple solution to this problem but they are inefficient and would require heat sinks so switching regulators were chosen to get the job done.

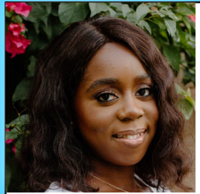
The circuit designs for each level were created through TI's Webench design center.

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

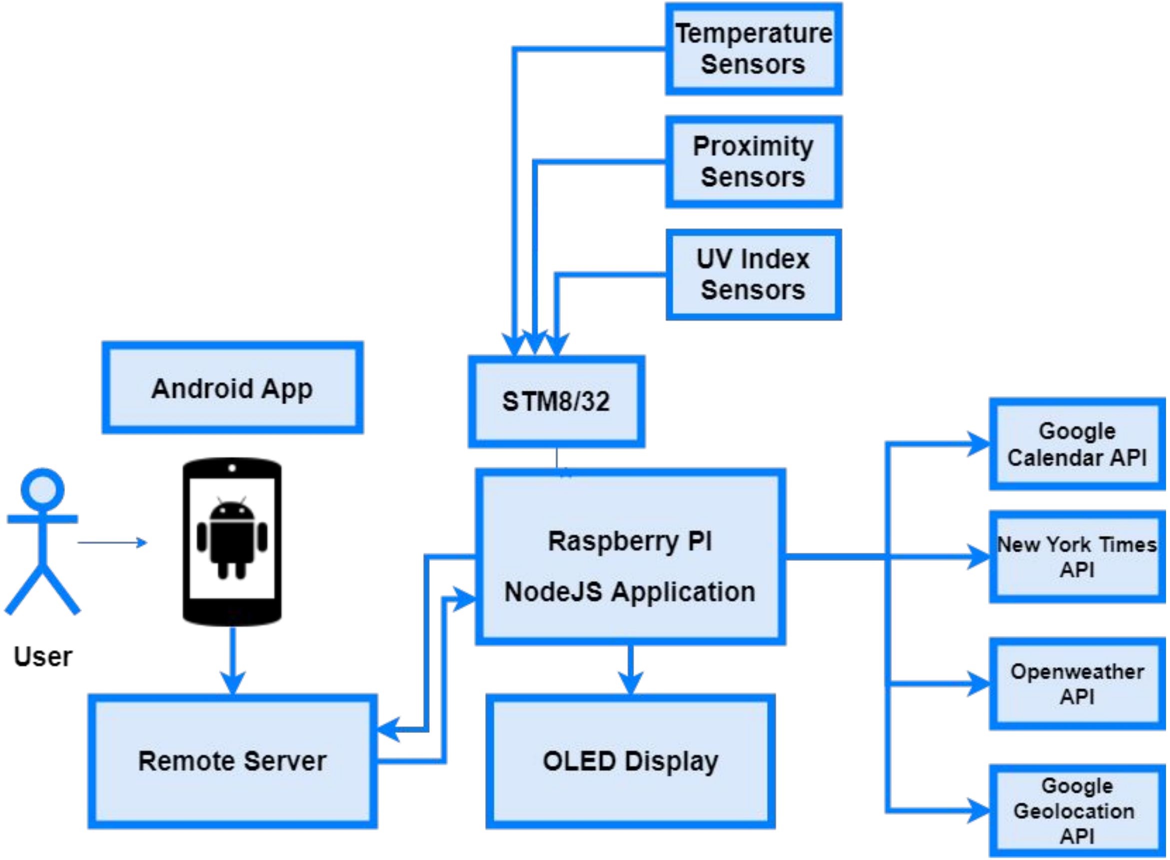


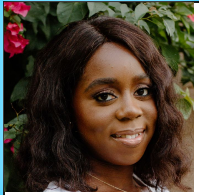
Component Selection Summary

Part	Model Selected	Status
Display	Acer S201HL 20” LCD Display	Tested
Glass Window	Home Depot Model #92436 Clear Glass	Acquired
Smart Film	Smart Tint ® PDLC Film	Tested
LED Strips	LEDSupply IP20 HD 3ft Strips	Tested
LED PWM Control	Hiletgo B073R7H52B	Tested
Microcontroller	STMicroelectronics STM32L432KC	Ordered
HDMI Output, Runtime Environment	Raspberry Pi 3 Model B+	Acquired
Batteries	LG MH1 INR 18650 Cell	Acquired
Battery Charger IC	Texas Instruments BQ24765	Ordered
Temperature Sensors	Texas Instruments HDC2010YPAR	Acquired
Humidity Sensors	Texas Instruments HDC2010YPAR	Acquired
UV Sensor	DigiKey SI1132-A10-GMR	Acquired
Proximity Sensor	Sharp GP2Y0A02YK0F Long Range Sensor	Acquired



Software Block Diagram



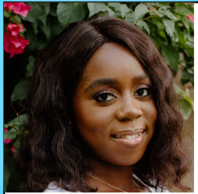


Raspberry Pi 3 B+

- 5V DC via USB-C connector (minimum 3A)
- 5V DC via GPIO header (minimum 3A)
- Supports up to 4kp60 resolution
- 2 × micro-HDMI ports

Used to:

- Communicate with STM8/32 microcontroller
- Support Node.js runtime Environment
- Drive HDMI output to LCD display



Sensor Algorithms

Temperature:

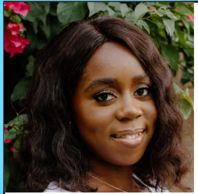
- Tested against three different temperatures to check accuracy
- Measured in Celsius

Humidity:

- Tested against three different humidity measurements to check accuracy
- Measured in Relative Humidity

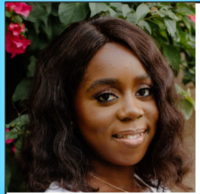
Light Sensor:

- Will be exposed to different light levels and UV Indexes to check accuracy
- Measured in UV Index (25 mW/m^2)



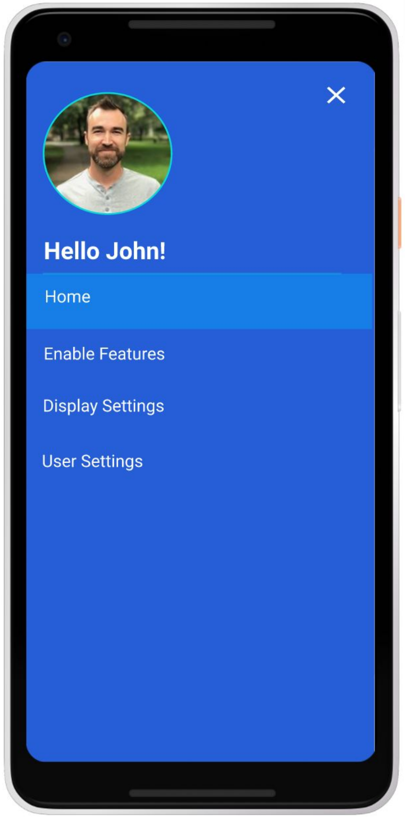
Mobile Application

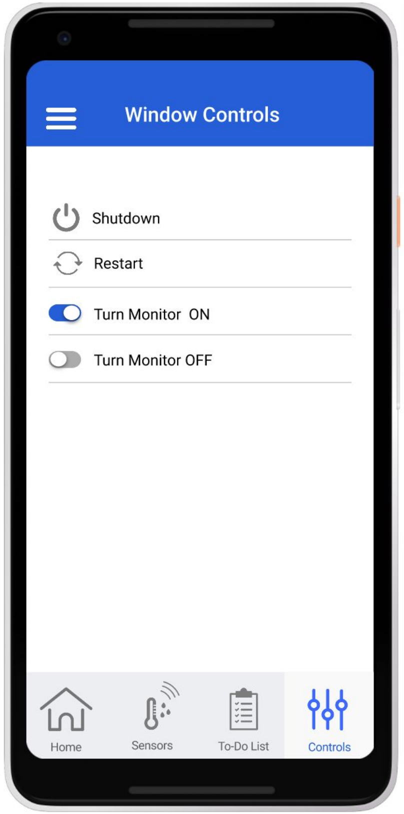
- React Native for Android
- **Capabilities:**
  - Connect to Google Account using Google Auth 2.0 API
  - Turn on/off Display
  - Toggle objects displayed in window
  - Show weather notifications on mobile device
  - Read push notifications based on app permissions
  - Access sensor measurements collected by window

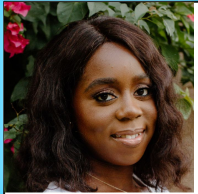


Mobile Application GUI

- The application will begin with a login screen
- Authentication redirects user to tab based interface a with hamburger menu
- **Views:**
  - Login
  - Display Settings
  - Edit Welcome Message
  - Read Sensor Measurements
  - Read Regional Weather Forecast
  - Read App Notifications
  - Edit To-Do List
  - Google Calendar Display Options



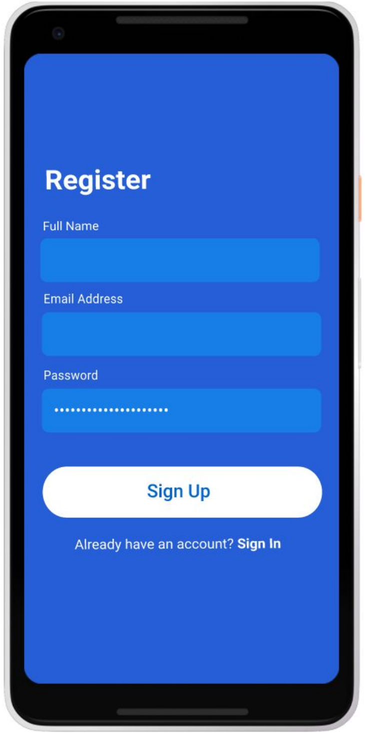


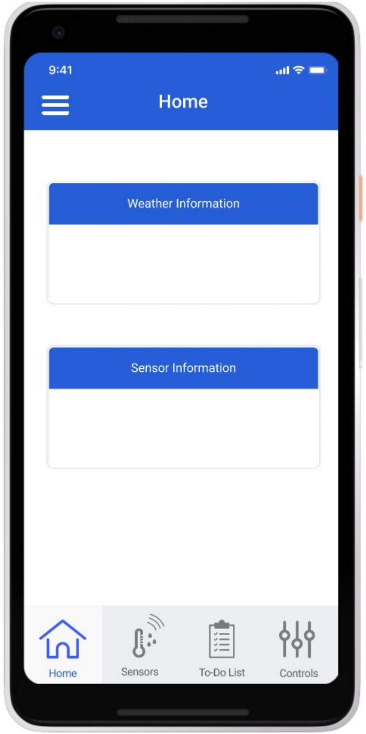


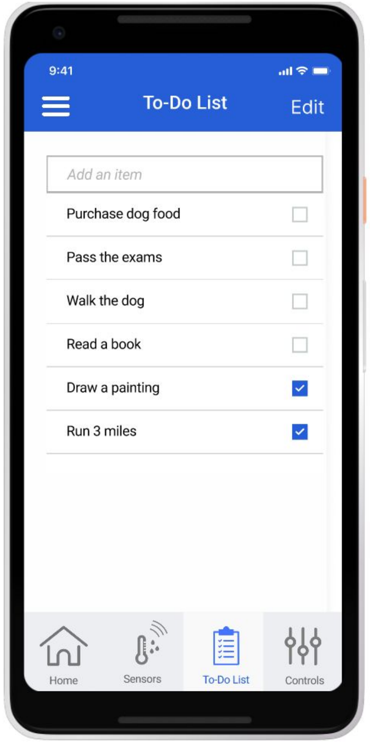
Mobile Application GUI Continued

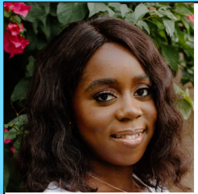
Views:

- Create Account
- Weather and Sensor Information
- To-Do List



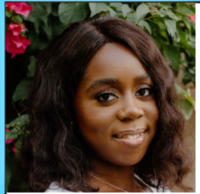






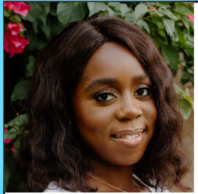
Window Application

- **DeskGap** - cross-platform npm package that runs on Node.js (Javascript runtime environment)
  - Used to create desktop application for Raspberry Pi
- Uses WebKit Rendering Engine on Linux to display GUI
- Displays a browser window of 1600x900 resolution
- **UI Elements include:**
  - To Do List
  - Calendar
  - Sensor Measurements
  - Regional Forecast
  - Phone Notifications
  - Welcome Message
  - New York Times headline

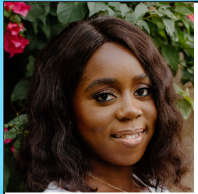


Window Application GUI

- **Sensor Measurements** - Polls the microcontroller for sensor measurements 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 ToDo List on their phone to be displayed in mirror
- **Calendar** - When a user is signed in using their Google Credentials in the mobile app they will have the option to display a subset of their calendar lists
- **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 mirror
- **Welcome Message**
- **New York Times headline**

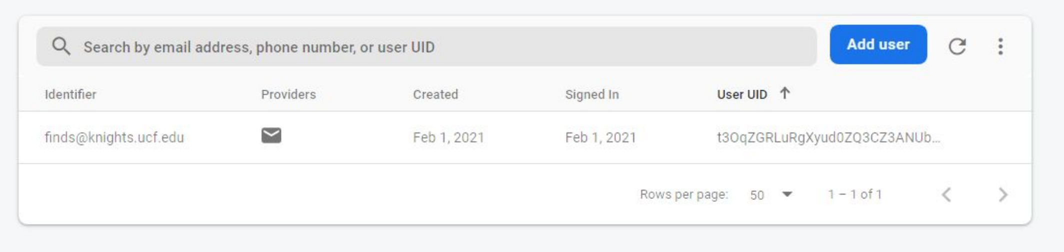


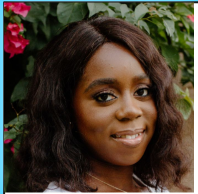
Window Application GUI Continued



Database

- Firebase Admin SDK:
- 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, display preferences, and collected measurements
- Collections:
  - Users
    - App Permissions
    - Calendar Settings
    - Display Preferences
    - Sensor Readings





Weather API

- 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

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 work 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 hopes to become. 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 workplace standards will be 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

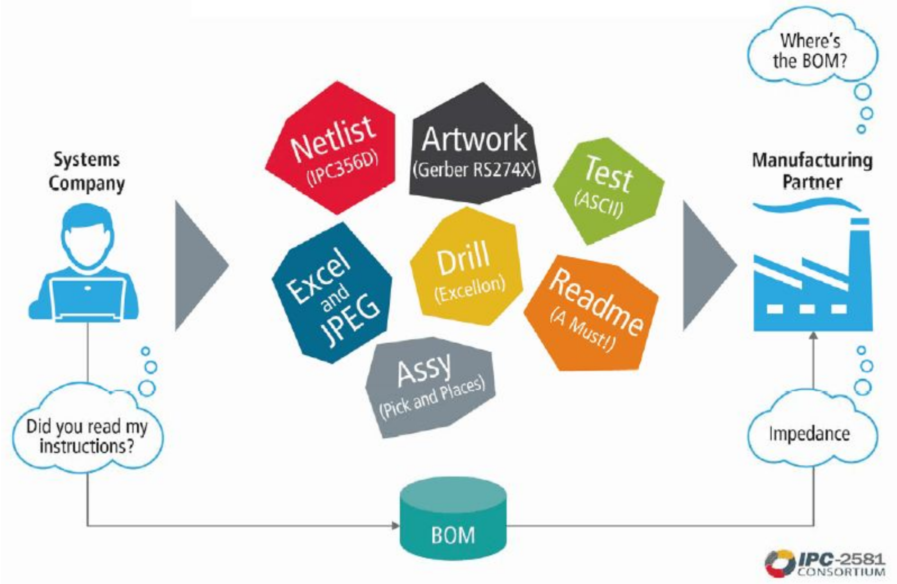
This standard specifies methods of determining the luminous and solar characteristics of glazing in buildings.

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.



Display Subsystem 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

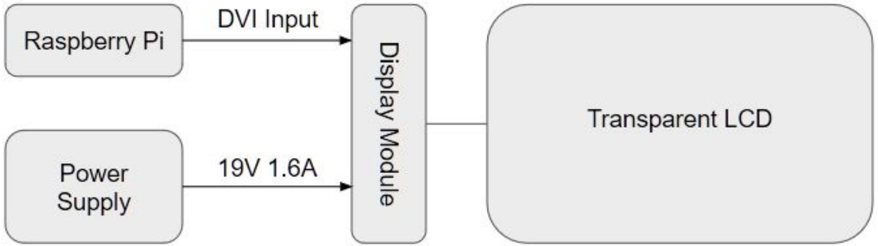
Positives: Display disassembly went smoothly, and the screen has thin bezels which will looks nice attached to the edge of the window frame. Transmissivity was very high.

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.

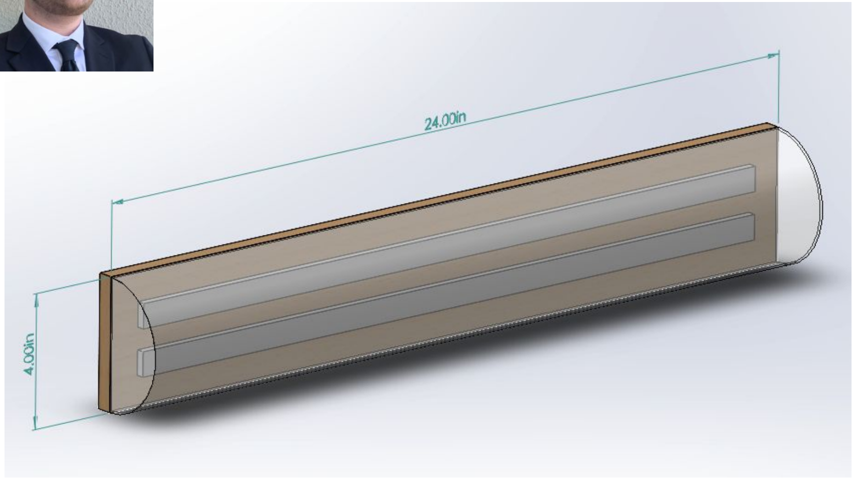
Average light transmitted through the display was almost exactly **48%**.

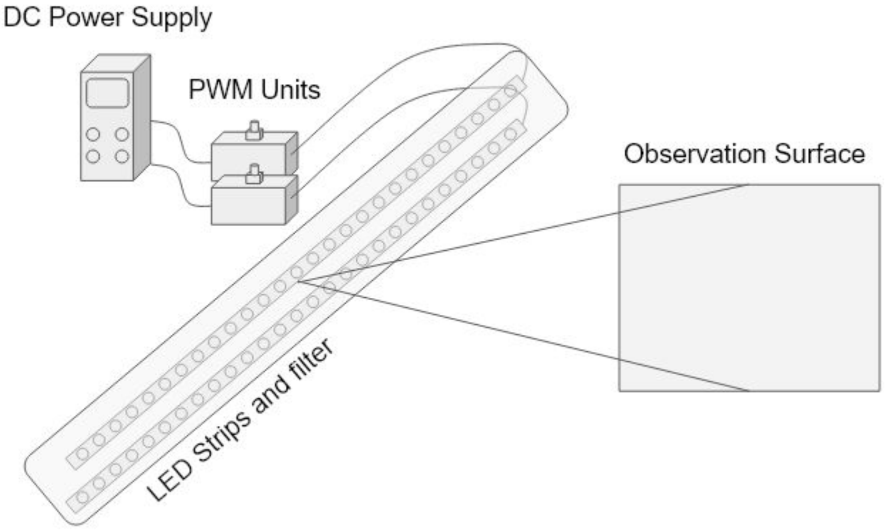
This is greater than the minimum 45% of the testing criteria, with a hypothetical maximum of 50% expected in an ideal case.

The main power supply will supply the same electrical characteristics of the AC to DC adapter which was supplied by the panel manufacturer, and the display signal will be supplied from HDMI output from the Raspberry Pi, to DVI input to the display.



Lighting Subsystem





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 will likely be modified to fit inside of this shortened form factor. One solution would be to cut the strips at 24”, leaving a partial strip of 12”. These two additional 12” strips from both the warm and cool colored LED could be attached in series to their longer original piece, and therefore the original output power could still be maintained.

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. As the LED subsystem is further developed, more testing with formal laboratory equipment will be done.

PDLC Testing

- Custom size PDLC film was ordered in mid-December and has already been delivered
- Basic testing of power supply and functionality
- Next steps
  - Apply film to glass pane
  - Test IR and UV transmittance
  - Testing results will be used to make a final decision on the implementation of a UV blocking film

[OFF State] - Opaque

[ON State] - Clear

PCB Testing

Sensors

- Sensors have been acquired but passive components are still shipping
- Testing will begin with assembling the PCBs and connecting power
- The MCU will need to be programmed via ST Link programmer
- When values can be read through UART to computer finalization or redesign of PCB will go into effect

Battery Charger / Voltage Regulators

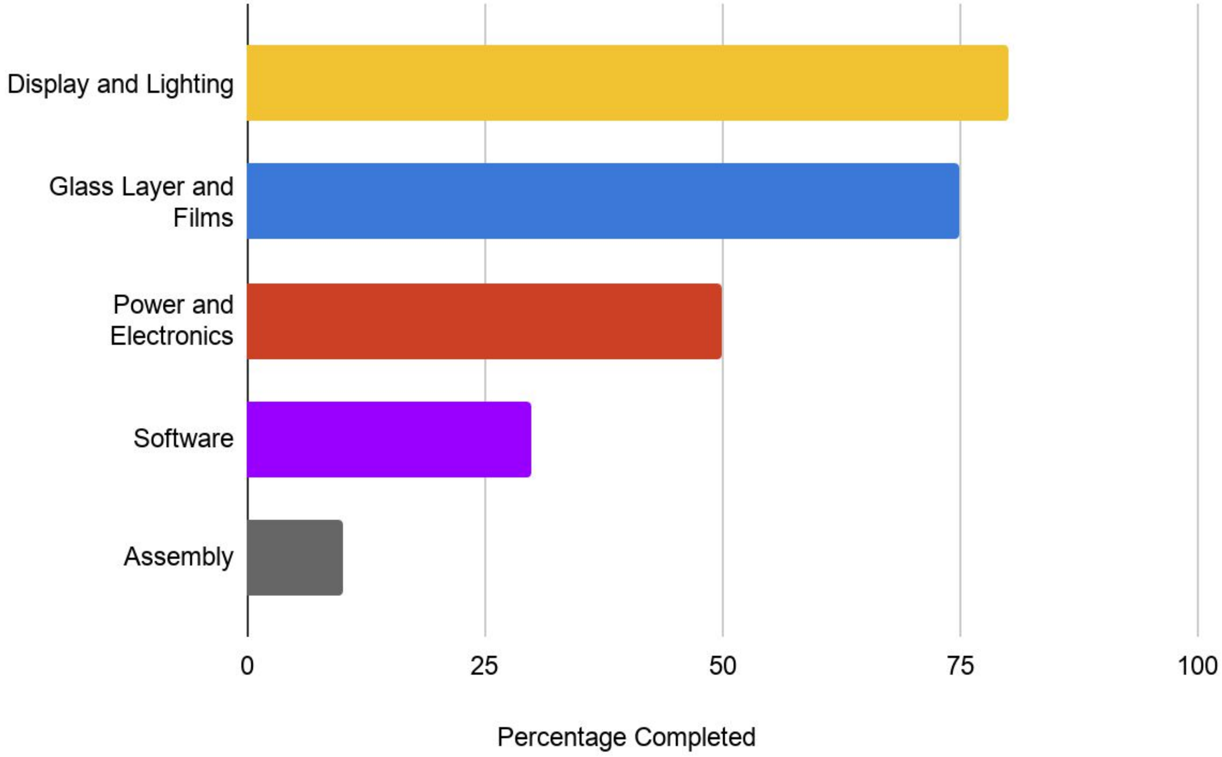
- PCB has been ordered
- Testing will begin with assembling PCB and connecting the 12V adapter and battery pack
- The input and output voltages and currents will then be measured
- Based on the results of the testing, a finalization or redesign of the PCB will go into effect
- Testing the voltage regulators will be as simple as measuring the output voltages to ensure they work as intended

Budget and Financing

- No sponsors
- Project is fully self-funded by team members
- Expected total contributions: $500
- Group is flexible in case more financing is needed

Expected Bill of Materials	Expected Cost (USD)
Window frame	<$30
Glass Pane	<$15
18650 Lithium ion batteries (x8)	<$40
Temperature/Humidity sensor (outdoor)	<$5
Temperature/Humidity sensor (indoor)	<$5
UV sensor	<$7
LED strips	<$25
LED Peripherals	<$25
PDLC Film	$225
Testing Products	<$50
Minor Electrical Components	$30
Shipping	<$50
Total	**$487**
Group Member Contributions	**$500 (Flexible)**

Smart Window Progress



The team feels that we are on track to complete the subsystems with enough time to assemble components into the final design.

Once all the components are tested and in-hand, we will be able to finalize the size of the Window's frame, and begin assembly.

Plans for Project Completion

- Finalize and Test PCBs
- Connect Subsystems
- Construct Frame and assemble
- Implement onboard software on desktop application
- Finalize mobile application
- Tune UI and features to enhance user experience.

Thank you for watching! - Smart Window Team