Cam Norris

Polar Reflection

Abstract

Polarized film is used for many applications from cameras to sunglasses in order to prohibit visible light from passing through a transparent medium. Given its ability to block to visible light, can polarization provide a solution for a low-cost, low-tech shading system? The thought being that if less light is allowed to pass through a transparent medium, the less electromagnetic energy allowed to heat the space. Polarized film has microscopic strands running parallel to each other in a given direction. This erases half of the light as it moves through the filter. If these filters are placed in a series at certain angles, it can drastically reduce the amount of light let into a space, even completely blocking out light if oriented perpendicular to each other. Current solutions in reactive solar shading, such as thermochromic glass and electrochromic glass, are either costly to install and upkeep or make the window opaque robbing the observer of a connection to the exterior. With the known psychological and practical benefits of direct sunlight on buildings and their occupants, architects have been using an increasing amount of glazing on their buildings. However, this comes with a major drawback, reduced performance. Buildings with a higher window to wall ratios perform much worse than ones with a lower window to wall ratio. The two factors that affect this performance are heat loss through the glazing and solar heat gain. Applying polarization to architectural glazing presents an opportunity to offset solar heat gain and improve performance. This study will examine if layers of polarized film applied to glazing is a viable low-cost, low-tech option for reducing solar heat gain. Measurements of the kind of light passing through the filter will also be recorded.

Introduction

An architect's main responsibility, while creating beautiful spaces that people want to occupy, is respecting the Earth and being conscious of the resources that we are using. Architecture is an inherently destructive process. In order to build something, another thing must be harvested and processed. Knowing the harm that architecture causes, architects must find ways to offset these effects and measure the positives and negatives of materials that we choose. Life cycle costs should be at the forefront of most every architectural conversation.

While the energy cost of producing a space is often high, managing that space consumes much more energy over the life of a building. Performance driven architecture creates a more respectful architecture for the environment. When considering places to improve performance, it makes to observe the breaks in a building's envelope. While a buildings envelope is often overdesigned with walls that are able to efficiently condition an interior space and oppose the exterior environment, wall penetrations such as glazing, can completely offset all of the good done by a well-designed envelope. To compound this problem issue, window to wall ratios have been rising decreases a buildings performance. Western cultures are obsessed with over conditioning their spaces, pumping the AC in the summer and running their furnaces all winter. According to the United States Department of Energy, "Air conditioners use about 6% of all the electricity produced in the United States, at an annual cost of about $29 billion to homeowners. As a result, roughly 117 metric tons of carbon dioxide are released into the air each year." (DOE)

As temperatures continue to rise across the globe, people will use their air conditioning at a much higher rate adding fuel to this already burning flame. Some measures have been in the production of glass to make it more efficient and mitigate the amount of thermal energy passing through the transparent medium, namely low emissivity glass. These methods can greatly increase building performance, but what about the windows that are currently not treated for low emissivity? His goes back to the destructive process that architecture is and weighing the energy cost of certain operations.

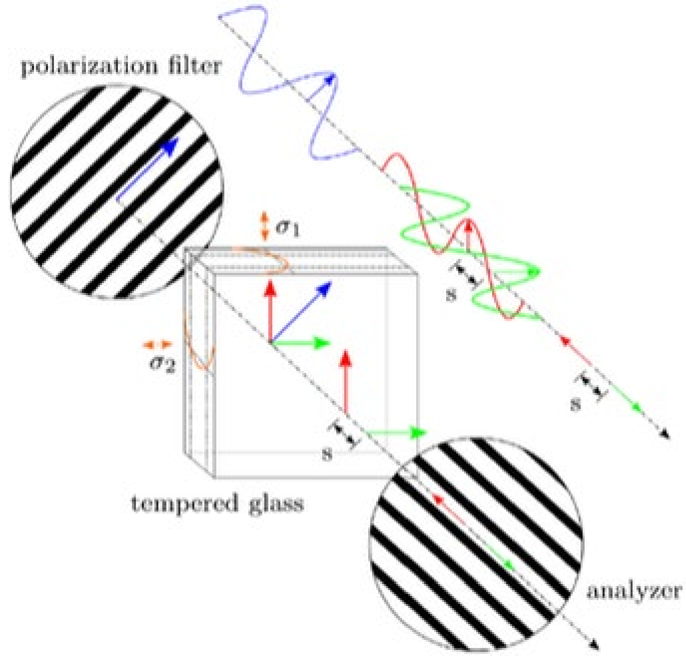
One option for reducing solar heat gain is polarization. It provides the ability filter light and could be applied to existing windows, instead of replacing whole glazing units. This investigation includes background research on how light behaves. It then moves into the construction of a small, enclosed chamber that is used to measure solar heat gain and the effect that polarization can have on heat gain in a controlled environment. This data is then extrapolated, and suggestions are made for further research.

Background

The inclusion of natural light in the built environment has many positive effects on its occupants and the building as a whole. Studies have shown that occupant happiness and overall physiological wellbeing can be greatly influenced by the addition of natural light. "daylight…most closely matches the visual response that, through evolution, humans have come to compare with all other light" (Franta & Anstead 1994). This evolutionary need for light can have massive effects on our natural processes and sleep cycles. In their article *The Effects of Natural Light on Building Occupants* Edwards (2002) states that "With properly installed and maintained daylighting systems, natural light has proved to be beneficial for the health, productivity, and safety of the building occupant". With these known advantages of natural light architects implement massive amounts of glazing onto their facades to capture the light of the sun. Glazing has practical advantages as well, they can help to reduce energy consumption of heating and cooling loads and lighting requirements. However, this comes with drawbacks, especially in sub-tropic climates. The main drawback is solar heat gain. There are many factors that influence solar heat gain such as the buildings' location, its orientation to the sun, and the products used. In this study I am going to focus on a building's specified glazing and the validity of using polarized film as a low-cost, low-tech solution to mitigating heat gain.

Solar heat gain is simple; the more sunlight that enters the building, the hotter it gets. Strategies for mitigating this phenomenon date back centuries and can range from simple to very complex implementations. Shading is the simplest solution available, and the most basic form solar mitigation found in most buildings. This act of blocking of the sun can greatly reduce solar heat gain but deprives the occupant of the outside view. Another strategy that architects employ is the use of low emissivity glazing. "The surface of low-emissivity objects will strongly reflect infrared radiation and block heat transfer". (Kewei 2018) This method is very effective but can be costly and production is not globalized. Glazing systems with opaque finishes again deprive the occupant of the view to the outside but can reduce solar heat gain. Systems such as electrochromic windows have the ability to change their transmittance levels and reduce solar heat gain. "Electrochromism, the reversible change in optical properties when a material is electrochemically oxidized". (Rauh 1999) These systems are transparent when electrified and opaque without the charge. The systems can be very effective but lead to high costs of installation and maintenance. I believe that polarization can provide an option to reduce solar heat gain that is low cost while the transparency of the glass.

To understand how polarization can be harnessed, it is important to understand how light behaves. Light vibrates in two directions, horizontal and vertically. Polarized film is an anisotropic material, meaning it has directional properties. Polarized film has microscopic strands that run parallel along a single axis. When light passes through a one of these filters "only light that vibrates parallel to the axis of the polarizer are transmitted." (Illguth 2015) When two filters are placed in a series and oriented perpendicular to each other, "the components eliminate each other, and the observer will notice a black screen" (Illguth 2015). If one of these polarized planes is set in a fixed position and the other is free to rotate the occupant can control the amount of light transmitting into a space. Hypothetically, if one polarized plane is oriented in one direction and a second polarized plane is free to rotate behind it, solar heat will be reduced by a coefficient of (.555x) + 50%. Where x equals each degree of rotation from the fixed axis.



Light Wave Mitigation. Sourced from Illguth 2015

There has not been much research done on this topic and I believe there is an untapped market as polarization has a lot of potential, especially in reducing solar heat gain.

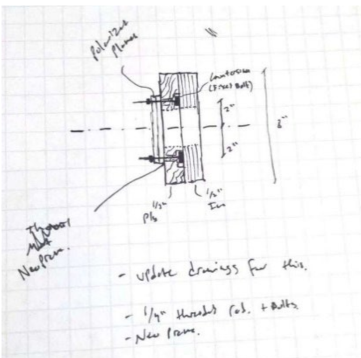
Fabrication

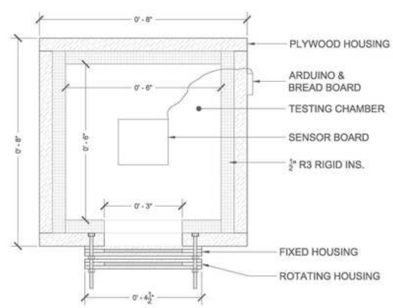
In order to effectively test how well polarization can reduce solar heat gain, a controlled environment was constructed that was able to undergo a repeatable and observable testing arrangement. Starting with the exterior of the box, a cost-effective material was chosen. For this iteration of the box ¾" plywood was chosen. This allows for the future iterations to be repeatable and scalable and for penetrations, for light and control wires, to be easily drilled. Cuts for the exterior pieces were done on a table saw and glued together. 90º corner clamps should be utilized to ensure the glue sets at the correct angle. Also, while the glue is drying screws are placed into the adjacent piece to draw them together and provide an airtight seal. The testing environment must also be insulated to reduce interference with from outside sources and prevents heat from leaving the space. This assembly replicates, at a much smaller scale, a traditional building. This insulation is pivotal in collecting accurate data.

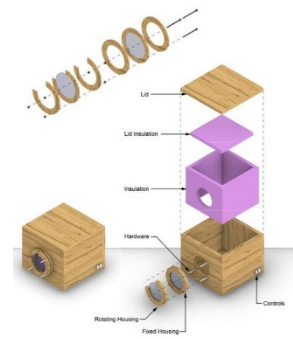
In this assembly there is only a few penetrations. The first being the operable lid. This detail is important, as without it the lighting conditions inside the box could not be observed. It is important that insulation be placed on this lid to mitigate any heat leaving the box through the top. What allows light to pass into the space is the penetration at the front of the box. There are a few ways to achieve this penetration. In the first iteration the material was removed by hand planning the front piece, but in the final iteration a CNC milling machine was used to get the greatest amount of precision. Once the penetration has been made in the wood, the penetration through the insulation can be cut. This either be done by hand using the penetration through the wood as a guide, or on a CNC milling machine.

At this point the assembly is just a box with a hole in it. In order to create a controlled environment a system similar to a glazing unit must be produced. To achieve this, pieces of plexiglass and sandwiched between craft plywood to be held in place. Cuts for both the plexiglass and craft plywood should be done on a laser cutter to ensure precision. Since measurements are to be taken with different levels of polarization, it is important that the housing which holds the polarized plexiglass is interchangeable. This was done by recessing bolts into the wood with the threads extending out of the box. It is important that the bolts are between the exterior and the insulation. If these metal bolts were allowed to be inside the enclosure, thermal energy would transfer into the space. Nuts attached to the bolt then hold the assembly to the rest of the box. To allow for the second plane of polarization to be operable, a quarter of the housing is removed. This allows the plexiglass to spin in place while attached to the bolts. Polarized filters are then applied to the plexiglass planes with glue. It is important to keep the glue toward the outer edges of the plexiglass to avoid obstruction of light passing through the plexiglass planes.

In order to collect data for testing controls must be placed inside of the enclosure. In this experiment temperature, lux, visible intensity, infrared intensity, and full spectrum intensity are measured and the sensors chosen reflect that. The DHT 11 is capable of measuring temperature and humidity and the code to do so is available online. The TSL 2591 measures lux, visible intensity, infrared intensity, and full spectrum intensity and this code is also available online. Both of these sensors are connected to an Arduino board that relays data to PC. In order to accommodate the wires connecting the sensors to the Arduino a small hole must be bored in the side of the enclosure near the bottom, but not the insulation. The hole should be drilled before the insulation is installed allowing the insulation to slide over the wires. The sensors could be coded in a way that they run in sequence, but for this experiment they were run separately, since the spectral sensor just takes static measurements this was vital.



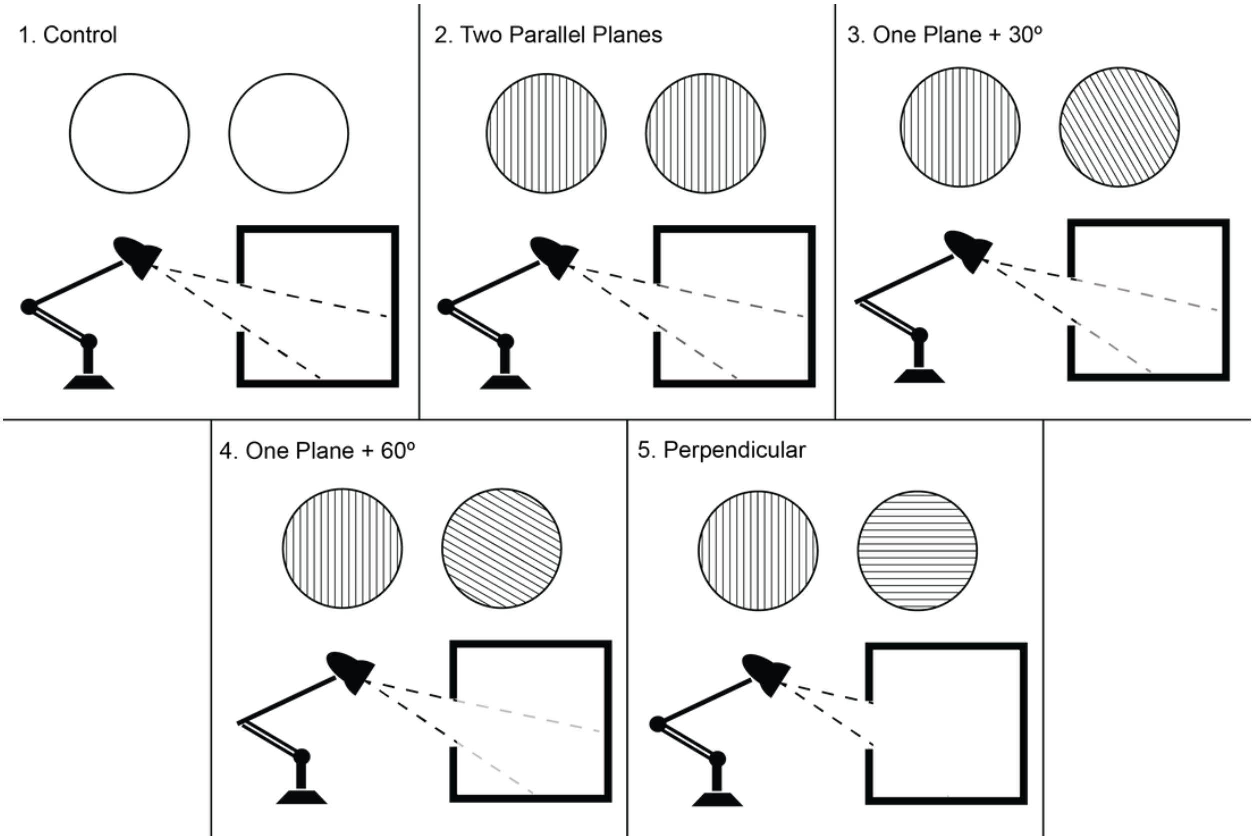




Methodology

Testing consisted of focusing a 150W lightbulb on the 3” opening on the side of the box for 15 minutes per test. It is imperative that an incandescent light bulb be used. Given the commercially available options, incandescent bulbs most closely replicate the light emitted from the Sun. The main spectral difference between incandescent and other bulbs is its production of infrared light, which causes most of a buildings solar heat gain. Where the light source is placed in relation to the enclosure depends on the strength of the light source, but it should not be close enough to melt the plexiglass, but not so far that there is no measurable data. It is also important that it is focused directly into the box. Wherever the light source is placed it must be kept constant throughout testing.

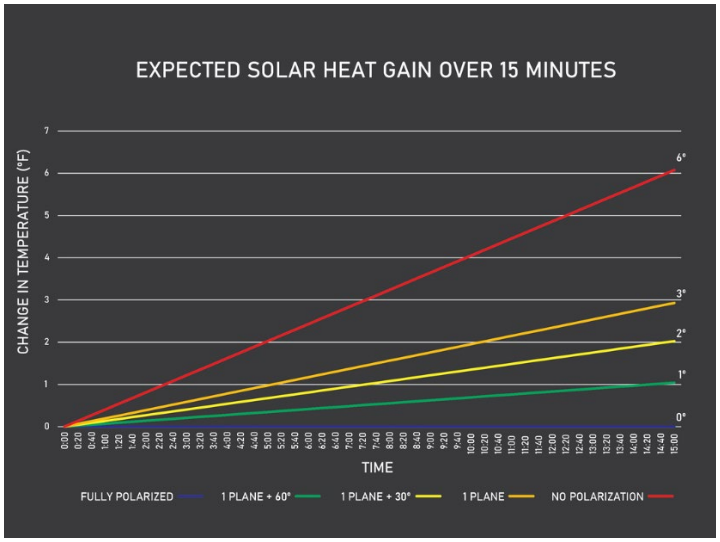
Control data is collected first with two bare pieces of plexiglass. The bare pieces are then interchanged for pieces which have been polarized. The first test collects data with polarization running parallel to each other. The next two test rotates the second plane 30º and subsequently 60º. The final test has the planes of polarization placed perpendicular to each other. Data was collected on two separate days and averaged together in order to reduce any interference. A graphic of the testing arrangement is provided below.



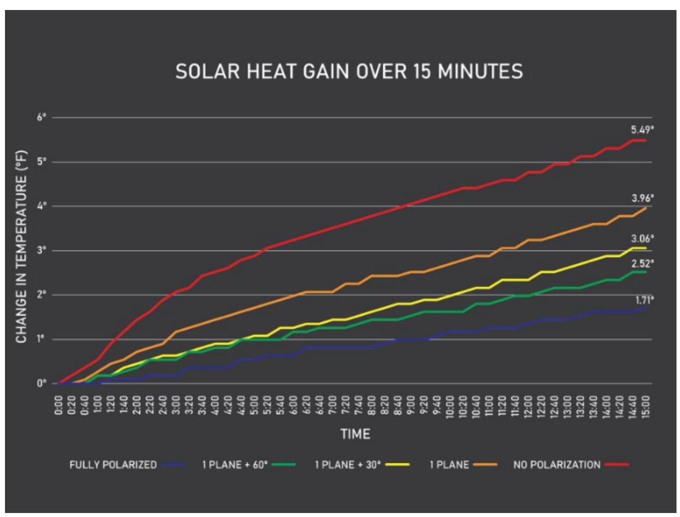
Results

My hypothesis states that wen polarization is applied to the box it would reduce the control amount of heat gain by (.555x)+50%, where x is each degree of rotation of the second plane. For example:

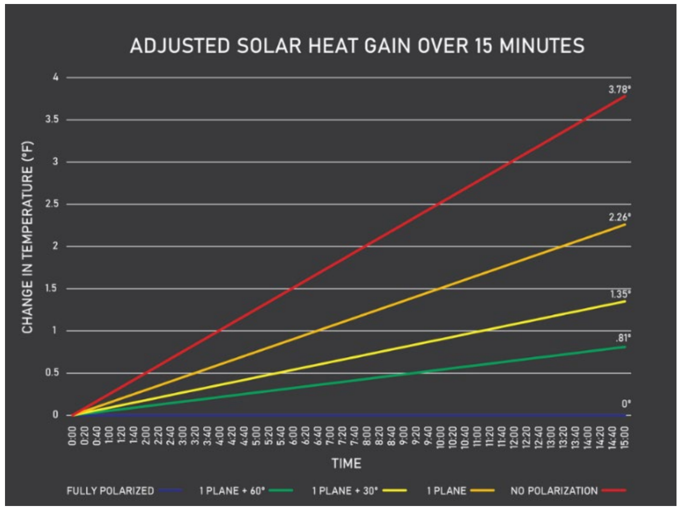
Control = 6º
(.555*0) + 50% = 50%
    (.5*6) = 3º
(.555*30) + 50% = 66.6%
    (.334*6) = 2º
(.555*60) + 50% = 83.3%
    (.167*6) = 1º
(.555*90) + 50% = 100%
    (0*6) = 0º



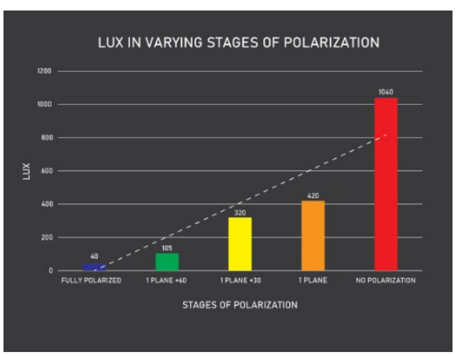
Below are the actual measured results of the solar heat gain experiment. The main outlier is the fully polarized number. I predicted that this value would be close to zero, but after testing it was closer to 1.71°F. However, the rest of the numbers fall close to what my predictions were. There are many factors that may have skewed my data, but I believe the main factor was thermal radiation through the box. If 1.71°F is taken as the amount of radiation through the box and subtracted from each final value the results are much closer to what my hypothesis.

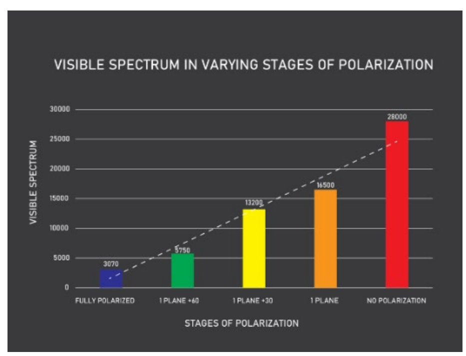


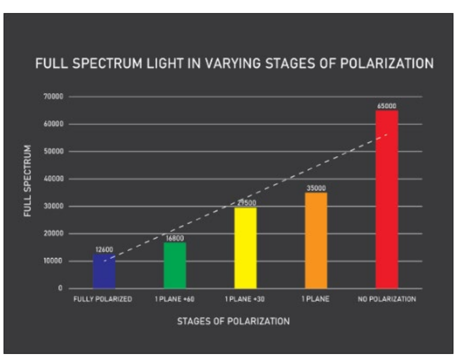
Shown below is the adjusted data to account for thermal radiation through the box. I believe these numbers are a better representation of how polarization affects solar heat gain. Of course, this is hypothetical and a better testing set-up, that mitigates radiation through the box, could prove this.

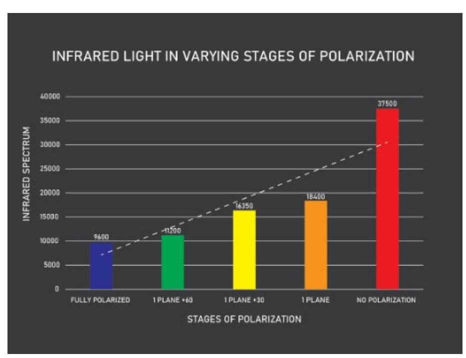


The four graphs shown below are measurements for the intensity of infrared, lux, full spectrum, and visible spectrum light that entered the box. This data was as expected, especially the trend line. The main exception to note are the infrared and full spectrum figures, as they were not as effectively filtered through via polarization. The most interesting bars to look at the two on the right, as adding just one plane of polarization drops by about half.









Moving forward a better assembly could be constructed that would decrease interference of thermal radiation through the box. This could be done in many ways. The most obvious being more insulation on the interior of the box. In the current iteration R-3 insulation was used. Increasing the R value could create a better experiment. Also, insulation could be placed on the outside of the box to not allow thermal energy to reach the box. The lid enclosure could also be improved to reduce heat escaping the top of the box. The bolts that hold the housing could also be affecting the data.

In future iterations of the experiment the enclosure should be scaled up to observe if these findings are consistent at a building scale. Since polarized film is only available in small sections connections with a manufacturer would need to be made in order to create larger pieces of film. A very interesting experiment could also be conducted if the rotating plane were attached to a servo motor and was able to responsively polarize light more if the temperature became too hot.

As far as collecting more data it would be important to understand where the thermal energy goes after it is polarized. Since energy cannot be created or destroyed, if the thermal energy is reflected back into the environment, it could have adverse effects. Visibility at these varying degrees of polarization is also important. Connection with the outside environment is important to an occupant's health and happiness and polarization does decrease visibility. Finding the balancing point between visibility and heat gain reduction is crucial. It is also crucial to understand that these experiments were completed using relatively cheap off the shelf sensors. This data is most likely within an accurate range, but not exact.

Conclusion

In summary, this experiment tested whether polarized film applied to a transparent medium can reduce solar heat gain. The experiments found that over a 15-minute period polarization has a massive effect on solar heat gain. When one plane of polarization is applied, and adjusted for radiant energy, it reduced heat gain by about 40%, One plane plus 30º was 65%, one plane plus 60º was about 79%, and two perpendicular plane was 100% heat reduction. These numbers reflect my hypothesis of 50%, 66.6%, 83.3%, and 100% respectively.

Overall, the experiment was a success. It demonstrated that polarization can be utilized a passive, non-intrusive shading device. Though, it should be considered that as polarization is increased visibility is decreased. A similar project at the University of California was awarded a five-million-dollar grant in 2015 and I believe with some more research UNCC could secure something similar.

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