SkyLight Glass

Keep It Glassy ™

Group #13

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1. Executive Summary

One of the leading causes of high energy usage in houses is energy inefficient windows. Letting uncontrolled sunlight through heats the house causing the homeowner's air conditioning unit to expend more energy to keep the house cool. To keep houses cooler and more energy efficient, the direct sunlight needs to be blocked off.

Most windows use blinds and curtains to prevent unwanted sunlight. Blinds and curtains collect dust, are difficult to open, and often break. Additionally the blinds themselves heat up and since they are inside the house warm the surrounding area. A better method is to create a barrier that prevents most direct sunlight from entering the house while still allowing indirect sunlight to enter through windows that are not in contact with direct sunlight. Rooms with smart film have measurably lower temperatures compared to rooms that use traditional means of blocking out sunlight.

Blocking out the light creates another problem: the lighting in the house is obstructed. When the window becomes opaque, the light level within the room needs to adjust to compensate for the loss of natural light. This can be achieved through artificial lighting. Natural light in the room also affects the development of melatonin which helps regulate sleep cycles. To ensure the homeowner's quality of sleep is not impacted by the artificial lighting in the room, certain hues in the light must be removed. Considerations must also be made for homeowners that sleep during the day, allowing them to adjust light levels according to their sleep habits.

Multiple products already exist that use smart film technology in order to provide energy savings to homes and businesses as well as added privacy. Many of these products react to time of day instead of direct light impingement resulting in the entire building having reduced natural light levels. There are also films that may be applied to preexisting windows that rely upon solar energy to transition from transparent to translucent states. There are two types of smart film material: active and passive. Active smart film responds to user-provided stimuli (such as electric current) while passive smart film relies upon environmental stimuli (such as heat and UV radiation).

Many of the aforementioned products often do not offer the ability to adjust light levels in the room the window is attached to in response to reduced light levels entering through the windows. As the windows darken, internal light sources are required for homeowners to compensate for the lack of natural light. The homeowner must do this manually because existing products surveyed do not tie the window's transmissivity to interior lighting levels. The hue of the interior lights is also not tied to time of day resulting in light levels that are not conducive to melatonin production that aids in regulating sleep cycles.

Most smart film products have low power draw but also do not have to provide illumination of the interior room as described above. Any prototype that incorporated both of these features would have to be designed to operate on low power levels to maintain the cost savings from the reduced energy bills.

2. Project Narrative and Description

2.1 Motivation

The motivation for this project is to gain experience in the application of knowledge and skills acquired from the electrical and computer engineering program at the University of Central Florida. In addition, the project grants the opportunity to build interpersonal skills as will be applied in the field after graduation. By working with engineers of varying backgrounds, this project exposes the team to an environment one might find in the workforce: building the ability to effectively communicate with other engineers and project managers.

2.2 Project Goals and Objectives

The objective of this project is to develop a prototype window and lighting system that adjusts based on sunlight intensity and time of day to modify the transmissivity of the window. The prototype shall also adjust light levels and hues within the room the window resides in. To accomplish this, a smart window will be developed which adjusts light levels according to the environment and user inputs.

The smart window will be easy to set up and use. While a marketed product based on this technology would fit in a standard sized residential window, the prototype will be smaller scale for demonstration and cost purposes. The window will block most visible light when activated and will function within the normal range of temperatures for Central Florida. The LEDs shall automatically adjust their hues based on time of day to incorporate a range varying from warm to cool color temperatures. On top of adjusting their hue, the LEDs shall be able to illuminate a small bedroom. All light features of the prototype system may be manually adjusted by the user.

The goal of this project is to develop a prototype smart window that may be implemented throughout a homeowner's entire house that can detect and adjust window transmissivity based on light levels in order to increase energy efficiency of cooling systems inside the house to save money. The concept is that windows that are receiving direct sunlight will respond by turning translucent, blocking most heat and UV radiation that would pass through normally while other windows in the house that are not receiving direct sunlight will remain open to help increase natural light levels.

A software interface will be developed that allows the user to override the passive response to sunlight in order to keep a window open or closed and modify the hue of the LEDs as well as their intensity. In instances where the user does not have access to the software interface, a manual keypad will be integrated with the prototype.

2.3 Marketing and Engineering Requirements

Identified requirements for SkyLight Glass are listed in Table 2.3.

Marketing Requirements	Engineering Requirements	Justification
6, 7	Window dimensions: The window shall fit a frame of dimensions 12 inches wide and 12 inches tall.	Based on size needed for a demonstration prototype.
4	Visible light transmission: When opaque, system shall block at least 70% of visible light.	Based on existing smart window technology and material which can block at least this much.
2, 7	LED illumination: LEDs shall be capable of illuminating a 10 foot by 10 foot room.	Based on the size of a small bedroom; shall be in accordance with OSHA (Occupational Safety and Health Administration) standards for illumination.
3, 5, 7	LED hue: LED color temperature shall be capable of varying color temperature between 3000 Kelvin (reddish orange light) and 5000 Kelvin (blueish white).	In order for a human to produce melatonin for sleep, omitting blue hues from lights is beneficial. Range given is from lights with minimal blue components to light that is more similar to natural light.
1, 3, 5	System control: The window transmissivity, LED intensity, and LED color temperature shall be controllable by the user to match preferences within specifications listed.	Based on the need of the user to adjust light levels according to an individual's needs.

Marketing Requirements

1. The LEDs must be dimmable.
2. The LED at full power must be able to illuminate a small room.
3. The LED color temperature range should range from warm to cool colors.
4. The window must be able to block most light from outside.
5. System controls must be easy to use.
6. The system should be easy to install.
7. The system should have low cost.

Table 2.3 - Marketing and Engineering Requirements

2.4 House of Quality

Table 2.4 indicates the marketing requirements (y-axis) and how they relate to the engineering requirements (x-axis) and details the relative importance of each to help facilitate trade-offs and design.

Legend

→Marketing Requirements →Engineering Requirements

↑ = Positive correlation ↑↑ = Strong positive correlation

+ = Positive polarity - = Negative Polarity

↓ = Negative correlation ↓↓ = Strong negative correlation

		Tinting Efficiency	Cost	Installation Time	Dimensions	Power Consumption	Luminous Flux
Correlation		+	-	-	-	-	+
Lighting (LEDs)	+		↑			↑	↑↑
Effective Tinting Material	+	↑↑	↑			↓	
Dimming (LEDs)	+		↓			↑	↑↑
Hue Range	+		↑			↑	↑
System Control	+	↑	↑				
Installation Ease	+		↓	↓↓	↓		
Cost (Yearly)	-		↑↑	↑	↑↑	↑↑	
Targets for Eng. Reqs.		≥ 70%	< $1000	< 1 day	12 x 12 Inches	≅ 20-50 W (avg.)	≅ 1000-2000 lumens

Table 2.4 - House of Quality

Some of the polarities are negative. For example, the cost has a negative polarity indicating that, as cost of the item goes down, the desirability of the product goes up. For tinting, as the ability of the glass to block light goes up, the desirability of the product increases.

2.5 Block Diagram of System

As part of the initial design process, the team identified the major components of the final product. Each component was assigned to a team member based on that team member's proficiency as indicated in Figure 2.5.

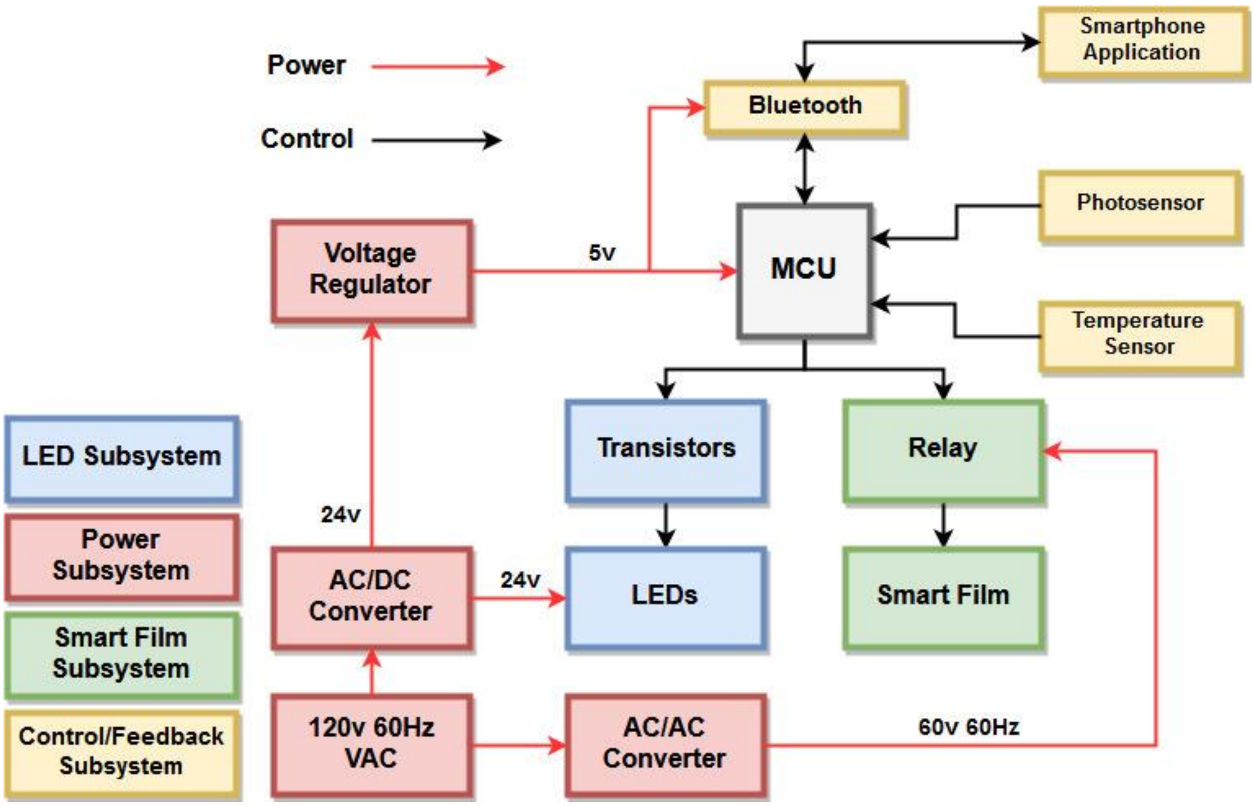


Figure 2.5 - Block Diagram of the System

2.6 Preliminary Sketches of the System

Concept drawings of the final product are included in Figures 2.6a and 2.6b. Figure 2.6a provides a concept drawing of the overall system from the outside and the lights as seen from inside the house. Figure 2.6b illustrates the control application for the window that will be provided to the user. The drawings are concept only and do not necessarily reflect the final product's design.

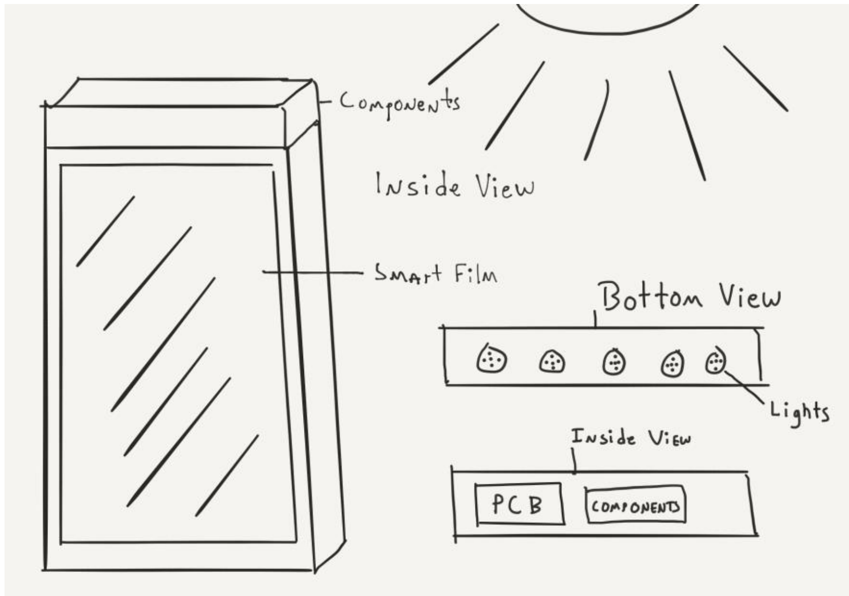


Fig 2.6a - Concept Window

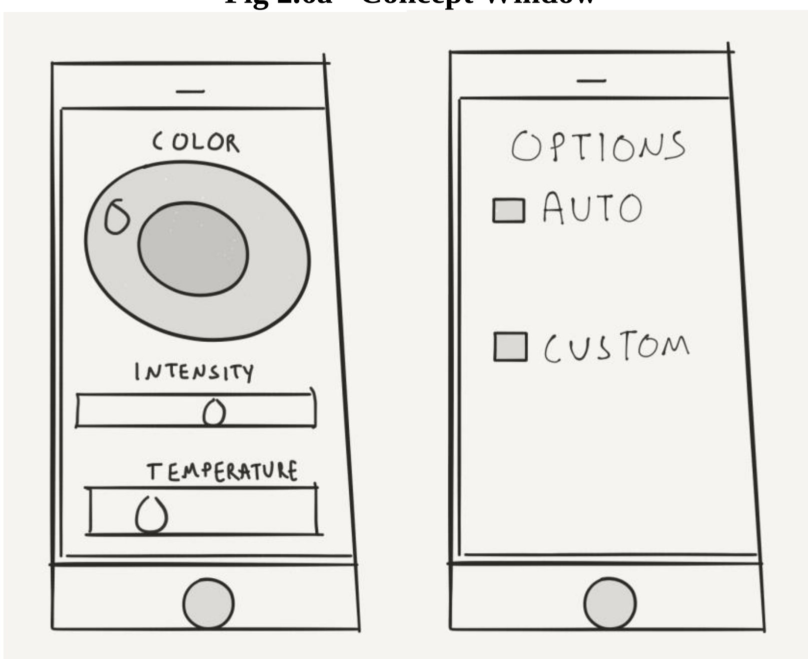


Fig 2.6b - User Interface Concept

3. Research and Strategic Part Selection

The purpose of the research and strategic part selection section is to identify products and technologies that meet the requirements and specifications set by the SkyLight system. Preliminary research was done to identify technology that is best suited for the purposes of the system. After the relevant technologies were identified and compared, the most capable technology was selected. Research was then conducted to find products that used the relevant technologies that could be implemented in the SkyLight system given the requirements in Section 2.

3.1 Related Technology

3.1.1 Smart Glass

Smart glass is separated into two categories: active and passive. In passive smart glass, outside stimuli provide the required means for the glass to transition between transparent and opaque (or tinted) states. Examples of such stimuli include heat and light. Active smart glass requires the user to supply an input in order to change states. The transition between states is normally triggered by an electrical stimulus.

3.1.1.1 Active Smart Glass

Electrochromic

Electrochromic smart glass technology is able to transition between opaque and transparent states when a voltage is applied to the material. After the voltage is initially applied, the material becomes more opaque. This transition is not instantaneous: requiring up to several minutes to properly transition from transparent to opaque states.

This particular smart glass makes use of two electrodes that move lithium ions back and forth across a separator. As displayed in Figure 3.1.1.1a, the electrochromic material is placed between two sheets of glass. Each piece of glass is placed in direct contact with a conductor. Both conductors are attached to ion storing electrodes and both of these layers are separated by an ion conductor in the middle. When a voltage is applied to the conductors, lithium ions move across the separator to electrodes on the side closer to the outside face depicted in Figure 3.1.1.1a.

When the lithium ions move across the separator to the electrodes nearer the outside face, visible light is impeded and reflected: thus causing the material to appear more opaque. Once the lithium ions move to the other side, the voltage source may be switched off. The material will remain opaque without the need to continually apply an electrical stimulus. This property of the electrochromic glass can be used to create states of variable transmissivity by implementing multiple electrode layers.

Electrochromic technology is capable of blocking a significant portion of ultraviolet radiation (up to 99%) to maintain cooler environments when applied to windows of a home or business.

This provides energy savings in the reduction of the amount of time the air conditioning unit must run to maintain a particular temperature that traditional blinds and drapes are unable to achieve.

While there is an advantage with electrochromic glass in that it requires only an initial input voltage to change states and remain in that state, this technology is best suited for application where a fast transition time is not necessarily desired such as in automobiles. One of the drawbacks of electrochromic glass is its transition time: taking several minutes to transition between the desired states. Another downside to electrochromic glass is the fact that it generally requires two solid pieces of glass to function properly. While electrochromic film is available to be applied to the outside or inside of existing glass, very few vendors carry the film variant as other active smart glass technology is more suited for film opposed to glass.

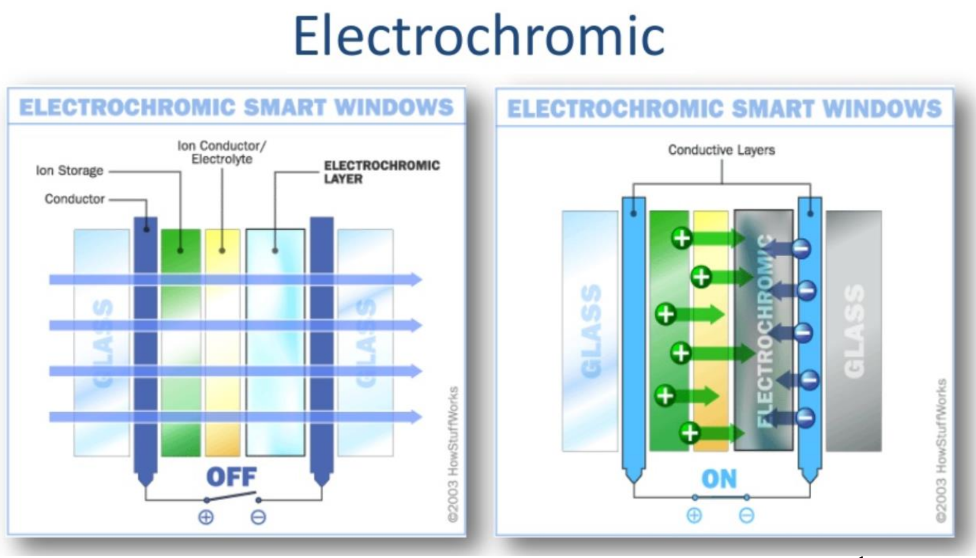


Figure 3.1.1.1a - Electrochromic Technology [*HowStuffWorks*[1], *2003*]

Polymer Dispersed Liquid Crystal (PDLC)

Polymer dispersed liquid crystal (PDLC) devices are another technology used in the smart glass industry. PDLC devices require the application of a constant voltage to the conductive coating in order for the device to exhibit a transparent state. The transition time between states is almost instantaneous: between 30 to 50 milliseconds.

In PDLC, liquid crystals are placed inside of a polymer before the polymer is solidified. During the solidification process, a reaction occurs that causes the liquid crystals to form into molecular groups throughout the polymer. These molecules of liquid crystals, shown in Figure 3.1.1.1b, determine the state of the device. When a voltage is applied to the conducting layers, the liquid crystals align in the same direction: allowing light to pass through. When no voltage is present, the liquid crystals become randomly arranged: reflecting and scattering light as it attempts to pass through the polymer.

PDLC technology can be applied to both glass and film to achieve varying degrees of transmissivity. Both the glass and film variants may be cut into a variety of shapes in a wide range of dimensions. Variable transmissivity may be achieved by varying the magnitude of the voltage which increases or decreases the strength of the electric field. At lower voltages, the applied electric field is weaker which causes fewer liquid crystal molecules to align. In this state, the liquid crystals that are aligned to the electric field allow light to pass while the molecules that have not been influenced by the electric field continue to scatter and reflect light.

The primary advantage of a PDLC device is its fast transition time between states. PDLC is also one of the most common smart glass and film technologies employed in the field: making acquisition of the material easier than other smart glass and film technologies. Another advantage of PDLC technology is its ability to block out up to 99% of ultraviolet radiation and a significant portion of infrared radiation. By applying this technology to a homeowner's windows and skylights, energy may be conserved as a result of the presence of cooler temperatures in the interior of the room or building the PDLC glass is attached to. Optimal results may be obtained when paired with a photosensor or programmable device.

In the case of a photosensor, the PDLC glass or film is able to become opaque when sunlight is directly incident on the sensor and transparent otherwise. By using an embedded system on the PDLC device, the PDLC glass or film may be programmed to become opaque during hotter parts of the day while remaining transparent during others. If an embedded system is implemented in conjunction with the PDLC technology, there is also a possibility to access the Internet to obtain temperature information for the current area and adjust transmissivity based on this information.

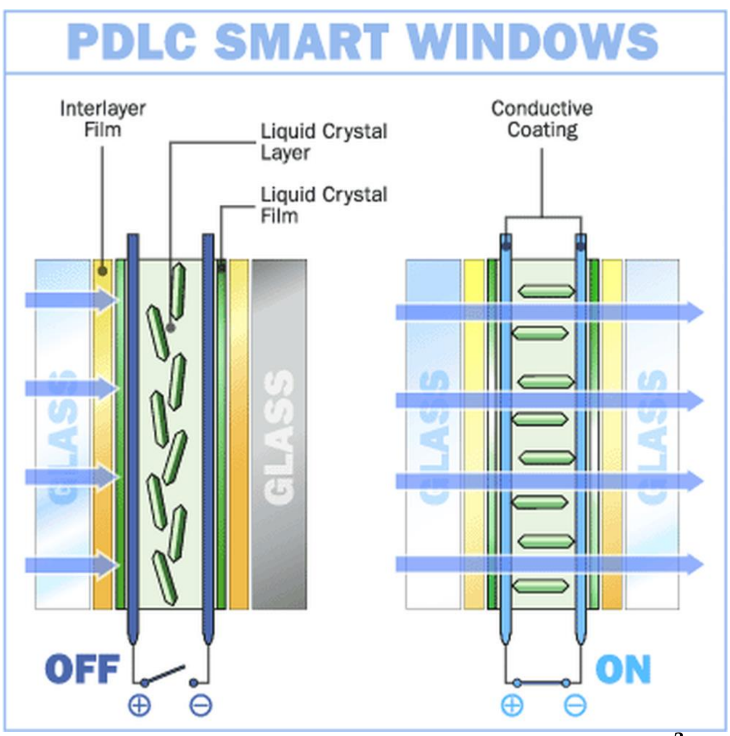


Figure 3.1.1.1b - PDLC Technology [*HowStuffWorks*[2], *2003*]

Suspended Particle Device (SPD)

Suspended Particle Device (SPD) technologies, initially patented by the public nanotechnology company known as Research Frontiers, are used in a variety of applications ranging from the automotive industry to the aircraft industry to personal use in homes. SPD technology may be controlled manually through use of a rheostat, wirelessly with a controller using a radiofrequency signal, or may take input from a photosensor and adjust transmissivity as a result.

In SPD technology, two pieces of glass are put in contact with two conducting layers. In between the conducting layers, a suspension film is used to hold the suspended particles as shown in Figure 3.1.1.1c. To change the transmissivity of the glass, a voltage is applied to the conducting layers which causes the suspended particles to align to let light through. By varying the voltage that is applied to the conducting material, the transmissivity of the glass may be altered to a specific level. When no voltage is applied to the conducting material, the suspended particles arrange in a random order: reflecting and dispersing light which causes the glass to become completely opaque.

SPD technology is capable of eliminating up to 99% of ultraviolet radiation and a significant portion (up to 50%) of infrared radiation. This allows for cooling of interiors that the SPD is attached to by up to 10° C. By providing cooler interiors, energy savings may be provided when the SPD technology is applied to the windows and surfaces in contact with outside light of businesses and homes.

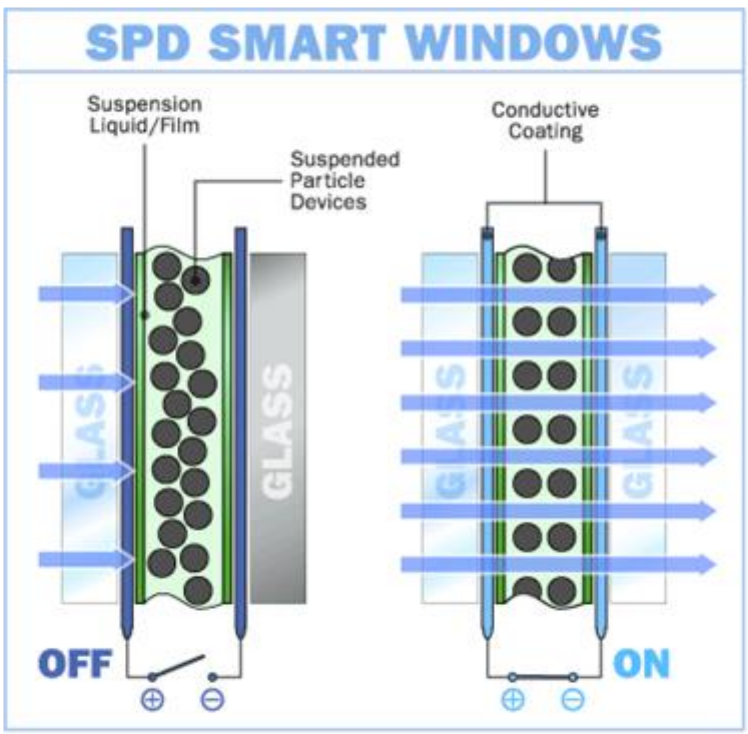


Figure 3.1.1.1c - SPD Technology [*HowStuffWorks*[3]*, 2003*]

There are several advantages to SPD technology. SPDs are able to transition between states in a matter of seconds. Not only are they able to switch between transparent and opaque states, SPDs enable for variable transmissivity by controlling the voltage applied to the conducting layers.

However, one of the major disadvantages for SPD technology is that the suspended particles require a container in the form of the two pieces of glass used to hold the conducting layers that are attached to the suspension film. While SPD film is patented and available on the market, there are fewer vendors that sell it compared to other smart glass technologies.

With SPD film, it is possible to change the transmissivity beyond the binary states of opaque and transparent. However it is often marketed as a binary film despite this. This is because the circuitry required to vary the specific transmissivity beyond the binary on and off values is surprising complex. It cannot be done with simple voltage reduction or pulse width modulation like LEDs or motors. A possible control system for varying the transmissivity can be seen in Figure 3.1.1.1d.

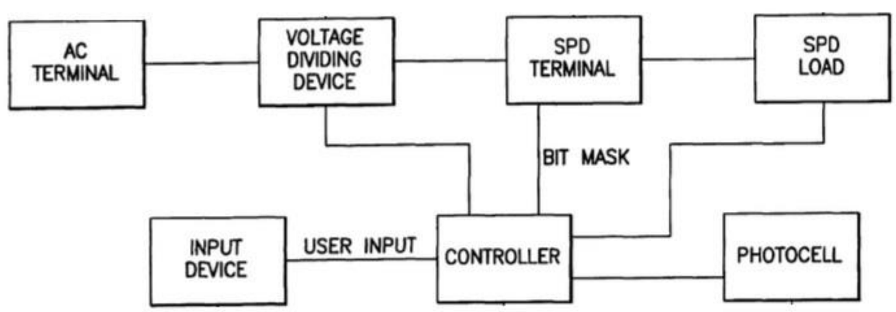


Figure 3.1.1.1d - Smart Film Variable Transmissivity [*Patent US6804040 B2*]

Since SkyLight is going to be able to produce its own light through the pulse width modulation controlled color temperature adjustable light emitting diodes there, isn't an immediate need to control incoming light through varying transmissivity. Allowing the light through also allows the heat through and defeats a major part of the purpose of the SkyLight system as an energy efficient device. Obscured sunlight doesn't create the feeling of an open space the way a window does. Additionally, many aspects of the capacitive control circuit seen in Figure 3.1.1.1e would have to tolerate the 60V and would be difficult to implement on a printed circuit board where special precautions have to be taken to handle that kind of massive potential difference.

Additionally, the already existing feature of variable brightness through artificial lighting negates many aspects of variable transmissivity. This leaves SkyLight with a binary film. It is then controlled by a single signal: off or on. Such a signal can be done by a single digital pin, however the microcontroller cannot supply the power or voltage required, nor can it supply any kind of alternating current. Because of this, a power transmission device will be used.

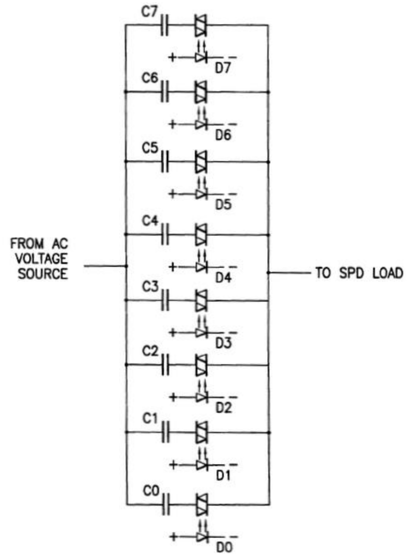


Figure 3.1.1.1e - Capacitor Array for Variable Transmissivity [*Patent US6804040 B2*]

Micro-blinds

Micro-blinds are a relatively new technology being developed by the National Research Council in Canada. One of the motivations behind the creation of micro-blinds is to rectify the problem of reduced lifetime (<20 years) in other smart glass and film technologies by using a metallic material. These metal micro-blinds are embedded onto glass through a process known as sputtering: the deposition of a source material onto a substrate by using high energy particles to dislodge the material.

The active mechanism that enables the micro-blinds to transition between opaque and transparent states is illustrated in Figure 3.1.1.1f.

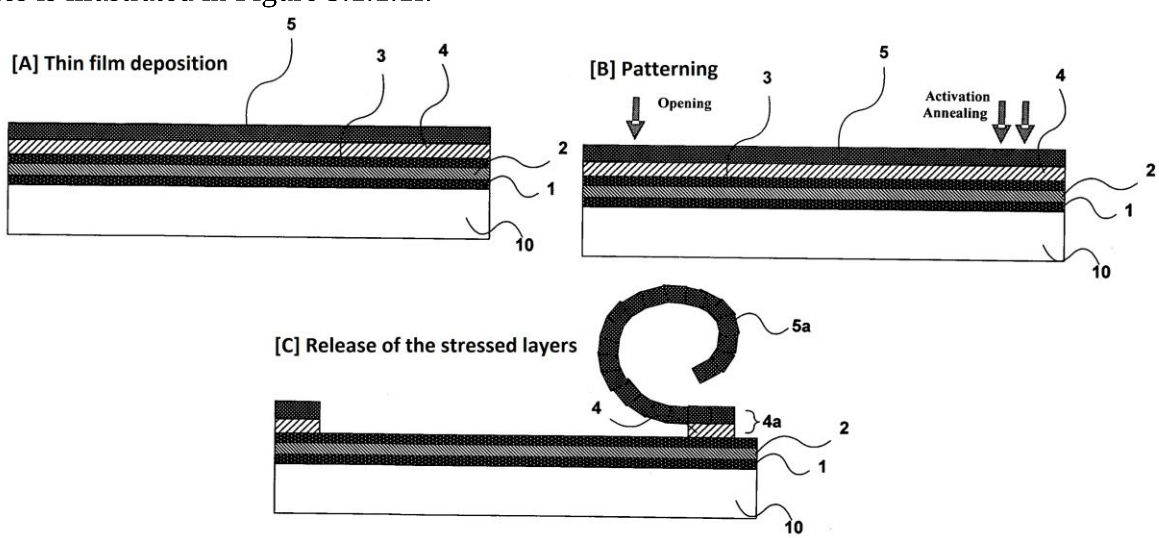


Figure 3.1.1.1f - Micro-blind Technology [*Microblinds, 2006*]

The sections of Figure 3.1.1.1f labeled A, B, and C represents the deposition process where thin metal is placed onto a substrate. The adhesive layer (labeled [1] in Figure 3.1.1.1f) in this instance is titanium-based. After the adhesive layer is set, the conducting layer [2] is applied followed by an insulating layer [3]. The insulating layer inhibits the current conduction between layer [1] through [5]. The layer that enables the micro-blinds to curl [4] is generally composed of silicon. The next layer [5] allows the micro-blinds to curl, exhibiting transparent and opaque properties. This layer is made of small electrodes (less than 100 micrometers across) and can be made to either permit light to pass through the substrate the micro-blinds are attached to or inhibit light and block both ultraviolet and infrared radiation.

After the thin film deposition process is complete as illustrated in [A] and described above, the micro-blinds are patterned by a laser as shown in [B]. After patterning is complete, the top layer [5] is released and anchored to the stressed layer [4]: enabling the micro-blinds to curl.

The electrodes in the micro-blinds are able to be curled through application of an electrostatic force (via the electric field) which allows or reflects and scatters light depending on whether voltage is present or not. When no voltage is applied, the micro-blinds remain in their curled state and allow light to pass through. When voltage is applied, the micro-blinds stretch back to the position shown in [B] and block visible light.

The main advantage of micro-blind technology is its fast transition times and increased lifetime compared to other smart glass technologies. By blocking a majority of the ultraviolet radiation (up to 99%) and infrared radiation passing through the glass that the micro-blinds are attached to, temperatures on the interior side of the glass are decreased. This reduces the need for indoor cooling devices to run as often and provides energy savings to the home or business owner. The major disadvantage to using micro-blinds is that, since it is a relatively new technology, very few vendors sell the glass. This technology is applied to glass and has not expanded into adhesive films as of yet.

3.1.1.2 Passive Smart Glass

Photochromic

Photochromic glass changes states based on the intensity of light incident on the glass. This particular glass is made in two different ways. In one method, a silver halide or silver chloride (AgCl) is embedded within the glass substrate. The glass substrate remains clear in artificial lighting. Another method for creating photochromic glass is to use an organic molecule (often called a photochromic molecule) such as naphthopyrans or oxazines. When the photochromic molecule is exposed to ultraviolet radiation, their chemical structure is changed but reversible as shown in Figure 3.1.1.2a. The oxygen atom’s bond, bound to the carbon configuration, breaks and is configured into the irradiated state as seen in the figure.

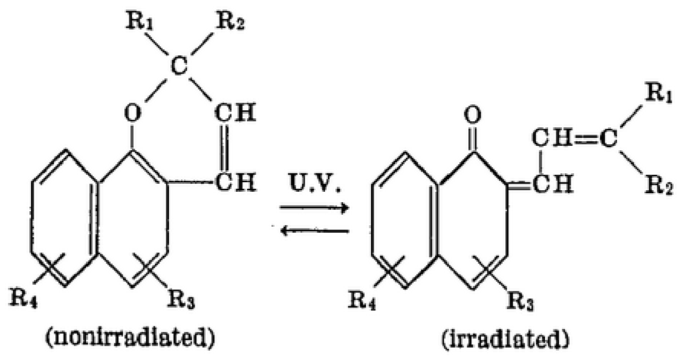


Figure 3.1.1.2a - Photochromic Molecular Structure [*Photochromic Molecule, 1971*]

When both types of glass are exposed to sunlight, the glass darkens depending on intensity. Generally, the transition between transparent and opaque states takes several minutes of exposure to ultraviolet radiation. As shown in Figure 3.1.1.2b, there are generally three states for the glass. In the transparent state when intensity of light incident on the glass' surface is low, both visible and infrared light are permitted to pass. When exposed to weaker ultraviolet radiation, the glass exhibits variable transmissivity and blocks infrared radiation while permitting visible light to pass. When exposed to high intensity ultraviolet radiation in the third state, the glass darkens and permits limited visible light while blocking all infrared radiation.

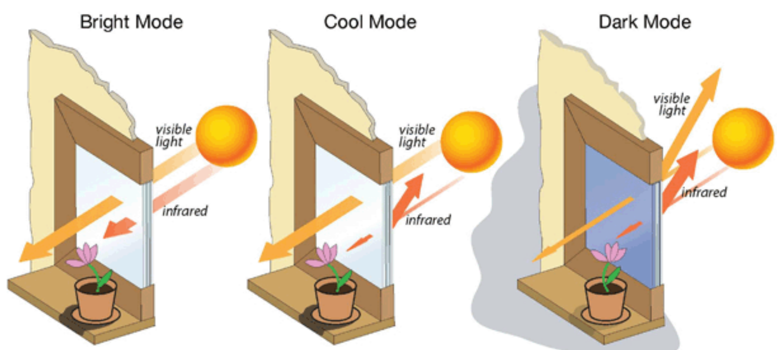


Figure 3.1.1.2b - Photochromic Technology [*Photochromic and Thermochromic, 2017*]

Given photochromic glass' slow transition time and lack of control over transmissivity, it is best suited for use in glass fitted for automobile windows or eyeglasses where it has been employed to great effect. Another disadvantage is that, even in its darkest mode, the photochromic glass is not 100% opaque and still allows light to pass through. It is important to note that the transition time between states is not equivalent: taking far longer to transition from the opaque to transparent state than the transparent to opaque state.

Thermochromic

Thermochromic glass is yet another type of passive smart glass technology that uses thermal stimuli to change states. It relies on the property of thermochromism: the ability of a material to change its color when exposed to varying temperatures. This technology is applied to glass through an adhesive film and is designed with energy efficiency in mind. When temperatures increase, the film becomes increasingly opaque until it reaches 100% opaque and turns white. Since the film becomes white, it is able to more effectively reflect and scatter visible light.

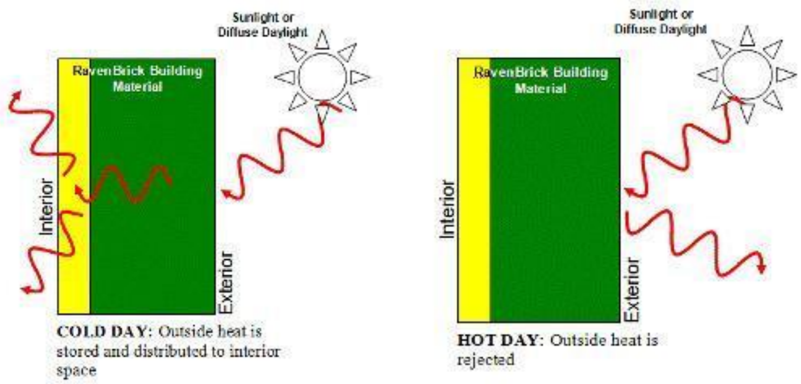


Figure 3.1.1.2c - Thermochromic Technology [*Photochromic and Thermochromic, 2017*]

Unlike many other smart film technologies, thermochromic film aids in heating the interiors the film is attached to when colder temperatures are present. Since colder temperatures cause the film to become transparent, ultraviolet and infrared radiation are permitted to pass which heat up the interior surface the film is attached to as demonstrated in Figure 3.1.1.2c.

The advantage of thermochromic film is its ability to provide energy savings in two ways. When temperatures increase outside, the film is able to block ultraviolet and infrared radiation from the interior it is attached to, thus preventing the indoor cooling systems from running longer as a result. When colder temperatures are present, the film is able to become transparent and heat up the interior it is attached to: preventing the heating systems in the interior from working harder than necessary. The disadvantage of thermochromic film is its inability to be controlled manually. Also, its tendency to become fully opaque means that visibility is lowered: making it a poor choice for a window intended for viewing out of.

3.1.2 Light Emitting Diodes (LED)

While the light emitting diode (LED) is considered a simplistic circuit element, SkyLight's design requires implementation of more sophisticated LEDs to achieve the range of intensities and color temperatures that are defined in the project's scope. The SkyLight LED must not only be able to change intensity through dimming but also must change color temperature to accommodate a variety of ranges to simulate natural sunlight. For this reason, it is important that all relevant LED technologies are considered

Before discussing the LED selection process that was undertaken, it is important to characterize the properties of light and how they affect an LED's output and differ from normal incandescent technology. The intensity of normal incandescent bulbs is correlated with how much power they consume (Wattage). Since LEDs dissipate very small amounts of power, the Wattage of an LED is not an accurate representation of its intensity. Instead, LEDs are measured using lumens which is the actual brightness emitted from a light source or LED. For example, a normal 60 Watt incandescent bulb is equivalent to 800 lumens. An LED of a similar lumen rating dissipates approximately 10 Watts of power. In this way, the efficiency of the LED light is highlighted: approximately 600% more efficient than its incandescent counterpart.

Another property of light that is fundamental to SkyLight's design is color temperature. Color temperature is defined as the temperature radiated from an ideal black-body by a light source of comparable color. Color temperature affects melatonin production in humans. As displayed in Figure 3.1.2a, orange and yellow colors ("warm") have a color temperature in the range of 2500K to 3500K while blue colors ("cool") range from 4500K to 5500K. At night when temperatures are considered "warm", melatonin production is facilitated by exposure to this warm light. On the other hand, sunlight exhibits "cool" temperatures during the morning and afternoon hours of the day which inhibits melatonin production when humans are exposed to it.

Color is normally defined by chromaticity coordinates represented by x and y on Figure 3.1.2a. Color temperature is used to determine the spectral power distribution of a blackbody radiator across these coordinates at a specific temperature in Kelvin. Correlated color temperature (CCT) of a non-ideal black-body radiator is determined by comparing the chromaticity coordinates of emitted light with an ideal black-body. In doing this, one value can be used to describe the color of light rather than two. This is the metric the lighting industry uses to describe LEDs.

When liquid crystal and LED technology was first invented and considered for application in smartphones, computers, and other electronic devices, the color temperature that these lights emitted was neglected. Standard computer and smartphone screens were assigned a color temperature that is similar to broad daylight. This has a negative impact on the human circadian rhythm as developers of these technologies have discovered. People who are on their devices late at night often have a hard time falling to sleep because of the constant exposure to color temperatures associated with broad daylight. [Color Temperature and Melatonin Production, 1996]

This has led to advances in algorithms and filters to subtract certain hues from the light of electronic devices to mimic natural light at specific hours of the day to facilitate proper melatonin production and normal circadian rhythms. LEDs can achieve differing color temperatures in multiple ways. The method that was selected for SkyLight involves using an LED strip with SMD technology as seen in Figure 3.1.2b [1]. On the 3528 strip, there are two sets of LEDs with two different color temperatures. One of the LEDs has a warm color temperature around 3000K and the other LED has a cool temperature around 6000K. By using the power supply unit (Figure 3.1.2b [2]) to step down the voltage to 24 volts DC, SkyLight will be able to activate one or both of the LED strips based on the voltage supplied. By activating them both at once, an intermediate color temperature is achieved and variable color temperature required by SkyLight may be demonstrated.

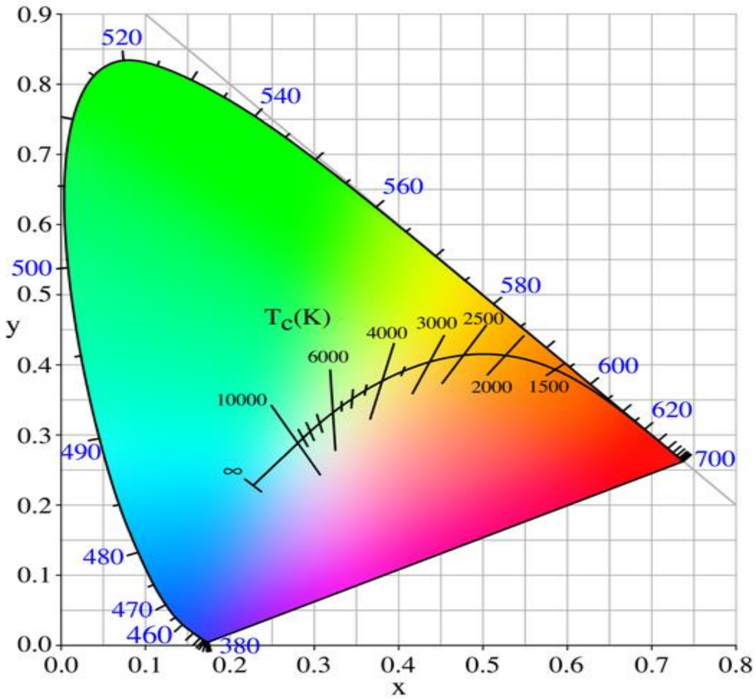


Figure 3.1.2a - Color Temperature and Chromaticity Spectrum

Another requirement of the SkyLight system is to modify the intensity of the LEDs. This will be achieved through pulse width modulation (PWM). In PWM, the LED is quickly turned on and off depending on the current duty cycle of the PWM signal. This is done at such a quick rate that the human eye cannot detect when the LED turns off or on. Instead, the apparent intensity of the LED is reduced or increased.

The LED PSU shown in Figure 3.1.2b is a lower power voltage (LPV) 20 Watt 24 volt 1 channel device. As shown in Figure 3.1.2b, the power supply takes the provided AC signal from an outlet (at 120v with a frequency of 60 Hz) and performs several transformations on this signal to make it usable by the LEDs which require a DC signal of 24 volts. First, the waveform is converted to a DC signal using a rectifier circuit. The frequency component of the AC signal is converted to a PWM signal at 100% duty cycle to emulate a DC signal. The overload protection (OLP) and over voltage protection (OVP) protect the circuit in case of irregularities in the signal.

To integrate the LEDs into the SkyLight system, a PWM signal will be sent from the microcontroller as demonstrated in Figure 3.1.2c. The PWM signals are generated by pin #12, #13, and #14. To control the rate at which the LEDs are turned on and off, two transistors will be used for each channel of the LEDs: one for the “warm” color temperature and the other for the “cool” color temperature.

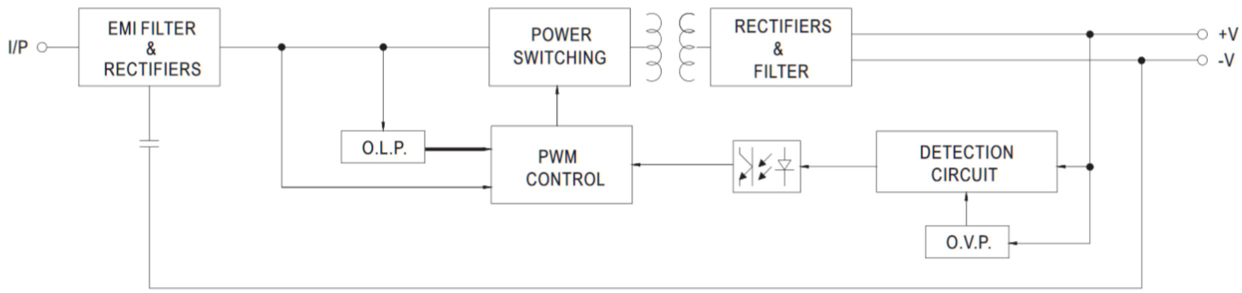


Figure 3.1.2b - LED Power Supply Schematic [LPV-20 Series by Mouser]

To prevent noise being generated by the system, all the elements will share a common ground. Noise occurs in the system as a result of a ground or earth loop: when multiple grounds are placed throughout a system that cause interference through extraneous currents as a result of electromagnetic induction. Either a metal oxide semiconductor field effect transistor (MOSFET) or bipolar junction transistor (BJT) may be used but ideally, for switching applications, a MOSFET is preferred.

While using a PWM signal generated by the microcontroller has many benefits, one of the downsides is that two channels of varying color temperatures may become out of sync due to the constant switching caused by differing duty cycles. This may create health problems as described in the Section 4 on LED standards.

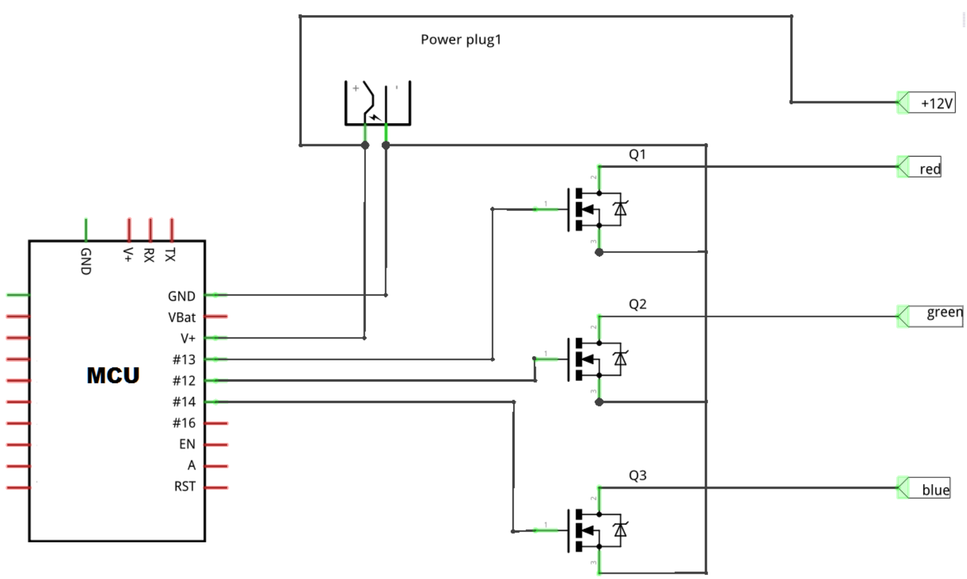


Figure 3.1.2c - PWM Signal to LED [*5050 SMD RGB, 2016*]

By programming the microcontroller to send a PWM signal to the LEDs by using analogWrite(), a value of 0 through 255 will be assigned to correspond to particular duty cycles. Based on the current duty cycle, the intensity of the LED will be adjusted. For instance, a value of 0 will correspond to a 0% duty cycle and the LED will be off. A value of 191 corresponds to a 75% duty cycle and the LED will be on but not at full intensity.

This method is described in Figure 3.1.2d using a 5v square waveform.

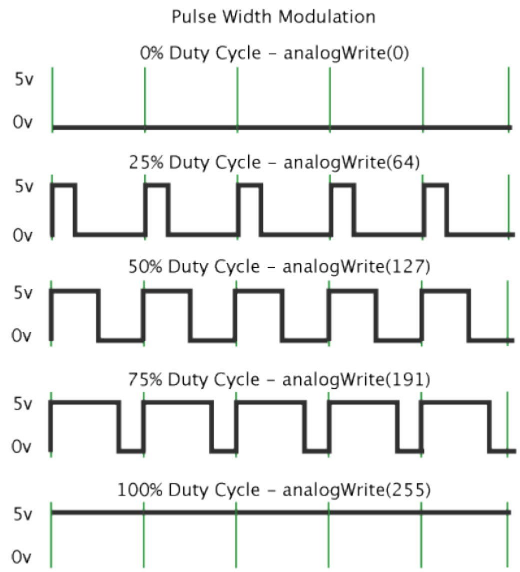


Figure 3.1.2d - PWM Duty Cycles [*PWM Duty Cycles*]

The LEDs will be placed on the interior side of the window. Based on the time of day, the color temperature and intensity of the LEDs will be modified by the microcontroller's program. If sunlight is directly impinging on the window, the window becomes opaque and the LEDs turn on. Based on the time of day, the color temperature and intensity is adjusted. For instance, in the middle of the day with direct sunlight hitting the window, the LEDs should be emitting cool light (5000K to 6000K) at full or near full intensity. When the sunlight is not directly impinging on the window during the day, the window becomes transparent and the LEDs are dimmed or turned off. There will be an option to reverse the day and night cycle for people who sleep during the day and are awake at night. Seasonal changes will also be considered. The user will also have the option to modify the LEDs manually through a keypad.

3.1.2.1 Dual In-Line Package (DIP)

Dual In-Line Package LEDs were developed nearly 60 years ago and are still used in a variety of applications today: serving as indicators for devices such as phones, modems, and power supplies or used in displays and signs. These LEDs have a traditional diode appearance and are generally placed onto through-hole printed circuit boards (PCBs) by soldering the two connecting leads. DIP LEDs are inexpensive to manufacture and generally measure less than five millimeters across. They consume very little power, up to 0.08 Watts [LED Technology, 2013], and may be activated with typical voltages (12v being the most common) used in many embedded systems.

There are several disadvantages to DIP LEDs. Their "intensity" generally ranges from only 2 to 4 lumens whereas a normal 60 Watt incandescent light bulb can produce up to 800 lumens. While manipulating the LED is relatively simple, its functions are limited. Controlling the rate at which it turns on and off, to a lesser extent, its intensity are the two parameters that can be altered. If color is desired, multiple DIP LEDs must be dyed to achieve this. The fact that they are mainly soldered to PCBs for use and have a low lumen rating also means that they are not a good choice for external applications. Due to how DIP technology was developed, a case must be used to contain the LED, normally made of epoxy, which prohibits the viewing angle of the LED substantially. Common viewing angles for DIP LEDs range from 45° to 60°.

3.1.2.2 Surface Mounted Device (SMD)

Surface Mounted Device LEDs are generally smaller in size compared to DIP LED technology and are capable of producing higher intensities that are desired in lighting applications. These chips are mounted on PCBs and thus have no leads like the traditional diode. Unlike DIP technology, they have a very wide viewing angle since DIP technology uses an epoxy shell to incase the LED: constricting its viewing angle since LEDs are designed as directional, focused beams.

As shown in Figure 3.1.2.2, SMD LEDs are often placed on strips of PCBs and come in a variety of sizes. The numbers next to the SMD indicate its size and the most common sizes for strips are 2835, 3014, 3528, and 5050. The number directly relates to the dimensions of the SMD LED. For instance, the 2835 SMD LED has dimensions of 2.8 millimeters by 3.5 millimeters and the 5050 SMD LED has dimensions of 5.0 millimeters by 5.0 millimeters.

SMD LEDs produce minimal heat, require low voltage and current to operate, and consume little power. They can produce up to 100 lumens per Watt making them ideal for lighting. SMD LEDs may be placed in rows next to each other with varying RGB values to produce a variety of colors. The viewing angle of a SMD LED generally ranges from 90° to 120°. Due to its energy efficiency due to lower voltage and current draw, SMD technology has a longer lifespan than the average LED. The primary disadvantage of SMD LEDs is its high cost compared to other LED technologies and incandescent lights.

Two SMD strip sizes were considered for this project: 3528 SMD and 5050 SMD LED. The 3528 SMD LED considered is more cost effective as it is smaller but lacks the ability to control an entire color range. Three color temperatures are able to be produced from the 3528 SMD LED strip. On the other hand, the 5050 SMD LED strip, while more expensive, can achieve all RGB values. Since one of the features of SkyLight is to not only vary color temperature but color hue, the 5050 SMD strip is the strongest contender for use in this system.

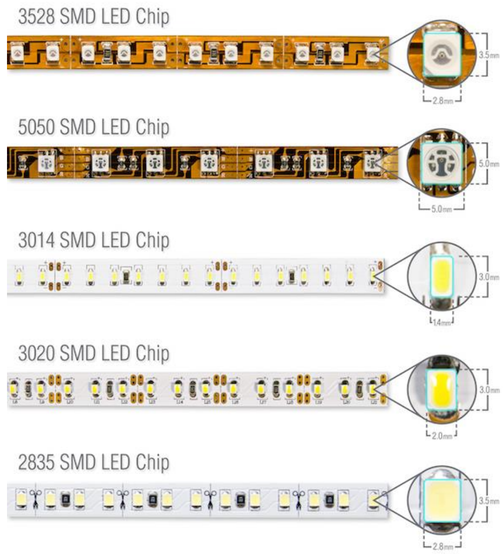


Figure 3.1.2.2 - SMD LED Strip [*SMD LEDs, 2017*]

3.1.2.3 Chips on Board (COB)

Chips on Board LED technology is similar to SMD LED technology in that COB LEDs contain multiple diodes on the same chip. However, COB LEDs differ from SMD LEDs in that they have many more diodes on one chip. This provides for a higher intensity and simplifies circuit design because COB LEDs are controlled as a group rather than individually. COB LEDs are often used in applications and devices that require high intensity but simplistic circuitry such as in flashlights, electronic flash units in cameras, and spotlights. A typical COB LED can produce up to 3000 lumens.

However, the high intensity can be problematic if normal lighting is desired. The fact that COB LEDs function as a single circuit also provides problems in applications where differing LED colors are desired. COB LED technology trades versatility for high efficiency, low power consumption, occupation of less space, and longer lifetimes. Cost is also prohibitive compared to DIP, SMD, and incandescent lighting technology.

3.1.3 Power Supply Concepts

As a general rule of thumb, different components might have different power supply needs. It's often the case that different circuits and components work at different voltages for logic or just for power. Power supply is an inherently important factor as incorrect power supply, either high or lower than needed, can cause catastrophic failure of components or otherwise poor performance of electronic systems. While things like motors are robust to excess power, microcontrollers are not.

Since all power for SkyLight is taken from the outlet, it must be robust to both 110v AC and 220v AC sources. The most common component that does this is a full power supply, which most commonly consists of step down transformers which reduces the voltage to usable levels and a diode rectifier circuit to convert the AC into DC. With the help of some capacitors, the rectified voltage becomes even DC voltage. Of course, if there isn't a need to change from AC to DC then simple voltage regulators will work. In their simplest form they consist of a resistor in series with a diode, though modern voltage regulators are more sophisticated. [Kitronik]

Several of the components have different power requirements. This means that multiple stages and kinds of power supply are needed to power all of the components. Below you can see the primary power needs of SkyLight Glass.

Component	Required Input
Microcontroller	5v DC
Light Emitting Diodes	24v DC
Smart Film	60v AC

Table 3.1.3 - Power Requirements

Despite this challenge, there is still some convenience though: each needed power is different enough where we can easily have multiple stages of power supply. For instance:

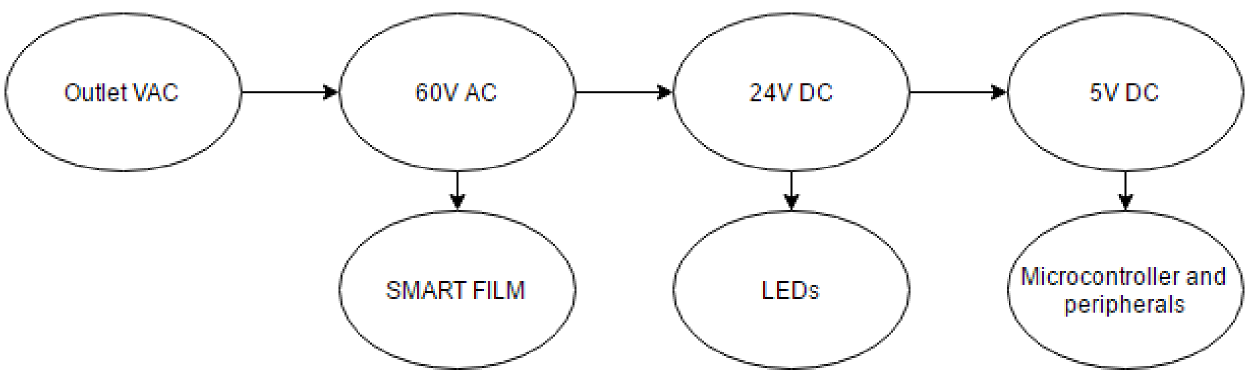


Figure 3.1.3a - Power Distribution to System: Method 1

To do this SkyLight Glass will need several different power converting devices. This includes: a device to convert from Outlet VAC to 60v AC, from 60v AC to 24v DC, and from 24v DC to 5v DC. The Smart Film includes a power supply which converts the VAC into 60v AC.

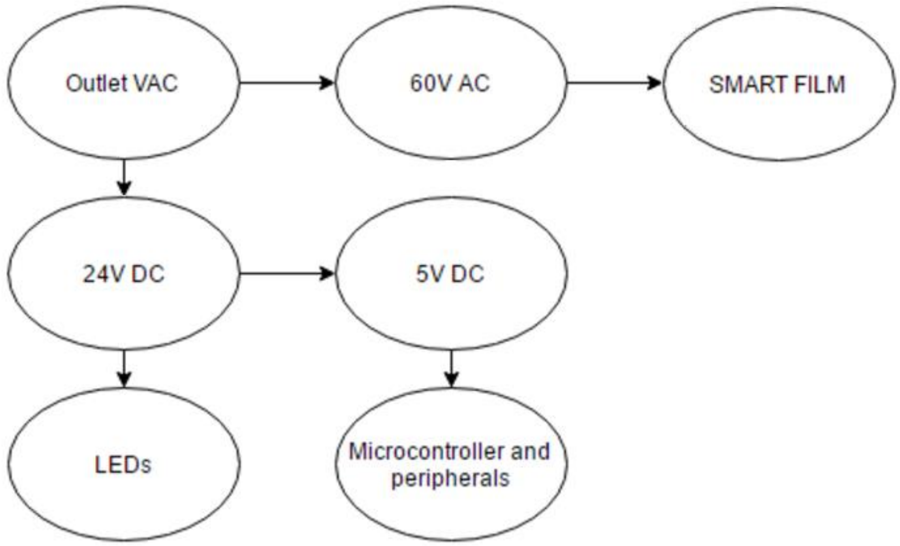


Figure 3.1.3b - Power Distribution to System: Method 2

Since only the 60v AC adapter is included, Skylight next needs to take that 60v AC and convert it to 24v DC. There are two main commercially available options to do this: a voltage regulator or a power supply. Most voltage regulators require a DC input, so a Power Supply becomes the most preferred option. This changes the stages of power supply:

Finally the SkyLight needs to convert 24v DC to 5v DC. This can easily be done through a voltage regulator. In general a TO220 sized voltage regulator would be desired, since the small size makes it easy to put on a PCB. An example schematic can be seen below:

3.1.4 Power Control

Even with power supplied to all of the components, that power needs to be controlled. The microcontroller needs a way to activate the components. The Smart Film is binary in that it only needs to be turned on and off, and not dimmed. Meanwhile, the LEDs will require two different PWM signal to control, each PWM signal controlling a separate specific kind of Light Emitting Diode (one to warm, one to cold).

There are two main types of power control that are useful in this context: transistors and relays. Transistors are specially doped semiconductors that turn ‘on’ if voltage is applied to the proper pin, allowing current to flow from one of the other pins into the last pin [StackExchange, 2011].

There are two main types of transistor available to SkyLight: Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and Bipolar Junction Transistors (BJTs). In a through-hole size BJTs are cheaper and more widely available, but they don’t tend to handle high voltage, high currents, or high power, and they generally have undesirable frequency responses compared to MOSFETS. MOSFETs are generally superior to BJTs, especially since the current the microcontroller would need to provide is generally considered insignificant. Both BJTs and

MOSFETs tend to only work one way - that is, they would not work with AC without additional support circuits. [DifferenceBetween, 2011]

MOSFETs were first invented by Bell Labs in 1959, specifically by Dawon Kahng and Martin Atalla as a variation to the existing field effect transistor design. Unlike other field effect transistors at the time MOSFETS didn't generate localized electron traps. MOSFETs are one of several things that eventually led to the photolithographic revolution which would come to shape modern civilization. [Wikipedia Contributers, 2017]

MOSFETs traditionally have three pins: the GATE, the SOURCE, and the DRAIN. The MOSFET acts as a switch with the GATE being the control input. In an N channel MOSFET the SOURCE is traditionally ground and the DRAIN is traditionally the lead. Current can only flow when the Gate-Source voltage is above a certain point. This voltage is frequently also referred to as the threshold voltage or the turn-on voltage. [Wikipedia Contributers, 2017]

Unlike MOSFETs, relays work well with AC. Relays generally work well with higher power, voltage, and current than MOSFETs as well. Relays are not as instantaneous as MOSFETS though, which makes PWM a thing of dreams and not reality. Relays work by using an electromagnetic switch. That is to say that the relays are also a physical switch, which is why they can handle so much more than MOSFETs. Power provided by the microcontroller activates an electromagnet which forces the switch closed. When the power is not provided a spring forces the switch open. [RB7]

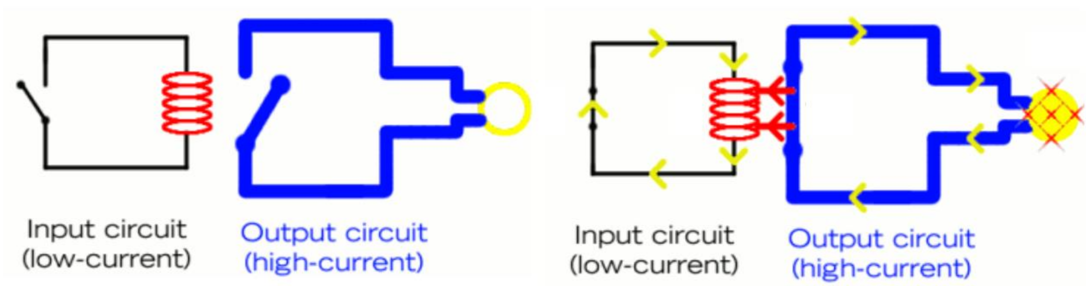


Figure 3.1.4a - Relay Functionality [*Relay Functionality, 2017*]

Relays often have a transistor, most commonly a MOSFET integrated into them. This is because the electromagnet, while efficient, still can draw more current that many microcontrollers should supply. The relays themselves come already on a PCB breakout board, and the circuitry is already in place. The relay will then take an input of VCC (most commonly 5v DC), Ground (for the microcontroller), control signal, and the AC voltage source. [RB7]

Ultimately, the two LED controls require the same thing: good frequency response and near immediate switching to support it. They also require 24v tolerance, and at least a 4 amp rating (100 watts). Once again there are many options available. The two most sensible ones are MOSFETS and BJTs, but BJTs have trouble keeping up with the frequency response and the amperage. Additionally 100 watt MOSFETs are fairly abundant.

For both consistency and ease of use, a TO220 sized MOSFET would be ideal. As it happens, several IRF3034L MOSFETs are available to SkyLight. IRF3034L MOSFETs also are well over 100 watts, 24v, and 4a, and have the desired frequency response. 3034 MOSFETs are also very common and can be found in plenty of places outside if SkyLight ever needs replacements or additional MOSFETS. While IRF3034L MOSFETs can properly be called overkill in this situation, their increased availability for the SkyLight team makes that despite this they are still the most budget friendly choice. And since the TO220 size components aren't too space consuming for the SkyLight there really isn't a good reason not to use this MOSFET, even though it's much stronger than necessary.

The Smart Film requires 60v AC, so a MOSFET (or any transistor) probably isn't a good idea. Instead, a relay is a much better option. While frequency response is virtually non-existent, that's okay since the Smart Film is binary - it only needs to be turned on and off.

Figure 3.1.4b - Two Relay Module

A relay for the Smart Film would have to be able to supply 60v AC at 33.4 milliamps, be able to handle at least 1 watt, and have be compatible with the microcontrollers 5v logic. While there's a number of products capable of doing this, it's most convenient to get one from a source we're already ordering from.

Right now, options for ordering (without incurring a new shipping charge) are Amazon and adafruit. All of the relays on Adafruit are already mounted to a PCB, making them unsuitable for SkyLight. This leaves Amazon as the only potential from SparkFun source for a relay. Thankfully there are several multichannel relays rated for up to 250v and 10a, most of which have a 5v turn on voltage, which is perfect for SkyLight.

Specifically SkyLight will use "SunFounder 2 Channel DC 5v Relay Module with Optocoupler Low Level Trigger Expansion Board" which accomplishes all of the above goals and also allows the SkyLight to individually control each piece of Smart Film, should the user decide that they want to do that. [Amazon - SunFounder]

3.1.5 Light Control Considerations

Providing energy efficiency to a household is one of our primary goals, shutting the blinds results in lower power consumption since the temperature stays cooler and the A/C unit does not run. However, it comes at the cost of losing indoor lighting an issue that can be resolved by providing artificial lighting conditions which a user can control. Is worth mentioning that this tactic would only work for warm places that require cooling but for cold places it might be beneficial to do the opposite all of which should be configurable from our system. For the absence of user interaction, we want our system to automatically match the outside lighting conditions to better aid sleep rhythms. There are different ways of managing this task, we can utilize the internet to acquire information about the weather, time, a light sensor or a combination of each with different advantages. For times when the A/C is required to cool the indoor temperature, the first approach would result in energy savings but for a cold place that requires heating leaving the blinds open so that the heat of the sunlight is allowed to come in would result in better efficiency.

3.1.5.1 Sunlight

For our purposes of recreating lighting conditions the main driver of outdoor lighting is the sun. To better understand how to recreate outdoor lighting conditions and how our system could reduce power consumption we must understand how our primary energy provider in the universe, the sun works. The sun emits two different types of energy: one caused by plasma and the other radiation. [*Berkeley*] Plasma, which the sun is composed of, contains ions, electrons, neutral atoms and usually stays a part of the star unless there is a disturbance in its magnetic field which could result in a flare. Solar radiation is the part we are concerned for our project since it is the energy that produces heat.

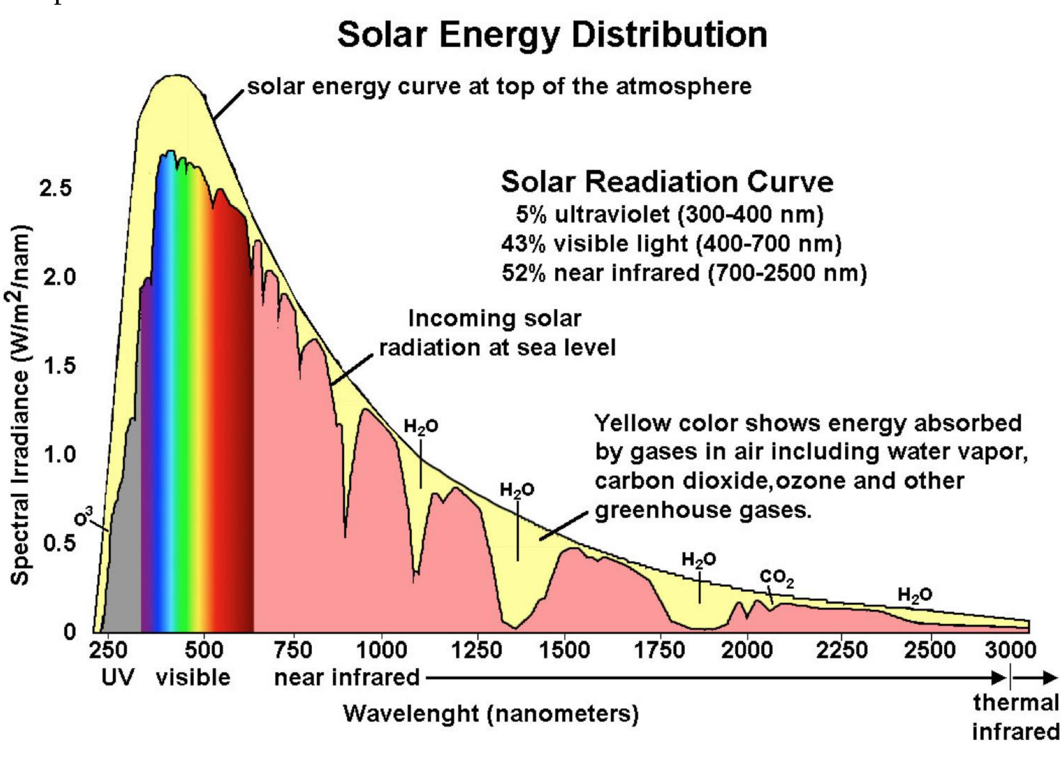


Figure 3.1.5.1 - Solar Energy Distribution [*Oceanography*]

It manages to do this by resonating with the molecules that are in found in the object which are always suspended in the surface and the radiation makes it vibrate similar to how a microwave heats up food. Thus, sunlight is a part of the electromagnetic spectrum being comprised of infrared waves (IR), visible waves, and ultraviolet. Having this understanding can better allow us to deliver the proper solution for our system that will come from its programmability. This knowledge will come in handy because we have a way of shielding most of this radiation. However, is necessary to understand it in order to properly employ for the best result in energy efficiency.

3.1.5.2 Internet Data

One approach could be acquiring data conditions over the internet which means that we can part ways with having a physical sensor. This can be a pro when designing the PCB since we would not need to incorporate a sensor into our design. The main issue with this route would be that we would need to add a WIFI module to gain access to the internet. This can impact the energy efficiency of the project since WIFI consumes more energy than a Bluetooth device.

Another complication is losing internet connectivity, at which point the ability for a device to acquire the data is compromised and so is our ability to control conditions. This issue can be bypassed altogether by simply utilizing time and having a preprogrammed set of lighting conditions by the time of the day. Although, an advantage to adding a WIFI module to our board could mean that given all conditions are working properly we can have access to temperature over the internet, this is a big component of determining what our system should do to ensure conditions are optimal for energy savings. Not having access to the internet could signify having to add a thermostat to the system. The importance of having temperature information is critical in order to determine whether the home is being cooled or heated. Since there is not a one size fits all condition that will give the user the best energy saving conditions.

3.1.5.3 Light Sensors

Using a light sensor, incorporates a physical device that retrieves real time information that can be utilized to then control our light color temperature based on the intensity. There are many sensors able to acquire lighting conditions, such as photoresistors, phototransistors, photodiodes all based on the level of background light intensity and inexpensive for the most part. There are other more precise sensors that measure multiple waves to determine light intensity which can be more precise but at a higher cost. Also, since they are more precise that signifies they require access to an I2C pin in our chip for communication which we might not have available since we are communication with other devices. The simpler devices are simply read using an analog pin to measure changes in voltage that correlate to a specific intensity of light.

Photoresistor

Photoresistors are sometimes referred to as a light dependent resistor and can be utilized as a light sensor since its resistance varies with respect to light. Photoresistors are built to a specific wavelength, usually around 528 nm. As the light intensity increases, the resistance of the device decreases. This is a very simple and inexpensive device which makes it desirable. However, the downfall for this option is that these devices tend to be is not very accurate.

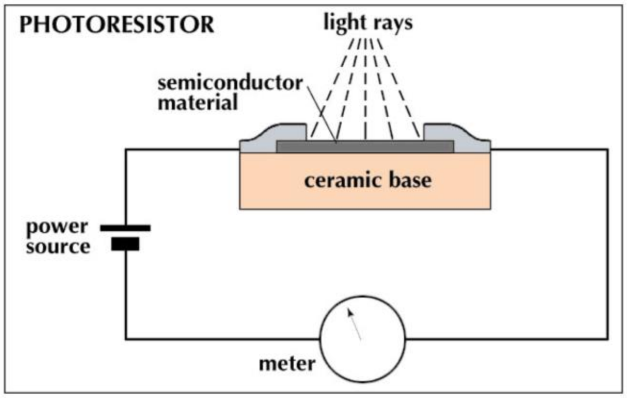


Figure 3.1.5.3a - Photoresistor Functionality [*Nilza*]

Phototransistor

A phototransistor is built from a bipolar junction transistor with the exception of having the base region exposed to light. A regular transistor has three pins the base, collector and emitter. The base controls the flow of current from the collector to the emitter but in this case the base is left exposed to light which controls the flow of the current based on intensity.

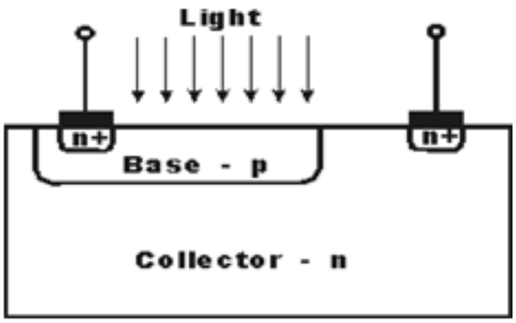


Figure 3.1.5.3b - Phototransistor Functionality [*ElProCus*]

This device is desirable for the team since its accuracy can be modified by simply alternating the resistance in the circuit until reaching a desired working level. This device is very inexpensive which also allows the team to stay in budget. Another point that makes a phototransistor suitable is its simplicity and through-hole construction that will allow the system to be built with ease.

This circuit is very easily built and incorporated to the main system to perform its desired task. Although, this system is quite simple it does not represent a setback but rather a major gain. Such a simple system can be easily tuned by swapping the resistor to enable it to read the lighting condition it will be picking up from outside. Having a simpler subset of systems allows for a simpler incorporation later that will greatly aid the team by saving time and money.

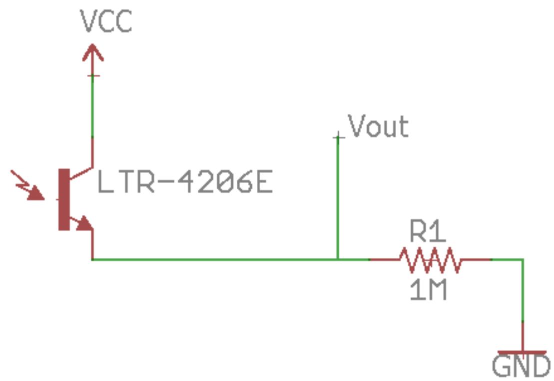


Figure 3.1.5.3c – Phototransistor Schematic

This output (figure 3.1.5.3c) will be connected to one of the analog to digital converters in the microcontroller once it is incorporated with all the major systems.

LTR-4206E

Manufactured by Lite-On, the LTR-4206E is a phototransistor and works as such to provide a way to sense light. This device is adept to our project because it can be reconfigured by simply varying resistance in order to change accuracy of the readings. This device has almost no downfalls and the price at $0.46 makes this unit desirable because the team is concerned with keeping the budget in check. Another feature going for this unit is the that is through-hole construction makes it favorable to ease the construction of the main board at a later point.

Feature	Specification	Additional Information
Voltage Breakdown	30 V	Much higher voltage than supplied is an advantage.
Collector Current	4.8 mA	The sensor must be cared not to exceed this current.

Table 3.1.5.3a – LTR-4206 Information

PDV-P8103

The PDV-P8103 is a photoconductive photocell (photoresistor) manufactured by Luna. This device comes at a cost of $0.89 which is considerably inexpensive for the allocated budget of the team. Also, this is a simple two pin device that can make construction much simpler for the team. However, the downfall of this device is that it has a very low accuracy that cannot be improved past 33K Ω that produce readings up to 100 lux. This is not acceptable for our needs since a cloudy day still puts out 80,000 lux.

Feature	Specification	Additional Information
Power Dissipation	100 mW/°C	Low power dissipation keeps system cool
Collector Current	4.8 mA	The sensor has to be cared not to exceed this current.

Figure 3.1.5.3b – PDV-P8103 Information

PT12-21B

The PT12-21 B is a phototransistor with high sensitivity and right angle lens manufactured by Everlight. This device has a high photosensitivity with a very fast response. This device has many features that make it desirable while maintaining a low cost at $0.40. The downfall of this device is that is surface mount and the team wants to steer away from this direction unless is absolutely necessary. Another negative for the purpose of the project is that this unit is side view thus it has to be looking directly at the source, which might not be suitable.

Feature	Specification	Additional Information
Voltage Breakdown	30 V	Much higher voltage than supplied is an advantage.
Collector Current	50 mA	The sensor has to be cared not to exceed this current.

Figure 3.1.5.3c – PT12-21B Information

3.1.6 Temperature Considerations

For our system, the film is the mechanism that serves as a barrier for controlling how much sunlight is allowed inside, which is how we impact energy savings by modifying the conditions and implementing what would be most beneficial based on the conditions. For most of the year in central Florida we have warm conditions that require cooling a home which is about half of where the electricity is spent and for those conditions our system would block outside lighting and simulate the light conditions indoors. However, for the times of the year where a home requires heating we need to allow the light to come indoors to keep the household warmer and avoid heating it.

Although there are specific months where temperatures are colder our system must be able to automatically detect via current condition basis which method would result in the best power savings. For us to be able to implement such a system we need to measure what the temperature outside the household is which could be done either via the internet or a temperature sensor.

As discussed above, the energy consumption of the system itself must be considered and thus having a Wi-Fi module on our circuitry would result in much higher energy consumption that we want to stay away from leaving it up to a temperature sensor would be the next best thing.

3.1.6.1 Temperature Sensors

Temperature sensors are quite common in modern electronic devices, since having this information is crucial for so many different tasks. In our case, our system must have the information in order to have a larger impact in our main goal. An advantage of using temperature sensors is that given their necessity there are many choices and price points giving us the ability to select a device that meets our goals and fits our budget.

Contact Temperature Sensors

As stated by their name, these sensors require to be in contact with the medium that is being measured. This type of sensor offers temperature changes by measuring the conduction, for our purposes this device would not work because it makes integration much challenging since it needs to be in contact with the surface. Thus, not desirable for our system.

Non-Contact Temperature Sensor

In the other hand these devices acquire temperature information using convection and radiation. This makes it desirable for the purposes since sunlight is part of the electromagnetic radiation and is exactly what we need for our purposes.

TMP36

The TMP36 is an active three pin device from Analog Devices that provides temperature readings with a low voltage operation. This is an active sensor thus it requires a voltage supply for its operation. They offer a surface mount version of the device as well as a through-hole. For our system, we would select the through-hole mount since it would allow us to very easily replace the component if it was not functioning properly. Operating the device is quite simple, since we are only concerned with three of the pins, or voltage supply V_S, Ground, and V_{out}. This implicates that we need to consider having a pin to read the output voltage from this device. This output voltage is proportional to the temperature meaning it represents it and is how we read it. Aside, this device is not too expensive at a $1.50 making it very desirable for our board.

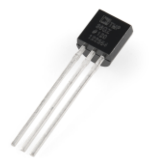


Figure 3.1.6.1 - TMP36 Device

Feature	Specification	Additional Information
Voltage Operation	2.7 V – 5.5 V	Low voltage operation ideal for our system.
Supply Current	50 µA	Low current draw results in a cooler system.
Sensing Temperature	-40℃ to 12℃	More than what we need with an accuracy of ±3℃

Table 3.1.6.1a - TMP36 Information

MCP9700T

The MCP9700T is a device manufactured by Microchip, specifically to consume very little power while retaining very high accuracy. The device is very straightforward, having just three pins. One is utilized for source, ground, and one that outputs a voltage relative to the actual temperature. The simplicity of this device makes it highly desirable because having a simpler system frees more time for the team to work on other issues.

The device has a very low cost at $0.26 one of the biggest concerns for the team is the ability to save as much money as possible. This sensor having such a low cost is highly desired by the team. The one drawback is that is surface mounted which involves having a third party solder the device and the team has agreed that having a through-hole construction would be the best idea.

Feature	Specification	Additional Information
Voltage Operation	2.3 V – 5.5 V	Ideal voltage operation for the system.
Resolution	10 mV/℃	Great resolution for the project.
Sensing Temperature	-40℃ – 125℃	Range is best with an accuracy of ±2℃

Table 3.1.6.1b – MCP9700T Information

LM75B

This digital temperature sensor is manufactured by NXP USA Inc. and uses a band gap temperature sensor. This device communicates via an I2C bus. The device is great solution that bypasses the need for analog to digital converter that is needed by an analog device. Along with that the device can be shared between many components thus it has great application. At $0.74, the price fits within the budget and does bring many extra features.

On the other hand, this sensor is surface mount, a major issue for the construction of the main board that will control the entire SkyLight system. Aside, this sensor being digital is much more than the team needs but at the same time could be a huge problem taking the I2C bus for temperature since there are other components that are more important that will utilize the channel.

This particular sensor also can measure colder temperatures. While this would be a good thing if the project's focus was to provide smart film to colder areas, this is not the intended purpose of SkyLight. SkyLight is designed with Central Florida temperatures in mind. Even if this sensor can read the colder temperatures, it doesn't necessarily make it ideal for the system. On the contrary: a larger temperature range usually implies that the component costs more for the added performance.

Feature	Specification	Additional Information
Voltage Operation	2.8 V – 5.5 V	Low voltage operation ideal for our system.
Resolution	11 b	Great resolution for the project.
Sensing Temperature	-55℃ – 125℃	More than required we with an accuracy of ±2℃

Table 3.1.6.1c – LM75B Information.

3.1.7 Real Time Clock

A real time clock is a hardware device that, with the aid of an oscillating crystal, keeps track of real time that correlates to the actual time of day. Executing millions of instructions per second is one of the reasons why computers are so powerful and allow us to perform incredible feats otherwise not possible. Instructions are executed cyclically but some executions involve knowing the real time of day and this is where real time clocks come in. Even though time could be acquired without one of these modules, a real time clock has a higher accuracy since it uses an oscillating crystal.

For our project, it is important to have enough accuracy to keep the system running properly and performing as desired. A real time clock can help us to be more accurate which is very important for our project because if a user would like to set their window to open at 6:00AM they are relying on our system to work without issues and a real time clock allows for the system to work accurately without problems.

Additionally, a real time clock allows us to have access to real time which is required for the system to function as desired. Another way to acquire time would be through the internet but this means we need to add a Wi-Fi module that consumes more energy and have ruled it out of our project. This device is the only way that the system would be able to access the time without internet access.

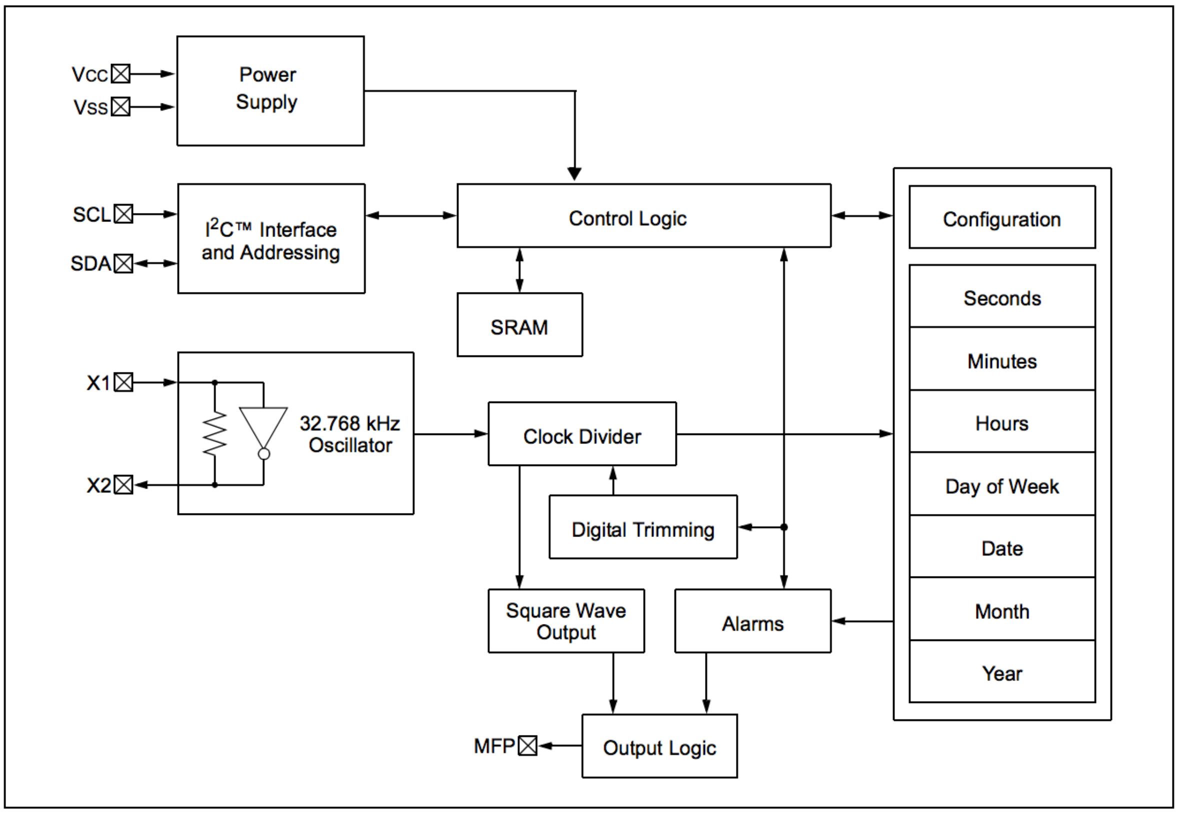


Figure 3.1.7 - Real Time Clock Block Diagram [MCP7940M**]**

3.1.7.1 MCP7940M

Manufactured by Microchip, at $0.66 is a low cost real time clock at that offers all the required features at a very low cost. This device uses a 32.768 kHz crystal, so keeping accurate time is not a problem. It includes a calendar to keep track of day, month and year which is sufficient for the needs of the project. The system simply needs a device that can tell what time it is without having an internet connection and this device is more than enough for the task.Another advantage of this clock, is that it has multiple communication channels offering I^2C and 2-Wire serial interface allowing for flexibility with the chip when building the circuitry. The only drawback is that the crystal is not included in the module therefore it must be bought separately.

3.1.7.2 AB-RTCMC

This real time clock is manufactured by Abracon LLC and includes several features aside from simply keeping track of time. Some of the features include Square Wave Output and a Watchdog Timer but while these are neat little extras that can be beneficial the team simply does not require them. This device does more than is required for the system but one downfall is that all the extra features bring along a price increase that puts this unit at $4.84 for one. Another important consideration is mounting type, this device is surface mounted a feature the team wanted to steer away from to avoid using third party companies that could greatly delay construction.

3.1.7.3 DS1307

This real time clock is manufactured by Maxim Integrated and offers serial and I^2C communication. Having multiple ways to acquire information from this device could prove beneficial in the case that the microcontroller was already utilizing a channel for another component we could access it in another port that is free. Another pro for this unit is that it has a through-hole construction a major key in the design of our circuit board is that these components will speed up and facilitate the overall build in the long run. The only downfall to this unit is the price at $3.37 for each one. One mission for the team is to keep the budget tight and while this real time clock offers all the features we are looking for, the price is detrimental.

3.1.8 Keypad

SkyLight Glass' "keypad" will more than likely consist of a couple of knobs and buttons directly connected to the system. The keypad system will be used for users that do not have access to a Smartphone device, which will be a direct link through Bluetooth with an application. The application part will control features such as dimming the LEDs, setting alarms for the SkyLight for waking up in the morning or deciding when to let light into the household, and other options such as changing the colors of the LEDs.

With the keypad, some features may not be reached unless used by the application, which could be an incentive to download the application. Such features could include, but not limited to, setting the alarm for the windows to "wake up", adjusting the temperature of the lights, or changing the colors of the LEDs. However, this could not pose a problem because the keypad could still allow for other features, including On/Off capability, dimming the LEDs, and perhaps dimming the Glass itself as well. This keypad will need to be small, yet effective, as well as hardy to prolonged sunlight and heat.

Some users will benefit using this manual mode, but the real action and control will come via the SkyLight Glass App. Refer to Figure 5.1.7 for example of a prototype keypad. However, in later stages, another potentiometer will be added, giving another degree of freedom when controlling the interfacing of the system, which will need to cover a few bases to ensure that customer satisfaction is ensured, and that the system can be user friendly.

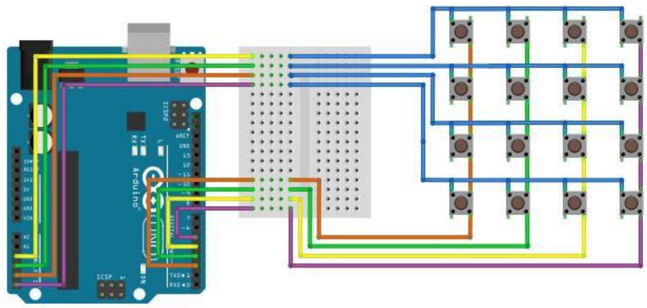


Figure 3.1.8 - Keypad Prototype Example [*Arduino Keypad, 2016*]

3.1.8.1 Keypad Analysis

It is likely the case that manual user input will be desired. Even though it has become absolute commonplace, having access to a smartphone should hardly be a prerequisite for using a device like SkyLight, and devices like SkyLight have high potential to become intrusive instead of useful if they're unable to be controlled, say if a user lost their phone or had a phone malfunction. Instead of completely deactivating the device, which would leave them without a window since the smart film is normally on instead of off, having manual controls becomes necessary.

The most common type of manual control is the simple pushbutton. When combined with other push buttons they can for a 'keypad'. In general, having more buttons means using more pins on the hardware. Also, in general, buttons are digital devices. Alternatively there exists an analog device, a potentiometer, which detects which position it is in. Depending on the position it will have a different resistance, giving it a different voltage in a voltage divider circuit. These can be used for things like brightness, where there aren't a small handful of options but a large scale of possible output.

Pushbuttons work by physically connecting a circuit. When plunger is pressed by the user it presses a movable contact between two solder lugs. Because pushbuttons are a physical circuit they suffer from "bounce" which is caused by physical bouncing of the contact against the solder lugs. In order to minimize this 'debouncing' techniques must be used, the best of which is the schmitt trigger and the simplest of which is a timer check. Because SkyLight is computationally intensive, and we do not expect manual commands at the same time as Bluetooth commands, time based software debouncing is a fine solution to any potential bouncing problems. [Fabio, 2010]

Potentiometers work differently and don't suffer from debounce. Unlike pushbuttons they are an analog device, not a digital one. Potentiometers contain an internal member of uniform resistance. When a user turns the potentiometer a varying amount of electricity bypasses the resistive member changing the overall resistance of the potentiometer as a whole. When coupled with a voltage divider circuit the potentiometer becomes a very power user input devices that allows for relatively non-discrete input (as non-discrete as the analog to digital converters will allow). [Wikipedia Contributors 2, 2010]

There are two main options that are available for a keyboard peripheral for SkyLight: make a keypad or buy a keypad module. Premade keypads are available on both Amazon and Adafruit, and both have options suitable for SkyLight. There are two main types available: a three by four numeric keypad and a one by four 'controller' keypad.

A three by four keypad has several advantages and disadvantages. One of the main advantages is the ability to specify a time for it to turn on, an LED brightness, an LED warmth, and turn on and off the smart film. The key disadvantages are the high amount of pins they require and the need for an output device to communicate the complex control scheme to the user.

A one by four keypad is much simpler, uses less pins, and does not need an output device. But it cannot control nearly as many functions as the three by four. Instead it works as the four arrow keys, and would allow the user to control the color temperature and brightness of the lights, but not an alarm time. These keypads also take up four pins, which is much less than the three by four, is still more than necessary.

Making a keypad requires more work from the SkyLight team, which isn't a good thing since they are already pressed for time given the short development cycle and the unnecessarily tedious and large documentation requirements. Documentation requirements such as these limit and stifle the engineering process and inhibits others from learning about the product as the requirements end up forcing the team to produce an abundance of unnecessary information that cloud and obscure the otherwise useful documentation.

Still, despite this, the selfless, noble and valiant members of the SkyLight are willing and able to take on the task. This allows for a custom control scheme that fits the product in a way that is absolutely preferable to the user, and unlike ABET, SkyLight cares more about user than making a profit by bullying the users into cooperating with a poor system.

That said, a custom control scheme would have the most recent command override the previous one, whether the command was entered via bluetooth or by manual entry. It's a safe assumption that manual entry would most likely be for immediate needs like turning the smart film on or off or adjusting the brightness of the LEDs. This can be done through a simple button and potentiometer. The potentiometer would adjust the brightness of the LEDs and the button would turn on or off the smart film.
In total, this would consume only two pins, though one would have to be an analog pin. While analog pins are more valuable to SkyLight than digital pins, it's better to use the one analog pin instead of using three digital pins.

There's still a major challenge: picking out the type of potentiometer and push button, as there are many types available.

3.1.9 Microcontroller Options

The SkyLight system does not require too many complex elements; however, it is essential that the team utilizes a chip powerful enough that will make it easy to achieve control over any wireless module chosen. User control is very important for this device; hence wireless connectivity is a very important component for the end product goal. Aside from that, the chip needs to have enough room to control lighting conditions, as well as receive input from multiple sources (light sensor, wireless module).

The smart window system, having the ability to run independently signifies it is in operation for long periods of time, therefore the chip must also remain energy efficient. Another aspect that could impact the project is previous knowledge, meaning acquaintance with the technology of the MCU because that could implicate whether the team has enough time to complete the project. Also, in order for the budget to remain within bounds is important to consider the price, cutting costs as much as possible to stay within budget is important in case the team runs into any issues later. Additionally, is of high importance the ability of the team to easily test the system before building it and if we run into any event that might cause our board to not function properly, it might be worthy to have a chip that can be easily swapped out.

3.1.9.1 Architecture

One aspect worthy of inspection is the architecture the chip is built upon since the team must write the code to operate the system at a later point. RISC or Reduced Instruction Set Computing, sprouted from the idea that is better to have simple instructions that can be executed within similar clock cycles. Driving away from Complex Instruction Set Computing (CISC), which at some point was a better option since programmers had to write programs in assembly language and this was a long and tedious process that sometimes involved utilizing the same instruction many times and to avoid this problem complex instructions would perform a specified task while removing repetition and thus saving the programmer time.

Although this appeared to be a good idea for the time of assembly, as Assembly was proceeded with higher level languages such as C, the task was handled by the compiler to complete the job thus having complex instructions was no longer an advantage. However, the main problem with (CISC) is that as our ability to fit more and more transistors into a chip grew exponentially the idea of parallel processing was born. Parallel processing, refers to the idea of having more than just one processor not necessarily in the same chip but with the shrinkage of transistors, this is how is implemented, multiple processors in the same chip. The advantages are obvious, more processors amount to getting more work done within the same amount of time but granted at some point this reaches a limit where the idea no longer holds truth. For the frame of operation where the idea of parallelism is ideal is where CISC starts running into trouble since complex instructions can sometimes take a different amount of clock cycles and it becomes quite challenging to split the instruction workload equally amongst other processors and still synchronize the execution successfully. Here is where RISC shines, even though it would be very challenging for an assembly programmer that is not an issue any longer. Therefore, RISC gains a lot of traction because given that the instructions have similar clock cycles they can be divided among other parallel processor and finish execution without losing synchronization.

A newer architecture, ARM or Advanced RISC Machine is still based on RISC but is utilized in many different devices today. Utilizing a chip with this architecture could have great benefits since it would allow the team to gain knowledge over the technology that is currently used in popular hardware especially but not limited to smartphones. This route could mean that the team needs to spend time learning how to program such a chip and maybe even a new programming environment or language which can have a negative impact in terms of time constraints to finalize our project. However, if the level of difficulty is not much to overcome it can be of great advantage for everyone since the team would gain another level of knowledge into a newer heavily used platform.

For our purposes, the system is not going to be running anything too complex that would require having multiple processors to accelerate the process. A single core RISC architecture chip should be more than enough, since the system is performing very straightforward tasks. Acquiring information from a light sensor, a temperature sensor, a real time clock and taking commands from a mobile device. In return the chip must also have enough output pins to control the lighting environment and open/close the blinds. These are very simple tasks that do not require too much computational power but the system must have enough storage to save the instructions without compromising response time which is of high importance from the perspective a user.

Selecting a microprocessor involves many different factors, but to reach our goals effectively the team must keep the project manageable and avoid overcomplicating it as much as possible. Thus, having a microprocessor that is are even a bit acquainted with will enable us to simplify many of our tasks and at the time of writing our programs will propel us much further leaving us with room for mistakes in the case we run into any complications.

3.1.9.2 MSP430FG4618

The MSP430FG4618 is part of the Texas Instrument’s family of MSP430 CPU lines and is one of the MCUs we have all had experience with as part of our academic curriculum. This is a 16-Bit RISC architecture microcontroller. One of our requirements and mission for our device is saving energy which is very important. This chip has a very low power consumption which makes it very likeable. Another key is the fact that since everyone already has experience with the chip this means that we can hit the ground running since we are acquainted with the programming environment and have gotten many different things done with it already. This simple fact could mean that the team does not have to waste very precious time learning how to program a new chip but does imply that we are closing our doors to learning something new but for a very good cause which is saving time for any other problem that might arise in the way.

Aside from the exposure that the team already has with this chip is also important to keep in mind local availability. The TI innovation lab has a few of this boards in stock, giving the team multiple opportunities to experiment with a Launchpad and save costs at the same time. The team is responsible for developing a printed circuit board (PCB), but having a developmental board available for testing saves the team money since TI offers this kit free of charge. Also, saves time because there is no need to wait for a shipment to arrive because the development kits for this microcontroller are already available. Another major advancement is that we can test our entire system with this kits, which allows for peace of mind because once the system is altogether the chips can be ordered and the system would behave similarly.

This microcontroller has many great features to offer and is more powerful than we might need and even though it appears to be likeable based on the previous points. This device has too many extra features that the team is just going to waste, which would not be a problem except that this chip is expensive for what the budget allows at $10 a piece. This price point makes the device undesirable, but another problem is that even if it was chosen it does not have wireless capabilities: a problem that would still require a solution that will increment the overall price of the project. Another disadvantage for this chipset is that it is surface mounted a problem the team would like to steer away from as much as possible for the foreseeable problems is going to bring.

Feature	Specification	Additional Information
Power Consumption	1.3 µs – 400 µs	Power Down vs Active
Clock Speed	1 - 8 MHz	Clock speed not too bad for a MCU and suits the needs of the team.
Analog-to-Digital Converter	12-bit	Might be needed.

Table 3.1.9.2 - MPS430G4618 Information

3.1.9.3 CC2640RF

This is a newer Texas Instrument chip that has low power Bluetooth capabilities embedded in the system. Making it a very viable option since the team would not have to worry about buying a separate connectivity module saving money, time and allowing for a more robust system with one less item to worry about. Not to mention that TI, provides a lab that offers opportunities to get help or a Launchpad that will allow the team to test the system without having to spend any extra money. At the same time this will save costs since there will be no need to buy an additional wireless module since is all integrated. Also, as part of TI technologies, they provide examples of how to utilize their device, which will allow us to implement our project much faster without having to run into too many complications.

This unit is based on the ARM architecture and is probably more powerful than the team needs. However, it offers an opportunity to acquire knowledge about this architecture that is being utilized in the industry at the moment. Another advantage for this unit is that is not too expensive for the features the team gains, $5.7 per chip fits in with the budget. This MCU has 8 16-Bit PWM capable outputs, which is more than enough pins for controlling the lights and film. Also, it has a real time clock (RTC) peripheral, this is another module that is required for the system because the team would like to avoid having to add a component to connect to the Wi-Fi mainly for energy saving reasons and this chip offers such capability.

One of the biggest drawbacks for this microcontroller is that is surface mounted and the team would like to have all components through-hole to simplify the construction. However, for all the features this microcontroller offers, the team is willing to overlook this since it is a very desirable choice. Although, that signifies having another party solder the chip, the components that are incorporated in this MCU could further simplify the design of the printed circuit board which would make it more compact and free the team from other complications that could arise from using a third-party module.

Feature	Specification	Additional Information
Power Consumption	61 µs	Active per MHz
Clock Speed	1 - 48 MHz	Higher clock speeds improve performance but gives room for the team to find a balance
Radio Frequency	2.4GHz RF Transceiver	Bluetooth module embedded capable of low energy operation

Table 3.1.9.3 - CC2640RF Information

3.1.9.4 CC3200

This is another module that is part of TI's simple link family with an embedded wireless module, Wi-Fi in this case. This is one device that is available in the TI innovation lab that allows the team to have a Launchpad to play with. An advantage to a system built with this chip means there is no need for an additional hardware for connectivity since it is already in the device. This module while offering wireless connectivity brings some drawbacks with a few pros.

One major point that makes this device unfit is that Wi-Fi connectivity requires quite a lot more power than Bluetooth does. Sometimes such systems also require a router with internet connection in order to have other devices connect to it which could be an issue. For such a setup a major advantage is that the user gains the ability to control the system remotely. Is not likely that an user would care about controlling their blinds remotely but it can have applications for some. However, this route requires that team learns many protocols to develop the system to control the blinds over a mobile device, making the process much complicated.

This MCU, has four 16-Bit pins capable of pulse width modulation, enough for what the Skylight device requires. It also uses ARM construction which the team has an interest in learning for future endeavors. Even though this chip consumes more power and is a greater challenge to overcome for the team, it does remove the need for a wireless connectivity module.

Also, this takes away the necessity of having a real time clock since the information could be accessed through the internet. On that same note, this chipset would allow weather information as well. By acquiring the weather information in this method, this could allow for the removal of a temperature sensor all together.

This microcontroller would allow the team to part ways with many components, but at the cost of having to overcome many other challenges such as creating a bridge between it and the controlling mobile device. Also, this chip is not as energy efficient as the previous Bluetooth embedded module along with having a cost of $12 pushes this microcontroller further from making into the product the team envisions.

Feature	Specification	Additional Information
Power Consumption	59 µs – 229 µs	Active RX traffic vs TX Traffic.
Idle Consumption	825 µs	A bit higher than others
Clock Speed	1 - 80 MHz	Much higher clock than needed.

Table 3.1.9.4 - CC3200 Information

3.1.9.5 ATmega328P

Manufactured by Atmel, this chip is very popular in the do it yourself (DIY) community for its ease of use and integrated development environment. This 8-bit microcontroller because of its popularity is very well documented with tons of reference material that could come in handy if the team runs into any issues that are not familiar from previous experiences. Even though this platform is not a part of the scholar package implicating the team would need to learn to program the device, for the most part everyone has already utilized this platform before so this would not be a problem.

The ATmega328P is a through-hole construction which the team considers for building the printed circuit board, since it allows for the ability to easily swap the chip at any moment for any given reason. An advantage to this chip is that the team can use the readily available development board Arduino for prototyping the system and then easily integrate it at a later point. It offers six PWM pins that is sufficient for implementing control. A drawback from this chip when compared to the previous is that its simplicity dictates that it does not contain any wireless connectivity modules. This means that the system will require to have additional components to achieve different tasks.

This microcontroller is not extremely powerful having an 8-Bit RISC architecture. However, is sufficient to bring to the idea to life, since the system does not require any super complex computational problems. In addition, this system is very power efficient consuming only 0.2mA when active, this is important. Another advantage is the price for this microcontroller is only $2 which is beneficial for keeping the cost of the project low.

Feature	Specification	Additional Information
Power Consumption	0.1 mA – 0.2mA	Power Down vs Active
Clock Speed	1 - 20 MHz	Variable clock speeds could signify improved energy efficiency.

Table 3.1.9.5 - ATmega328 Information

3.1.10 Microcontroller Software

In addition to the hardware of a specific MCU the team might select, another deciding factor is the integrated development environment (IDE). Even though most modern environments offer similar tools, it still important to compare options and arrive at the best one for a particular system. Of course, the features of microcontroller have a higher priority but these devices are usually locked to their respective environments. Although the IDE is of low importance as a collective body, if the team is more comfortable with a specific workspace and the chips have similar specs then this is could be a valid consideration.

3.1.101 Code Composer Studio

Code Composer Studio is the standard (IDE) for the Texas Instruments (TI) microcontrollers. It offers many of the features that programmers come to expect for a development environment, most importantly for our intents an optimizer for C/C++, source code editor, and a debugger. One advantage to this environment is that we have all been exposed to it as part of our curriculum, this signifies we do not need to spend time learning something new and can allocate that time to working on developing our system instead. Additionally, this environment offers many code samples from the manufacturer that can greatly aid us at the time of developing our project.

3.1.102 Arduino IDE

This IDE is one of the most popular for developmental Arduino boards which use the ATmega328P microcontrollers that the team is using for the project. This IDE is very simplistic and facilitates in acquiring knowledge of electronics and microcontroller communication. An advantage to this platform is that it has a large open source community that backs the project which allows for vast resources and references that can aid the team in case of debugging issues or general inquiries about specific functions on a particular MCU.

3.1.11 Bluetooth and Wireless Communication

3.1.11.1 Serial Communication

Serial communication is the telecommunication and data transmission of single bits at a time, sequentially, over a communication line or computer bus. This is used for most networks because it is cheaper and sometimes more easily implemented. It is also becoming more popular over parallel communication because of signal integrity is beginning to become more preserved, and transmission speeds are becoming faster. Since SkyLight Glass also has embedded systems in within it, this also helps the systems communicate and share a common protocol.

There are many protocols but serial communication makes the most sense for SkyLight Glass and we can use a simple clock pulse to control the amount of data sent. So, this means a reduction in materials and in cost since only two wires initially will be needed to send very basic information. Obviously as more embedded systems are added to the project, more wires and material will be needed, but initially only two wires would be needed instead of several, for example, parallel communication.

Buses are also popular when using communication between integrated circuits or between printed circuit boards. Buses were initially created just for this sole purpose of communication when speed was not a factor. The more pins on a chip the more expensive the chip becomes, so by using less pins and a serial bus, the data may be slower, but the overall design falls in price. This is ideal for the SkyLight Glass because information is not constrained by speed. If more features were added, speed of data may become an issue for a customer. The most communication that will be taking place is between the sensors and the microcontroller, and even still this is not an issue. Thus, the general idea is to offer the best product to the buyer, at the lowest cost possible, so this protocol makes the most sense to implement.

3.1.11.2 Bus Contention

Serial communication is also used strictly for two devices to communicate, if more than one device is trying to talk over the same serial line, one could run into what is called bus-contention. Usually this scenario will end in either devices communication not being able to place values on the data bus, much like if 2 or 3 people were trying to talk to a single person at the exact same time. Worst case is that the actual pins burn up from too much communication happening over the bus, however, most microcontrollers and ICs protect from this. Contentions can lead to breakdowns of hardware, and can arise in systems with programmable memory mappings, and when illegal values are written to registers that are responsible for the mappings. Ways of controlling bus contention include, using buffers for the output of the memory-mapped devices, however, high impedances from one device can and normally will still interfere with the bus values placed.

3.1.11.3 Serial vs. Parallel Communication

There is also parallel communication, which like serial communication, transfers bits of information, however these bits in parallel are all transferred with several streams of data simultaneously along multiple channels, where serial links are strictly a single channel of data. This parallel communication has its benefits obviously, however with the chip we will be using there isn't much pin real estate, so it may be beneficial to sacrifice potential speed for more pin connectivity, especially since we are going to have a few different embedded systems within in the module using a few different input/output lines.

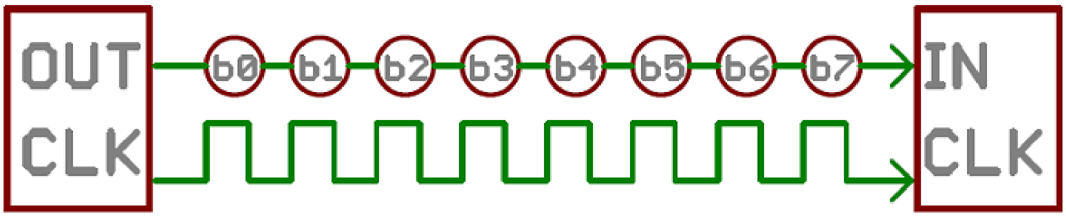


Figure 3.1.11.3 - Example of Synchronous Serial Communication [*Sparkfun*]

3.1.11.4 Synchronous vs. Asynchronous Communication

The biggest implementation of serial communication is USB, or universal *serial* bus, and Ethernet, which are both well-known serial interfaces, including other common examples include I^2C, SPI, and the serial standard. These examples can be broken down into two exclusive groups, *synchronous* and *asynchronous*, which deal with whether there is a clock dependency or not. A synchronous serial interface is completely dependent on the clock pulse, so all devices that are linked to this interface all share a common clock.

This can result in a quicker and often more straightforward serial transfer between devices, but can incorporate more wires needed, which could take up more pin space, and this could be limited depending on design. For our design, we will be using an asynchronous approach, meaning that the data will be transferred without support from an external clock pulse.

This will help minimize pin use and wire use on the I/O of the microcontroller, which will eventually be translated onto our Printed Circuit Board, however we will be implementing a little extra effort into reliably transferring data, as well as receiving it. Embedded electronics take advantage of this effort as shall we for the SkyLight Glass implementation, especially for sensing light temperature, as well as communication via Bluetooth from the mobile app to the system.

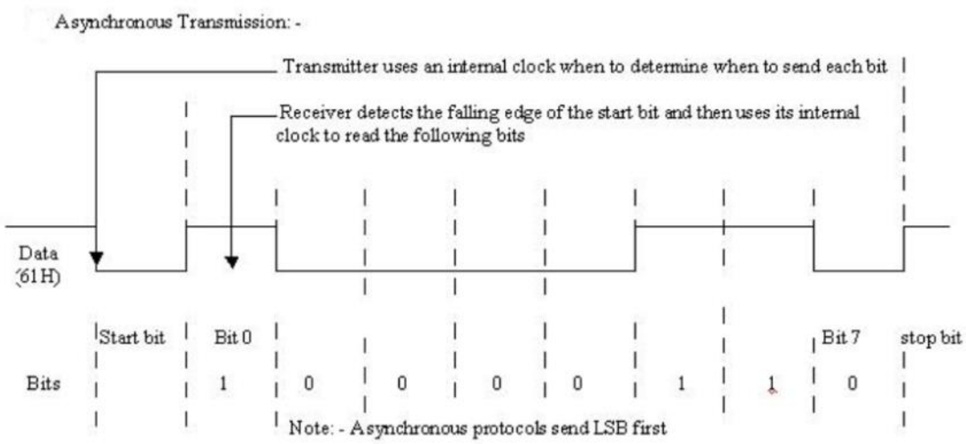


Figure 3.1.11.4 - Example of Asynchronous Transmission [*Sparkfun*]

3.1.11.5 Implementation of Asynchronous Technology

There are basic rules for Asynchronous technology to help robust the system and ensure error-free transfers of data which we will be implementing into the software, and these rules include:

- Data Bits
- Synchronization bits
- Parity bits
- Baud Rate

Baud Rate

Baud rate is the speed at which data is transferred across the communication line. The higher the baud rate, the faster the information is being transferred. Although, this value must be within reason (see Bluetooth Constraint), so there is a limit to which this speed can be. Usually speeds do not exceed more than 115200, which is really quick for microcontroller standards. If information is being received/transmitted to quickly, the system will begin to see errors on the receiving end, which is caused by clocks and sampling periods not being able to keep up with the given frequency of bps.

Data Bits

Data bits are sent by blocks, which are usually in bytes, of information called *packets* or *frames*, which include Start bit, followed by data bits, some sort of Parity bits, and then finally a bit or more of Stop bit(s). Some of the serial framing has configurable sizes, depending on data being carried, or how important error elimination is. The data section of the frame is obviously the biggest section of information, so this is directly related to the process being transmitted. This data size is normally from 5 to 9 bits of information, but there is a standard of 8 bits. 8 bit is the norm because a byte of information is 8 bits of data, but other sizes also have their own reasoning for implementation.

For example, 7 bits could be more useful if the data needed to transmit ASCII characters, since they are 7-bit characters. After agreeing upon a baud rate between devices and the size of the length of data bits, *endianness* must be considered, since information can be relayed with either Most Significant Bit (MSB) or Least Significant Bit (LSB) first. So what to decide? Most users consider the LSB being sent first, so ultimately it is a choice of preference, rather than a standard.

Synchronization Bits

Synchronization bits are bits that are transferred with each new block of data. Rightfully so, these bits are referred to as the *Start* and *Stop bit(s)*. These bits signify the beginning and end of the packet being transferred, such that the information doesn't all run together as the system is communicating amongst the different components. There is *always* only *one* start bit, unlike stop bits which are configurable to either 1 or 2 bits, yet the common practice is to leave this number at 1. Start bits are always indicated by an idle position of the data line, this will pulse from 1 to 0, as the data is transferred this idle line continues at 0 until a packet encounters the stop bit, this takes the holding line from 0 back to 1 indicating back to an idle state.

Parity Bits

Parity bits are a low-level feature for error checking when it comes to transferring packets to the system and are not required. A developer can set this to two different settings, either an odd parity or even parity, there is no standard for this and is strictly preference or design utility. To take advantage of the parity bit, the data sent is added up, the 5 to 9 bits of 1's and 0's, the sum of these bits whether even or odd, is added up to determine whether the parity bit is set or not. For example, let's set the parity bit to be even and we encounter a packet of data it is being added to like 011111011, this data has an odd number of 1's (7), so the parity bit would now be set to 1, and vice-versa if parity mode was set to odd, parity here would be set to 0. Working in parity into the system is helpful across noisy mediums, however it does slow the transfer of the data at hand, also it requires both the transmitter and receiver to handle error, like resending packets, or parts of the packet, depending on what protocol is performed. For SkyLight Glass, since we will have a few, but important features, parity may not be implemented since the system will be directly connected to the customer via phone app and/or remote control.

Figure 3.1.11.5 - Packet Frames with Configurable Sizes [*Sparkfun*]

3.1.12 Bluetooth Module

There are two types of Bluetooth, external plug and play module and an internally embedded module directly in the chip.

Internally Embedded Bluetooth Module

Two chips in consideration now for SkyLight Glass are the CC2650 TI SimpleLink multi-standard 2.4 GHz ultra-low power wireless MCU and the CC2640 SimpleLink ultra-low power wireless MCU for Bluetooth low energy.

The CC2640 is a wireless MCU that targets Bluetooth applications, which has an embedded BLE controller into the ROM and runs partly on an ARM processor. The interface is ideal for external sensory for analog or digital data autonomously while the rest of the system can be in sleep mode, which helps in Power consumption, and is synonymous to the BLE trait. This extends battery life, and TI claims ease of use [TI].

The CC2650 has a few added features from the prior MCU. These features include an added ZigBee and 6LoWPAN, and ZigBee RF4CE remote control applications. Like the previous MCU it still has the embedded BLE module, however unlike the last, this MCU makes use of the IEEE 802.15.4 MAC embedded into the ROM, which is also running partly on an ARM processor as well. This improves overall system performance, and frees up flash memory for the application.

External Bluetooth Module

External Bluetooth modules are usually the norm for projects. Bluetooth modules are normally pretty cheap and offer a lot of capability for low cost. They can be reused and removed if not needed anymore on a board. Bluetooth HC-05 or HC-06 is about $10 on an Ebay seller’s site, and this includes a breakout board. There are more advanced BT modules as well like the ESP32 Thing.

This device is actually a hybrid of Wi-Fi, as well as BLE, and has nearly 30 I/O pins. This is great for projects that are affiliated with IoT (Internet of Things), but for SkyLight Glass will more than likely be overkill. SkyLight Glass’ control can be functionally ran with a basic BT module and a breakout board. As long as the user has access to a Smartphone device, a user can literally sit wherever they would like in their household and be able to control SkyLight Glass.

Figure 3.1.12 - HC-05 Bluetooth Module

3.1.12.1 Hardware for Data Transfer

The Bluetooth module will obviously consist of hardware affiliated with sending, and receiving data. It is imperative to note as well that labels of the pins are with respect to the device itself. So the receiving pin (RX) of one device should be wired to the respective transceiver (TX) pin on the other device. In other words, the transmitter should be talking to the receiver not a receiver to a receiver or a transmitter to another transmitter. There is also *full-duplex* or *half-duplex*, meaning that a device that is full-duplex can RX and TX simultaneously, while a half-duplex set up can only have serial devices do one at a time, if a device is sending then the other must wait to begin transmitting. Some machines can get away with this, depending on the amount of information being sent and how time imperative that information is. A developer would not want this set-up for something that the information was needed on-the-fly, or immediately. One must take into account what the devices in question will be used for, are some of the devices strictly *listeners*, if so then half-duplex *could* be considered.

Normally, microcontrollers “talk” to each other using a TTL or “transistor-transistor logic” level. This information is usually communicated via voltage signals, normally indicated by the controllers VCC level or Ground level. This level is usually varying between 0V, 3.3V, or 5V, these varying levels let the serial TTL know if a signal is idle, with bit value equal to 1, or if a stop bit is being transmitted, where the bit is equal to 0. Ground can be used to represent start bits of the data, or even a data bit that is equal to 0. Some voltage signals can even range between -25V to +25V, which is fine but could result in lossy data across transmission lines. Another important note is that any two devices cannot simply match up, one must take into account the respective voltage levels, if the levels do not match up then the user will need to shift the signals to match.

TTL is usually the easiest of the signal standards to implement, which is great for a project like SkyLight Glass. Since we will be communicating via app and controller, there will not be much feedback resulting from the glass components, so this means that even a half-duplex process could be considered. However, for a more robust and exciting product that may have extra features in the future, this will still be a something to consider when deciding between a half or full-duplex product.

3.1.12.2 UART

One of the final pieces which is normally embedded in more IC’s and Microcontrollers are what is known as the Universal Asynchronous Receiver/Transceiver, otherwise referred to as the UART. This module creates serial packets and control physical hardware lines. It is no more than a block of circuitry embedded on the chip, microcontroller, IC, etc. The UART is basically the “middle man” of the two devices trying to communicate. There is usually a bus of eight or more lines, and some control pins as well, on the other side there are serial wires, this UART is now ready to translate between the parallel and serial communications between interfaces. Note, this is a very simplified explanation of how the UART is actually implemented.

SkyLight Glass will more than likely not need a UART, in fact SkyLight Glass is looking to have strictly all the hardware communicate with implementation of code, this will help alleviate some of the intense intricate web of all the serial communications going on between the app or controller, to the SkyLight Glass interface. Some microcontrollers do not come out of package with a UART module embedded, in this case an external module will need to be purchased and integrated with the hardware being implemented. Some however, come with *many* UARTs for example, some of the new Arduino boards have up to *4 UARTs*, which is overkill for this project, the team will need to use only one if it is decided to go that route. For transmitting, UARTs create a data packet, which is the appending and syncing of bits, including parity bits if implemented, then transmit with precision with respect to time, which is controlled with the baud rate implemented by the user.

For receiving the UART must sample the RX rate at the expected baud rate, choose which bits are sync bits, and then relay the data. Some UARTs make use of buffers, these modules are normally more advanced and usually more expensive as well more extensive when dealing with data. This means that it stores information and then when the microcontroller needs the information it will simply call for it and receive it. FIFO, First in First Out, implementation is normally what is used by UARTs and can range from a few bits, to thousands of bytes. *Bit-banged* data can be used instead of a UART and may very well be what SkyLight Glass implements, as this is a big feature of Arduino. The information may not be as precise and also uses more CPU power, but if the board can handle it, this can be used for smaller projects, much like SkyLight Glass.

3.1.12.3 Bluetooth Features

Bluetooth will be a big part of the SkyLight Glass system. This will control almost all features that are going to be connected to the controller of the system. Bluetooth is a device that uses radio waves instead of cables or wires for connection. It is normally an embedded system of phones, computers, or electronic device, that make connection easier, this is done through "pairing". Communication happens over short ranges over "piconets", where a piconet is a network of devices connected using Bluetooth technology. One device takes role of Master while all other connected devices will take the role of Slave.

These connections are dynamic and automatic as devices enter and leave the proximity of the given radio radius. The newer version of Bluetooth, which is Bluetooth Low Energy (BLE), is optimized for a range of power consumptions, however when it comes to data streams it is not like the prior version of Bluetooth. The original version, which is still used widely, supports and is optimized for long data streams. BLE *can* be used for long data streams, however it is "once in a while", the frequency of the data can be sent over a given amount of time, configured by the user, and goes into its power saving mode, which is given in greater detail in the next section.

Technical Specification	Bluetooth® Classic	Bluetooth Smart
Frequency	2.4 GHz	2.4 GHz
Range	10-100 meters	10 meters
Throughput	0.7-2.1 Mbps	25 kbps
Max Nodes	7	No limit
Latency (Time between packets)	2.5 ms (Data) + 100 ms (Conn.)	Several ms (Data) <6 ms (Conn.)
Target Applications	High throughput & interoperability	Low power consumption

Table 3.1.12.3 - Operating Differences Between BT and BLE [*Appliance Design*]

3.1.12.4 Power Consumption

Bluetooth also features low energy functionality. Some BT modules, especially the BLE modules, can shuttle among various power modes: Active, Hibernate, Sleep, Deep Sleep, and Stop. This keeps power at a minimum which BT is famous for. Leaving a module on but powering off the CPU, the BT module can figure out to put the device into a Deep Sleep mode while still keeping the BLE link active. This is explained by sending a data stream with a BLE, the device will then send the information, go to sleep. Now, while this module is in sleep mode it is using very minimal power consumption. An interrupt is sent to the system from the CPU client telling it to wake up, now the BLE module will now begin to send data again, and so forth. The small duty cycle taking place is what is directly responsible for the lower energy use.

Power of the Bluetooth module represents its class, as well as its emitting range for information transfer. So a Bluetooth module then is represented by it “power class”. Some Bluetooth devices can vary their transmit power while others must stick to a single class. Figure 5.1.13.4 shows different classes of Bluetooth modules as well as their respective Max Power Outputs in dBm and mW, and Max Range as well.

Class Number	Max Output Power (mW)	Max Output Power (dBm)	Max Range
Class 1	100 mW	20 dBm	100 m
Class 2	2.5 mW	4 dBm	10 m
Class 3	1 mW	0 dBm	10 cm

Table 3.1.12.4 - Power Classes of Bluetooth Classic Module

3.1.12.5 Breakout Boards and Bluetooth

Breakout boards are common electrical components that take a bundled cable and “breaks out” each conductor to a terminal. In this regard, it can easily be hooked up to wires for distribution to another device [Sparkfun]. This enables an easier and cleaner installation of electronic devices, also offered with a breakout board is circuit protection and signal distribution. However, only active breakout devices that include said circuit protection come default with it, an operator should not formally assume the circuit protection comes standard, as this is not a standard used in practice.

Optocouplers and fuses are normally acceptable ways to protect a circuit, and provide isolation in lieu of excessive current trying to travel through important circuits, or isolated sections of circuitry. They are handy devices and can connect components to a computer source, as long as they can interface with the Numerical Controller (NC) you are using. There are big steps to selecting a breakout board, and they should all be considered thoroughly. Some key features to exercise when choosing a breakout board should be Connector type, Number of I/O signals, Power Distribution, and if there is offered Circuit Protection from the device.

SkyLight Glass’ biggest challenge will be getting all components to integrate nicely together, the breakout board will need regulate voltages between these integrated components, and also ensure appropriate I/O interactions. Design should incorporate and take into consideration the run voltage and phase for the different grids of voltages, and output overall power to drive our interface. This distribution of power and phase is an important function that should be extensively researched to keep the components of SkyLight Glass safe and running efficiently. There will be no need for cooling feature, but emergency stops, and dust control could be available in latter versions of SkyLight Glass. Some breakout boards may have as many as 24 I/O pins. If more are needed, more breakout boards will needed to be accounted for.

Figure 3.1.12.5 - HC-05 Bluetooth External Module with a Breakout Board [*Techbitar*]

3.1.13 Bluetooth Software

SkyLight Glass’ Application will be the brains of the product. The app will control everything from dimming capability and whether that is automatic or not, LED color, setting the alarm, turning the system ON/OFF, helping control temperature, and other features. This will mostly, if not all be strictly controlled via bluetooth from the owner’s Smartphone. The application aspect will be done in Android Studio for Android devices. Android Studio supports many various aspects and holds a lot of libraries for up-and-coming developers.

Applications for Android devices are primarily created using this software and there is a lot of great help out there for project developers as well. The Android platform includes support for a

Bluetooth network stack, which allows a device to wirelessly exchange data with other Bluetooth devices [Android Developers]. The application framework makes use of the libraries, or also knows and Android APIs, which allow for the Bluetooth functionality. The APIs let separate applications also create links with each other via Bluetooth, enabling point-to-point and multipoint wireless features for Smart devices. According to the official Bluetooth Android Studio Developer website, Using the Bluetooth APIs an Android app can perform the following actions:

- Scan for other Bluetooth devices
- Query the local Bluetooth adapter for paired Bluetooth devices
- Establish RFCOMM channels
- Connect to other devices through service discovery
- Transfer data to and from other devices
- Manage multiple connections

Depending on the type of Bluetooth module used, i.e. Classic or BLE, will change how the module interact with the system, for now SkyLight Glass is on track to use a Classic Bluetooth module. Still, Android Studio APIs can still handle BLE, the implementation will just be slightly different to make up for the BLE's ability to handle Power consumption at a much more efficient level. The Bluetooth module to be functioning correctly focuses primarily on 4 imperative goals:

1. Setting up the initial implementation of the Bluetooth.
2. Searching and finding devices that are either paired or available to pair within the proximity of the given Bluetooth module.
3. Connecting the devices.
4. Being able to transfer information between the connected modules.

3.1.13.1 Pairing

For Bluetooth to function correctly, both devices must be enable their Bluetooth signals, this will form an initial channel of communication aptly called *pairing*. One of the respective devices must be *discoverable*, which makes itself available for a request to ensure a connection through the pairing process. The other device then finds the discoverable communication device using a *service discovery* process. Once the two machines complete their "bonding process" they exchange security keys, then the devices cache the keys for quicker connection next time, as well as for the current connection taking place. In order for this to be successful one of the Once information is done being processed the device that linked to the discoverable device releases the link, still the two devices remain bonded so that they can reconnect sometime in the future as long as they are within range of one another, and neither device has removed the bond permanently, if so then this whole process must be restarted.

3.1.13.2 Permissions for Bluetooth Application Software

The Android Studio guide suggests that in order for the Bluetooth features to work in your application you must first declare the Bluetooth permission BLUETOOTH. You will need this to perform any and all Bluetooth communication, this includes requesting a connection, accepting the connection, and transferring the data. For the SkyLight Glass app to initiate discovery, or to manipulate settings, a user must declare a BLUETOOTH_ADMIN permission, in addition to the prior permission. Most apps need this to activate their ability to discover Bluetooth devices, other permissions should be used unless there is some type of power management that modifies the Bluetooth setting, solely upon a user's explicit request.

3.1.13.3 Setting Up Bluetooth

Our app will need to connect with the system, with SkyLight Glass' Bluetooth capability quick snippets of code should do the trick. The code will check for an adapter that is Bluetooth capable, and once that happens the application can interact with the system. Checking for a *null* connection will ensure if the system being connected to is in fact adaptable. After the call is made to the device, the application will "listen" for an action and then broadcast the Bluetooth state change. The broadcast contains two extra fields, one contains the new Bluetooth state and the other contains the old Bluetooth state. It is these states the system uses to save the state of on or off. Listening is helpful for applications that need to detect runtime changes made to the Bluetooth state.

3.1.13.4 Finding SkyLight Glass via Bluetooth

Finding remote devices via Bluetooth must make use of *discovery* or in other words, querying a list of paired devices. This discovery method is a way of scanning for devices within the local area for Bluetooth signals. However, a nearby device can only respond if it is within range, and is currently accepting requests by being discoverable. In regards to Bluetooth resources, discovering uses a lot of the adapter's resources, so after a device has been discovered and connected, within the application code the developer must remember to cancel the discovery. This frees up a lot of the used resources such that the Bluetooth is now free to act upon further instruction from the application. This is because of the Bandwidth being shared becomes significantly reduced for what is available to existing connections.

The discovery process is asynchronous and returns a Boolean value indicating if the discovery was successful or not, or if it has even started. This scan is on average about twelve seconds of inquiry followed by another page scan to retrieve the Bluetooth device's name. An example of how the inquiries interact is given in a flowchart in Figure 5.2.2.4a below. If successful after the Paging (connecting) stage it will respond to the request by sharing the unit's name, class, and MAC address, and now an initial connection can be made. The MAC address is must for two devices to connect, a MAC address can be scanned for and retrieved by using Android Studio's API library, getAddress( ), a MAC address and device name is shown below in Figure 5.2.2.4b. It is a good idea for developers to query a set of paired devices to see if the desired connection is already known, this ensures a quicker transaction of information. This is done in the app via a preset function called getBondedDevices(), which return a set of Bluetooth device objects, which are representing devices that can be pairable.

SkyLight's module will connect a user via Bluetooth to the Arduino board, which will eventually become a printed circuit board or PCB. For SkyLight Glass' remote device the developers will not need to instantiate a discovery stage because the device is always discoverable to an inquiry. Enabling the discoverability is only necessary when the app is hosting a server socket that is accepting connections from outside sources, since remote devices must be able to discover other devices before initiating a connection to other units. A big confusion and often troubling ordeal is the device being *paired* versus being *connected* which a user must be aware of the difference. Pairing means the two machines are acknowledging each other's existence, and have a shared link-key that is used for authentication, which is capable of an encrypted connection to one another. Connected means that they share an RFCOMM channel and have the ability at this time to transfer data from one another. Currently, according to the Android Studio API document, is that the pairing *must* occur *prior* to data exchange, meaning before an RFCOMM connection can take place.

For completed connection after the paging process, a device can actively participate in information sharing, or simply keep the bond created and go into sleep mode, or low power mode. There are a few different types of modes created by Bluetooth connections, each differs a little in how the module is interacting, and also takes into account Power. These different modes will alleviate the power use and activate at different time cycles, depending on how the user needs the system to work, the different modes are listed below and can be seen figuratively in Figure 5.2.2.4a.

- **Active Mode** - The regular default mode when devices are participating in active data transfer.
- **Sniff Mode** - A power saving mode when devices are deemed as less active. The unit will sleep and listen only for transmissions at a set interval, which can be delegated by the developer in milliseconds i.e. listen for a transmission every 200ms.
- **Hold Mode** - This mode is a temporary power-saving mode, where a machine will sleep for a specific amount of time period, and then returns back to active mode when the time interval has passed. Only the master can tell the slave to hold.
- **Park Mode** - This is the deepest of the sleep modes, and only a master can command a slave to enter into the "park". The slave chosen to receive this command will become inactive until the master tells the slave to wake back up.

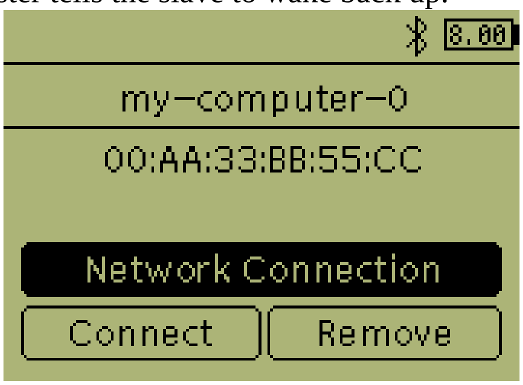


Figure 3.1.13.4a - Device Ready to Establish a RFCOMM Connection [*ev3dev*]

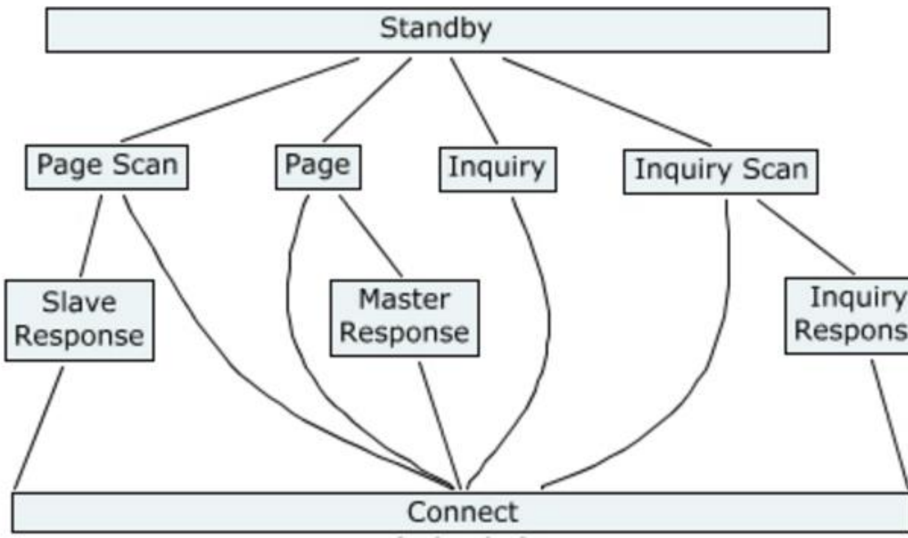


Figure 3.1.13.4b - Example of Inquiries and Page Scans During Discovery [*Cmaps*]

3.1.13.5 Master and Slave Piconet

SkyLight Glass will have a Master and Slave relationship over the Bluetooth piconet to relay information over from the application to the the glass' film. In a piconet and single master device can be connected up to seven different slave devices, and any single slave can be connected to a single master device. The master coordinates this communication through the piconet, it can also request data from the slaves as well as transmit any data to them. Slaves are not allowed to talk to other slaves within the piconet. According to Sparkfun, every Bluetooth device has a unique 48-bit address, normally abbreviated BD_ADDR, and will normally be presented in the form of a 12-digit hexadecimal value. The MSB within this address are the upper 24 bits which is presented as the Organization Unique Identifier (OUI), and identifies the manufacturer.

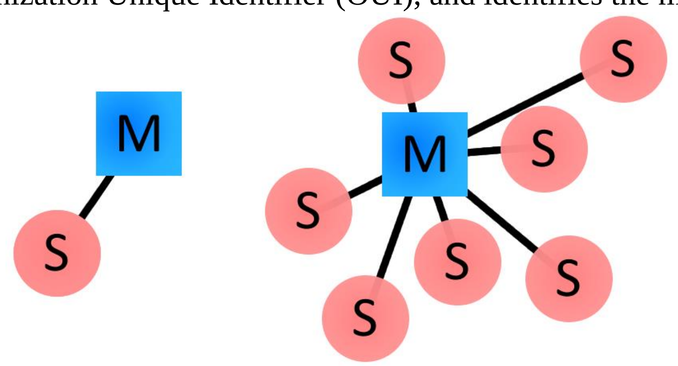


Figure 3.1.13.5 - Diagram of Master and Slave Bluetooth Piconet [*Sparkfun*]

3.1.14 Smartphone Application

The smartphone application will have a lot of functionality and coincide with the SkyLight Glass hardware. The team is looking to implement many user-friendly features that will make life easier, and more fun, when interacting with SkyLight Glass. SkyLight features of the smartphone application will include, but not be limited to the following:

- Activating the SkyLight Glass' ability to turn on or off
- Changing the RGB values of the LEDs located around the glass' frame via color wheel located within the app.
- Setting a timer for the tinting ability to act as an alarm to let sunlight inside of the household, or to act simply as a timer when the individual would prefer the windows to be translucent or not.
- The ability to set modes such as "Summer" or "Winter" mode, where the tint will respond accordingly to seasonal changes wherever the user may reside.
- The ability to dim the LEDs to a user's exact brightness preference.
- The ability to change from Automatic to Manual mode if keypad is installed and present and User would like to interact with the system that way.

The application will be written with C/C++ language, and IDEs may include Android Studio, Arduino, or Code Composer Studio. The expected interface shall connect with the SkyLight Glass hardware via an Android device. If extensive production was to be implemented, then IOS users could also be included within this expected production. However, due to time constraint and purpose of example, IOS shall be excluded. Models have been chosen for the application from a prior company, MiLight 2.0 application, however, the ratings for their application are quite unsatisfactory, which SkyLight Glass' application will develop upon to bring up to a higher standard. Please note that SkyLight Glass' team does not have any prior code for a skeleton, and will be making use of C++ libraries within Android Studio and other IDEs as deemed necessary. First and foremost, a user will need to download the application Skylight Glass Android Suite, turn on their Bluetooth on the device, search, discover, and pair with the SkyLight Glass module. Figure 5.2.4a below portrays a what the RGB color wheel as well as the dimming capability will be modeled after.

Figure 3.1.14a: RGB Color Wheel and Dimming Capability [MiLight application]

Figure 3.1.14b: Timer Capability for Alarm Mode [MiLight application]

3.2 Major Part Selection

The purpose of this section is to pick the major components based on the researched technology that meet the requirements of the SkyLight system. Multiple vendors were considered to determine the best product with the lowest price.

3.2.1 Smart Film Vendors

The goal of this section is to examine smart film products that are are able to meet the requirements of the SkyLight project that exist currently on the market. Since SkyLight uses smart film technology, an appropriate vendor must be carefully selected to ensure that all of SkyLight's requirements will be met.

3.2.1.1 Smart Tint® by Smart Tint, Inc.

Smart Tint®, created by Smart Tint, Inc. based in the United States, features a Polymer Dispersed Liquid Crystal (PDLC) smart film that changes states from opaque to transparent. There are two variants of this particular film: adhesive that is applied to a surface or a non-adhesive glass. The adhesive option uses a technology called Smart Cling® to apply the PDLC film to the glass. Smart Tint® has maximum dimensions of 1778 millimeters wide by 3400 millimeters long.

Smart Cling® is able to create a seal on the surface in such a way that heat and moisture is not trapped inside upon application of the adhesive to a given surface. Other positive attributes of Smart Cling® include the ability to be applied without voiding factory glass warranties, the ability to not interfere with the clarity of the smart film once applied, and lack of cracking or damage to existing glass that is associated with traditional adhesives.

The high on clarity smart film (HC-NF) employed in Smart Tint® operates on 100 to 120v AC at a frequency of 50 to 60 Hz. Smart Tint® is sold to users that may use 120v AC at 60 Hz to 220v AC at 50 Hz. The smart film provides a total light transmittance of 90% ± 1% when in the "on" state (transparent) and 4% ± 2% in the "off" state. Switching speeds for the film range from 50 to 100 milliseconds. Operational temperatures range from -10° C to 60° C. The coefficient of haze determines visible interference in the atmosphere: a coefficient of 1 represents clean air while a coefficient of 3 represents unclean air. Smart Tint® has a haze coefficient ranging from 0.03 ± 0.01 in the "on" state to 0.89 ± 0.02 in the "off" state.

The solar heat gain coefficient for light measuring 650 nanometers, defined as the portion of radiation admitted through a window, is 0.71. The solar heat gain coefficient ranges from 0 to 1: the lower a window's solar heat gain coefficient is, the less solar heat is transmitted. Infrared filters (IR filter) are implemented in Smart Tint® that reflect infrared wavelengths while allowing visible light to pass through. The IR block technology used in normal Smart Tint® smart film is rated at greater than or equal to 20% admission.

Smart Tint® also offers a low driving voltage (LV-NF) version of the smart film, both adhesive and non-adhesive, for low power applications. This particular film operates at 35 to 75v AC, remaining at a frequency of 50 to 60 Hz, in tandem with a power supply. It differs from the HC-NF smart film in that its solar heat gain coefficient and IR filters are improved substantially.

To lower the solar heat gain coefficient and improve infrared blocking, Smart Tint® offers IR90 technology that improves both non-adhesive and adhesive smart films for the low driving voltage smart film. Applying this particular technology to the smart film, a solar heat gain coefficient of 0.1 is achieved and IR blocking is elevated to greater than or equal to 90%.

Smart Tint® offers features such as high clarity, ultraviolet radiation blocking greater than or equal to 99% depending on transmissivity, low energy use, quick transition time between states, low energy costs (from 0.3 to 0.49 Watts per square foot), a large range of temperatures under which the smart film may be operated, differing colors for the film, and the ability to be paired with WiFi so that the transmissivity may be controlled through a computer program or phone application.

While the smart film technology that is used in Smart Tint® meets the expected requirements for SkyLight's smart film system, Smart Tint® lacks the ability to correct for lighting inside the room based on the state of the smart film's transmissivity. SkyLight seeks to implement PDLC smart film technology for variable transmissivity while adjusting the indoor lighting to accommodate for the differing light levels. When paired with an appropriate LED technology, this smart film would be able to control the natural lighting levels in a room while the LED technology controls the artificial lighting which meets the requirements of the SkyLight system.

3.2.1.2 SONTE Film by SONTE

SONTE Film, created by SONTE based in the United States, Asia, and Europe, features a Polymer Dispersed Liquid Crystal (PDLC) smart film that changes states from opaque to transparent. When a varying voltage source is applied, the film becomes transparent by aligning the liquid crystals in the same direction. When no voltage is applied, the film becomes opaque which causes the liquid crystals to have a randomized arrangement: reflecting and blocking light.

SONTE Film is sold as an adhesive smart film that can have maximum dimensions of 1200 millimeters by 4000 millimeters. The film can be cut into custom sizes for users to fit a variety of surfaces. Included with SONTE Film is a radio frequency controlled remote (named SONTE RF) and the SONTE Hub that serves two purposes: it allows the user to access the film remotely via WiFi and steps down the AC power source from 120v AC at 60 Hz to 60v AC with the same frequency for use by the film. The remote operates at a frequency of 433 MHz. WiFi is used to connect to and control the smart film remotely. The smart film can also be operated at 220v AC at 50 Hz for international users.

The smart film employed in SONTE Film provides a total light transmittance of greater than or equal to 76% when in the “on” state (transparent) and less than or equal to 50% in the “off” state. Switching speeds for the film range from 50 to 100 milliseconds. Operational temperatures range from -20° C to 70° C. The film’s ultraviolet absorption index is greater than or equal to 95% and its infrared absorption index in the “off” state is greater than or equal to 80%. The smart film consumes less than 5 Watts per square meter. The coefficient of haze determines visible interference in the atmosphere: a coefficient of 1 represents clean air while a coefficient of 3 represents unclean air. SONTE Film has a haze coefficient ranging from less than 0.08 in the “on” state to greater than 0.80 in the “off” state. The product life for SONTE film can exceed 10 years if used indoors. SONTE Film consumes less than 5 Watts per square meter.

Like other smart film vendors, SONTE Film allows the user to control the amount of sunlight allowed into the room by using opaque and transparent states in its PDLC design. However, no method for controlling the light inside the room via artificial lighting are considered. SkyLight seeks to implement PDLC smart film technology for variable transmissivity while adjusting the artificial lighting of the room the window is attached to in order to accommodate for the differing light levels. However, when an appropriate lighting technology is used in conjunction with this smart film, the desired result of altering the lighting levels in a room may be achieved.

3.2.1.3 InvisiShade 4.0 by InvisiShade™ LLC

InvisiShade 4.0, created by InvisiShade™ LLC based in the United States, features a Polymer Dispersed Liquid Crystal (PDLC) smart film that changes states from opaque to transparent. There are two variants of this particular film: self-adhesive/laminated film and non-adhesive glass. InvisiShade film has maximum dimensions of 1200 millimeters by 3000 millimeters. For windows larger than the dimensions listed, multiple films are used.

The self-adhesive film has two modes: in the “on” state, the film is transparent and consumes 0.65 Watts per square foot. In the “off” state, the film is opaque. The film can operate between -68° F to 140° F. Power requirements include 110v AC at 50 to 60 Hz, supporting adapters for various countries. In the “on” state, the film’s light transmittance is 78% while it is 7% in the “off” state. The time to transition between states is 400 ms.

The coefficient of haze determines visible interference in the atmosphere: a coefficient of 1 represents clean air while a coefficient of 3 represents unclean air. Invisishade has a haze coefficient ranging from 0.05 in the "on" state to 0.78 in the "off" state. Invisishade self-adhesive film is able to reduce ultraviolet exposure by up to 99% and claims to reduce solar rays by up to 42%. The laminated version of this smart film is similar to the adhesive film except that it requires support from two glass panes. This product is offered to consumers who are not within reach of InvisiShade™ LLC's normal operating area and to contractors who wish to develop windows that use smart film technology.

InvisiShade, like other smart film products, does not incorporate systems that allow for the ability to control the artificial indoor lighting depending on the transmissivity of the film's current state. This differs from SkyLight. SkyLight seeks to implement artificial lighting to control the lighting in a room based off of the film's current transmissivity. The artificial lighting will have varying intensity and color temperature to mirror the Sun's natural lighting depending on time of day.

3.2.1.4 Polyvision™ by Polytronix™

Polyvision™, created by Polytronix™ based in the United States, features a Polymer Dispersed Liquid Crystal (PDLC) smart film that changes states from opaque to transparent. Polytronix™ is the only manufacturer in the United States that makes PDLC film. [Polytronix™, 2016] By applying a varying voltage, the film's liquid crystals align in one direction: allowing light to pass through the film and exhibit a transparent state. This is similar to how the electric field interacts with electrons in a parallel plate capacitor. When no voltage is applied, the liquid crystals then arrange randomly: reflecting and blocking light. The film becomes opaque as a result. Polyvision™ is sold in three forms: Polyvision™ Glass, Polyvision™ Film, and Polyvision™ Adhesive Film.

Polyvision™ Glass has maximum dimensions of 1828 millimeters by 3048 millimeters and is available in four colors: clear, green, bronze, and gray. An advantage of Polyvision™ Glass is that it can be partitioned in such a way, using PolyPattern™ panel segments, to allow partial privacy. The film is operated at 65v ± 5v AC at 60 Hz. The visible light transmittance of Polyvision™ Glass ranges from 75% ± 3%. The operational temperatures for the glass range from -10° C to 60° C. The power consumption of Polyvision™ Glass is less than 0.5 Watts per square foot. The glass takes less than 100 milliseconds when at room temperature to change states from opaque to transparent. The solar heat gain coefficient in the "off" state for the film is less than 0.10. Infrared blocking in the "off" state is 1% while in the "on" state is 50%. The coefficient of hazing for the film is 0.07. Visible light transmittance for the film is approximately 75% when the film is in the "on" state.

Polyvision™ Film is similar to the adhesive film except that it requires support from two glass panes. This smart film allows for 75% light transmittance in its transparent state to 55% light transmittance in its opaque state. Polyvision™ Film consumes up to 0.5 Watts per square foot. The viewing angle for Polyvision™ Film is approximately 150°. Infrared blocking is rated at

80% and ultraviolet blocking is rated at 99%. The minimum off time for this product is 4 hours a day. This product is intended to be used by glazing laminators only.

A disadvantage of Polyvision™ smart film technology is the cost of the power supply used to operate the smart film. The power supply, described in the datasheet [Polyvision™ Power Supply], coupled with the required smart film dimensions exceeds the price range of SkyLight's budget.

Like other smart film vendors, Polyvision™ Film allows the user to control the amount of sunlight allowed into the room by using opaque and transparent states in its PDLC design. However, no method for controlling the light inside the room via artificial lighting is considered. SkyLight seeks to implement PDLC smart film technology for variable transmissivity while adjusting the artificial lighting of the room the window is attached to in order to accommodate for the differing light levels. This result may be achieved with this smart film when paired with an appropriate LED technology.

3.2.2 Smart Film Selection

Various technologies were explored to determine which smart film would best fit the SkyLight system. Passive smart glass technology was ruled out due to the need to control the lighting of the room at all times. Another contributing factor that eliminates passive smart film technology as a possibility is the transition time of the film. Passive technology often requires several minutes to fully transition from a transparent to opaque state. The transition time can be even longer when transitioning from the opaque to transparent state. Active smart glass provides the ability to control transmissivity through an electrical stimulus. The most common type of active smart glass technology for windows is polymer dispersed liquid crystal (PDLC).

All smart glass and film vendors considered use PDLC technology. Each vendor offered both film and glass variants. The active state for all four films considered is transparent while the inactive state is opaque. Some vendors offered the option to laminate the film by shipping the film to a local glass manufacturer. This option was considered but deemed too costly as a film is more than suitable to apply over base glass for the purposes of the SkyLight system.

In Table 3.2.2, all of the relevant information regarding the four companies was compiled and compared. Certain parameters, such as the solar heat gain coefficient, were not listed by two of the companies. Specific values could not be found for one of the companies. This company opted to use inequalities to express ranges instead.

Product	Smart Tint®	SONTE Film	InvisiShade 4.0	Polyvision™
Light Transmittance (opaque state)	4% ± 2%	<50%	7%	55%
Switching Speed	50-100 ms	50-100 ms	400 ms	<100 ms
Operational Temperature Range	-10° to 60° C	-20° C to 70° C	-55° C to 60° C	-10° C to 60° C
Coefficient of Haze (transparent)	0.03 ± 0.01	<0.08	0.05	0.07
UV Absorption Index (opaque)	99%	>95%	99%	99%
IR Absorption Index (opaque)	20% (regular) 90% (LV-NF)	80%	42%	80%
Solar Heat Gain Coefficient	0.71	Not available	Not available	0.10
Energy Consumption (W/ft^2)	0.3-0.49	<0.46	0.65	0.5

Table 3.2.2 - Smart Film Comparisons

One of the engineering requirements for SkyLight requires that 70% of visible light be blocked when the window is in its opaque state. Smart Tint® and InvisiShade 4.0 are both able to satisfy this requirement while SONTE Film and Polyvision™ do not meet this requirement. When comparing Smart Tint® to Invisishade 4.0, Smart Tint® is equivalent to or outperforms Invisishade 4.0 in all categories except for operational temperature. Given that SkyLight will be designed with temperatures common to Central Florida, the listed operational temperature range for Smart Tint® is adequate for the purposes of the SkyLight system.

Smart Tint® was selected over Invisishade 4.0 due to the fact that it has a lower power draw, reducing operational costs for the system. In addition to this, Smart Tint® has a faster switching speed resulting in better performance. Smart Tint® also has an identified solar heat gain coefficient which ensures the amount of heat transmitted through the window is within acceptable parameters. One of SkyLight’s goals is to increase energy efficiency in the home by reducing heat allowed to pass through the window and the selected film’s specifications indicate that it will be able to meet this goal.

3.2.3 LED Vendors

The goal of this section is to examine LED technologies that are currently on the market that can achieve the desired effects and meet the requirements for the SkyLight project. SkyLight requires LEDs that have a high viewing angle so that a small room may be illuminated, are able to vary intensity using pulse width modulation or a similar technique, and can vary color temperature. The LEDs must also be able to cover the top panel's inner side of a small window as described in the preliminary sketches of the system in Section 2.5.2.

3.2.3.1 6W E27 LED Bulbs by LEDENET®

LEDENET® 6W E27 LED bulbs, created by ENET Light Technology Corporation and based in Asia, features a bi-colored LED that allows for adjustable color temperatures ranging from 2700K to 6500K. The LED bulb is WiFi compatible and can be controlled up to 30 meters away from the operating device. The wireless capabilities are handled by a remote controller and can control the LED light’s intensity and color temperature. There are two variants of this bulb: a 6 Watt version and a 9 Watt version.

The voltage required to operate this device ranges from 85v AC to 265v AC: enabling different countries that use different AC voltages to use this device. The operational frequency of the LED bulb ranges from 50 to 60 Hz. The current drawn from the device ranges from 36 mill amperes to 65 mill amperes. The bulb outputs a maximum of 450 lumens which is equivalent to the lighting levels of a 40 Watt incandescent bulb.

Power factor is involved in calculating a devices real power: the product of the power factor and the apparent power. The power factor of an LED bulb ranges from 0.5 to 0.9 and is a requirement, set by ENERGY STAR®, that must be met for LEDs on the market. [ENERGY STAR, 2008] The LEDENET® 6W E27 LED bulb has a power factor (PF) of 0.65. The bulb is 120 millimeters in length and has a diameter of 60 millimeters.

While this particular LED is capable of varying the color temperature using bi-colored LEDs, implementation of the bulb into a system like SkyLight isn’t feasible given that the dimensions of the bulb is too large to accommodate on a demonstration window as intended.

This product also is incapable of altering the light produced from the Sun that protrudes through a normal window. SkyLight requires that both the indoor and outdoor lighting levels and color temperatures are controlled at all times. When paired with an appropriate smart film technology, the desired result of controlling lighting levels through artificial and natural means is achieved which meets the requirements of the SkyLight system.

3.2.3.2 2 Chip SMD LED Light Strip by Super Bright LEDs, Inc.

The 2 Chip SMD LED light strip, sold by Super Bright LEDs, Inc. based in Missouri, features a 39.4 inch and 196.9 inch strip that contains 6 SMD LEDs per segment and offers 36 SMD LEDs per foot. The SMD LED technology used is 3528 (3.5 millimeters by 2.8 millimeters) and operates on a 24v DC power supply. The strip offers 10 lumens per LED, 366 lumens per foot, and consumes 5.5 Watts per foot. The color temperature of the strip ranges from 2500K to 6800K. The LED strip may be cut into segments for a variety of applications and uses.

To achieve variable color temperature, the 3528 SMD LED strip uses two dual-phosphor LEDs paired next to each other. One of the LEDs is able to emit a light with a color temperature around 2500K while the other LED emits a light with a color temperature around 6800K. Variable color temperature is achieved by activating one (or both) of the LEDs. By mixing the two LEDs of differing color temperatures, an intermediate color temperature is achieved.

The 39.4 inch strip is capable of reaching illumination levels can sufficiently light a small room: a requirement of the SkyLight system. Variable intensity can be achieved by the SMD LEDs: reaching up to 1200 lumens and consuming around 5.5 Watts per foot with a viewing angle of 180°. This intensity is equivalent to a 75 Watt incandescent bulb's intensity with lower power draw. These LEDs have a lifetime of 30,000 hours. In comparison, a 75 Watt bulb generally has a lifetime of 10,000 hours.

This LED strip is driven by a 24v DC power supply unit and draws 750 milliamperes of current. The intensity can be controlled via pulse width modulation by varying the duty cycle from 0% to 100% to achieve the desired intensity. The strip is capable of being operated remotely up to and greater than 15 meters away in an open area using a wireless radio frequency remote operated at 433.92 MHz.

This particular LED strip meets all of the requirements of the SkyLight system. When paired with an appropriate smart film technology, the ability to control the inside lighting through natural and artificial means may be achieved. The intensity of the LED can be adjusted based on the current transmissivity of the smart film. The color temperature of the LED can be adjusted based on the time of day.

3.2.4 LED Selection

Of the LED technologies explored, two were able to meet the lumen engineering requirement of the SkyLight project. Dual in-line package LEDs, while very inexpensive and consume little power, are not able to obtain the high intensity required for lighting a small room. While chip on board (COB) LED technology meets the lumen requirement, there are several aspects to this technology that are not suitable for the SkyLight system.

A flexible strip is required to be placed on the SkyLight window frame. Many COB strips are rigid in structure, using an aluminum bar as a base, and cannot be cut to meet the specific lengths required for different size windows. To obtain a specific sized COB strip, a custom order must be placed which can increase construction time of the SkyLight system. Another disadvantage to COB technology is its maximum intensity. COB LEDs are generally used in flashlights and floodlights which require high intensity beams. The goal of the SkyLight project is to illuminate a small room but not to be too intrusive to the occupant of the room. High intensity LEDs like COB LEDs could cause discomfort and serve as a distraction instead of adjusting artificial light levels to match the natural light of the Sun outside. The last consideration for COB LEDs was pricing. Since COB LEDs consume more power on average, better power supplies are required to power the COB LEDs which has two disadvantages. One, this drives up the cost of the LEDs which would exceed the allotted budget amount and increase the price of the system overall. Two, this drives up the energy consumption of the entire system. One of the engineering requirements of the SkyLight system is for power consumption to be in the 20 to 50 Watts range. One of the reasons LEDs were sought as a lighting solution for the SkyLight system is because of their low power draw.

This leaves surface mounted device LEDs as the last technology option to meet the requirements of the SkyLight system. SMD LEDs come in a variety of sizes with varying amount of LEDs per strip length, can be cut to fit custom sizes by a user, consume very little power, can be driven by a relatively cheap power supply, and have an acceptable intensity for lighting the interior of a room. There are many vendors that sell SMD LED strip. However, very few are able to accommodate for color temperature ranges. Of the ones examined, the 2 Chip SMD LED Light Strip by Super Bright LEDs, Inc. meets all the required specifications for the SkyLight system including luminous flux rating, color temperature ranges, power consumption, and ease of installation.

There are some selection concerns in regards to SMD LEDs derived from the fact that they come in a variety of sizes. The two most common sizes are the 3528 SMD LED strip and the 5050 SMD LED strip. The 5050 SMD LED strip is 5.0 millimeters by 5.0 millimeters and consumes up to 7.5 Watts per meter. This size of strip is capable of delivering much higher intensity since there are approximately 30 chips per meter which equates to 360 lumens per meter.

5050 SMD LED strips are designed as shown in Figure 3.2.4a. Each color value (red, green, or blue) has a channel that connects to it. Through this channel, the user is able to alter the RGB values to obtain different colors of light. Using sophisticated algorithms, these RGB values can be modified to exhibit correlated color temperature properties. The channels are altered via PWM just like in the 3528 variant.

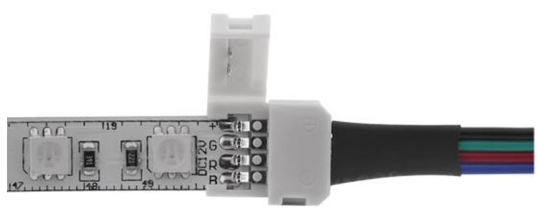


Figure 3.2.4a – 5050 SMD LED Strip

The general schematic of a 5050 SMD LED can be seen in Figure 3.5b. The LEDs are grouped into sections and each section contains approximately 9 LEDs. These 3 groups of LEDs cover the color range from dark purple to bright red. Mixing the intensities of the 3 different channels can produce color temperature qualities by driving the LED circuit with a PWM signal. A downside to the 5050 SMD LEDs is the pricing.

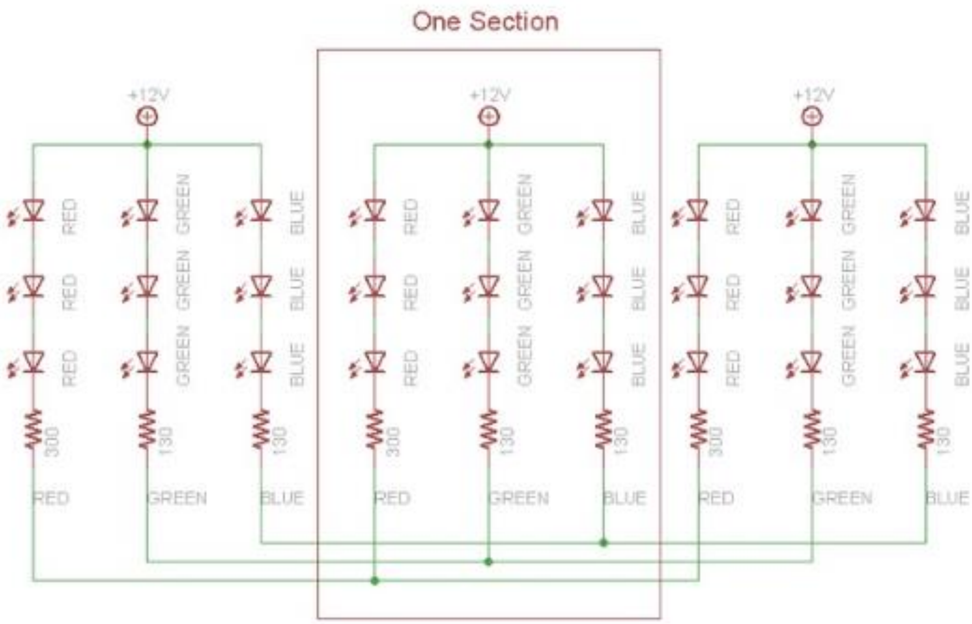


Figure 3.2.4b – 5050 SMD LED Schematic

The 3528 SMD LED strip is 3.5 millimeters by 2.8 millimeters and consumes up to 5 Watts per meter. This size of strip is capable of delivering midrange intensities up to 220 lumens per meter for normal densities of LEDs and 440 lumens per meter for higher density versions of the strip. The advantage of the 3528 SMD LED strips are their price ranges. They are generally used for projects with low luminosity requirements and when cost is a key factor. [About LED Strips, 2010]

The pricing of both LED strips is relatively the same. The difference is in how they are used. The 3528 SMD LEDs are less adaptable and usually designed with a specific use in mind. They offer lower lighting intensities but are sufficient for the SkyLight system. The 5050 SMD LED strip has specific pins dedicated to RGB values and can therefore vary not only color temperature but also change the general color of a room by subtracting certain hues from the light. SkyLight will use the 3528 SMD LED strip for initial testing and prototyping. The 5050 SMD LED strip will be integrated into the final product.

3.2.5 Relay Selection

Relays come in many shapes, sizes and flavors. Since Relays are made of many components it's possible for one relay to operate very differently than another. After all, relays each have an electromagnet which determines the amount of power needed, a transistor which determines the turn-on voltage from the microcontroller, and the physical switch itself which will have turn-on/turn-off time and voltage, current and power limitations.

There are two key features that a relay must have to work with SkyLight Glass: the relay must be able to be turned on by the Atmel ATmega328P microcontroller and it must also be able to handle the voltage, current, and power required to activate the smart film. In this case it means that the relay must be able to be turned on by a potential difference of 5V provided to the gate of its transistor and be able to handle the 60VAC required by the Smart Film.

As a third (less technical) requirement, the relay must also be able to be shipped quickly at a reasonable cost. This eliminates most available vendors, leaving only amazon.

As already noted, Amazon is not a desirable vendor for electronics parts as almost all electronics parts sold on amazon are actually bootleg. Thankfully relays are a rather robust component - it's hard to mess up a simple switch, even with the shoddy standards and practices of your average amazon vendor.

This does limit part selection considerably though - to those available on amazon prime. Unfortunately, most of the relays available on Amazon are activated by much higher voltages than the Atmel ATmega328P microcontroller is capable of handling, and having external circuitry to support the relay is both unnecessary and undesirable.

Most of the applicable and available relays were made specifically to work with arduino development boards - which makes sense because the Atmel ATmega328P microcontroller is at the heart of all of arduino's flagship products. There are reasonable three relays available that fit this description: the Tolako 5v Relay Module, the SainSmart 2-Channel Relay Module, and the SunFounder 2 Channel DC 5V Relay Module. All three of them use the Songle SRD-05VDC-SL-C relay switch as their base which makes them very similar. It makes sense that they are so similar though - ultimately there's a narrow margin of requirements that meet up with a narrow margin of availability.

Their main difference is that the Sainsmart and SunFounder support two channels while the Tolako only supports one. Since there are two pieces of smart film, the SkyLight Glass team has decided to opt for a two channel, which eliminates the Tolako as an option.

The SunFounder two channel relay module is cheaper than the Sainsmart two channel relay module by about a dollar (US currency). Additionally it has seventy percent more reviews and the reviews are mostly positive. Because of the price difference and lengthier test history, the SkyLight Glass team ultimately chose the SunFounder two channel relay module.

3.2.6 Power Component Selection

As previously mentioned, the smart film includes an VAC to 60v AC converter. That means that the 24VDC power supply and the 5VDC voltage regulator still need to be selected. That said, there are many components that could be used for this, and one of the main factors that will be considered is part availability. Things available from Amazon have free two day shipping, but are very likely to be counterfeit (bootleg) and also have a higher initial cost. Meanwhile the components at legitimate electronic component distributors often have high lead times and an absolutely unbelievably high shipping cost despite the many easy and convenient ways to quickly ship light weight packages.

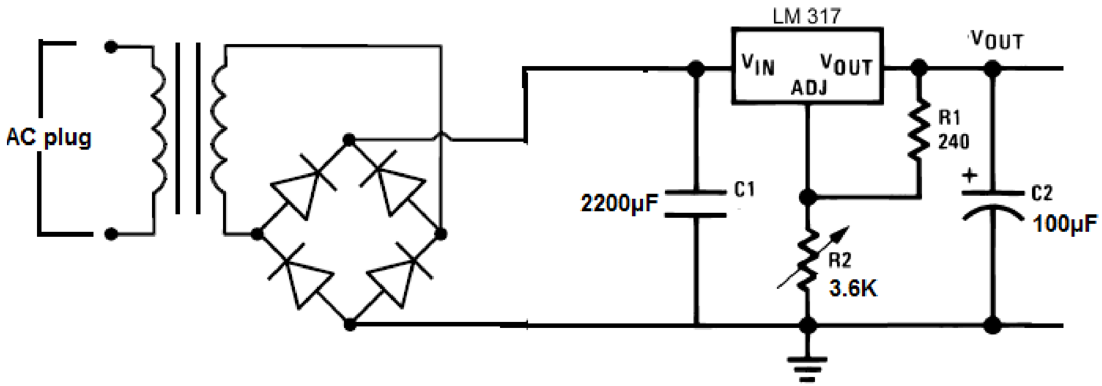


Figure 3.2.6 - AC/DC Conversion and Rectification

Amazon has a few options for 24v power supplies, however most of them have considerable negative reviews. The exception is a DROK brand power supply without a case, which probably works best for our desired form factor as well. Additionally, it’s rated for 4A, which is more than ample for SkyLight, especially since few parts from amazon actually works at its rated value. [Amazon - DROK]

Converting 24v DC to 5v DC is much simpler than the other power conversions. Instead of using a power supply, a simple voltage regulator will suffice. There are many many voltage regulators that convert to 5v since there are a vast amount of components that run off of 5v logic. Unfortunately, since the actual microcontroller will be the most voltage sensitive component, it is important that our voltage regulator is very consistent and never over volts. This is in contrast to the LEDs and Smart Film, neither of which are particularly sensitive to small variations in voltage.

Because of this, it would be irresponsible to run SkyLight on something as likely to be bootleg as any component bought off of Amazon. [AllAboutCircuits, 2011] Still, the shipping charges and lead times from dedicated electronics component distributors are simply unacceptable for a project of this small scale. Thankfully there is an in-between of the two - because 5v voltage regulators are so common, they are something that can be bought at hobbyist sites like Sparkfun or Adafruit.

From these sources, the most sensible power supply is the 7805 from adafruit, which can easily step down to 5v with only 2% (0.1v) variance, and costs less than a dollar. It’s TO220 size, which means that it’s very small compared to the available space, that it’s ROHS compliant, and that there are a large number of heat sinks should they become necessary. [Adafruit]

These two components along with the power supply included with the film should fulfill all of the power supply needs of SkyLight. If a component draws too much current for the power supply, capacitors will be used before replacement power supplies or voltage regulators are bought. With the exception of the outlet VAC to 60v AC power supply, and the outlet VAC to 24v DC the components will all be connected directly to the PCB and mounted on the actual window frame of SkyLight.

3.2.7 Light Sensor Selection

Having the ability to sense the ambient light is important to acquire the outside conditions and then adjust indoors accordingly. There are many different ways to accomplish this task as well as many different devices that the team considered while researching components. However, the team must be able to so efficiently and in a cost effective manner that suits our needs.

After looking at many options the team opted for a phototransistor that is made by Lite-On, LTR-4206E. This is a very simple device that still allows for a sufficient light reading that satisfies our criteria. This device’s range can be varied by simply swapping a resistor in the circuit for the desired conditions which makes it extremely versatile. Another very important factor for this selection was the cost, this device is only $0.46. The team would like to keep costs low and this device surely meets that requirement.

Additionally, the device is quite simple since it only has two pins that are connected to ground and a voltage source and then the current varies depending on the light conditions. Lastly, this device has a through-hole mount construction making it desirable in many ways since it manages to fit all requirements at a low cost.

3.2.8 Temperature Sensor Selection

Selecting a temperature sensor that that accomplishes the task is very important for the system to operate reliably. However, for the purposes of the SkyLight glass, the team is looking to accommodate all the features possible that will allow for the most energy efficient system. As a part of that goal the temperature sensor plays a minor role but for a system to work flawlessly all the small components add up to play in that major symphony.

Sensing temperature will allow for the proper development of a system that saves the user energy. For warmer times, a user would be concerned with cooling costs which the system helps provide by blocking the sunlight that warms up the property and thus the A/C runs for less time resulting in less energy consumption.

However, for colder times it might be a good idea to let the sunlight help with keeping the property warmer and avoid or at the very least restrict the time that the calefaction must run resulting in energy savings.

To do that the team required a temperature sensor since the internet is off limits. While all of these sensors are more accurate than needed, there are some key differences that leaned the team towards selecting the TMP36.

Mainly, for its simplicity, price and accuracy. This sensor is straightforward since it only has three pins but reading the output requires an analog to digital converter since the output is analog. However, the ATmega328P contains more than enough pins for the task and makes it feasible.

Although the TMP36 costs more and is a little bit less accurate is favorable for the project. This sensor is still very accurate for the purposes of the team. Most importantly, this device has a through-hole construction that simplifies the construction of the board later. This would save the team time at a bit higher cost but retaining accuracy.

Device	**TMP36**	**MCP9700T**	**LM75B**
Price	$1.48	$0.26	$0.75
Accuracy	±3℃	±2℃	±2℃
Construction	Through-hole	Surface mount	Surface mount

Table 3.2.8 – Temperature Sensors Comparison

3.2.9 Real Time Clock Selection

A real time clock is a device that is usually powered by a coin battery in case the system is disconnected from main power it can continue to track time once the system comes back online. For the purpose of our project, this is an essential component in order to acquire time without the need of an internet connection since our system will remain offline to save energy. A few devices were considered in order to make a final selection.

All the real time clocks researched provided very similar features although some more than others. The MCP7940M was selected for the task since this device grants us the features that are required for our system. This device is able to keep track of time in a very efficient way while remaining relatively low cost at $0.60. The price point is not the only reason, this unit also is constructed with through-hole components a feature that the team believes makes the most sense to simplify the construction process later.

The MCP7940M will be integrated into the overall system with the ATmega328P MCU as seen in Figure 3.2.9. Pins #27 and #28 will be used to obtain the necessary data from the RTC.

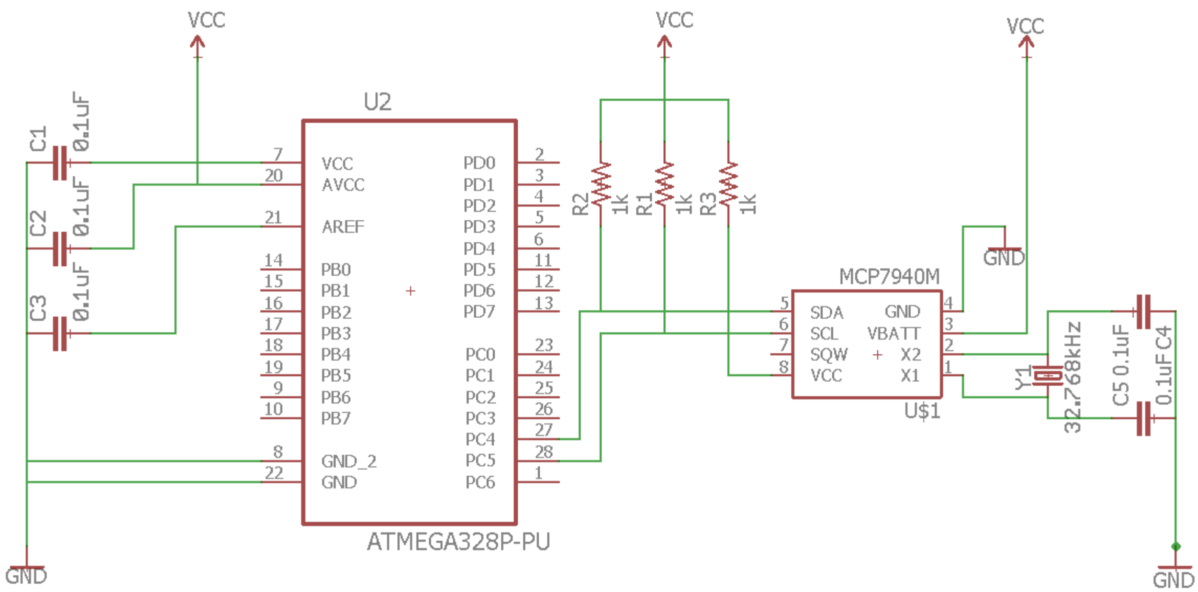


Figure 3.2.9 – Real Time Clock Schematic

3.2.10 Microcontroller Selection

Many of these modern MCU share many features although each having its own advantages and disadvantages. The team has debated with the idea of having a system that is either built with surface mount or through-hole components which heavily affects our selection. Our primary concern is avoiding any roadblocks right from the beginning since is of utter importance that our device works in the end or it would all be in vain. This is where a big debate between us have sparked, since through-hole construction gives us the ability to build a very sturdy system that is easily cared for and in the case of any failures the team can replace parts without the need of having to send the board to be soldered by a third-party company which would take time that the team might not have.

Selecting a surface mount chip encounters its first major drawback at the time of building it, since we would not have the ability to solder it by hand and represents that in case there was an unlikely event that would cause the board to fail. In the other side of the coin surface mount MCUs can have many advantages. For one we save a lot of space since the chips tend to be much smaller than those with through-hole construction. Another important factor involving our project is that we are very concerned with having wireless connectivity, which some of the newer chips from TI already have included.

This is a tremendous advantage that is worth looking into since it means that we would not have to connect any other modules to our system, this would save us time and remove any constraints an external module could have. Not to mention, that since the wireless module is embedded in the chip, it has a lot of information that we can utilize to develop our system. This allows the team to avoid the need to learn how to operate a different module and any problems that might come from connecting a chip with a wireless module and getting it running. This is a major advantage for the system we want to build that could be overlooked for the time of construction since the benefits appear to be greater. One solution for putting our board together while still removing most of the problems in case we needed to add or remove any components would be to design the entire board with through-hole components except for the driving microcontroller. This would allow us to save space in a wireless module, since it would already be in the chip, and also we would only need to solder this one part.

The next option for the team is to leave the surface mount microcontrollers behind and opt for a through-hole construction to keep the system easy to fix while staying within budget. One major advantage of through-hole components is that they tend to be cheaper because the technology is a bit more outdated and occupies more space. This signifies that the printed circuit board is going to be larger but for our application this is not problem since the construction of the system would allow for enough room for this to not be a problem. However, since these devices are simpler in nature and intended for smaller applications they do not have some of the needed features embedded. Representing that the system will require many modules to conduct all the operations that our system requires.

MCU	MSP430FG4618	CC2640	ATmega328P
Architecture	16-bit RISC	16-Bit ARM	RISC
Manufacturer	Texas Instruments	Texas Instruments	Atmel
Cost	$10	$6	$2
Supply Voltage	1.8 v – 3.6 v	1.8 v – 3.6 v	1.8 v – 5.5 v
Power Consumption	400 µs / MHz	61 µs / MHz	200 µs / MHz
Standby	1.3 µs	1 µs	0.1 µs
Memory	116 KB	128 KB	32 KB
PWM Channels	2 (16-bit)	8 (16-bit)	6 (8-bit)

Table 3.2.10 - Microcontroller Comparison

The team has decided to go with the ATmega328P since it suits the project well. One of the main reasons for this selection is that this is a through-hole construction device that allows the board to be easily repaired. Having an entire system built with through-hole components allows the team a lot more flexibility in case something was to go wrong. This ensures that at once the main circuit board is developed all other items can be soldered by hand, removing the need for a third party. This could mean the difference with having a system that works in the end because in the case of any last minute problems can be addressed in time.

Additionally, this microcontroller is quite inexpensive at $2 a piece allowing the team to stay within budget. The team is concerned with making this project as inexpensive as possible thus this fits the part. Another reason was the ability of easily getting an Arduino UNO development board which is largely used and therefore has many resources that could help with the project.

This unit is not extremely powerful but is sufficient for our needs, offering all the I/O pins the system requires for getting information and controlling the system.

3.2.11 Bluetooth Module Selection

The SkyLight system will be remotely controlled using Bluetooth paired with a smartphone application. In order to do this, a short-wavelength ultra high frequency radio wave in the industrial, scientific, and medical radio (ISM) band from 2.4 to 2.485 GHz will be used. The 2.4 GHz band may be used and/or shared by other devices such as car alarms, microwave ovens, Wi-Fi networks, and other equivalent isotropically radiated power (EIRP). This type of interference is quite common and can distort the Bluetooth signal significantly if no precautions are taken.

This presents a design challenge for SkyLight as the window may be attached to a kitchen or placed in an apartment with many cars around. Careful consideration was taken to find a Bluetooth module that would be able to handle discrepancies in the signal sent over the 2.4 GHz radio frequency band. In a search for Bluetooth modules, two potential ones were found that are compatible with the selected microcontroller unit that was selected. Two, in particular, were considered: the HC-05 and HC-06 Bluetooth modules. Table 3.2.11 lists some of the important differences between the HC-05 and HC-06 modules.

	HC-05	**HC-06**
Master/Slave Mode Toggle	Supported	Not supported
Pairing with Multiple Devices	Supported	Supported (limited)
Multiple Active Modes	Supported	Not supported
Power Consumption	0.25 mA	0.25 mA
MCU Compatibility	ATmega328P support	ATmega328P support

Table 3.2.11 - Bluetooth HC-05 and HC-06 Comparison

While the power consumption, a major concern for the SkyLight system, is the same for both modules, the HC-05 allows for more flexibility. The HC-05 is also more readily available for purchase and is generally the same price or less expensive than the HC-06.

There are many vendors that sell the HC-05. One of the primary considerations for the SkyLight system is shipping cost. The most accessible HC-05 module could be found from ITEAD Studio with relatively low shipping costs.

Section 3.3 Major Component Overview

The major components selected to build the SkyLight system prototype are listed in Table 3.3. The requirements column details which requirements are satisfied (either directly or indirectly) based on Section 2.3's table of engineering and marketing requirements. All parts were selected with cost as a primary motivator for their selection and therefore all components meet requirement seven listed in Section 2.3's table.

Major Component	Product Selected	Manufacturer	Technology	Requirements Met
Smart Film	Smart Tint®	Smart Tint, Inc.	PDLC film	4, 6
LED	Two Chip SMD LED Strip	Super Bright LEDs, Inc.	3528 SMD LED 5050 SMD LED	1, 2, 3
Relay	2-Channel Relay	SainSmart	MCU Compatible	4, 5
Light Sensor	LTR-4206E	Lite-On Inc	Phototransistor	1, 4
Temperature Sensor	TMP36 Temperature Sensor	Analog Devices, Inc.	MCU Compatible	4
Microcontroller	ATmega328P	Atmel Corporation	RISC-based	1, 2, 3, 4
Bluetooth Module	HC-05 Serial Bluetooth Module	ITEAD Studio	Serial Communication	5, 6

Table 3.3 - Major Part Selection Details and Requirements Satisfied

The major components may be found in Figure 3.3 and are labeled as follows:

1. PDLC Smart Film
2. 3528 SMD LED Strip and Connectors
3. 2-Channel Relay
4. HC-05 Serial Bluetooth Module
5. LTR- 4206E Ambient Light Sensor
6. TMP36 Temperature Sensor
7. ATmega328P Microcontroller Chip
8. MCP7940M Real Time Clock

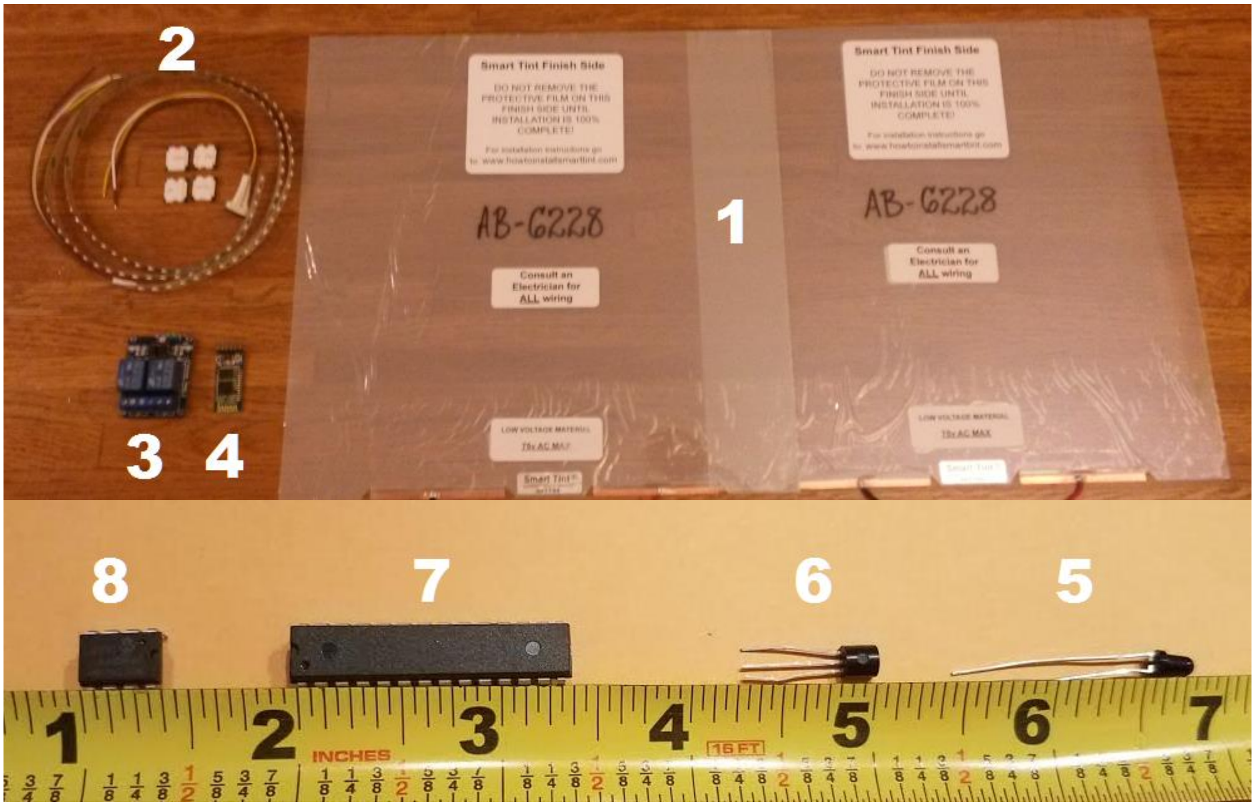


Figure 3.3 - Major Components

The only major component not listed is the window frame itself. The frame can be acquired easily through multiple means from different local vendors. One option for the SkyLight system would be to fabricate a custom frame from parts bought from a local hardware store. This would fit the system requirements. However, purchasing a frame may be the primary choice since due to time constraints placed on the project

The frame would be much like a picture frame: it would sit around the SkyLight Glass. Attached in a discrete manner around the frame would be the power supply wiring, the receiver for the MCU which will relay the signals of the Bluetooth, which in turn would be receiving data from the user's cellular device via application. Since this component is strictly used in the construction of the project and can be easily acquired from multiple local vendors, the purchase of the frame will be delayed until Senior Design 2 when the PCB size is finalized.

4. Standards and Constraints

Standards are one the most critical parts of any design, and even of engineering as a profession. Standards are the key to compatibility between devices. Without standards there would be no ability to repair, upgrade, or connect devices. When it comes to computerized electrical devices connecting is extremely important. In this day and age there are very few devices that are intended to be used in isolation, and even fewer that aren't hacked into working outside of isolation.

Constraints are equally important. If a production or development team does not properly evaluate their constraints then they're very likely to run into multiple issues during every phase of product development. Similarly, ignoring constraints is enormously likely to lead to an end product which is hazardous for its user - something which is quite possibly a worst scenario.

4.1 Standards

Standards are a specific way of doing something. An everyday example of a standard is spoken language. If everyone spoke their own unique language then nobody would be able to communicate. The same can be said for computerized electronic devices. Just like how there are competing languages (i.e. English, Spanish, Chinese, etc.) There are a huge variety of competing standards, all with benefits and deterrents. SkyLight Glass will try to use the most common standards that solve the problems at hand, so it is compatible with the most amount of outside devices.

The standards used by SkyLight glass will be, for the most part, provided by the IEEE Standards Association. While there are a large amount of competing standard-providing organizations, like NSSN or ANSI, SkyLight glass will be sticking to IEEE standards as much as possible. SkyLight will need to use standards in all communication, including Bluetooth communication, serial communication to peripheral devices, and communication to the users. Peripheral devices such as the Bluetooth module, the real time clock, and while sending PWM signals.

Still, standards are also needed for PCB and hardware design, along with communication. This is to make sure that all of the components fit properly on the PCB. These standards are mostly a product of the IPC, which is accredited by ANSI, and is a generally considered the leading authority in several electronics standards, including printed circuit board standards, and assembly and design standards.

By using these standards, SkyLight Glass will be able to work with the largest variety of components and communication. While most of the printed circuit board components used will be through-hole instead of surface mount, that itself is an important standard to uphold.

4.1.1 UL Standard UL8750

LEDs are an integral part of SkyLight Glass. It's one of the two main features for the user. So it should go without saying that the LED related standards are very important. That said, aftermarket compatibility and networking isn't a real concern since the LEDs aren't a component meant to be replaced nor are they capable of networking on their own. Still, the ability for SkyLight Glass to be hackable by its user is desired and the standards also act as a stellar guide for best practice (which is critical for such an integral component of SkyLight Glass) [UL Standards, 2016].

The UL Standard UL8750 requirements are an absolutely critical part of any luminaire or any other kind of lighting that operates between four hundred and seven hundred nanometers, which spans the entire range of the whole visible light spectrum. Note that by including any lighting device it also includes Light Emitting Diodes (LEDS) in its scope, which makes this standard extremely important for SkyLight Glass [UL Standards, 2016].

The UL Standard UL8750 is inclusive to those on branch circuits of six hundred volts nominal or less, which is in accordance with another standard by the National Electric Code (NEC), and also by the ANSI and NFPA 70 standard. It also covers connection and isolation, which are not connected to any utility, like things that are only connected to power supplies, function generators, batteries, fuel cells, solar cells and similar things [UL Standards, 2016].

It specifically also covers LED equipment that is used in any way, shape, or form in complies with any high end product standards like Electric Signs, UL 48, Portable Electric Luminaires, UL 153, Underwater Luminaires and Submersible Junction Boxes, UL 676, Emergency Lighting and Power Equipment, UL 924, Stage and Studio Luminaires and Connector Strips, UL 1573, Track Lighting Systems, UL 1574, Luminaires, UL 1598, Direct Plug-In Nightlights, UL 1786, Low Voltage Landscape Lighting Systems, UL 1838, Self-Ballasted Lamps and Lamp Adapters, UL 1993, Luminous Egress Path Marking Systems, UL 1994, and Low Voltage Lighting Systems, UL 2108 [UL Standards, 2016].

As one can clearly observe, many of these standards that interact with the UL Standard UL8750 are critical for SkyLight Glass. Through using these standards SkyLight Glass seeks to achieve best practice with their extremely high priority lighting system [UL Standards, 2016].

4.1.2 IEEE PAR1789

IEEE PAR1789, also known as FLICKER, is a new IEEE recommended practice. Visible flicker can cause neurological problems as extreme as epileptic seizures, but they can also cause more mild symptoms like migraines headaches, fatigue, poor vision, and eye pain/strain. In addition to being generally unpleasant, these things also have a dramatic effect on a person's' ability to do work in an environment with this kind of unnatural stimulation. It can even increase autistic behaviors in those that are on the autism spectrum, and of course distract people. None of this is desirable in any environment, so it is definitely not desirable for Skylight Glass [Naomi, 2015].

To understand it, you first must understand the terminology [Naomi, 2015]:

Flicker: Algorithmically repetitive change in the brightness amplitude over a period of time, or a modulation of the luminous flux of a source of light. Also called light source modulation.
Sensation: Any external conditions that are detected by a persons, where neurons respond.
Visible flicker: Luminous modulation that is both received as a sensation and is capable of being perceived.
Invisible Flicker: Luminous modulation that is received as a sensation but is not capable of being perceived.
Stroboscopic effect: Luminous modulation with invisible flicker that becomes visible flicker when the object is in motion and the observer is not in motion.
Phantom Array Effect: Luminous modulation with invisible flicker that becomes visible flicker when the object is in not motion and the observer is in motion.

Visible flicker is made worse proportionally by the length (in time) of the exposure, to the area of the retina in the eye that receives the stimulation, the amount of central it is in the visual field, the amplitude of the brightness of the light that is flickering , the relative amplitude of brightness compared to the amplitude of brightness of the environment, and the wavelength of the flickering light on the visual spectrum (deep red creates the worst symptoms) [Naomi, 2015].

Both visible and invisible flicker is increased by the modulation frequency, the modulation amplitude, the DC component, and the duty cycle, as shown below [Naomi, 2015].

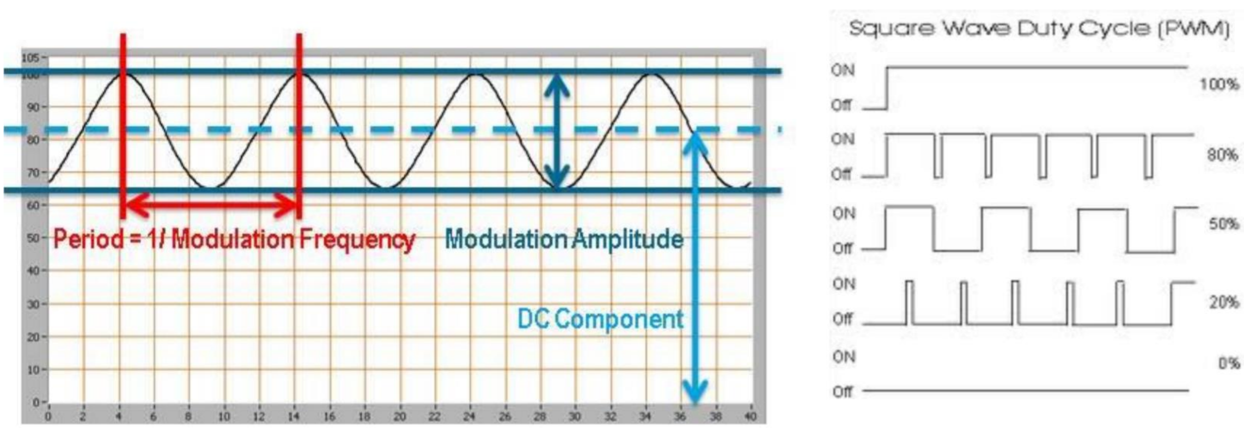


Figure 4.1.2a - Flicker Calculations [Energy.gov]

There are two defined metric for flicker by the IESNA: a percent flicker and a flicker index. The former is more well known and commonly used, but the latter is newer and accounts for shape and duty cycle, while the former does not. The flicker index works on Area 1 / (Area 1 + Area 2) and is a number between zero and one, as shown in Figure 4.1.2b.

In LED sources, flicker and dimming both depend heavily on the DED driver. This means that using dimmers and other electronics can increase flicker. AC LEDs are very likely to have flicker. So are DC LEDs with simple and inexpensive drivers. Integral lamp LEDs are likely to have flicker, as are LEDs dimmed with phase cut dimmers. Unfortunately Pulse Width

Modulation can produce a flicker, which makes it critical that SkyLight Glass adheres to theses standards [Naomi, 2015] so as not to cause injury to the user due to flicker.

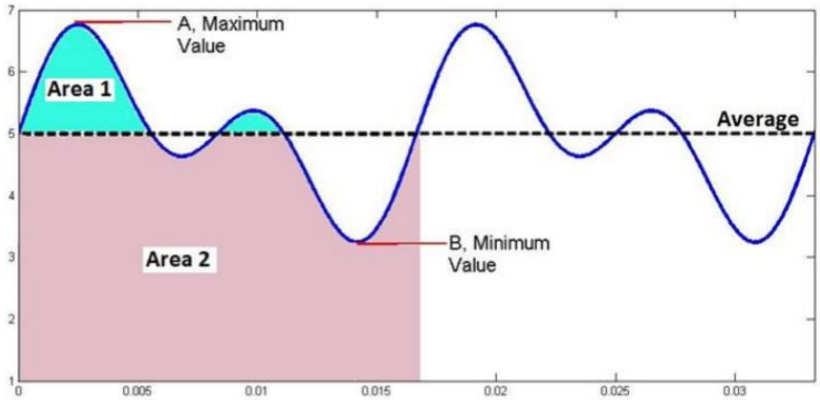


Figure 4.1.2b - Flicker Calculations [Energy.gov]

The IEEE PAR1789 recommended practice has a methodology for developing recommendations. It's plotted data from multiple studies that correlate risk level, probably of exposure, and severity of exposure. It characterized data reliability on a scale of opinion to solid data. The recommended practice was published in June 2015 [Naomi, 2015].

Though, in general it comes down keeping the flicker frequency above 10 Hz. Then, after determining the percent of flicker, multiply the frequency by 0.08 and round up to the nearest whole number. That is the max allowable percent of flicker. If the flicker is lower than the acceptable flicker, it is generally usable for most people, though an incredibly small amount of people who are unusually sensitive might still experience some of the symptoms. If the frequency is difficult to determine, the flicker percentage must be below ten percent [Naomi, 2015].

It is very important that SkyLight Glass is usable in the home, in an office, and generally in a place that people will be. Given the potential severity of the symptoms of flicker, especially visible flicker, it is imperative that SkyLight Glass stay within the IEEE PAR1789 recommended practice standards [Naomi, 2015].

4.1.3 IEEE 802.15.1: Bluetooth Standards

IEEE has developed standards for the Bluetooth and WPAN, they range along a *wide* variety of different procedures and test sets. For more information about Bluetooth and WPAN standards of Frequencies, Rates, Application Layer, Data Layer Information, etc. Their most recent publication is from 2005, which is around the time Bluetooth and wireless networks were starting to grasp the world. The standards surrounding the Bluetooth wireless capacity is a great amount of information and shall be explained thoroughly here. With the "new" 2005 edition of the IEEE Std. there are major areas of improvement, which include:

- Architectural overview
- Faster connection
- Adaptive frequency hopping
- Extended SCO links
- Enhances error detection and flow control
- Enhanced synchronization capability
- Enhanced flow specification

The standards are defined primarily by the physical layer (PHY) and of course the medium access control (MAC). Specifically, this applies to the Bluetooth and WPAN, which is touched upon in greater detail in the next section, connectivity with fixed and portable, as well as moving devices upon entering a personal operating space (POS). A POS, defined by IEEE is, the space about a person or object that typically extends up to 10 m in all directions and envelops the person whether stationary or in motion. This all takes place within the PHY layer, which is a channel characterized by synchronized occupancy of a sequence of radio frequency carriers by one or more devices.

Many physical channel types exist with characteristics defined for their different respective purposes. This encompasses a physical link which is a connection on the BB level between two devices established using paging. Bluetooth makes connections using a Slave and Master shared physical channel. So, in retrospect, a piconet is a collection of devices occupying a shared physical channel where one of the devices is the piconet master and the remaining devices are connected to it. This is a channel that is divided into time slots in which each slot is related to a radio frequency hop frequency. This standard is true within the IEEE 802.15.1-2005 standards manual and states that consecutive hops normally correspond to different RF hop frequencies, and occur at a standard hop rate of 1600 hop/s. These consecutive hops follow a pseudo-random hopping sequence, hopping through a 79-RF channel set, or optionally fewer channels when adaptive frequency hopping (AFH) is in use.

The piconet Master is the device in which the respective domain acts within its clock and device address, i.e. the piconet will correspond all its physical channel attribute clocks to this master device. Likewise, the piconet slave is any device within the piconet that is not the piconet master, but is connected to the master. This device must communicate through the master, and cannot communicate to other slaves, in which its timing and access is all delegated by the Master hub node. However, there is a such thing defined by standards as a *scatternet* in which two or more piconets include one or more devices participating in more than one piconet, an example can be found below in Fig 4.1.3.

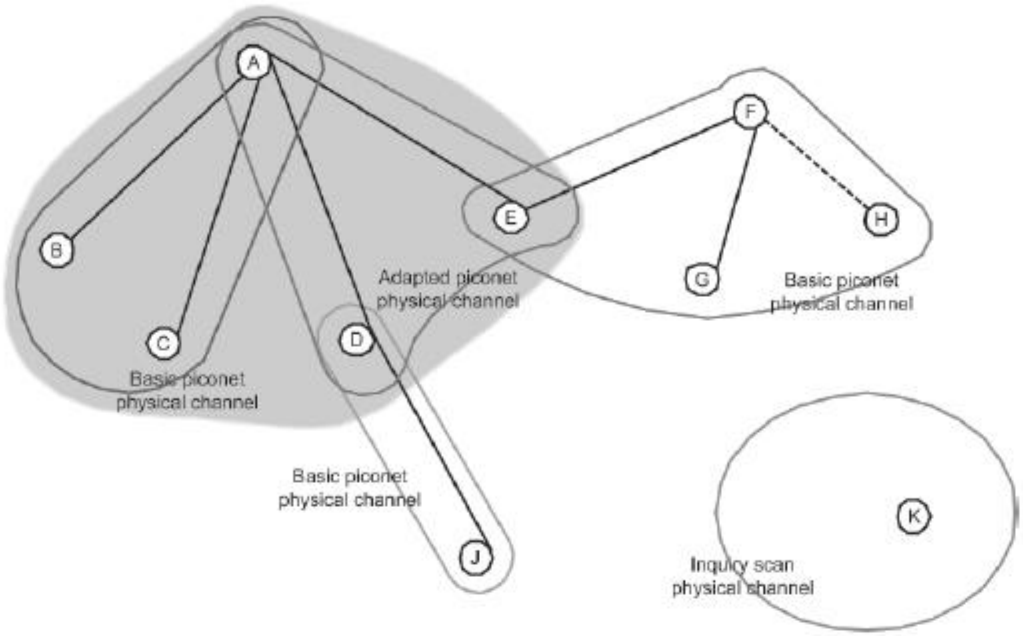


Figure 4.1.3: IEEE 802.15.1-2005 Topology Standard Example of Piconet and Scatternet

The original aspect of the IEEE 802.15.1 Task Group was to achieve a level of interoperability that could allow the transfer of data between a WPAN device and any IEEE device. This was unfortunately being unfeasible, but IEEE standards (2005) at least proved it was better for coexistence with a new set of devices now being available in the coming years. Both, the standards and previous versions, are primarily based upon the originally developed Bluetooth Special Interest Group (SIG). The architecture of Bluetooth has been formally standardized as a wireless technology for short range communication systems. The intention was to replace the cable(s) needed for connection of portable devices and/or fixed electronic devices. Several main features of Bluetooth systems were standardized for robustness, low power consumption, and lowered costs. Many of the features of core specifications are optional, and allow for product differentiation. By core system, this denotes the combination of RF signals to the transceiver, BB, and protocol stack. The system offers services that enable the connection of devices and the exchange of a variety of classes of data between these devices. This IEEE clause of standards provides an overview of system architecture, communication topologies, and data transport features.

The Baseband layer (BB) is the part of the system that specifies or implements the MAC layer and PHY layer. It contains procedures to support the exchange of real time voice, data information streams, and ad hoc networking between devices. Bluetooth device addresses (BD_ADDR) makes use of this by using the specific address to identify a device conforming to this standard. A devices address is normally a 48-bit address used to identify each device. A procedure on the Link Manager Protocol (LMP) level is used for verifying the identity of a remote device. The procedure is based on a challenge-response mechanism using a random number, a secret key, and the BD_ADDR of the non-initiating device. The secret key used can be a previously exchanged link key. There is also an LMP pairing which authenticates two devices, based on a PIN, and subsequently creates a common link key that can be used as the basis for a trusted relationship or a secure connection. The procedure consists of the following steps:

- Creation of an initialization key, which is based upon a random number and PIN.
- Creation and exchange of a common link key.
- LMP authentication is based on the common link key

Bluetooth wireless technology is a general term that is used to describe the technology originally developed by the SIG. It defines a wireless communication link, operating in the unlicensed industrial, scientific, and medical (ISM) band at 2.4 GHz using a frequency hopping transceiver, in which the link protocol is based on time slots. Clocks are also a part of this frequency and standard of the IEEE, they can range from native clocks, master clocks, and slave clocks. When connecting to each other sometimes devices may have to estimate another device's clock. This estimated clock (CLKE) may be a slave's estimate of a master's clock or a paging device's estimate of the paged device's clock, or other various combinations. The master clock is the native clock of the piconet's master, a native clock is a 28-bit clock internal to a controller subsystem that ticks every 312.5 us [IEEE std 2005]. The value of this clock defines the slot numbering and timing in the various PHY channels.

Controllers are also a part of this standard when it comes to slaves and masters for Bluetooth connectivity. Controllers are defined as a subsystem containing the PHY layer, BB, resource controller, link manager, device manager, and a host controller interface, which all conform to the IEEE standard (2005). Controllers make use of secure connections, where the established connection includes authentication and encryption. This creates a *trusted relationship* where the remote device is marked ask a trusted device. This includes a common link key for future authentication and pairing. Hosts are slightly different than controllers, because a computing device peripheral, cellular telephone, access point to public switched telephone network (PSTN) or local area network (LAN) can be connected to a controller. So, in other words, a host can attach to a controller which helps communicate with other hosts attached to their respective controllers as well. There are also host controller interfaces (HCI) which command interfaces to the BB controller and link manager to provide a hardware status and control registers, and provides a uniform method of accessing the BB capabilities.

4.1.4 IEEE 802.15.1: WPAN Standards

The IEEE also has standards used for the WPAN's (Wireless Personal Area Network), specifically these standards are defined by the following ideas:

- The functions and services required by an IEEE 802.15.1-2005 device to operate within ad hoc networks. Ad hoc networks are networks typically created in a spontaneous manner, and the network requires no formal infrastructure and is limited in temporal and spatial extent.

- MAC procedures to support the asynchronous connectionless or connection-oriented (ACL) and synchronous connection-oriented (SCO) link deliver services, which include:
- The baseband layer (BB), specifying lower levels of operations at the bit and packet levels, i.e. forward error correction (FEC) operations, encryption, cyclic redundant check (CRC) calculations, Automatic Repeat Request (ARQ) Protocol.
- The Link Manager (LM) layer, specifying connection establishment and release, authentication, connection and release of SCO and ACL channels, traffic scheduling, link supervision, and power management tasks.
- The Logical Link Control and Adaption Protocol layer, forming the interface to standard data transport protocols. It handles the multiplexing of higher layer protocols and the segmentation and reassembly (SAR) of large packets. The data stream crosses the LM layer, where packet scheduling on the ACL channel takes place. The audio stream is directly mapped on an SCO channel and bypasses the LM layer. However, the LM layer is involved in the establishment of the SCO link. Between the LM layer and the application, control messages are exchanged in order to configure the IEEE std. transceiver for the considered application.
- The 2.4 GHz Industrial, scientific, and medical (ISM) band PHY signaling techniques and interface functions that are controlled by the IEEE std. MAC. Requirements are defined for two primary reasons:
- Providing compatibility between the radios used in the system
- To define the quality of the system.

Above the L2CAP layer, may reside the Serial Cable Emulation Protocol based on the ETSI TS 07.10 (RFCOMM), Service Discover Protocol (SDP), Telephone Control Protocol specification (TCS), voice-quality channels for audio and telephony, and other network protocols. These protocols are necessary for interoperable for the user product, but are outside the scope of this standard. The BB and L2CAP provides a channel-based abstraction to applications and services. It carries out segmentation and reassembly (SAR) of application data and multiplexing and demultiplexing of multiple channels over a shared logical link. L2CAP has a protocol control channel that is carried over the default ACL logical transport. Application data submitted to the L2CAP may be carried on any logical link that supports the L2CAP [IEEE Std.-2005].

The RF PHY layer operates within the unlicensed ISM band at 2.4 GHz, and employs frequency hopping to combat interference from fading frequencies within the spectrum, which is referred to as the Frequency Hopping Spread Spectrum (FHSS) [IEEE Std-2005]. RF operations make use of a binary, shaped frequency modulation to minimize the complexity of a transceiver. The standard symbol rate is 1 Msymbol/s, which supports a bit rate of 1 Mb/s. WPAN's also define piconets as ways of connection and interactivity with other devices. Devices are hopping in a pattern that is dictated by an algorithm, which relates the determined fields in the device address and the clock of the master. The basic idea is a pseudo-random ordering of the 79 frequencies in the ISM band. The pattern may be adapted to exclude a portion of the frequencies that are used by interfering devices.

The technique improves upon the coexistence of many devices hopping from these bands, and improves the coexistence of static or non-hopping systems when they are collected and implements some recommendations of IEEE Stds. The PHY layer during this time is divided into *slots*, which are considered time unit slots. Data in transmitted within these slots in terms of *packets*, which are just “chunks” of data.

Frequency hopping takes place between the transmission or the reception of packets, and this IEEE Std. provides the effect of full duplex transmission with a time-division duplex scheme. Within this PHY layer data is bi-directional between the two devices that are transmitting these packets. Within a piconet however, there are limitations to how this data is transferred between Master and Slave, and PHY links are not formed directly between slaves within a piconet.

A control protocol for the BB layer and PHY is carried over logical links in addition to user data. This is the LMP. Devices that are active in a piconet have a default asynchronous connection-oriented (ACL) logical transport that is used to transport the LMP signalling. For historical reasons, this is referred to as the ACL logical transport. The default ACL logical transport is the one that is created whenever a device joins a piconet.

Additional logical transports may be created to transport synchronous data streams when this is required. The LM function uses LMP to control the operation of devices in the piconet and provide services to manage the lower architectural levels (i.e., PHY and BB). The LMP is carried only on the default ACL logical transport and the default broadcast logical transport [IEEE Std.-2005].

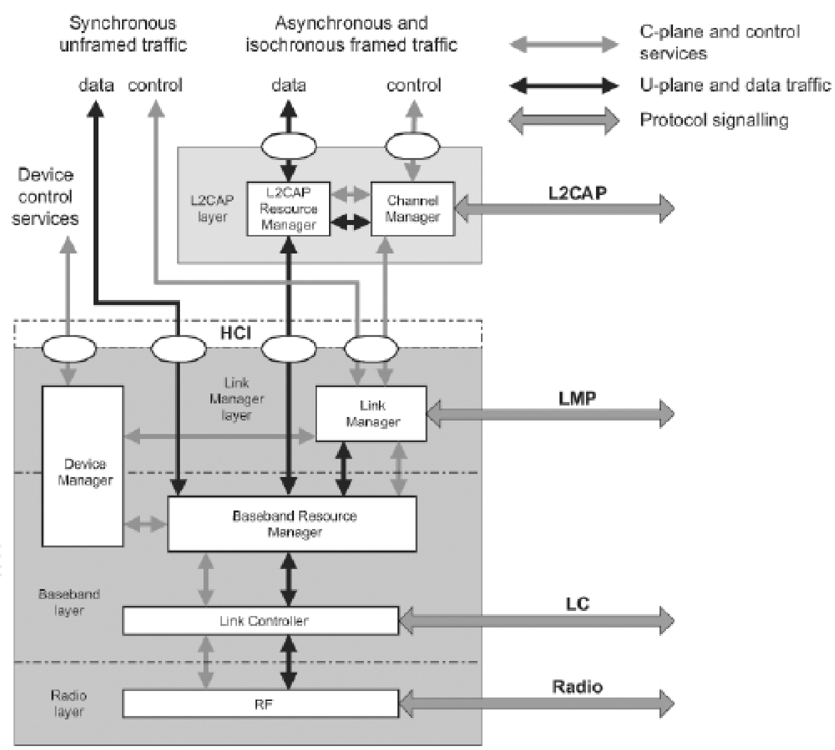


Figure 4.1.4a: Core Architecture IEEE Standards for WPAN and Bluetooth Devices [IEEE 802.15.1-2005]

A service interface to a controller subsystem is defined such that it is considered to be a standard part in accordance to the IEEE standards. It controls the lowest three layers and the L2CAP is contained with the rest of the application in a host system. This is an HCI, and its SAPs are represented within Fig. 4.1.4 as the ellipses in the upper edge of the HCI.

Channel Manager Standards

The channel manager is the primary handler of creating, managing, and destroying L2CAP channels, which are used for the transport of service protocols and application data streams. It makes use of the L2CAP to interact with the channel manager of a remote or peer device to create the L2CAP channels, and to connect the endpoints to appropriate entities. It also interacts with the local LM to create new logical links if need be, and configure the links to provide QoS for the data being transported.

L2CAP Resource Manager Standards

This block is used for managing the ordering of the submissions of PDU fragments and other BB scheduling between channels, ensuring that L2CAP channels QoS commitments are not denied access to the PHY layer, which could be due to controller resource exhaustion. This is a must because there is no assumption within the model that the controller has limitless buffering, or that the HCI pipe is of infinite bandwidth.

Device Manager and Link Manager Standards

The device manager in Fig 4.1.4b is responsible for the BB that controls the general behavior of the device, which one could imagine is quite important. Its responsibility includes everything of the devices operation that is not directly affiliated with data transfer actions such as:

- Inquiring for the presence of nearby devices
- Connecting to other devices
- Making the device discoverable or connectable by other devices
- Requesting access to transport mediums from BB controller
- Controlling local device behavior, local name, and stored link keys
- Other various functionalities

The LM's responsibilities are creation, modification, and release of logical links, as well as update parameters related to PHY links between devices. It must do this through the LMP which is defined by the IEEE 802 standards. LMP allows creation of new logical links and transports between devices, often through encryption on logical transports, adaption of transmit power on the PHY link, or adjustment of QoS setting for a local link [IEEE 802.15.1-2005].

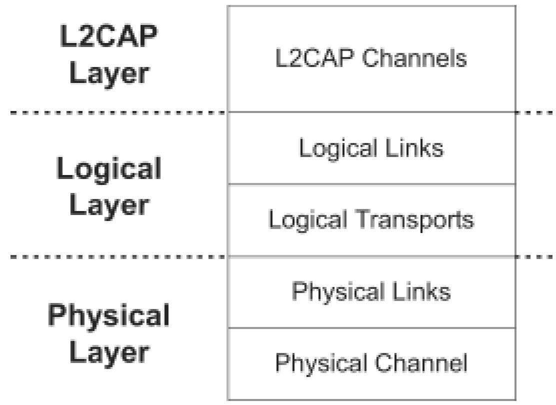


Figure 4.1.4b: Standard IEEE Data Transport Architecture

4.1.5: TIA RS-232 UART Serial Communication

Communicating with the bluetooth module uses standard serial communication for both the transmitter and receiver functions. Serial communications stream the data one bit at a time, and operate on a single wire. Specifically, SkyGlass Light will use asynchronous serial communication at 9600 bits per second (baud), which does not require an external clock to support it [TAL Technologies, 2017].

This asynchronous communication uses UART protocol, which stands for Universal Asynchronous Receiver Transmitter Protocol. This protocol is for a hardware device that enables asynchronous communication with customizable data transmission speeds and formats. The are multiple standards that work with this like RS-422 or RS-485. SkyGlass uses the RS-232 standard [TAL Technologies, 2017].

In the ATmega328 board being used, RS-232 is supported by hardware through an integrated circuit. RS-232, like all other UART protocols, take bytes of data and transmits them as individual bits sequentially. Once received the hardware component of the UART reassembles the bits into complete bytes, and then into the complete piece of data. It does this through a shift register, which is used in almost all methods of serial communication [TAL Technologies, 2017].

RS232 is used mostly for connecting data terminal equipment, like a computer terminal or a microcontroller, with data communication equipment, like a modem or Bluetooth module. While it is slow compared to more modern serial interfaces like Ethernet, or the previously mentioned RS-422 or RS-485, it is more than adequate for the needs of SkyLight Glass [TAL Technologies, 2017].

It was first used in 1960 by EIA as a recommended standard for connecting things like typewriters and modems. In 1969 a C revision was issued to the standard to accommodate electronic terminals. Many years later personal computers would use this standard to be able to connect with existing equipment that were made for this standard. The most recent release was in

2012, and it is the TIA tiA-232-F standard. Earlier, in 2002, it was also worked on by ANSI, and the ANSI/TiA-232-F-1997 standard was released [TAL Technologies, 2017].

Although RS-232 is a relatively archaic thing, it is still quite useful for products like SkyLight Glass. While the main reason for using RS-232 was availability, as it's the featured standard for its UART serial communication, the standard works perfectly for the relatively small amount of information sent and received by the SkyLight Glass, which includes LED brightness, LED color temperature, Smart Film state, temperature sensor readings, phototransistor readings, and real time clock readings, a total of no more than 6 bytes of information.

4.1.6 IPC-7251 Standards

SkyLight Glass will use entirely through-hole components, and will not use an surface mount components, sans when surface mount components are used on breakout boards that are integrated into SkyLight Glass through through-hole connections. IPC-7251 is the leading standard for through-hole design and land pattern control. It's first working draft was published in 2008 and covers topics like “discrete components”, “Dual-in-line package”, “three leaded semiconductor”, “pin Grid Array”, “Unique Multiple Function Parts”, “Connectors and Headers”, “Single Inline Package Resistor Networks”, and “Mounting Hardware” [IPCs, 2008].

Through-hole components are components that have pins that are inserted and soldered into holes that are drilled into the PCB. Often they are large enough to solder by hand, and importantly they are large enough to fit into connectors without an inhuman level of dexterity, which means that they can be easily mounted, dismounted, replaced, and modified without the need for a new PCB [IPCs, 2008]. Through-hole components will also have a footprint, which is a recommended copper pattern to be used for PCB design and ultimately component soldering. These recommended maps also have standards, in fact, many of the topics covered by IPC-7251 are for footprints [IPCs, 2008].

4.2 Design Constraints

4.2.1 Power

The electric power system is defined as the system with the goal to generate and to transmit the electric power user via the transmission system to the electric power end users. [Bacher, 1993] This can be done by using transformers, transmission lines, and a plethora of other energy sources. This was complicated at certain points of history due to the argument over direct current transmission versus alternating current transmission. Eventually, alternating current prevailed and this is the main source of power delivery to a majority of systems around the world.

A problem arises in how to deliver the alternating current power to households. Enormous voltages and currents that are lethal to humans must be manipulated in such a way so that they meet specific safety standards. These standards state that power delivery must be safe, reliable, and economical. [Bacher, 1993] The main motivators for these standards for power are twofold:

protection against electrical injury such as shock and protection against overheating elements that creates fires. The two biggest organizations for power safety standards are the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO).

One of the standards is called IEC60950-1 and directly correlates to a constraint. This standard is in relation to mains-powered or battery-powered equipment with a voltage requirement of less than or equal to 600v. The second edition of this standard is combined with two amendments from later time periods. The purpose of this standard is to minimize injury when installing electrical equipment, operating electrical equipment, and maintaining electrical equipment. There are four classes to this standard:

Case I pertains to equipment preventing electric shock by using covers, insulation, and proper grounding techniques. Case II involves equipment that uses more insulation than Case I. Case III protects against electrical shock in low voltage circuitry. On top of this, there are five categories for insulation that protect circuits and components from damaging voltages. These categories consist of basic and supplementary insulation. This standard acts as a constraint: limiting systems and applications to 600v of power or less.

As this relates to SkyLight, power will be a major constraint in the construction and implementation of the project. Careful measures must be taken to adhere to the safety guidelines of the standards mentioned above. Another constraint is that the required power must not exceed 120v AC because that is what is provided in a standard residential wall outlet. If the power supplied exceeds this value, the device will not function properly. This also has implications for the safe operation of the device. Personal injury can occur if proper precautions are not taken even with the standard 120v AC source that is used.

The standard power requirements in North America specify that mains electricity provide an AC signal of 120v at 60 Hz. This differs from other regions which typically use an AC signal of 230v at 50 Hz. Certain countries may have a wider variety of voltage and frequency ranges. The implications of this for the SkyLight system is that, due to the requirement to operate at 120v and 60 Hz, limits its operation to North America and other regions that follow the same standard.

4.2.2 Bluetooth

Bluetooth module transceiver and receiver must operate at the same frequency and Baud rate, with the Baud rate being something within reason. For SkyLight Glass, since speed is not a huge constraint, this will be a soft constraint of 9600 bits per second (bps). However, other baud rates may be implemented, with common "standard" requirements being 1200, 2400, 4800, 19200, 38400, 57600, and 115200. Data "chunk" of a serial frame must be between 5-9 bits, with average standard being 8 bits normally. Not only baud rate must be the same but voltages when it comes to bits being transferred, mainly start and stop bits. This deals with primarily TTL serial signaling, where VCC and GND pins will represent bits of data, exclusive to bit values of 1 or 0 indicating idle lines, start bit, stop bit, and data bits that could just be 0. If signal voltages are not within the same constraint, then the serial communication will not work.

The Bluetooth will be acting on a frequency band and channel arrangement which is set in North America by the FCC, Federal Communications Committee in relation to documents CFR47, Part 15, Sections 15.205, 15.209, 15.247, and 15.249. The IEEE 802.15.1 operates in the 2.4 GHz ISM band. This frequency band is from 2400 MHz – 2483.5 MHz [IEEE 802.15.1]. RF channels are spaced in 1 MHz increments, and guarded by lower and upper bands as shown in figure 4.2.3.1 below.

Regulatory range	RF channels	Lower guard band	Upper guard band
2.4-2.4835 GHz	F = 2402 + k, k = 0,.....,78	1.5 MHz	3 MHz

Table 4.2.2: Operating Frequency Bands and Guard Bands Set by the FCC

4.2.3 Ethical, Social, and Political

The current political climate is surprisingly anti-energy efficiency and anti environmentally friendly. Donald Trump has just been elected president and he's almost eliminated the Environmental Protection Agency. Additionally his supporters have reacted violently to those who work against his agenda. Given these facts, there are potential political consequences of creating or selling a device that is designed to save energy or have a relatively small environmental impact - both of which are things that SkyLight Glass strives to do.

Socially though, devices which seek to save energy and have a relatively small environmental impact are very well received. This is especially the case in larger cities where energy is more expensive the the people tend to be less politically republican.

Most of the ethical concerns are found in the health and safety constraints. Otherwise, it's beyond ethical to save energy which in turn reduces the environmental impact of the installing structure of SkyLight Glass. The entire project was created in part by a desire to have an ethically good project.

4.2.4 Health and Safety

Components used in SkyLight Glass must be compliant with RoHS codes, otherwise they are not suitable to be used in spaces cohabitated by human beings, which are of course the primary intended target user of SkyLight glass. RoHS stands for Restriction of Hazardous Substances, and it primarily bans lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, and polybrominated diphenyl ethers. Note that this is yet another reason to avoid bootleg chinese made products from Amazon, eBay, and other similar online commerce websites. As noted in the IEEE PAR-1789 standards artificial light can have some seriously detrimental effects on the human body. It is undeniably unethical to expose people to such health hazards, so it is absolutely imperative that such things are addressed and the IEEE PAR-1789 standards are met.

It’s generally been found that there are no negative impacts of LED light contacting human skin. That said, visible flicker can cause neurological problems as extreme as epileptic seizures, but they can also cause more mild symptoms like migraines headaches, fatigue, poor vision, and eye pain/strain. In addition to being generally unpleasant, these things also have a dramatic effect on a person's’ ability to do work in an environment with this kind of unnatural stimulation. It can even increase autistic behaviors in those that are on the autism spectrum, and of course distract people. None of this is desirable in any environment, so it is definitely not desirable for Skylight Glass.

Only by keeping to the IEEE PAR-1789 standards can we prevent such things from happening. This might mean eventually switching from our Pulse Width Modulation design to a voltage controlled design, but for now SkyLight will seek to use the Pulse Width Modulation design and work with the specifications given by IEEE PAR-1789.

If the SkyLight Glass team finds that they are unable to produce a safe product using the Pulse Width Modulation method, they will use Frequency to Voltage converters made by TI to control the voltage of the LEDs, since the ATmega328P board only has Pulse Width Modulation as means for analog output.

4.2.5 Economics and Time

The members of SkyLight Glass are all full time students and are likely to continue to be full time students during Senior Design Two. This not only has a dramatic effect on how much time is available, but also on how much money is available, as this time constraint prevents the members of SkyLight Glass from seeking full time employment and as such decreases their available funds.

The original budget would have each member of the SkyLight Glass team to spend around $80, for a total of around $320. However time constraints have prevented the cheapest available components from being used, and has forced the members of the SkyLight Glass Team to order more expensive components that have shorter shipping times since they were available from within the Continental United States of America.

The new budget has each member spending closer to $125, for a total $500 to go to the materials, manufacturing, and shipping of all components related to SkyLight Glass. Availability of PCB manufacturing to one individual member of the SkyLight Glass team has given them an advantageous position in terms of free Printed Circuit Board Manufacturing. However this does not give the ability to have things machine soldered to the PCB for free.

Here is an instance where time is being traded for money. In addition to other advantages, by using a through-hole design the SKyLight Glass team will be able to completely circumvent any money that would otherwise be spent on machine soldering of surface mounted hardware. This is because through-hole components tend to be large enough to solder by hand, even for the those of SkyLight Glass with poor dexterity.

The money for time trade isn't entirely one sided though, as it has the potential to make up for itself in terms of time as well. By using connectors to attach the through-hole components to the Printed Circuit Board the SkyLight Glass Team gains the ability to quickly replace components should one fail. Additionally this allows for programming hardware to be excluded from the printed circuit board which saves both money and time.

Time restrictions limit component selection to those available in the United States. It also prevents the SkyLight Glass team from making their own power supplies, instead having them use pre bought power supplies, some of which were already included in the purchase price of necessary components anyways.

SkyLight Glass needs to be completed by July 2017, and was started in January of 2017. This gives them no more than seven months to complete all senior design requirements and also create SkyLight Glass in addition to keeping up with their other responsibilities.

5. Subsystem Design and Testing

The purpose of this section is to test specific major components and integrate them into their respective subsystems. A majority of the tests were performed at the Senior Design laboratory on the University of Central Florida main campus in Engineering 1 Room 456. Some of the tests could only be performed outside of the laboratory due to constraints of the laboratory equipment when dealing with high voltages.

5.1 LED Subsystem

The LED subsystem's function is to provide variable intensity and color temperature to user of the SkyLight system. This is controlled and automated through the microcontroller unit. The LED subsystem uses pulse width modulation to achieve both variable intensity and variable color temperature using bipolar junction transistors as switches.

5.1.1 3528 SMD LED and P2N2222a Schematic

The schematic displayed in Figure 5.1.1 was used to test the operation of the 3528 SMD LED strip. The transistors were originally selected to be MOSFETs since FETs are designed with switching in mind. However, it was determined that the P2N2222a bipolar junction transistor was a better selection due to cost and availability.

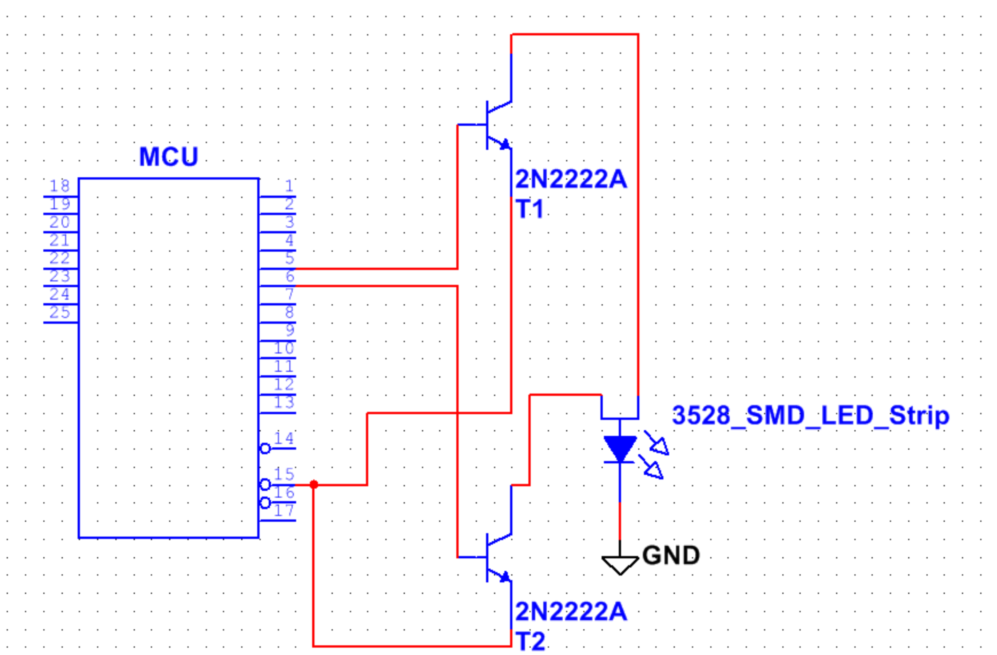


Figure 5.1.1 - LED Subsystem Testing Schematic

5.1.2 LED Subsystem Breadboard Testing

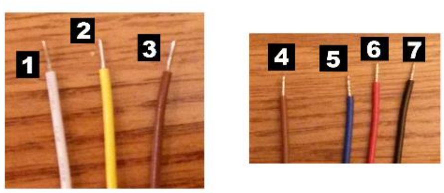
Objective: The goal of this test will be:

1. To demonstrate that the 3528 SMD LED strip is capable of varying intensity via pulse width modulation.
2. To demonstrate that the 3528 SMD LED strip is capable of varying color temperature to achieve a “cool” (approximately 6000K) temperature, a “warm” (approximately 3000K) temperature, and a temperature in-between these two values.

Materials:

- Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel
- Tektronix AFG 3022 Dual Channel Arbitrary Function Generator, 25 MHz
- Agilent E3630A Triple Output DC Power Supply
- Dell Optiplex 960 Computer
- Function Generator and Power Supply Cables
- Two P2N2222a Transistors
- 3528 SMD LED Strip
- ATmega328P Microcontroller

First, the procedure to test the LEDs was conducted using the function generator and power supply provided in the lab. After confirming that the LEDs were able to change color temperatures and intensities based on the PWM signal sent from the function generator, the microcontroller was tested. Instead of grounding the signals to the breadboard, the microcontroller’s ground was used instead. This way, all grounded devices share a common ground and do not suffer from noise as a result of leaking current from a ground or earth loop that often distorts the signals in circuits with multiple grounds.



1	**Negative Cool White**
2	**Negative Warm White**
3	**Positive 24v DC**
4	**AC Line**
5	**AC Neutral**
6	**V+**
7	**V-**

Figure 5.1.2a - SMD LED and PSU Wiring

Procedure: In order to ensure functionality, the following steps were performed:

1. Wire #3 from the SMD LED strip was connected to the positive terminal of the power supply.
2. Wire #1 from the SMD LED strip was connected to the collector of transistor #1 [T1] and

Wire #2 from the SMD LED strip was connected to the collector of transistor #2 [T2].

3. Wire PWM1 was connected from pin #5 on the microcontroller to the base of T1. Wire PWM2 was connected from pin #6 on the microcontroller to the base of T2.
4. Both T1 and T2's emitters were grounded using the GRD wire to the microcontroller's ground pin.
5. The microcontroller was programmed using pinMode(). pinMode takes two arguments: pin number and a number ranging from 0 to 255 which indicates the % of the duty cycle. The LED is turned off by writing 0 and on (full intensity) by writing 255. Increments between the two values results in varying intensities.
6. The 6000K LED strip was tested first. pinMode(5, 255) and pinMode(6, 0) were programmed into the microcontroller and the result was obtained in Figure 5.1.1c [1].
7. The 3000K LED strip was tested. pinMode(5, 0) and pinMode(6, 255) were programmed into the microcontroller and the result was obtained in Figure 5.1.2c [3].
8. The 4500K LED strip was tested. pinMode(5, 255) and pinMode(6, 255) were programmed into the microcontroller and the result was obtained in Figure 5.1.2c [2].
9. The intensity of the LED was demonstrated by writing pinMode(5, 0) & pinMode(6, 64) to alter the intensity of the "warm" LEDs. The result was obtained in Figure 5.1.1c [4].

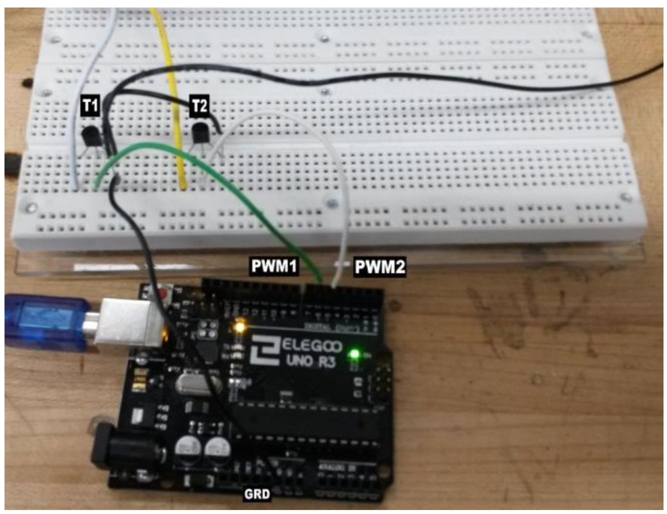


Figure 5.1.2b - LED Breadboard Test

Conclusion: The 3528 SMD LED strip demonstrated the ability to vary its intensity and its color temperature using two PWM channels as shown in Figure 5.1.2c. While the 3528 SMD LED strip was initially used for testing purposes to confirm that SMD LEDs can be controlled via pulse width modulation, the SkyLight system will consider using the 5050 SMD LED strips for their wider range of color.

In the 5050 SMD LED strip, there are three lines that control RGB values compared to the two lines that control two different colored chips on the 3528 SMD LED strip. Each line may be varied in intensity by using PWM just like in the 3528 SMD LED strip.

Figure 5.1.2c - "Warm" High Intensity (1), Mixed High Intensity (2), "Cool" High Intensity (3), "Warm" Low Intensity (4)

5.2 Smart Film Subsystem

The smart film subsystem's function is to provide a means through which the user may change the state of the smart film used in the SkyLight system. This is controlled and automated through the microcontroller unit. The smart film subsystem uses the VAC from a wall outlet in conjunction with an AC/AC converter to provide a signal to the smart film at 60v AC and 60 Hz. The film in its off state is opaque. When the AC current is applied, the film becomes transparent. To isolate AC elements from the system, a two module relay is used as a switching mechanism. This is also controlled by the microcontroller unit.

5.2.1 1-Channel Relay and External AC Load Schematic

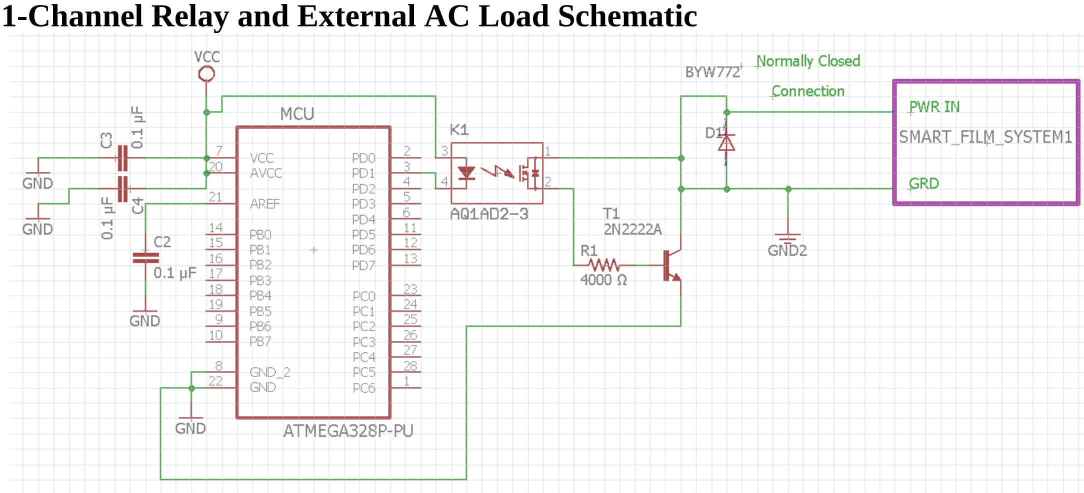


Figure 5.2.1 - Smart Film Subsystem Schematic

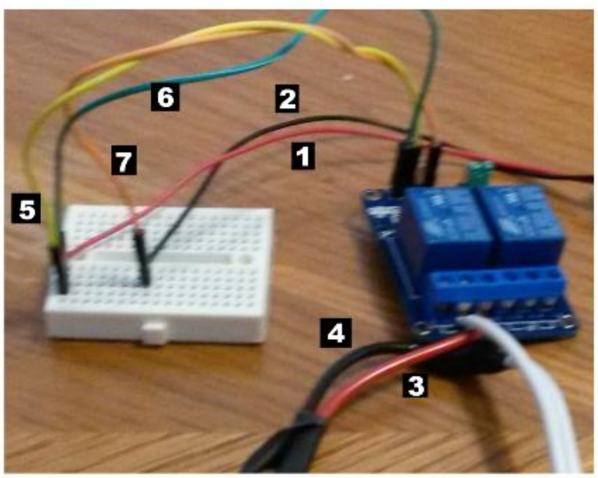
5.2.2 Smart Film Subsystem Breadboard Testing

Objective: The goal of this test will be:

1. To determine that the ATmega328P can turn on the relay though the internal transistor which activates the electromagnet.
2. To demonstrate that, once turned on, the relay can properly transmit a voltage with an alternating current.
3. To demonstrate that the smart film is capable of varying between opaque and transparent states when an AC current is applied to the film through the relay.

Materials:

- Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel
- Tektronix AFG 3022 Dual Channel Arbitrary Function Generator, 25 MHz
- Agilent E3630A Triple Output DC Power Supply
- Dell Optiplex 960 Computer
- Function Generator and Power Supply Cables
- SainSmart 2-Channel Relay
- Smart Tint® Smart Film
- ATmega328P Microcontroller
- Three spools of differently colored 22 gauge jumper wire
- Function Generator and Oscilloscope Supply Cables



1 red	**VCC from MCU**
2 black	**DGRD from MCU**
3 red	**NC (normally closed)**
4 black	**AGRD/Common**
5 yellow	**Digital Input 1**
6 green	**DGRD**
7 orange	**5v VCC**

Figure 5.2.2a - Smart Film and Relay Breadboard Test

Procedure: In order to ensure functionality, the following steps were performed:

1. Wire #1 connects the VCC pin of the ATmega328P Microcontroller to the activation VCC pin of the relay.
2. Wire #2 connects the ground pin of the ATmega328P Microcontroller to the activation ground pin of the relay..
3. Wire #5 connects the A0 digital output pin of the ATmega328P Microcontroller to the

activation input pin of the relay.

4. Wire #3 connects the smart film positive terminal to the relay’s normally closed [NC] terminal. This means that the relay is off by default and no power will be transmitted to the film until the relay is flipped using the MCU.
5. Wire #4 connects to the analog ground of the system.
6. Wire #3 was connected to the function generator’s positive terminal.
7. Wire #4 was connected to the function generator’s negative terminal.
8. The ATmega328 microcontroller was programmed using pinMode() to set the PD1 pin to a digital output pin.
9. The ATmega328 microcontroller was programmed using DigitalWrite() in order to turn the PD1 digital output pin on and off.
10. The function generator was initially set to a sinusoidal signal of 60v at a frequency of 60 Hz. The opaque state was observed in Figure 5.2.2 [1].
11. DigitalWrite(PD1, HIGH) was used to toggle the relay. The transparent state was observed in Figure 5.2.2 [2]

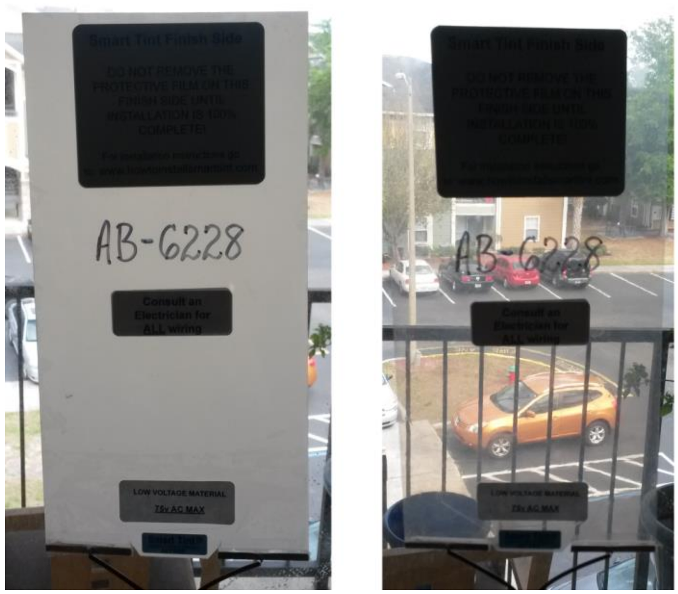


Figure 5.2.2b - Smart Film States (1) Opaque State, (2) Transparent State

Conclusion: Given a 60v sinusoidal AC signal at 60 Hz, the smart film was able to demonstrate full transparency using the 2-channel relay.

5.3 External Devices Subsystem

This subsystem devices play a vital role in tying the system altogether. It incorporates Bluetooth, Temperature sensor, and the light sensor. All play a major role in the functionality of the system, the light sensor is crucial to regulate indoor lighting properly to match those conditions outside. The temperature sensor measures the actual temperature for the system to best adapt to the proper conditions that will allow the user to have the best overall energy savings.

Lastly, the Bluetooth device is key because if a user is not able to operate the device as intended it will all be in vain.

Hence, all of these external systems play a major role in making a system that works seamlessly and grants users the best possible scenario for their desires.

5.3.1 External Devices Subsystem Schematic

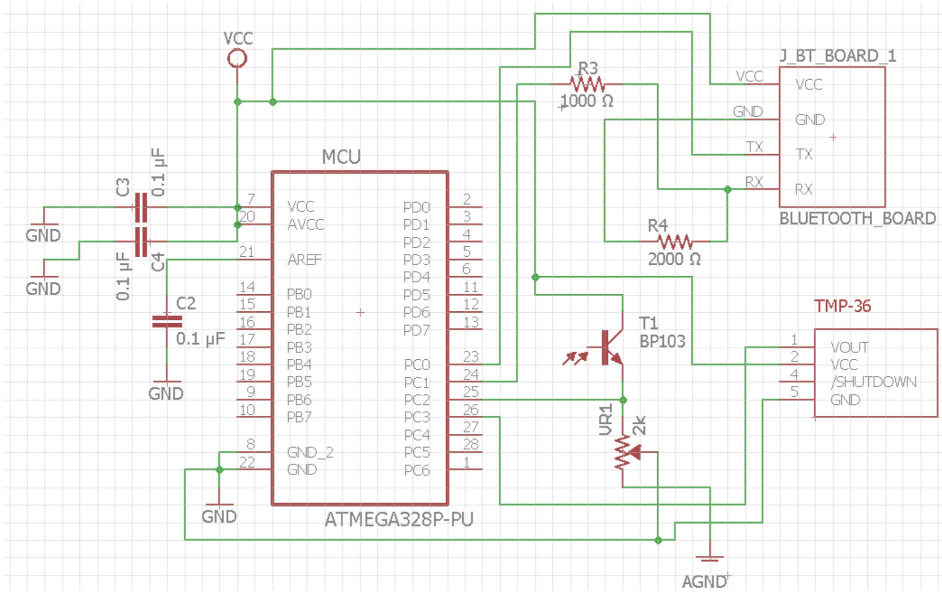


Figure 5.3.1 - External Devices Subsystem Schematic

5.3.2 External Devices Breadboard Testing

Please note that each device was tested individually to allow for ease of debugging and to make sure each part worked as specified in the documentation provided for the devices.

5.3.2.1 LTR-4206E Ambient Light Sensor

Objective: Another important component of the SkyLight system is the ambient sensor and hence the team needs to test it to ensure can handle the task.

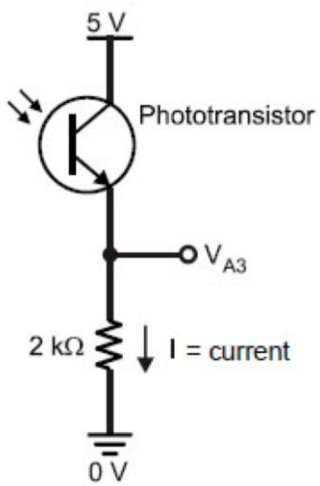
There are many different ways to measure light variations, the team having simplicity in mind selected a phototransistor. This is similar to a bipolar transistor with the middle pin left open to allow light through. This results in a current being controlled by the variation of light that can be measured and correlated to light intensity.

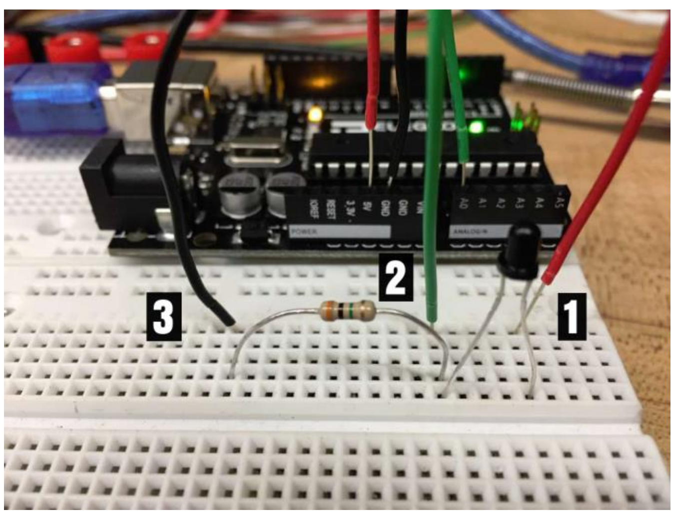
Environment: This procedure was performed in the senior design lab since there are many devices that facilitate the process:

- Tektronix DMM4050 6-1/2 Digit Precision Multimeter
- Keithley 2230-30-1 Triple Channel DC Power Supply.
- Arduino UNO with ATmega328P microcontroller.
- Arduino IDE
- Global Specialties PB-60 Solderless Breadboard.

Procedure: The circuit was built to test the ability of this sensor to translate light intensity to an output

1. Wire #1 was connected to VCC from the ATmega328P to the collector of the phototransistor.
2. Wire #2 was connected from the emitter to the analog to digital converter [A0]
3. Wire #3 finally provided ground to the circuit at the end of the resistor and connects to the developmental board internal ground pin.
4. The microcontroller was programmed using analogRead(). analogRead() converts an analog input to digital on a scale to from 0 to 1023.
5. This input must be converted to an actual voltage to map it to the light intensity
6. Finally, to determine that this output was correct the microcontroller was programmed with Serial.print() to monitor in the serial monitor what was occurring live.
7. Using a LED flash light as a source from far away and closing in allowed to measure the output changes.
8. This reading was captured in the Arduino IDE serial port.





3	Ground
2	Output
1	Source

Table 5.3.2.1a – Light Sensor Breadboard Test

This is a very simple two port analog device with through-hole construction with a very low cost. All features that the team considers very important for the success of the project. To test the device we simply build the circuit above, providing 5V to the collector, ground, 1 mega Ω resistor, and reading the analog input A0 to read the output voltage using the serial monitor.

The readings from the light sensor can be seen in Figure 5.3.2.1b as the voltage fluctuates with different light intensities. This test was done starting with room lighting and with the use of a flashlight. The light source was pointed at the sensor, initially from further away and gradually getting closer. That is the reason for the gradual increase in the voltage, corresponding with an increased intensity.

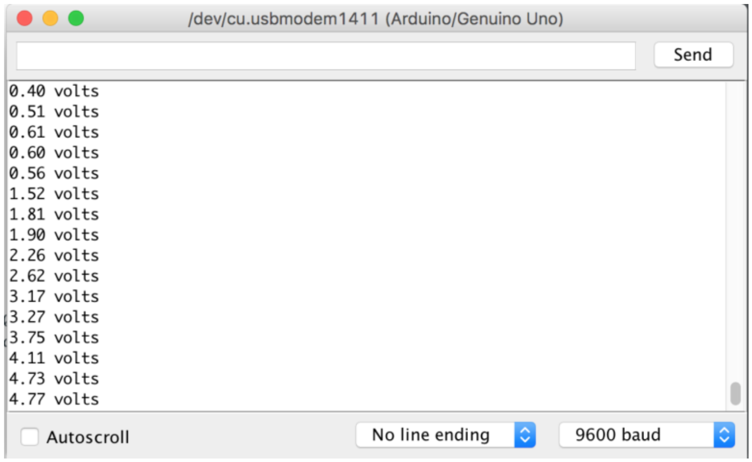


Table 5.3.2.1b – Light Sensor Output

This sensor is quite simple but at the same time very versatile since the accuracy of the reading can be modified by simply changing the resistance in the circuit. In our test a 1MΩ resistor allowed for the test to be successful indoor and acceptable for the purposes of what the project needs. Even though this test was performed indoors the sensor proved to be sufficient because the resistance can be varied for outdoor conditions.

Taking the sensor outside will require a smaller resistance but this is not an issue as the resistor in the circuit can be swapped out to best map a bright day and correlate that data to automate the artificial lights. In order to develop our system, the sensor can be utilized to map the conditions outside (sunlight intensity) and correlate that to what is the intensity translated indoors. Acquiring such data proves to be simple enough to later create a rough map to develop the automated system.

Part of reading the variation of light using this sensor is to allow for automatic artificial lighting conditions indoors, a feature the SkyLight team values.

Conclusion: The sensor proves to be quite capable and versatile for the project.

5.3.2.2 TMP36 Temperature Sensor

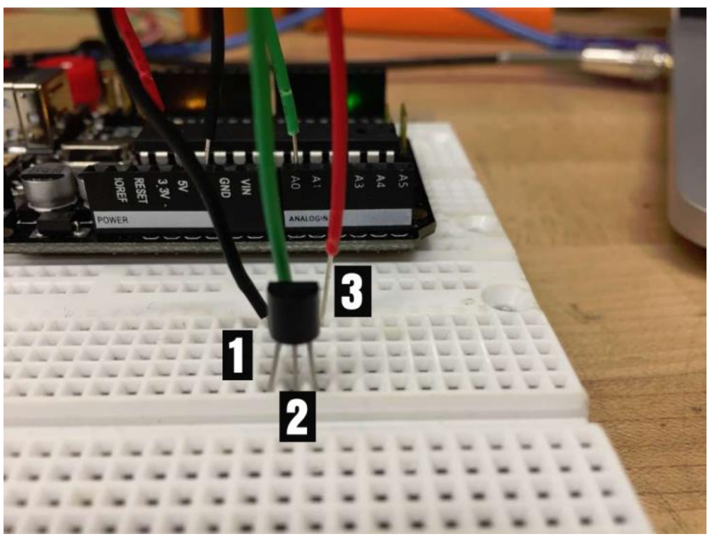
Objective: Sensing temperature is an important component for the team to develop a system that results in the best energy savings for a user. To test the selected TMP36 temperature sensor is quite simple since the three-port device only requires a voltage supply Vs, ground, and the final pin is Vout. This last pin outputs an analog voltage that correlates to actual temperature.

Environment: This procedure was performed in the senior design lab since there are many devices that facilitate the process:

- Tektronix DMM4050 6-1/2 Digit Precision Multimeter
- Keithley 2230-30-1 Triple Channel DC Power Supply.
- Arduino UNO with ATmega328P microcontroller.
- Arduino IDE
- Global Specialties PB-60 Solderless Breadboard.
- TMP36 Temperature Sensor

Procedure: Is important to test the temperature sensor to make sure that the team can acquire the required data to develop the system later.

1. Wire #3 was connected to VCC from the ATmega328P to the voltage source pin in the temperature sensor.
2. Wire #2 was connected from the voltage output of the sensor to the analog to digital converter [A0].
3. Wire #1 provided ground to the ground pin of the sensor and connects to the developmental board internal ground pin.
4. The microcontroller was programmed using analogRead(). analogRead() converts and analog input to digital on a scale to from 0 to 1023.
5. This input must be converted to a an actual voltage to determine temperature in °C. This is done by multiplying by Vsource and dividing by 1024.
6. Finally to determine that this output was correct the microcontroller was programmed with Serial.print() to monitor in the serial monitor what was occurring.
7. Using a LED flash light as a source from far away and closing in allowed to measure the output changes.
8. This reading was captured in the Arduino IDE serial port and compared to the temperature that the thermostat in the room provides



1	Ground
2	Output
3	Source

Figure 5.3.2.2a – Temperature Sensor Breadboard Test

Using the Arduino Uno prototype board makes testing this sensor a breeze. The board provides a 5V and a 3.3V voltage source to help with prototyping. The sensor is provided with 5V at the Vs pin (red), ground (black), and finally Vout is connected to an analog to digital converter that the microcontroller provides. In this case A0 (green), this is important since this port is accessed within the code by simply using an analog read in this port.

The analog input reading translates to a number between 0 to 1023. This then need to get converted to a voltage, in this case since 5V was provided all that is required is to multiply by 5 and divide by 1024 to get a raw voltage reading. This sensor has a resolution of 10mv per degree C, and a half volt offset. Taking that into account the voltage is translated to degrees C, which then in turn can simply be turned to degrees Fahrenheit.

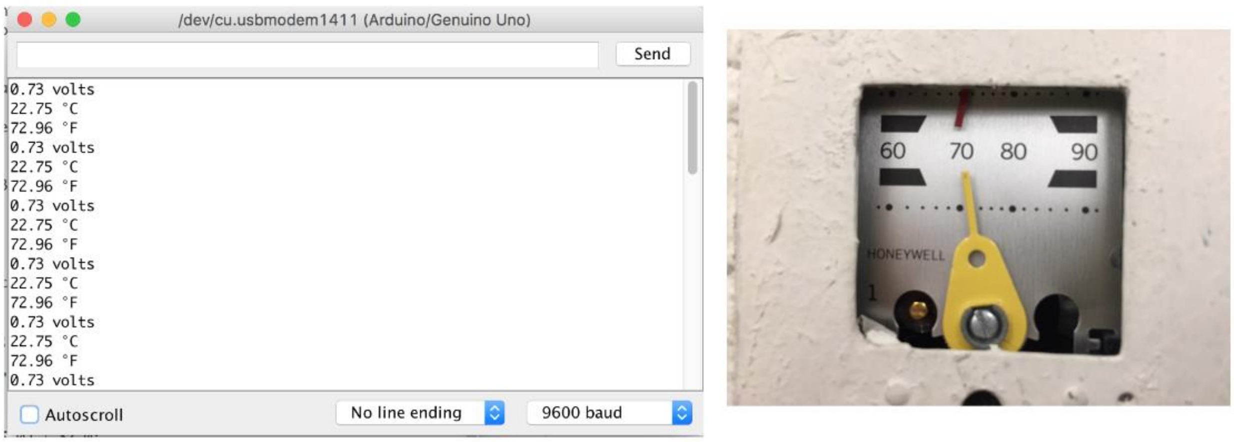


Figure 5.3.2.2b – Temperature Sensor and Room Temperature Readings

Conclusion: Comparing the readings from the sensor to an analog temperature sensor that is in the room results in good findings. The thermostat in the room reads around 72 degrees F and the sensor is getting readings within this range (72.96). This is a very simple device that has very good accuracy for our application. Also, testing this sensor was made easy with the microcontroller prototyping board saving time that can be best allocated into developing the logic later.

5.3.2.3 Rotary 10k Ω Potentiometer Testing

Objective: The goal of this test will be:

1. To demonstrate that the Rotary 10k Ohm Potentiometer is capable of varying its resistance by turning the knob.
2. To demonstrate that the ATmega328- is capable of using the analogRead() function to differentiate knob position of the potentiometer.

Materials:

- Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel
- Tektronix AFG 3022 Dual Channel Arbitrary Function Generator, 25 MHz
- Agilent E3630A Triple Output DC Power Supply
- Dell Optiplex 960 Computer
- Function Generator and Power Supply Cables

- Rotary 10k Ω Potentiometer
- ATmega328P Microcontroller
- Three spools of differently colored 22 gauge jumper wire

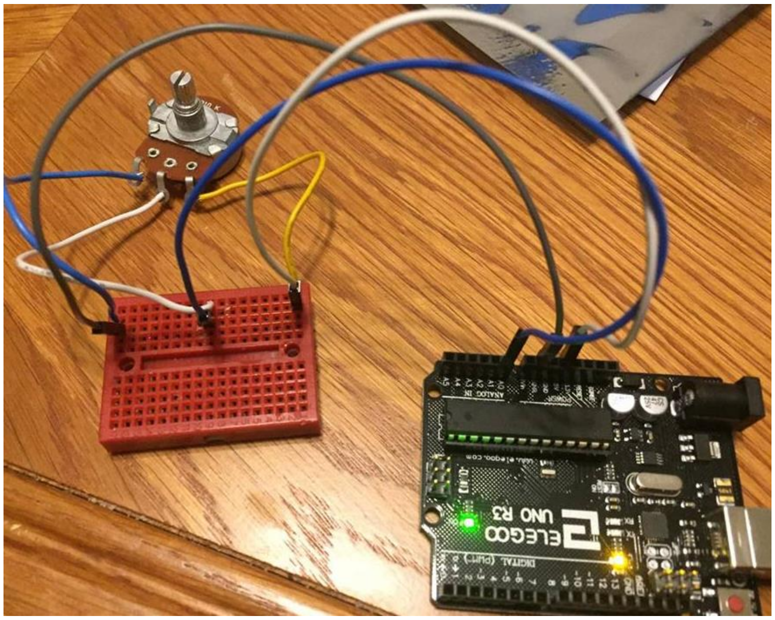


Figure 5.3.2.3 - Potentiometer Breadboard Test

Procedure: In order to ensure functionality, the following steps were performed:

1. Three wires of different color were gathered, cut and stripped.
2. Wire #1 was connected from the ground pin of the potentiometer to the ground pin of the ATmega328 microcontroller.
3. Wire #2 was connected from the VCC pin of the ATmega328 microcontroller to the INPUT pin of the potentiometer.
4. Wire #3 was connected from the output pin of the potentiometer to the A0 analog input pin of the ATmega328 microcontroller.
5. The ATmega328 microcontroller was programmed using pinMode() to set the A0 pin to an analog input pin.
6. The ATmega328 microcontroller was programmed using AnalogRead() to read the value voltage from the A0 pin as a 10 bit integer with values ranging from a maximum of 1023 to a minimum of 0.
7. The ATmega328 microcontroller was programmed using Serial.Begin() to set the baud rate to 9600 and to enable serial communication with an external device.
8. The ATmega328 microcontroller was programmed using Serial.Out to output the voltage of read as an input by the A0 pin to the serial monitor of a connected external device (Dell Optiplex 960 Computer).
9. The ATmega328 microcontroller was programmed using an arduino development board and a USB standard cable.
10. The Serial Output was read by the serial monitor of the Arduino IDE on the Dell

Optiplex 960 computer.

11. The nob on the potentiometer was turned back and forth and the output was viewed through the ATmega328 on the Dell Optiplex 960 computer and recorded.

5.4 Power Systems

The purpose of the power system is to distribute power across multiple devices inside the SkyLight system in a safe yet effective manner. Both alternating current and direct current are used and at varying voltages. The VAC signal will be stepped down to 60v AC at 60 Hz by smart film power supply. This will then be handled by the AC/DC converter of the LED system which will convert the 60v AC 60 Hz signal into a 24v DC signal. This will then we converted to a 5v DC signal using a voltage regulator.

As the smart film power supply and LED power supply were tested with their respective systems, only the 5v voltage regulator will be tested in this section.

5.4.1 Voltage Regulator to MCU (5v DC Signal) Breadboard Testing

5V DC Voltage Regulator Testing

Objective: The goal of this test will be:

1. To determine that the voltage regulator outputs 5v when receiving a 24V DC input from any external source.
2. To demonstrate that the voltage regulator will still output 5V as long as the input is between 26V DC and 5V DC.

Materials:

- Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel
- Tektronix AFG 3022 Dual Channel Arbitrary Function Generator, 25 MHz
- Agilent E3630A Triple Output DC Power Supply
- Dell Optiplex 960 Computer
- Function Generator and Power Supply Cables
- Voltage Regulator
- ATmega328P Microcontroller
- Three spools of differently colored 22 gauge jumper wire

Procedure: In order to ensure functionality, the following steps were performed:

1. Wire #1 connects the Agilent DC Power Supply to the voltage regulator.
2. Wire #2 connects the ground pin of the voltage regulator to the power supply.
3. Wire #3 connects the output pin of the voltage regulator to the Tektronix oscilloscope.
4. Turn on channel 1 of the power supply and set the voltage to 24V DC.
5. Measure and record the output voltage displayed on the oscilloscope.
6. Change channel 1 of the power supply by setting the voltage to 30V DC.

7. Measure and record the output voltage displayed on the oscilloscope.
8. Change channel 1 of the power supply by setting the voltage to 15V DC.
9. Measure and record the output voltage displayed on the oscilloscope.
10. Change channel 1 of the power supply by setting the voltage to 6V DC.
11. Measure and record the output voltage displayed on the oscilloscope.

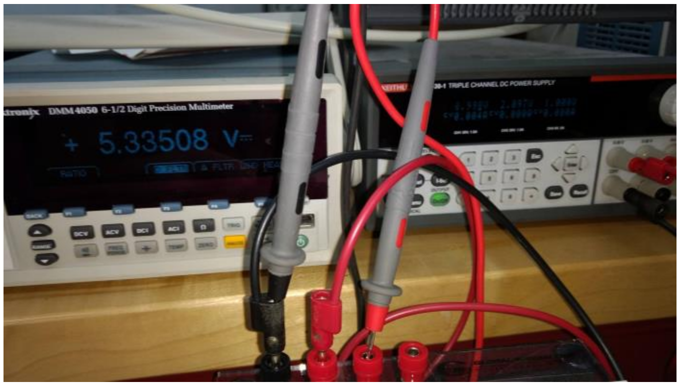


Figure 5.4.1 –Voltage Regulator Output

5.5 Microcontroller and System Interaction

This section is to illustrate the components of wireless communication with the MCU. Below in section 5.5.1 is a schematic of the MCU and respective BT module in question, this is what interacts with the system serially for multi-purpose communicative features. It is quite simple to get the components to connect externally, here for the time being is the externally connected module, which will eventually be placed into a PCB design such that everything can be locally contained onto a single board without any external connections, ideally. As from the figure one could tell there is plenty of pin real estate, and the HC-05 module is the most realistic and cost effective BT module on the market as of now, especially since what needs to be done is nothing that needs to be more than a range of about 30-50 feet.

5.5.1 HC-05 Serial Bluetooth Module Schematic

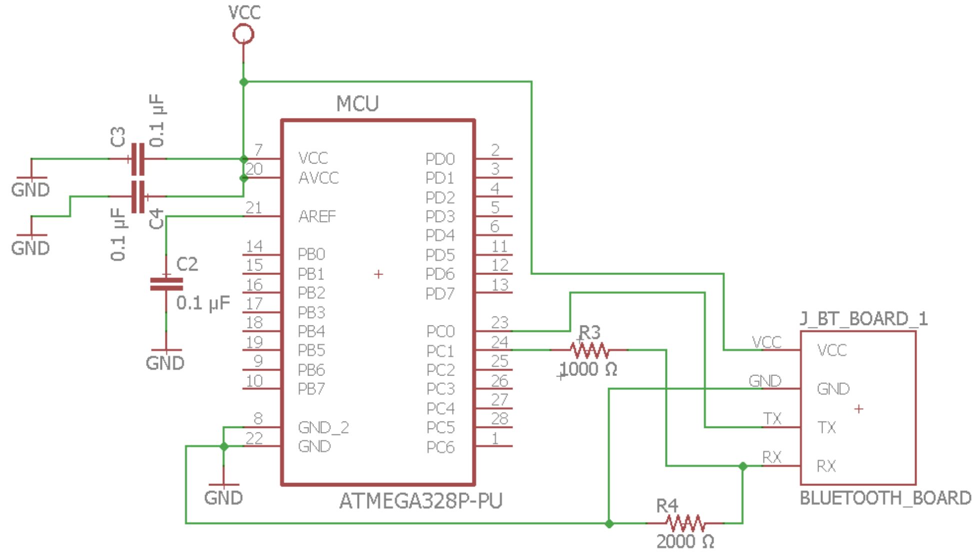


Figure 5.5.1 - HC-05 Bluteooth Schematic

5.5.2 HC-05 Bluetooth Module Breadboard Testing

HC-05 Serial Bluetooth Module Testing

As seen in the schematic above, the ATMega328 MCU is connected to the HC-05 Bluetooth module. This is how this subsystem will be implemented into SkyLight Glass' design. This will be the direct connection for the application to communicate with the system, controlling components such as LEDs, the tinting film, alarm mode, and other features. The HC-05 can only handle roughly 3.3v – 5v, so to keep the module safe from electrical damage the resistors are in place as shown in Figure 5.5.1.

HC-05 Bluetooth Module Testing

Objective: The goal of this test will be:

1. To test the HC-05 module to send responses through the UART to the screen such that the system can check to make sure it is working properly.
2. Commands tested:
    - AT Test
    - Software Version
    - Setting Module Role (Master or Slave)
    - Inquire Module Role
    - Inquire serial Parameter

Below is a table of all the testing commands for the HC-05 module, these will need to be implemented in the UART after the connection between the module and MCU unit has occurred. After a connection has been established, following these commands should give the following response as one can view later in the testing procedure.

Command	Return	Parameter	Description
AT	OK	None	Test
AT+VERSION?	+VERSION:<Param> OK	Param: Version number	Get the software version
AT+ROLE=<Param>	OK	Param:0=Slave role; 1=Master role; 2=Slave-Loop role	Set device's name
AT+ROLE?	+ROLE:<Param>	Param:0=Slave role; 1=Master role; 2=Slave-Loop role	Inquire module role
AT+UART?	+UART=<Param>,<Param2>, <Param3> OK	Param1: baud rate (bits/s); Param2: stop bit; Param3: parity bit	Inquire serial parameter

Table 5.5.2: Commands and Responses for Testing the HC-05 in UART

Environment and Materials:

- ATmega328P Microcontroller
- HC-05 BT Module
- Breadboard
- Laptop or Desktop device
- Power Supply

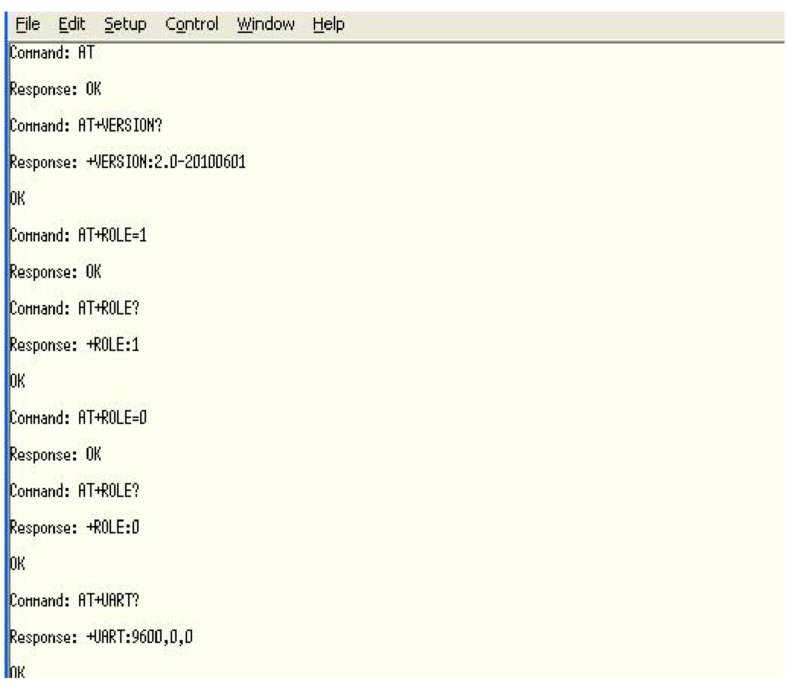


Figure 5.5.2: UART Verification of Command Signals

Procedure:

- First set up the HC-05 module and ATMega MCU by taking the TX pin and run Wire A to the ATmega's RX (Pin 45) pin.
- Likewise run Wire B from RX pin from the HC-05 to the TX (Pin 46) pin designated area and validate the connection.
- Run Wire C, GND wire from the module to the GND of the MCU (Pin 32).
- Then connect the VCC pin (Pin 31) to a source of electricity, using 3.3V is valid for testing, however if using a higher voltage please consider using a voltage divider circuit, as to not damage the HC-05's pins, or burn the board out completely. The HC-05 module can also run at a 5V signal as well from an Arduino MCU, as the module has a built in voltage regulator for up to 5V by utilizing Level Shifting.
- After connection has been established and the BT module is on, it is time to run your tests through the Arduino IDE, after trivial instantiation of the BT module.
- The module has two modes, DATA mode and COMMAND mode. DATA mode TXs and RXs while COMMAND mode modifies things such as baud rate and Slave or Master modes.
- Testing will be done in command mode and whenever in command mode the command must start with "AT" (without quotations).
- After the UART is up and ready type in the commands listed in Figure 5.6.1a and the output should be like what is in the figure below

6. System Architecture

This section aims to create a functioning system by assembling the four subsystems tested in Section 5 into one overall schematic. Preliminary PCBs will be designed and tested using EAGLE software. After a satisfactory PCB is obtained, the design will be sent off for manufacturing. Once the PCB is received, any external soldering will be handled and the PCB will be tested.

This section also considers the preliminary logic required to operate the system. Control and logic flow will be developed to ensure system performance standards are met.

6.1 System Schematic

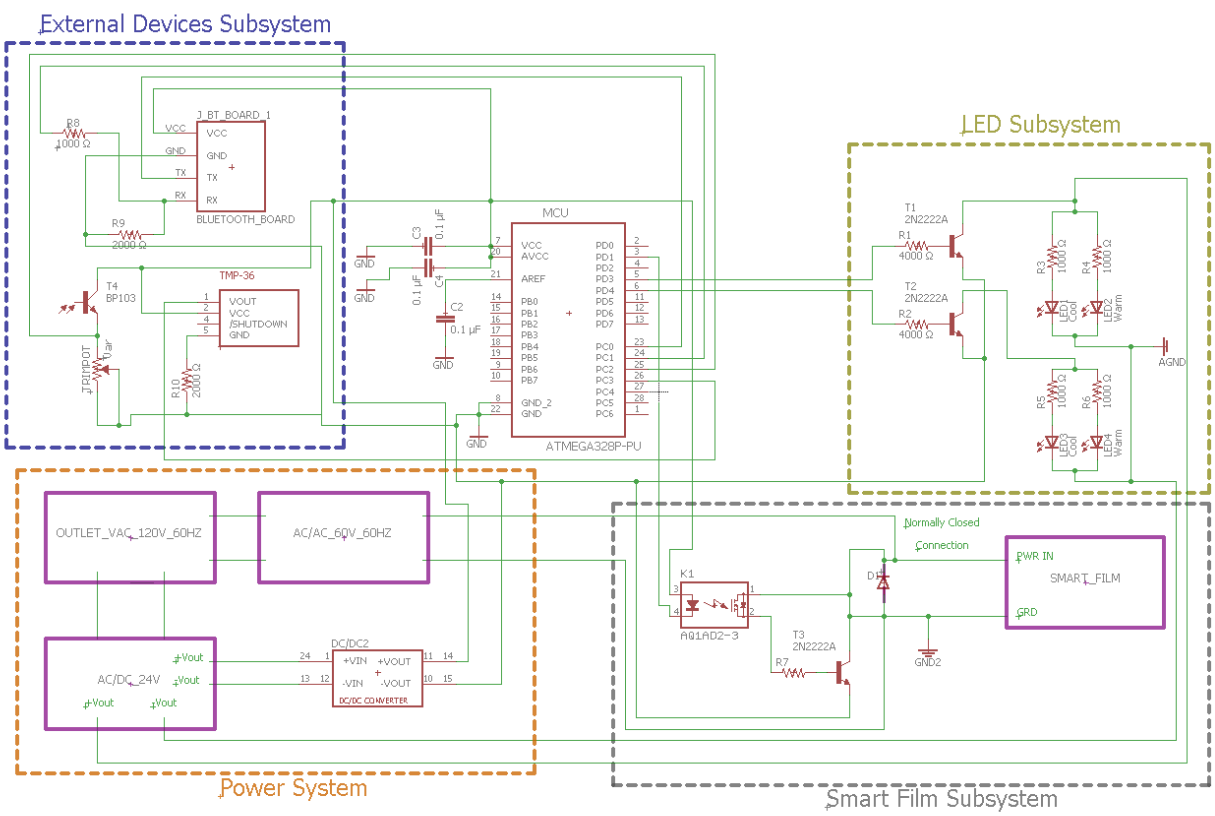


Figure 6.1 - Overall System Schematic

In Figure 6.1, the overall subsystems and power system are labeled in dashed boxes. These boxes do not necessarily represent the distance one system is from the other. For instance, the external devices subsystem requires that two of its major components be mounted on the window far from the PCB itself. However, looking at Figure 6.1, the external devices subsystem is located right next to the microcontroller unit. This will not be the case with the finalized PCB.

6.2 PCB

Printed Circuit Boards are the most common form of connecting circuitry in modern consumer electronic devices. They can be found in everything from laptops to flashlights. Even though many circuits can be created on a breadboard, PCBs allow the designer to create custom logic with ‘wires’ called traces that are as small or large as needed. This leads to one of the most size efficient circuits possible for a particular product.

As the name implies, PCBs are ‘printed’, and then etched by a mill (or router) or a chemical process. They consist of copper sheets laminated on non-conductive substrates. Components are often soldered directly onto the PCB, however it’s also possible to solder on connectors and attach the components through the connectors. Components designed to do this are often referred to as ‘through-hole’ components. A PCB with a single or small amount of components designed to connect to another PCB is called a ‘breakout board’ and SkyLight will use several, such as the real time clock and Bluetooth module.

PCBs can be designed using several different types of software. This includes, but is not limited to: Eagle standard, Diptrace Standard, Eagle Free, and Diptrace Free. Because all of SkyLight’s needs are met by the Eagle Free software, which (as the name implies) is free, it will be used. Designing with Eagle Free is a simple 2 step process, the first step of which is designing a schematic, and the second step is designing a board for the schematic.

It is important that traces, the copper etched wires in a PCB, are wide enough to handle the necessary amount of power, and to deal with potential stray capacitance that could alter frequency response in operations like I2C, serial communication, or PWM. For particularly power hungry elements, it is best to bypass the PCB all together.

There are key design rules for the basic design of a good PCB according to Altium: Fine Tune your Component Placement, Properly place your power, ground, and signal wires, keep things properly separate, properly combat heat issues, and checking your work. [Marrakchi, 2016]

In order to Fine Tune component Placement it is important to pay close attention to orientation, placement, and organization. Similar components should be oriented in similar directions in order to aid the soldering process. Placement of soldered on components should be far from placement of through-hole components to prevent the soldering process of the through-hole components from damaging nearby things. Surface mounted components should be generally organized in such a way that they are all on the same side of the PCB, and that all through components be on the top of the board, if possible. [Marrakchi, 2016]

In order to properly place your power, ground, and signal traces, one needs to orient their power and ground planes, connect their signal traces, and define their net widths. In general it’s desired that the power and ground plans internal to the board, symmetrical and centered in order to prevent a PCB from bending. Then integrated circuits can be powered by common rails, and shouldn’t be daisy chained from one component to another. Signal Traces should be connected as shortly and directly as possible. Net widths will depend on the current that is to travel through it, but as a general rule of thumb no less than one-one hundredth of an inch should be used, even for low current digital signals. [Marrakchi, 2016]

Keeping things separate implies separation, placement, and coupling. Separation ties into power supply, which is a huge part of SkyLight. It is important to keep control, power, and ground separate for any and all power supply stages. If they must be connected then it is best to connect them as close to the end of the supply path as possible. As for placement: avoid placing the ground plane in the middle layer. If it is unavoidable, then make sure a path of impedance exists in order to prevent interference and protect control signals. Similar techniques should be used to separate digital and analog grounds. Coupling: having analog grounds only crossed by analog lines reduces capacitive coupling, and generally should be done. [Marrakchi, 2016]

Preventing overheating and fighting heating issues should first be addressed by finding high-heat components. Thermal resistances are often in component datasheets, and if a high heat component can't be replaced, it might be necessary to use a heatsink or fan. First though, one should try to use thermal reliefs, which are pads printed on a PCB and connected to coupor pour using a thermal connection. [Marrakchi, 2016]

Finally, checking one's work is simple and intuitive, but often overlooked, especially on a design as potentially overwhelming as a PCB design. But the same reason that it's overwhelming is the same reason that checking the work is so important - there's a lot of room for error. Additionally the lead times for PCB construction and PCB construction costs are significant, so not having to go back and repeat the PCB design phase will help keep SkyLight on a proper schedule. [Marrakchi, 2016]

6.2.1 Requirements

The PCB will handle connections between various components. This includes power supplies, peripheral devices, and connections to the microcontroller. If the microcontroller is the heart of SkyLight, then the PCB is the veins. The PCB must make many connections, some carrying several amps and some carrying scarcely any at all.

The PCB is required to handle connecting the various power supply systems. It will take in power from the Outlet VAC through a non-polarized universal power cord. This will connect directly to the 24v DC and 60v AC Power Supplies, which will connect to the components through barrel connectors. Following this, the 24v DC output will be connected to the input of a 5v voltage regulator through the PCB, which will power the microcontroller and its peripheral devices. This means that the PCB is responsible for the connection between the 24v power supply and the MOSFETs leading to the LEDs (which need 7 amps each) as well as the connection between the 24v DC power supply and the 5V DC voltage regulator.

The PCB is also responsible for connecting two analog output pins (PWM) to the GATE pins of the MOSFETs controlling the LEDs. These lines need to be able to have a near ideal frequency response as to properly transmit the PWM from the microcontroller to the MOSFETs, and ultimately to the LEDs.

Additionally a digital connection between the microcontroller and the relay must be made. This connection is responsible for the activation of the relay to turn on and off the smart film. Other digital connects include one pin for the keypad button. They keypad will also require an analog input to an analog digital converter from the potentiometer to the microcontroller.

Several sensors will be used, including a temperature sensor and a sunlight sensor, both of which will use an analog input pin from the microcontroller, and require a connection from the PCB.

Bluetooth will be required to send and receive serial data using the RX and TX pins of the microcontroller. These pins must respond well to frequency response for the communication to be undisturbed. Below you can see a summary of the connections that the PCB needs to handle.

Inputs:	Temperature sensor, sunlight sensor, Bluetooth, potentiometer, pushbutton
Outputs:	LEDs, Smart Film, Bluetooth
Analog inputs:	Potentiometer, sunlight sensor, temperature sensor
Digital Inputs:	Pushbutton, I2C real time clock
Analog Outputs:	Microcontroller to MOSFETs
Digital Outputs:	Microcontroller to Relay
Power Supply:	24v DC to LEDs, 24VDC to 5v, 5v to microcontroller, 5v to peripherals
TX,RX:	Bluetooth

The board being used is the ATmega328P. It has six analog input pins, six PWM outputs, a proper TX and RX, and six additional digital outputs. This easily handles the system requirements. It can also be run with 5v logic which allows immediate compatibility with a number of relays which 3.3v logic does not offer. The icing on the cake is that the ATmega328P is through-hole, which allows the SkyLight team to use fully replaceable components on the PCB, as to rapidly fix any errors, test individual functions, and replace any broken components.

The PCB also must handle power. Power from the MOSFETs to the LEDs can get to as high as 7 amps, which is a lot for a PCB to handle. This requires a wide trace width. Of course, another and potentially better option is to solder copper wire to the trace, which is frequently done is small projects like these. Eighteen gauge wire should easily suffice and also prevent the circuit from creating much heat, which could potentially reduce SkyLight’s cooling effect.

The PCB simply won’t interact with the high voltage AC that runs through the relay, or the raw high voltage that originates from the outlet. That will be done through thick low gauge wire mounted to the physical PCB, but without any connections to any traces that could cause failure. The Outlet connection will run through universal power cable to a connector mounted ‘above’ the PCB and feed directly into both the 24v DC power supply and the 30v AC power supply.

Pin	Function	Assignment
2	RX	Bluetooth
3	TX	Bluetooth
11	PWM output	LED MOSFET gate (Warm)
12	PWM output	LED MOSFET gate (Cold)
4	Digital Output	Smart Film Relay
7	VCC	5v power input
4	Digital Input	Manual Control Push Button
23	Analog Input	Manual Control Potentiometer
24	Analog Input	Sunlight Sensor
25	Analog Input	Temperature Sensor
13	Digital Output	Real Time Clock I2C line 1
14	Digital Input	Real Time Clock I2c Line 2

Table 6.2.1 - PCB Functions

6.2.2 Schematics

Each subsystem schematic was drawn on a PCB. The individual PCBs will be assembled into a single PCB once the subsystem interactions between one another have been confirmed through testing. The PCBs were designed using EAGLE software and based on the tests and schematics performed in Section 5. In some cases, such as in the power system, a PCB will not be generated as the schematic details the power distribution to the system and is more of a hybrid design than a PCB. Nevertheless, the power system is extremely important to the SkyLight system. The high currents that the SkyLight system requires must be handled with extreme caution in both the tester and the user’s case so as to prevent injury.

The subsystem schematics and PCBs are listed below in the following order:

1. LED Subsystem
2. Smart Film Subsystem
3. External Devices Subsystem
4. Power System Schematic

LED Subsystem PCB Schematic and Design

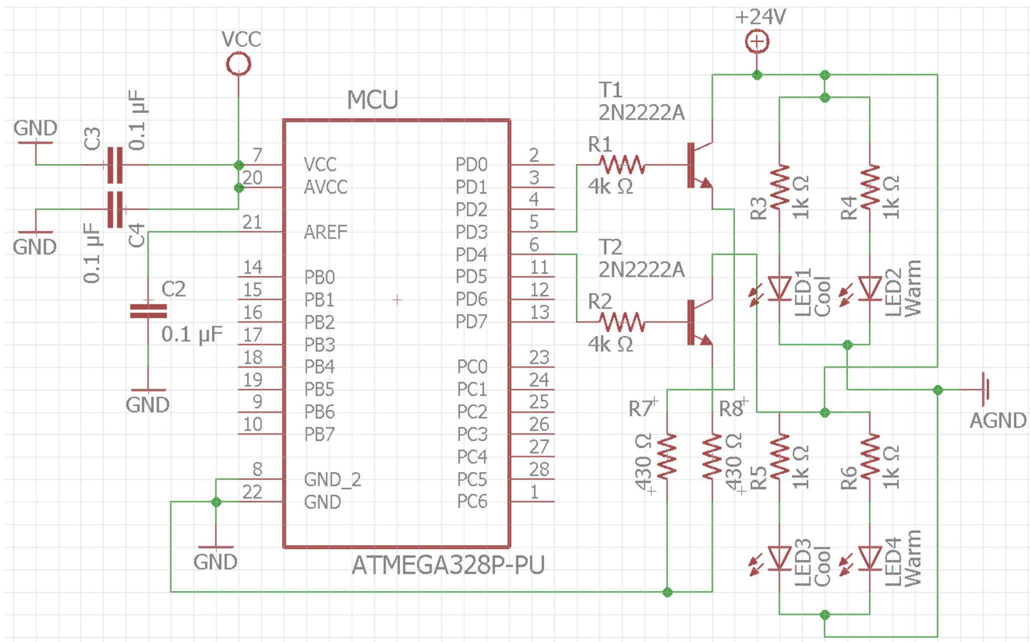


Figure 6.2.2a - LED Subsystem PCB Schematic

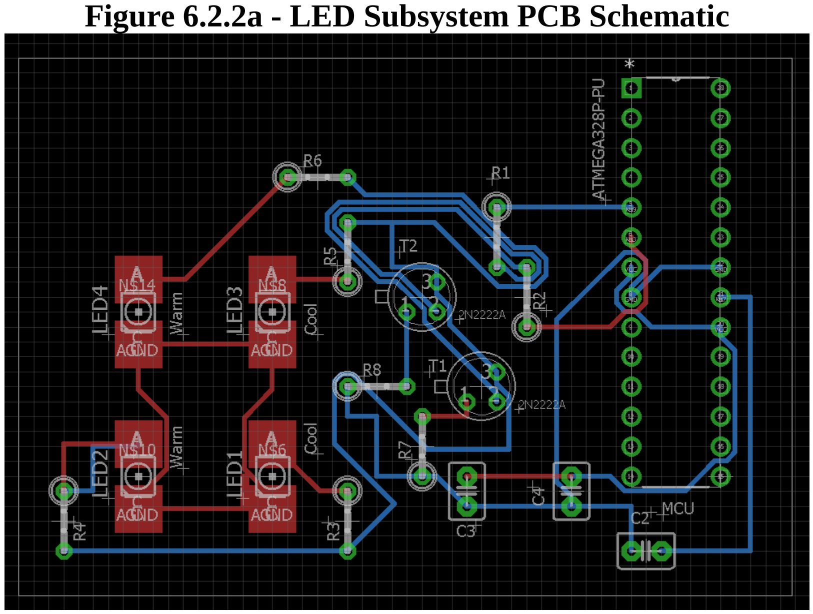


Figure 6.2.2b - LED Subsystem PCB

The LED subsystem handles variable color temperature using two SMD LED strips as seen in Figure 6.2.2a labeled "Warm" and "Cool". An external power supply supplies 24v DC to the strip itself which is connected to the analog ground on the outside of the PCB itself. The MCU sends PWM signals to the LEDs via BJT transistors to control intensity through pin #5 and pin #6.

Smart Film Subsystem PCB Schematic and Design

The smart film subsystem requires a relay to handle switching the film from opaque to transparent states. Note that the transparent state is considered active (or "ON") where the 60v AC current at a frequency of 60 Hz aligns the PDLC film so that light is able to pass. The film must receive a 60v AC signal at 60 Hz from the AC/AC adapter from outside the PCB and be grounded to the analog line. Pin #3 of the MCU controls the relay which allows for on and off states.

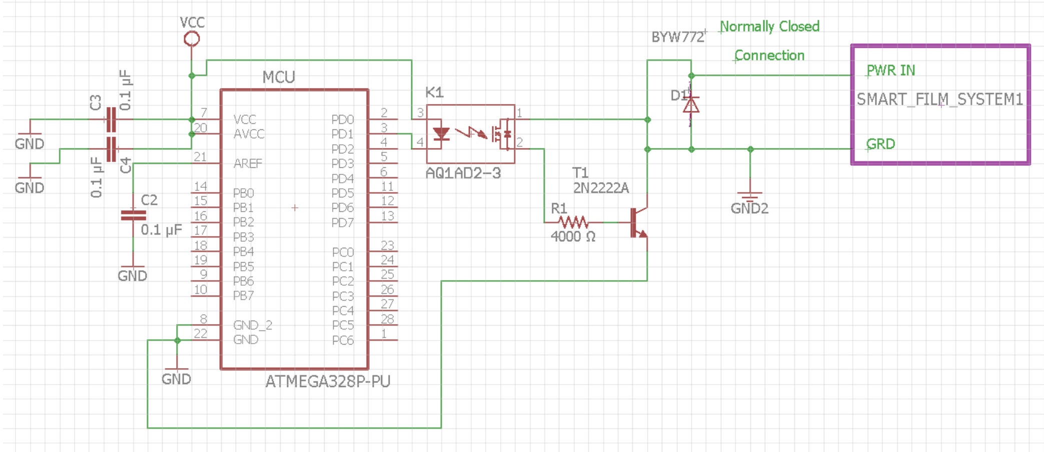


Figure 6.2.2c - Smart Film Subsystem PCB Schematic

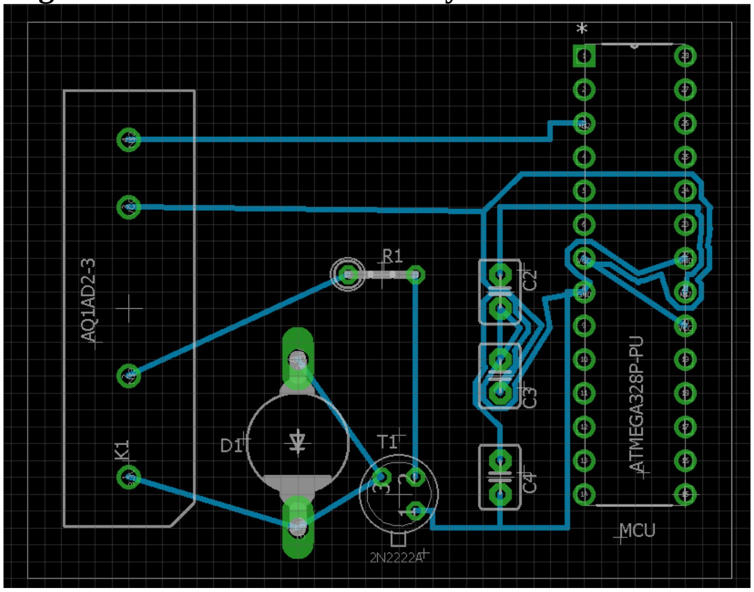


Figure 6.2.2d - Smart Film Subsystem PCB

External Devices Subsystem PCB Schematic and Design

The external devices subsystem manages the Bluetooth module, the temperature sensor, and the light sensor. The Bluetooth module is attached directly to the PCB while the temperature sensor and light sensor require placement on the outside of the window to obtain their respective data. This is handled with a through-hole connection as seen in Figure 6.2.2e with PAD1-5. Caution must be used when dealing with this system as there are multiple devices that require VCC input as well as a shared ground to prevent a ground loop from occurring in the system and causing interference through induced currents.

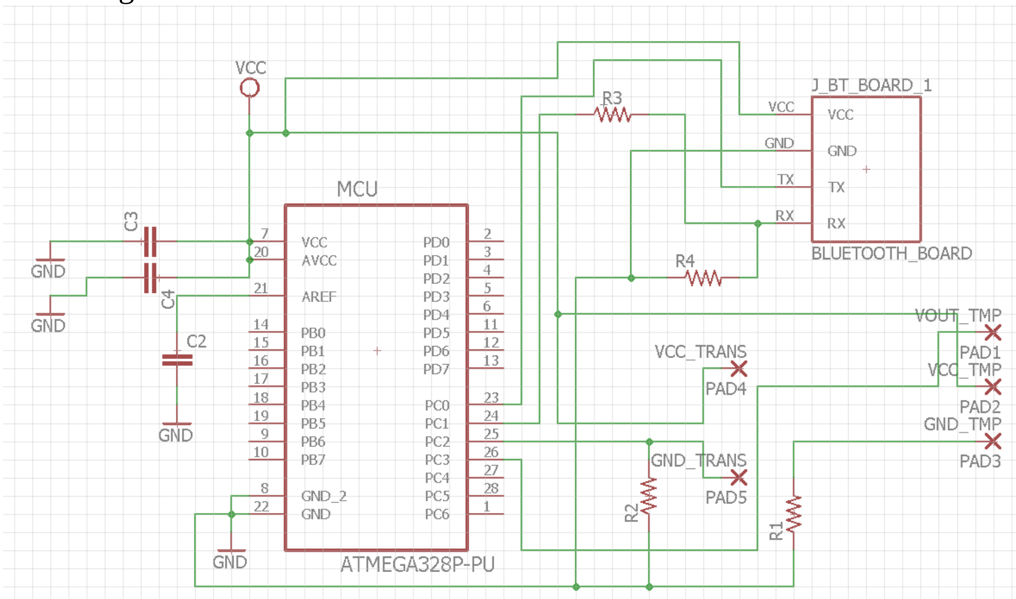


Figure 6.2.2e - External Devices Subsystem PCB Schematic

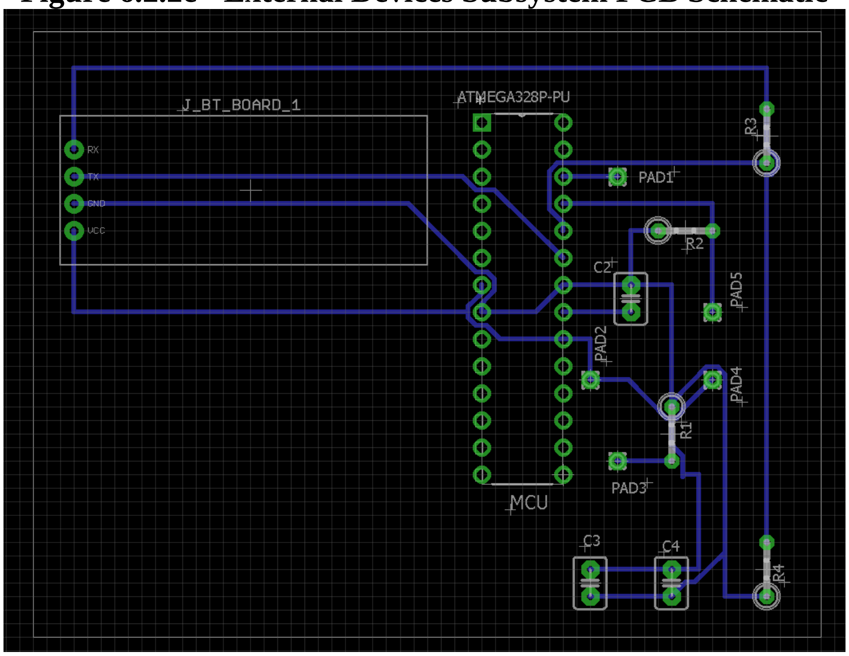


Figure 6.2.2f - External Devices Subsystem PCB

Power System Schematic and Block Diagram Hybrid Design

The power system is a unique system in that it illustrates how power is distributed to the system's components directly. The power supply units were tested with their respective subsystems to determine functionality. On top of this, all of these power supplies will be outside of the actual PCB and supply power through connections to the PCB (such as the 5v DC/DC voltage regulator to the MCU) or power a system with an indirect connection as indicated below. The power system has been incorporated into the overall schematic. However, it is still extremely important to detail how power distribution works in the SkyLight system as there are potential health hazards to the testers and users of the system as a result of working with a 120v 60 Hz AC signal.

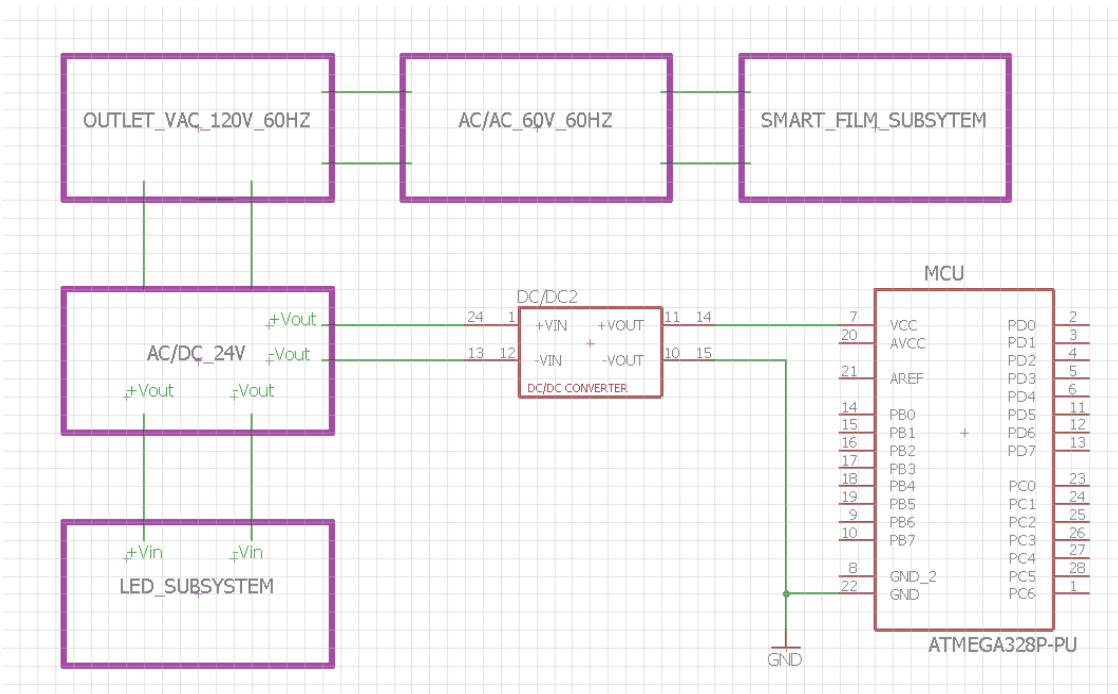


Figure 6.2.2g - Power System Distribution Schematic

6.3 Software Development

The SkyLight system will use user-modifiable control software to automatically adjust window transmissivity and LED intensity based on time of day, temperature, and light intensity. The user may override the automated settings using a smartphone application. The methodology to do this is described in the following subsections.

Several considerations must be made when developing the software for the SkyLight system. The major ones, privacy and energy savings, can be handled using custom modes or overwritten by the user manually. Considerations will be made to allow the user to program SkyLight with their preferred automated sequences.

6.3.1 Software Logic and Control

The SkyLight system will section the day into five segments as follows:

1. 7 AM - 11 AM [Morning]
2. 11 AM - 2 PM [Midday]
3. 2 PM - 6 PM [Afternoon]
4. 6 PM - 11 PM [Evening]
5. 11PM - 7AM [Night]

Throughout the day, the SkyLight system will adjust the transmissivity of each window and the LEDs on the inside based on the intensity of light impinging upon the window. The LEDs will also adjust based on the time of day and the current state of the smart film. There will be preset modes for users to select and also adjustable modes so that the user can pick based on their preferences. Figure 6.3.1 illustrates an example environment with possible windows that SkyLight system will be attached to.

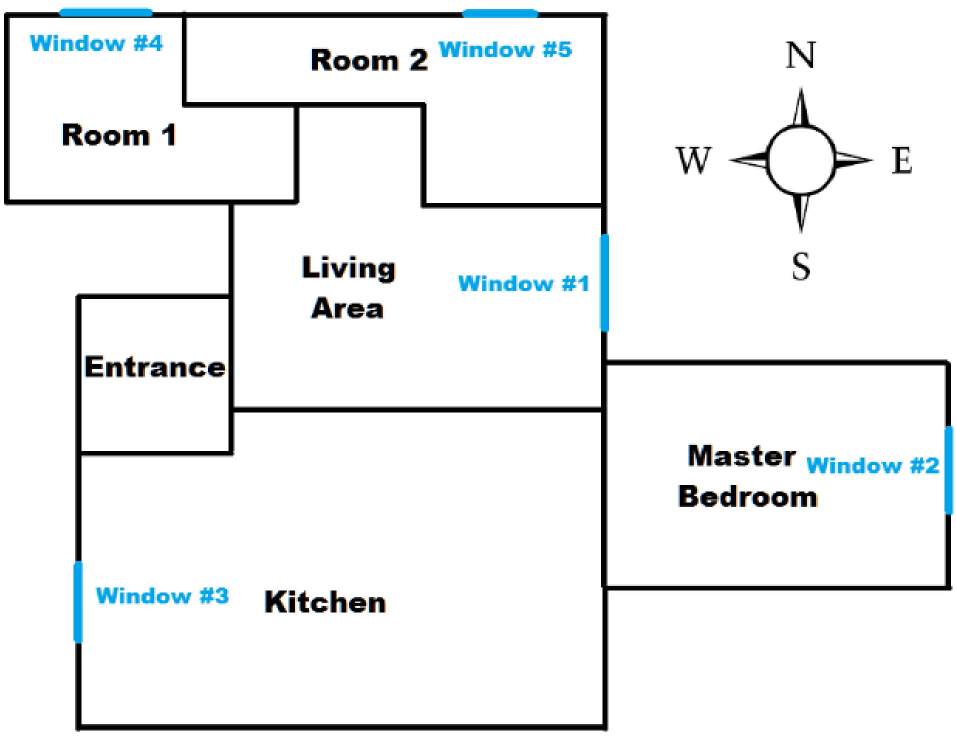


Figure 6.3.1a - Conceptual Operational Environment

Three of the presets in consideration are energy efficiency mode, privacy mode, and day-night swap mode. Energy efficiency mode will keep the windows opaque at all times while the LEDs change the light in the room. Privacy mode will keep certain windows closed when the user is most likely to be at home. Day-night swap mode will swap the settings of the LEDs and film for people who are active at night and sleep during the day. The default behaviors of the smart film and LEDs based on the time of day are indicated in Table 6.3.1a and Table 6.3.1b respectively.

Window	**1**	**2**	**3**	**4**	**5**
Room	Living Area	Master Bed	Kitchen	Room 1	Room 2
Morning	Off	Off	On	On	On
Midday	Off	Off	Off	Off	Off
Afternoon	On	On	Off	On	On
Evening	On	Off	On	Off	Off
Night	Off	Off	Off	Off	Off

Table 6.3.1a - Smart Film State by Time of Day

Window	**1**	**2**	**3**	**4**	**5**
Room	Living Area	Master Bed	Kitchen	Room 1	Room 2
Morning	High, 6500K	High, 6500K	Off	Off	Off
Midday	High, 6500K	High, 6500K	High, 6500K	High, 6500K	High, 6500K
Afternoon	Low, 4750K	Off	High, 4750K	Low, 4750K	Low, 4750K
Evening	Medium, 3000K	Low, 3000K	Medium, 3000K	Low, 3000K	Low, 3000K
Night	Low, 3000K	Off	Low, 3000K	Off	Off

Table 6.3.2b - LED State by Time of Day

Figure 6.3.1 describes the logic used by the SkyLight system to determine the state of the smart film and LEDs based on the presence or absence of user input. The time of day, in the absence of user input, is determined by the real time clock. Without user input, the system will follow the default settings described in Table 6.3.2a and Table 6.3.2b. If a user input is present, the smart film and LEDs will adjust accordingly.

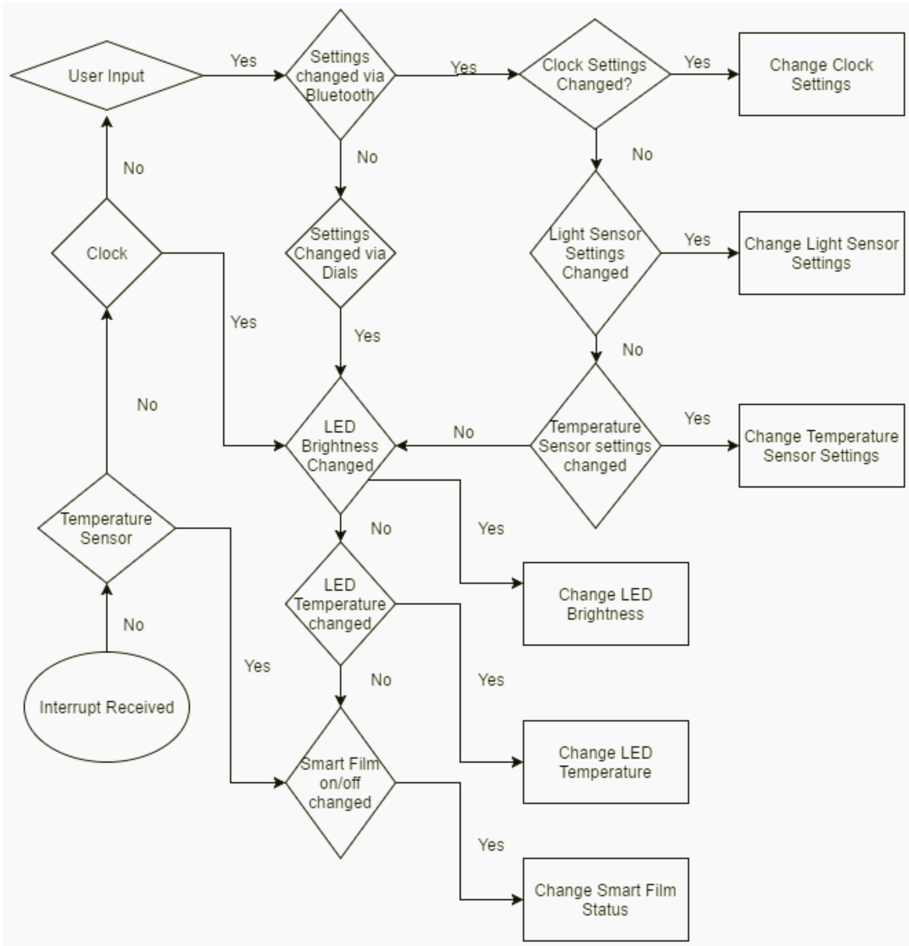


Figure 6.3.1b - Software Logic Model

6.3.2 Feedback Systems

Feedback systems will be used to address temperature changes, light intensity changes, and smart film states (assuming variable transmissivity is achieved). In most of these cases, control systems theory will be implemented in the form of a controller that will alter the input of a device based on its output.

For example, the light sensor is a part of the smart film's control system. The input to the light sensor is the light from the sun impinging upon the phototransistor. This input directly affects the transmissivity of the film and serves as a controller for the smart film subsystem. As light intensity increases, more current is generated in the light sensor circuit which is then detected by the MCU in the form of voltages. This information is then used to adjust the transmissivity of the smart film. As the light levels change, the light sensor acts as a controller to change the transmissivity of the smart film.

7. Hardware/Software Integration

The purpose of this section is to discuss how the SkyLight system was integrated in Senior Design II. Various changes were made to the system (both on the hardware and software end) to adapt the prototype system to the real-world environment that it was to be placed into. Several key changes were made to ensure that all requirements were met and to ensure the final product could be realized and demonstrated.

7.1 Overall System and PCB

Multiple changes were made to the overall system schematic. There are two primary reasons for these changes. The first change was made to ensure the through-hole approach could be realized. Every component besides the voltage regulator was removed and pads were used instead. This can seen in Figure 7.1a.

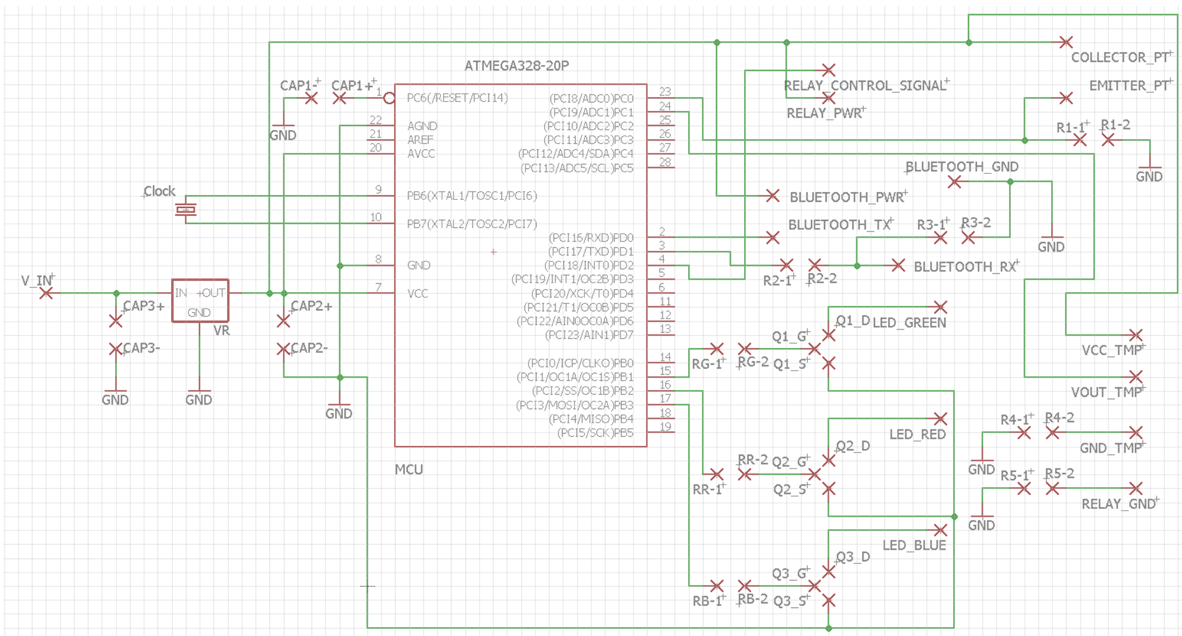


Figure 7.1a - Revised Overall Schematic

This added a complexity when dealing with PCB vendors overseas, however. Some vendors that were selected to get a quote from could not understand that a pad does not have a part number as it is just a hole in the PCB. Since there was such a fundamental misunderstanding, these PCB vendors could not be used which added to the cost of PCB development as a local vendor was selected instead. The second change was the addition of capacitors for the voltage regulator that were initially left out. The input capacitor to a voltage regulator needs to have a larger capacitance than the output capacitance in order to ensure proper functionality from the regulator itself. As there was no input capacitor, pads were added for one and a proper capacitance was selected.

Another addition that was made to the schematic was a control line from one of the PWM signals of the MCU to another transistor in an attempt to incorporate RGB LEDs: one pad for each value (red, green, and blue). Unfortunately, RGB LEDs could not be incorporated into the system due to time constraints. That said, the extra PWM trace on the PCB added some security to the testing phase. Were the team to damage one of the two traces needed during soldering and construction, a spare trace was available to accommodate the loss of one of the two traces.

Finally, a circuit element was added after the fact to the overall schematic. This critical circuit element was the MCU's clock which can be seen in Figure 7.1a labeled "Clock". Without the clock the entire system could not function properly. Since the PCB was fabricated without the clock's footprint, the clock had to be soldered onto the two MCU pins on the back of the PCB. While the solution was not as elegant as adding it to the overall system and PCB schematic initially, it worked. The PCB was then adjusted for all of these elements (including the clock) as seen in Figure 7.1b.

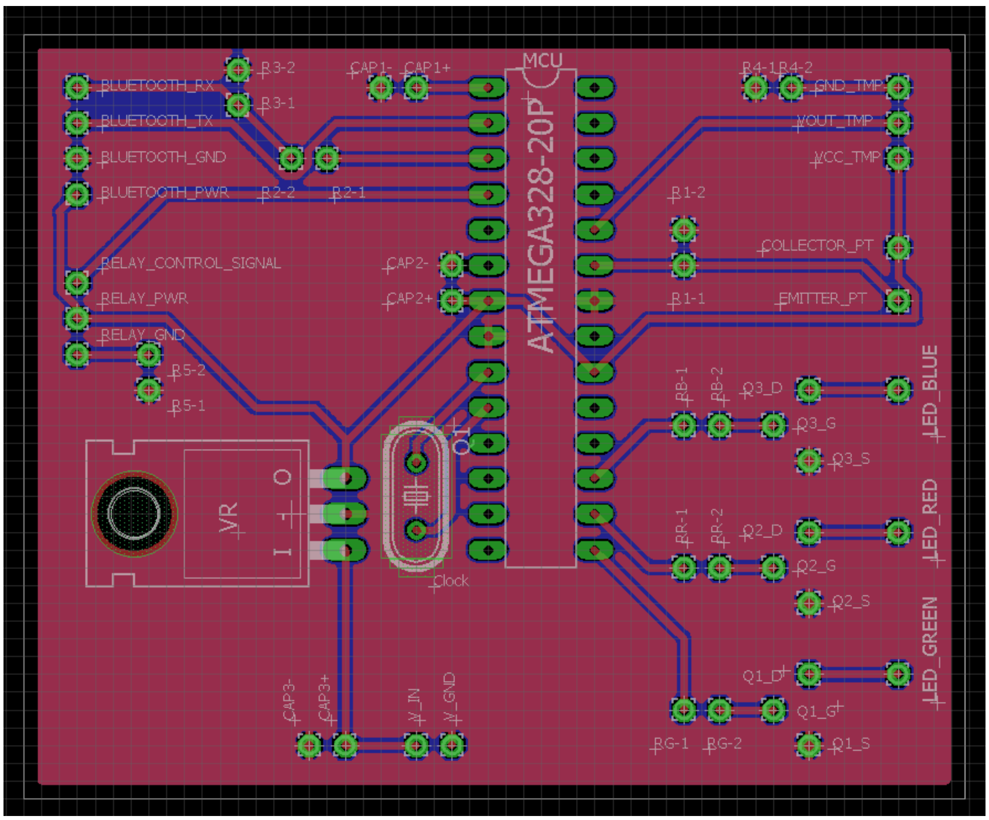


Figure 7.1b - Finalized PCB

The PCB incorporates a ground pour to aid in routing connections and to ensure stability between connections. The ground pour functions exactly as it is described: as ground. This is important because it allows the PCB to have a common ground amongst all ground connections to prevent issues like ground loops from adding unwanted interference to the circuit. While this is convenient in that sense, the ground pour has drawbacks when hand soldering components to the PCB itself. If the pads are too close together and the ground pour is too close to these pads that are supposed to conduct electricity, merging of the ground pour and the trace can occur which causes the signal to become distorted and it will not function properly as a result. This was encountered several times during the soldering process but was rectified by reheating soldered connections and readjusting the connection. Another consideration for the PCB is the trace length from certain pins of the MCU (such as VCC) to decoupling capacitors. Since longer trace lengths lead to more resistance, the length affects the stability provided by the decoupling capacitors. To ensure maximum stability, these capacitors were moved as close to the appropriate pins of the MCU as possible.

Another problem encountered during the soldering phase was the fact that two of the connections were not attached to the ground pour as they should have been. These two connections were the voltage regulator's common ground connection and trace. To get around this issue, a wire was connected from one of the regulator's traces to a ground on the PCB that was not used.

Finally, several capacitors needed to be added to the PCB itself due to power draw from the combined power supplies. During times of operation, the PCB would lose power entirely which would cause the Bluetooth to desync as well as disconnecting other devices from our system such as the LEDs and smart film. The integrated power system could not supply a constant 5v to the MCU at times due to power draw from the other devices in our system: particularly the LEDs. These capacitors stabilized the voltage supplied to the board, ensuring that all devices were receiving the appropriate supply voltage at all times.

7.2 Embedded Software and Logic

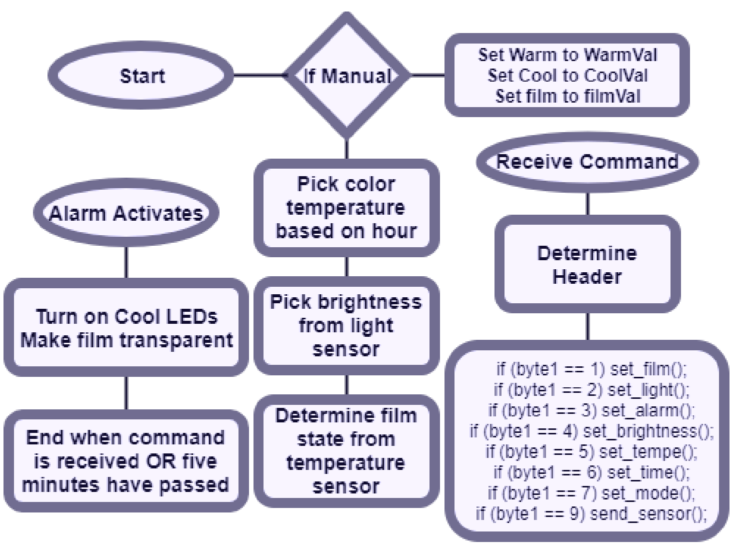


Figure 7.2: Software Flowchart

SkyLight Glass has two main states: automatic and manual. Automatic mode selects the LED color temperature based on time, LED brightness based on the light sensor, and film state based on the temperature. Manual mode selects these values based entirely on user input. SkyLight currently supports the LEDs by sending direct values (two bytes of 0-255), by sending a brightness value (one byte of 0-255) and using the most recent outputted color temperature, or sending a color temperature value (one byte of 0-255 that represents a fraction between 0 and 1). The film can also be toggled on and off.

Both modes support time-keeping and alarms. When an alarm goes off the film will become transparent and the cool LEDs will turn on at maximum brightness. Alarms turn off either after five minutes or as soon as another serial command is received. The time is kept with the Time.h Arduino library and alarms are kept by the TimerAlarm.h Arduino library.

Alarms are one of two interrupts. The other interrupt is triggered when a serial command is received from the HC05 Bluetooth module. When this happens, the command is parsed as a long and the first byte is used as a header to determine what function is to be called. The other three bytes are used as information for the function. There are several functions that were programmed on the ATmega328P side that didn't see use in the demo because of time constraints. These functions related to allowing users to change the behavior of the automatic mode. This includes things like changing the color temperatures per time values, changing the temperature threshold for the film, and changing the relative brightness of the LEDs compared to the light sensor values. It's very possible that these functions won't be included going forward as it might give users a confusing number of options.

Hour	Color temperature	LED Ratio
0-5	Off	-1
6	2500K	0
7-13	6500K	.93
14-17	4500K	.47
18-21	2500K	0
22-21	Off	-1

Table 7.2: Color Temperature Hours / Ratios

Automatic mode selects color temperature based on the time. In the figure above is the array that controls the color temperature. The ratio is the relative value of the cool LEDs to the warm LEDs. A ratio of 0 is very cool and a ratio of 1 is very warm. A ratio for the specific time is calculated based on the hour ratio. It is: ThisHour + (NextHour – ThisHour)*ThisMinute/59. Brightness is calculated by bit shifting the 10 bit light reading into an 8 bit (0-255) brightness value. Film state is determined by checking the sensor value with a predetermined Fahrenheit number.

In manual mode, the user can keep the current color temperature or brightness while changing the other value. To change brightness SkyLight Glass calculates the current ratio of cool to warm by dividing the current cool signal by the sum of the current cool signal and the current warm signal. That ratio is multiplied by the desired brightness value to get the new cool signal, and the inverse of that ratio is multiplied by the desired brightness value to get the new warm signal. If instead a user wants to keep the current brightness and change the color temperature, the current brightness is calculated by adding together the values of the cool and warm signals. The new cool value is determined by multiplying the desired color temperature ratio by the brightness and the new warm value is determined by multiplying the inverse of that ratio by the brightness.

Part of why this logic works is because of the brightness of the LEDs. Because the LEDs are prohibitively bright when on a full duty cycle it is okay (even preferable) to only use a half duty cycle. If a full duty cycle were used the maximum brightness units would move from 255 to 510. Since a single color of LEDs can only output 255 units changing color temperature and brightness using the above logic could risk an alteration of the other field. For instance, if both LEDs were on at a .5 ratio with max brightness in this new system, they would both have a value of 255. If the user wanted to change the color temperature the brightness of one of the LEDs would have to dim, and it would not remain consistent. This logic would also create other similar errors if more than half duty cycle were allowed.

7.3 Bluetooth Application

Major changes occurred from SDI going into SDII in regards of application development. These major changes included the following:

- Revamped imagery for activities, like background appearance, as well as user interactive buttons and slider bars.
- Added compatibility algorithms with Bluetooth for communication to make the system wireless. This was changing the Serial communication with a Port into SPP which is good for sending short bursts of data quickly over a Bluetooth protocol.
- Added new activates to control LEDs, which included getting rid of the RGB values and color wheel. Adding Warm and Cool settings to control LEDs for a more natural state, i.e. using a Kelvin scale. This was to help Circadian Rhythm for a more relaxed state of mind. Brightness stayed part of the system however, the way it was implemented in the application was changed around for an easier usability. This is achieved with a very simple conversion with the app sending a value of 0 – 255 and being converted in the code within the ATMega.
- Data Retrieval was added which was not mentioned in the beginning of the initial documentation. This was added now in SDII, which is part of the sensory portion of the system. The readings received were from the temperature and light sensor, in which the application will send to the user that asks for the information a display of both, with temperature in degrees F and light in units, reaching an inevitable max eventually. Before we had this set in terms of a voltage which would max out around 5V. These readings are in real time of what the system is experiencing and is a very simple echo of the system to the application.
- The Alarm section was introduced in the initial documentation. However, it has now been also updated with a new look and is now a much more usable feature included in the application. When activated the alarm will turn the system on, causing the amperages to flow through the system, and in turn causing the film to become opaque. This also activates the LED subsystem causing a mixture of the warm and cool lights to become apparent.
- Also added was the Main Screen now features the ability to control the film and LED subsystem directly from that page. This helps with users that want to quickly interact with the system without having to move through multiple activities of the application. This in terms saves not only time, but the hassle of more loading.

All of the above features were either added or improved upon, all decisions were added to maximize the usability of the software. Other than the differences shown between section 5.2.4 in the initial document for how the UI appears to the user, the basis of the idea stayed consistent throughout the project entirety. All of the algorithms work and seamlessly integrate with an Arduino interface to control SkyLight Glass. Below are all the official screenshots of the SkyLight Glass Application in respective order from top left to bottom right.

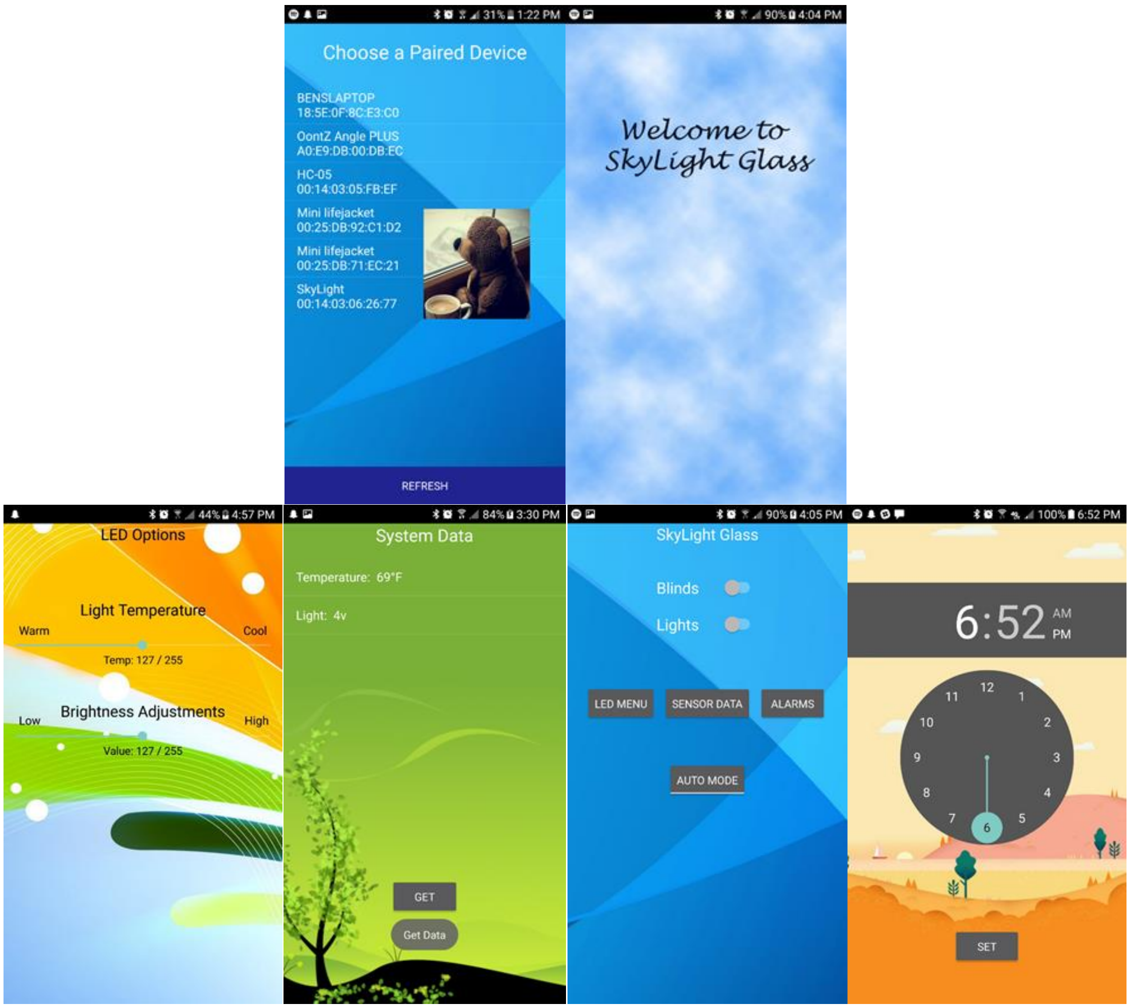


Figure 7.3 - Bluetooth Application Splash Screens

7.4 Design Challenges

One of the design challenges that the SkyLight system encountered occurred during testing of the LED system. Initially, the 3528 SMD LED strip was used to vary color temperature three ways using a strip that had two different LEDs attached to it. One LED had a color temperature of 6000K and the other LED paired next to it had a color temperature of 3000K. When both LEDs are turned on, the result is a color temperature around 4500K: in-between "warm" temperatures and "cool" temperatures.

The LEDs were driven with a PWM signal using the MCU's analogWrite command which has the following structure: analogWrite(pin #, value between 0-255). This quickly turns the LED off and on: faster than the human eye can detect. At a low duty cycle, this gives the impression of lower intensity lighting. The pins were set in such a way that each pin controlled one of the LED color temperatures for a total of two pins. Using a value of 0 through 255 allowed the LEDs to receive a signal with a duty cycle in-between 0% and 100% with 255 representing 100%. The design challenge occurred when both LEDs were turned on and a duty cycle of around 50% was assigned to both. The results can be seen in Figure 7.3.

Figure 7.4 - LED PWM Cycle Desync

The LEDs functioned normally when they were turned on and off individually and mixed with a 100% duty cycle. However, when the duty cycles of the two LEDs approached 50%, the above would occur. This effect was not visible to the human eye but the camera used to capture the output of the LEDs was able to detect the lines seen above. When compared with the output in Section 5.1.2 on LED testing, the lines become more pronounced as the other tests produced light that illuminated a solid background.

The cause was the out of sync duty cycles of the individual LEDs. While this was not observable to the human eye, caution was taken as this can cause issues that are discussed in Section 4 on LED flickering. However, the frequency required to cause issues must be sufficiently low. As these were driven at around 16 MHz, no health hazard was presented.

7.5 Modifications

There were many changes made when switching from the design phase into the building phase, some for building practicality, and others for user practicality. One of the most notable changes is that the keypad was entirely removed. This was done to be more practical for the user. Having too many methods for control was overwhelming and confusing, and having the keypad components increased SkyLight Glass' footprint. These changes made it necessary to change the software logic.

Also excluded is the RGB UI from the Android App. Due to time constraints the SkyLight team never implemented any RGB 5050 SMD LEDs and instead chose to use the Color Temperature 2935 LEDs. Because of this no RGB control was necessary. The RTC module was excluded and software was used to keep time instead. The power control scheme also changed. A third power supply was added (9V DC) to feed into the 5V voltage regulator. This was because the wattage needed to go from 24v to 9v with SkyLight Glass' current draw was too high.

8. Administrative

This section's purpose is to consider budget and cost analysis, set deadlines through scheduling, ensure system design and testing is handled in a timely manner by setting milestones, and deal with challenges encountered when designing the prototype system and finished product.

8.1 Budget

Estimated Budget

Table 8.1a is a breakdown of the expected materials to develop the SkyLight Glass system and their estimated prices. As the team enters the detailed design phase, price estimates will be updated and incorporated into the budget.

Item	Price	Quantity	Total
Window Film	$75	1	$75
Color Temperature LED Strip	$50	1	$50
Microcontroller Chip	$1	1	$1
Voltage Regulator for LED	$1.5	1	$1.5
Relay for controlling film	$30	1	$30
Voltage Regulator for Chip	$1.5	1	$1.5
Power Supply	$0	1	$0
Lux sensor	$6	1	$6
Bluetooth Module	$10	1	$10
RTC unit	$20	1	$20
Polycarbonate "window"	$10	1	$10
Wood for window frame	$5	1	$5
PCB related costs	$100	1	$100
Potentiometer	$0.95	1	$0.95
TOTAL			$310.95

Table 8.1a - Estimated Cost

Cost Analysis

Early on in the semester the members of SkyLight Glass came to the conclusion that they would each contribute an initial investment of $80USD into materials for the product development of SkyLight Glass. With four members, this puts the total budget at $360USD, which is above the estimated budget. Since then a resource became available that could minimize PCB development costs which made the $360USD budget even more powerful, which is good, since it became necessary to order from American distributors instead of distributors who work more closely with the manufacture - which increased component cost significantly for a few key elements.

Item	Part #	Price	Quantity	Total Cost
Smart Film	Not Applicable	$145.07	1	$145.07
60VAC Power Supply	EEIO-5VA	$0	1	$0
LEDs	NFLS-DW120-VCT	$24.95	1	$24.95
24VDC Power Supply	709-LPV20-24	$19.95	1	$19.95
Relay	srd-05vdc-sl-c	$3.39	2	$6.79
Voltage Regulator	L7805CV	$1.19	5	5.95
Bluetooth Module	HC-05	$7.99	1	$7.99
Real Time Clock		$0.66	3	$1.98
Potentiometers	BCBI5861	$3.25	2	$6.50
Temperature Sensor		$1.48	3	$4.44
Photosensor		$0.43	3	$1.49
MOSFET	3034	$1.60	10	$16
Microcontroller	ATmega328P	$5.05	3	$15.14
TOTAL				$256.25

Table 8.1b - Actual Cost

8.2 Milestones

The SkyLight Glass project will take place over a period of seven months (January to July 2017). Project milestones and initial schedule to meet the goals within the period of performance are detailed in Table 8.2.

Class	Topic	Item	Deadline	People
Senior Design 1	Tangibles	Form Group	Jan 12	Group 13
Senior Design 1	Tangibles	Initial Document	Feb 3	Group 13
Senior Design 1	Tangibles	Update Initial Document	Feb 17	Group 13
Senior Design 1	Tangibles	Table of Contents	Mar 24	Group 13
Senior Design 1	Tangibles	Final Document	Apr 27	Group 13
Senior Design 1	Research/Design	Power Supply/Control	TBD	Blake
Senior Design 1	Research/Design	Wireless Communications	TBD	Ben
Senior Design 1	Research/Design	Smart Film and LEDs	TBD	Paul
Senior Design 1	Research/Design	Chips and ICs	TBD	William
Senior Design 1	Construction	Order Parts	Apr 27	Group 13
Senior Design 2	Construction	Prototype Film/LEDs	TBD	Blake
Senior Design 2	Construction	Prototype PhotoSensor/RTC	TBD	William
Senior Design 2	Construction	Prototype Bluetooth/Keypad	TBD	Ben
Senior Design 2	Construction	PCB Design & Manufacture	TBD	Paul
Senior Design 2	Construction	Final Manufacture	TBD	Group 13
Senior Design 2	Construction	Final Presentation	TBD	Group 13

Table 8.2 - Project Milestones

8.3 Further Comments

While the SkyLight system was designed as a prototype window, the system may be generalized to windows of varying dimensions. To add on further, the SkyLight system can be extrapolated to a household system as described in Section 6.3.1: Logic. One of SkyLight's primary goals is to reduce energy costs by reducing the time the customer's air conditioning unit runs for. To do this, each window in the house may be controlled using this system: only letting in light from the outside when it is not directly impinging on a particular window. Another goal of the SkyLight system is to control lighting in all situations: both indoors and outdoors. The outdoor lighting is controlled via the smart film system coupled with the ambient light sensor and temperature sensor. The ambient light sensor determines the intensity of light hitting the window and adjusts the transmissivity of the window accordingly. The temperature, on the other hand, is used to detect season changes. Ideally, in the winter, the SkyLight system seeks to maximize window transparency when light sources are available to heat the interior of a house. This leads to energy savings as the user's heater needs to work less to maintain a comfortable room temperature.

While this controls the outside light, the LED system also adjusts based on the transmissivity of the window as well as the time of day. If a window is opaque, the LED system activates and uses artificial light on the interior side of the window to accommodate for lack of natural light coming through the window. Another feature of the LED system is its variable color temperature range. Based on time of day, different color temperatures and intensities are desired to facilitate good sleep habits for the user. By using the real time clock, the time of day can be ascertained and the LEDs can be programed to emit certain color temperatures as a result. On top of this, the LEDs can change intensity. At night, low intensities facilitate better sleep patterns.

The other advantage of the SkyLight system is to automate lighting levels in the house at all times. This allows the user to continue about their business without having to worry about continually turning lights on and off. Another advantage is that the SkyLight system may be programmed by the user directly to override any unwanted automation. For instance: some users prefer a darker environment in their house (extreme power savings) at all times and some users prefer more light. SkyLight will also have the ability to flip the day and night cycles for users that work at night and sleep during the day.

SkyLight may also be used in the workplace to facilitate productivity. In offices where natural lighting has difficulty entering, the SkyLight system's color temperature changing LEDs can help users stay more alert and active due to exposure of natural sunlight during the day which inhibits melatonin production.

The SkyLight system will become more advanced as newer LED technologies develop that focus more on color temperature and circadian rhythm regulation. Newer smart film technologies in development, such as micro-blinds, could also reduce the cost of the system due to how the micro-blinds are manufactured.

8.4 Project Summary

Initially, the SkyLight system sought to automate the blinds on a window to facilitate in energy savings by reducing the time a user's air conditioning system runs. During summer months, light is reflected when directly incident on a window and opaque in winter months to allow light to pass and heat the room. This idea was expanded to incorporate the automation of lights on the interior where the window was attached and to change the light's color temperature to reflect the Sun's current color temperature. All of these features were incorporated into our system and realized through integration of hardware and software. The requirements of the project were met and the product was able to be constructed and demonstrated within the span of two semesters.

Building this system required utilization of the team's knowledge about electrical and computer engineering acquired at UCF and through practical application in the field. For that, we thank our professors and mentors for what they have instilled in us. Some of the major pitfalls of our system were avoided due to the experience attained by several of the team's members in the field. Without this experience, the final product could not have been implemented and demonstrated as quickly or as precisely as specified.

In later revisions of the SkyLight system (tentatively: SkyLight 2.0), we hope to implement several key features that could not be added due to time constraints in the initial design. Our team realized midway through the project that WiFi, while perhaps more costly in terms of power and more restrictive in location, could handle several of our system's features with more ease. Another feature we wished to add was the ability to change the actual hue of the LED: not just the color temperature. This would be implemented using more complex SMD LED technology such as the 5050 strips that often come with four control lines and one power line. The four control signals are generally for red, green, blue, and white. Another feature that we would like to implement is variable opacity for the smart film. Currently, the film only has a binary state: on and off. There are various systems that use capacitive arrays that can be used to vary the opacity but they were not considered for this system.

While there is room for tweaking and improvement in later revisions, the main objectives of the SkyLight system were achieved: automation of a window such that energy is conserved and automated lighting to compensate for lack of light that mimics the Sun's natural light.

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Appendix B - Datasheets

[Polyvision™ Power Supply]

SPECIFICATION   Polyvision Electronic 1539

1 Part No: TAA66-6501000AU

2 Designed No: ADA-141205

3 Construction:

A:Size:As Drawn

B:Leads Class:

Terminal	1	2	3	4
Color	PIN	PIN	WE/BK	BK
Length	1800+50mm		1800+50mm	
Class	#18-SPT-1		#20-SPT-1	
Note	UL-2PIN		5.5*2.1*11mm	

C:Lead Pull Test:2kg For 10 Secnds.

D:Impregnation:Varnish

4 Characteristice:

A:Primary Rated Voltage And Frequency AC120V60HZ

B:Secondary Rated Voltage requlation

Input Voltage	No Load Voltage	Rated Voltage	Rated Current	Note
AC120V/60Hz	AC70.0V±5%	AC65.0V±5%	AC1000mA	3-4

C:Exciting Current Input Primay AC120V/60HZ IO:120mA MAX

D:Hi-Pot Test Input 60HZ 1800V For One Minute Between Primary And Secondary And Between Primary To Core 1800V For One Minute Between Secondary To Core.

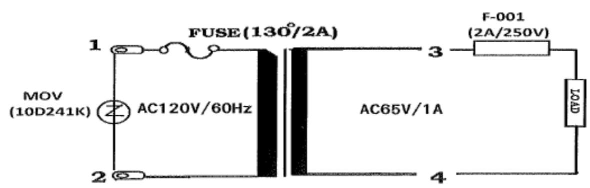
E:Insulation Test : 500V Dc 100M Ohm Min Windings And Core.

5 Environmental Conditions

A:Operating Temperature ------ 0℃ ~ 40℃

B:Storage Temperture---------- -20℃ ~ 85℃

6 Test Circuit:



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Appendix C – Permissions

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