HEC 09 Novel Non-Tracking Fiber Optic Solar Concentrator System

MENG 4216

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We certify that the narrative, diagrams, figures, tables, calculations, and analysis in this report are our own work.

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Executive Summary

Texas Space Grant Consortium has a design challenge in which it is described that NASA wishes to conduct research of Mount Malapert, located on the moon. To power their equipment on the moon, NASA hopes to use a Fresnel lens as a solar concentrator which gathers sunlight and redirects the optical/thermal properties to a collector. However, the environment has harsh conditions that can cause the Fresnel lens to not work at its optimum capacity and even damage the Fresnel lens's components. The Fresnel lens components must be non-moving parts comprised of materials and methods to withstand the harsh conditions and function optimally. The challenge participants are comprised of Team Hyperion and Team SOLIS. Team SOLIS has determined the lenses and collectors to be made of polycarbonate and acrylic (polymethyl methacrylate). They have also chosen to coat the lenses with silicon dioxide to mitigate the abrasive lunar dust. Team Hyperion then designed the dimensions for the lenses and collectors based on the selected materials. Team SOLIS then set out to fabricate the lenses and collectors by CNC milling, polishing, and coating. Through the process of fabrication, quality assurance procedure was followed to ensure that the lenses and collectors were made to required specifications. Team SOLIS then design and fabricated a test bench for the lenses and collectors, in order to test the optical and thermal concentration. The testing was found to show that acrylic lenses were able to increase thermal concentration by about 60 percent, while polycarbonate increase was about 80 percent. Testing also showed that silicon dioxide coating had negligible effects on thermal concentration. Team Hyperion then ran thermal simulations to find that their simulation was validated within 1 percent based on the data team SOLIS collected.

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1 Introduction

1.1 Background

NASA has an ambitious goal called the Artemis project, a program to establish a lunar base camp on the south pole of the moon by 2025. The purpose of a base on the moon's surface and establishing a lunar orbiting outpost known as the Lunar Gateway project is to set up a permanent base on the lunar surface for “scientific discovery, economic benefits, and inspiration for a new generation for a new generation of explores” [1]. The lunar base will need crucial components such as a mobile home, a Lunar Terrain Vehicle (LTV), and other equipment required for a long-term presence. These components will need to have a power source that is primarily constant and can be gathered on the lunar surface. Due to this, solar energy is the most suitable form of energy to meet the demand for the mission.

Due to the need for powering equipment on the moon using solar power, a location in the moon's south pole called Mt. Malapert was chosen to meet the demand. Malapert Mountain holds two aspects that provide key factors needed for site selection. One, the height of the mountain is roughly 8000 meters and receives full sunlight at the summit, roughly 89% of the year. The region will allow an abundance of sunlight for solar-electric power generation and decrease the time of the long lunar nights (>14 Earth days) while providing favorable Earth visibility for the direct communication link. Two, the location is in the South Polar region at 0° Longitude, 86° South Latitude. With the help of tidal locking (the moon maintains the same face towards the Earth), this location allows for “the summit of Malapert to always be in direct line of sight with the Earth for uninterrupted real-time control of robotic devices on the lunar surface (a virtual lunar presence for Earth-based operators)” [2]. Maintaining control of robotic devices from Earth is ideal since “The Moon’s surface thermal environment is among the most extreme of any planetary body in the solar

system. Lunar temperatures at the subsolar point approach 400 K, whereas temperatures in permanent shadow may be lower than 40 K [3]. Another challenge on Malapert's surface is lunar dust. Lunar dust is positively charged particles composed of 50% SiO2, 15% Al2O3, 10% CaO, 10% MgO, 5% TiO3 and 5–15% iron [4]. As shown in Figure 1, the lunar dust particles from the moon measure 20 micrometers and are in a reactive state due to the solar winds and flares. One of the most challenging problems with lunar dust is its abrasiveness; just a few particles can cause scratches that hinder performance. Additionally, since lunar dust particles are electrically charged, they can damage equipment. Applying a special coating on equipment can protect its abrasive nature to withstand the lunar dust.

Fig 1. Mountain Malapert and Lunar Dust Particle.

The use of solar power energy for the moon has been accepted as an energy source to power equipment. To collect this solar power energy, it is currently being studied how to use special lenses and collectors to further increase the concentration of solar energy into the focal point. The type of lens that will act as a solar concentrator is a Fresnel lens.

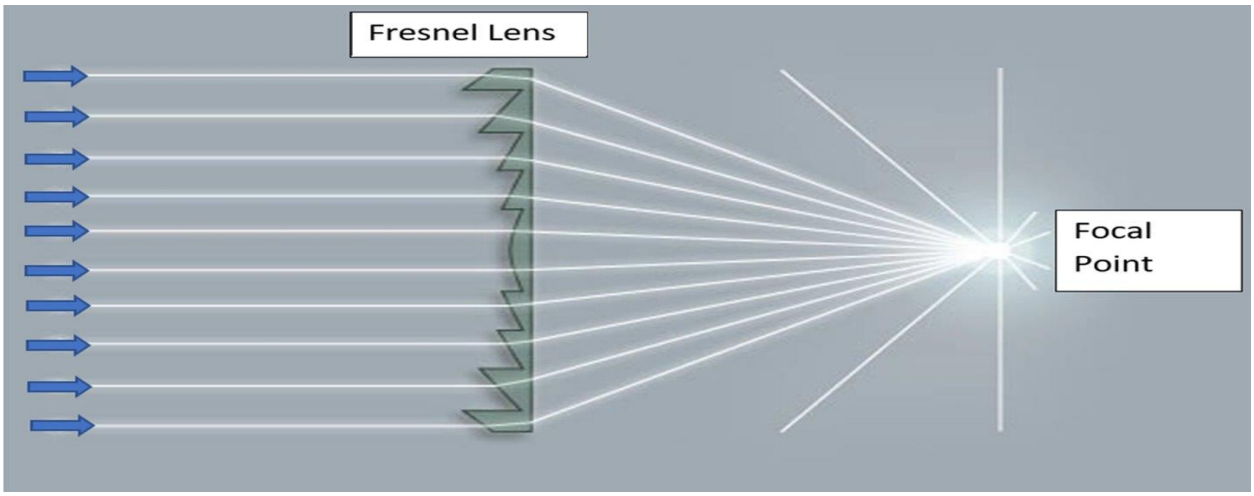


Fig 2. Light rays pass through the Fresnel Lens and are concentrated at the focal point.

Figure 2 shows a Fresnel lens, a lens with grooves that are concentric to reduce spherical aberration, which can use the refraction of its grooves to redirect light to its focal area for light and thermal concentration. This thermal concentration will be directed into a collector. The Fresnel lens shape that will concentrate the most sunlight on the lunar surface is a hollow cylinder, given below in Figure 3.

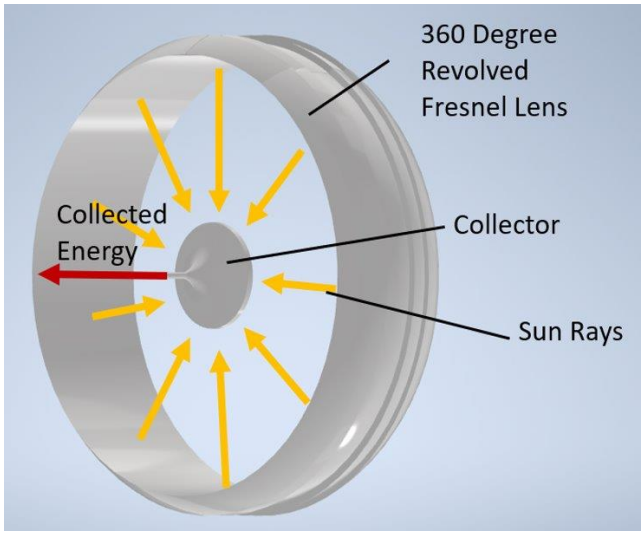


Fig 3. A non-tracking cylindrical Fresnel Lens is being used to concentrate power on a collector.

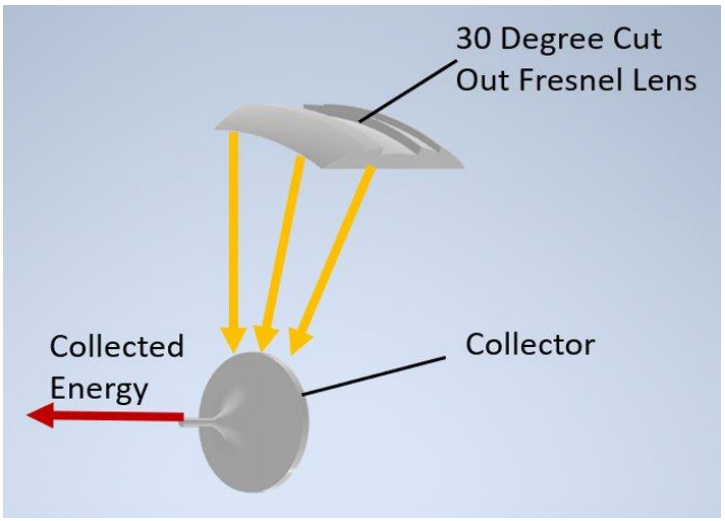


Fig 4. Design is simplified for simulation and prototype analysis to only have a 30-degree revolved piece of the lens.

The lens' exterior surface will be hit with sunrays and will pass through the lens coming from the interior of the lens towards its focal area. The collector input funnel will reside at the focal area of the lens, as shown in Figure 4 above, and collect all the sun rays that have been directed towards it. Then the rays will travel through the collector and exit towards the output port.

To accomplish the goal of a Fresnel lens acting as a solar concentrator, the lens project has been handed from NASA to the Texas Space Grant Consortium (TSGC). It will be worked on by two teams, Team Hyperion and Team SOLIS, shown in Figure 5 below. Team Hyperion oversees designing and simulating the lens and collector in various conditions, while Team SOLIS will fabricate the lens and collector using two selected materials and coating the lens. Finally, a test will be done through experimentation using the fabricated lens to validate Team Hyperion's simulations on the lens performance regarding optical concentration and thermal concentration. This test will be done when considering the lunar and Earth environments for materials with and without coating.

Fig 5. Shows the patches of the teams participating in the design challenge.

Team Hyperion has designed the lens in its dimensions using CAD software and is using a software called Optica EM. Optica EM can run simulations of how sun rays will be directed to materials such as the Fresnel lens in lunar and Earth environments. The following Optica EM results entail the surface intensity of the lens that is impacted by sun rays, the surface intensity of the collector that is hit by sun rays after being concentrated and estimates the produced power. A small portion of the cylindrical lens is being simulated for Optica EM to produce the best-simulated results with the equipment being used. This small piece is a 30-degree cut out of the complete cylindrical revolved lens shown below in Figure 6. through the lens to the collector. Team Hyperion uses a MATLAB model to simulate the heat transfer for the selected lens material with or without coating and a collector for both selected.

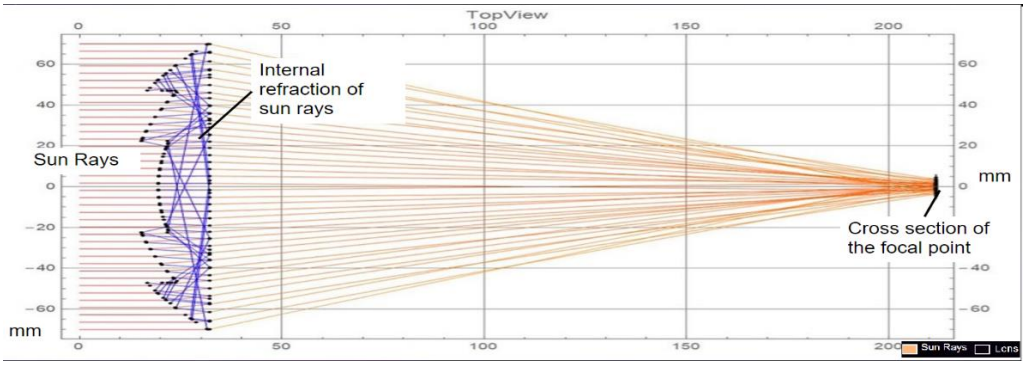


Fig 6. Team Hyperion Provided the following Ray Trace Simulation from Optica EM for Lens in earth environment.

Using the simulating software Optica EM as shown above in Figure 6, Team Hyperion can find the incoming amount of energy that will affect the initial part of the system, in this case, the lens. Hyperion can trace the sunrays through the lens to the collector and find the amount of energy that passes to the collector's output. Similarly, Hyperion has shown the effects on thermals by the coating on each material of the lens and material of the collector in both moon and earth environments that can be demonstrated using MATLAB models shown in Figure 7 below.

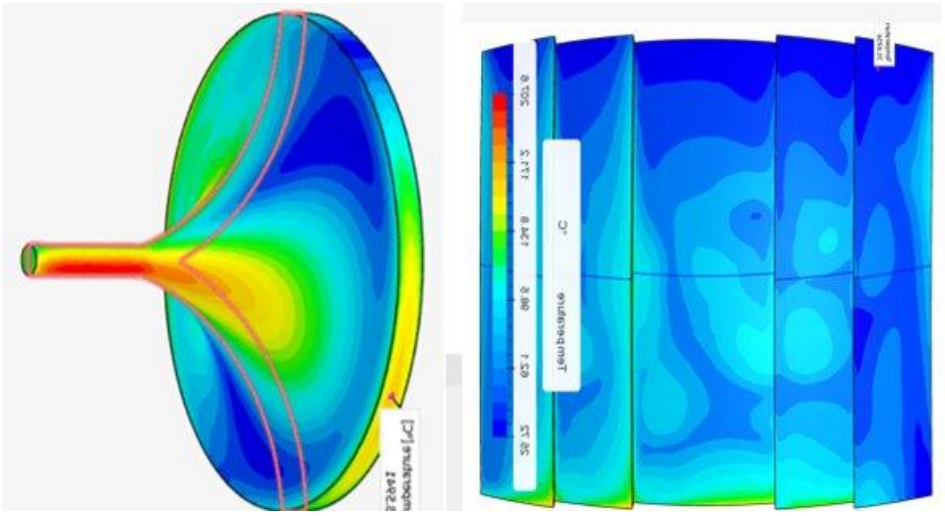


Fig 7. Shows MATLAB models that Team Hyperion is simulating.

Team SOLIS will research the lunar environment and develop parameters of what could withstand that environment. Then they will consolidate these parameters in a Requirement sheet. Next, Team SOLIS will determine which material is viable to produce a lens and collector prototype with the same qualities as the determined requirements. Similarly, a requirement sheet is also done for a coating applied on the following lens. Based on the requirement sheet, the coating is selected. Next, a fabrication method must be selected in what is available for the team and can manufacture the lens and collector. Based on what was found, the best viable method for manufacturing the lens and collector was using a CNC Machine.

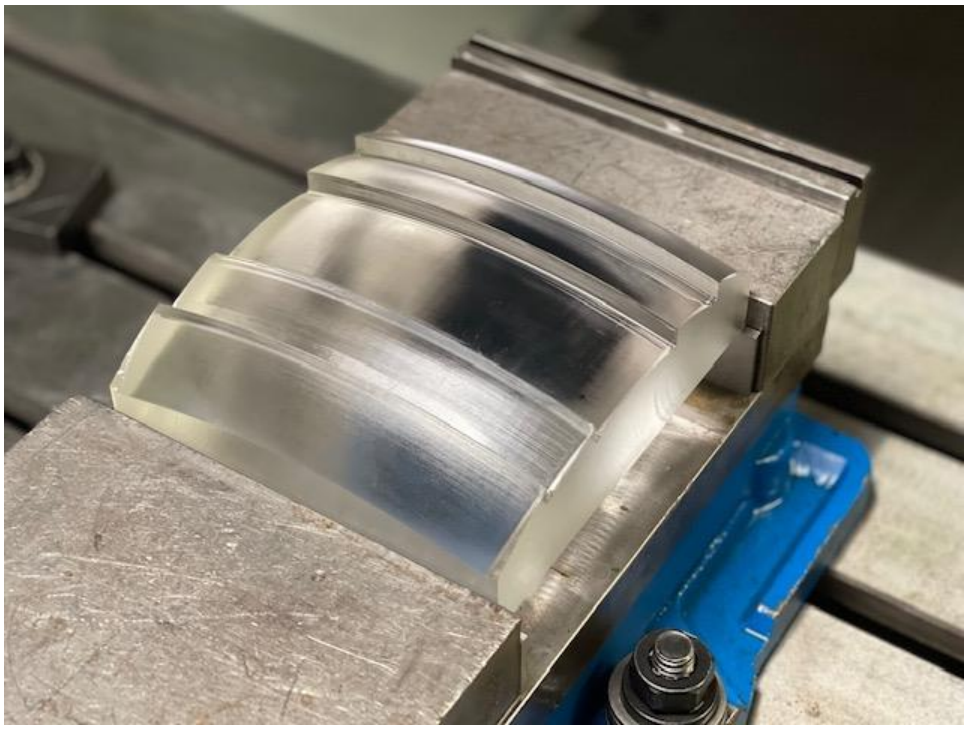


Fig 8. Acrylic Lens being machined.

After manufacturing the lens and collector, the following testing apparatus must be set up where the simulation for thermal analysis can be validated by testing the various lenses.

1.2 Problem Description:

A Fresnel lens is used as a solar concentrator in the lunar environment to power equipment. However, the lunar environment has certain conditions such as lunar dust and varying temperatures that can hinder the performance of the lens; as a result, the material selection for the lens can concentrate as much solar energy as possible and function in the environment and coating to protect the lens from the lunar dust must be selected. Team SOLIS will select material and coating for the lens based on the lunar environment, fabricate the lens prototype samples for each material with and without coating, and validate Teams Hyperion's simulation results in heat concentration.

2 Scope

2.1 Requirements, Specifications, and Constraints

The requirements, specifications, and constraints have been set in Table 1 below to make certain the materials can withstand the harsh environment of Mountain Malapert.

Table 1. Requirements, Specifications, and Constraints of Material and Coating selection.

ITEM	SPECIFICATION	VALUE AND LIMIT	UNITS	ACCEPTANCE TEST
1	Melting Point of Selected lens and collector Material and Coating	400	Kelvin	Material Datasheet
2	Refractive Index of selected lens and collector Material and Coating	1.4	No Units	Material Datasheet
3	Transmittance of selected lens and collector Material and Coating	At Least 80	Percent	Material Datasheet

Based on the specification in Table 1, the following materials have been selected from a shortlist provided by the Optica EM simulation [5].

Table 2. Acceptable list of materials that fit the criteria.

Material	Refractive Index	Transmittance (%)	Melting Point (k)	Cost ($/lb.)	Specific heat capacity (kJ/g K)	Density (g/cm-3)
ALON	1.79	86	2423.15	113	0.921	3.696-3.691
Calcium Fluoride (*Ca*F2)	1.4338	91	1691	57	0.85	3.18
(BK7)	1.5168	92	832.15	15	0.858	2.51
Crystal Quartz	1.54421	90	1983.15	30	0.74	2.649
Polymethyl Methacrylate (PMMA)	1.49	92	433.1	1.4	1.46	1.17
Polycarbonate	1.586	90	570.15	3.5	1.3	1.20

Based on the Refractive index, transmittance, melting point, and cost, PMMA and Polycarbonate have been chosen from the given shortlist in Table 2, as shown in the highlighted red box.

Table 3. List of materials that fit coating criteria.

Coating	Refractive Index	Transmittance (%)	Melting Point (Kelvin)	Cost ($/lb.)	Availability
Silicon Nitride	1.8	92	2170	20	Low
Tungsten Oxide	2.1	80	1746.15	62	Low
Teflon	1.4	90	600	9.60	High
Silicon Dioxide	1.45	93	1973	8.05	High

Based on the Refractive index, transmittance, melting point, and cost, SIO_2 has been chosen from the given shortlist in Table 3, as shown in the highlighted red box.

2.2 System and Subsystem Level Black Box

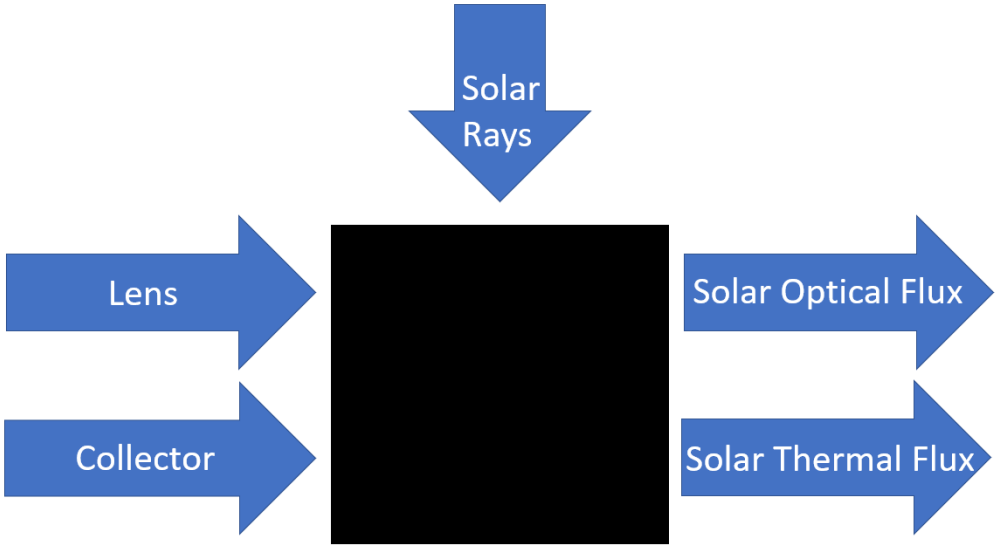


Fig 9. Testing Bench Black Box Diagram.

The following Blackbox from Figure 9 was used to design the test bench. The testing bench must be configured where the lens and collector are positioned to mimic the simulation so the lens and collectors' performance in the concentration of solar rays can be assessed by measuring the solar optical and thermal flux of the collectors' output. The lens should be tilted toward the sun while the collector is placed underneath the lens aligned with its center. The lens and collector should be accessible for testing equipment to test thermal and optical solar flux.

3 Selected Design

3.1 Final Design Details and Considerations

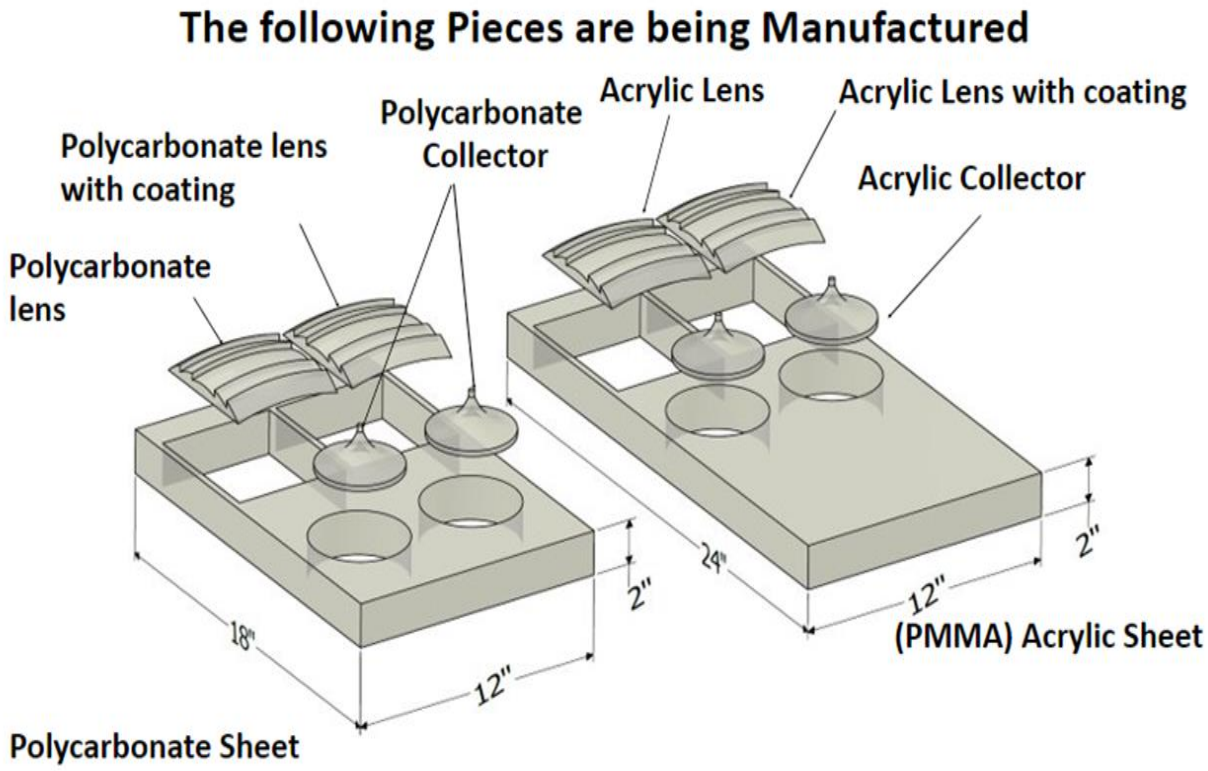


Fig 10. Each material sheet will be machined to produce two lenses, one with coating and one without coating and two collectors of each material without coating.

The method used to manufacture the lenses and collectors is shown in Figure 10:

- CNC machine for manufacturing lenses and collectors
- 2-inch-thick material of PMMA and Polycarbonate is used to make lenses and collectors
- Compound Paste is used for polishing both lenses and collectors
- Silicon Dioxide Coating Spray is used to coat 1 sample of each material set
- Quality Assurance by measuring the lenses and collectors' dimensions and lux output.

The CNC method of fabrication will allow the lenses and collectors to maintain the intended refractive index of the material. Next, the compound paste method will eliminate scratches on the lenses and collectors. Finally, the Silicon Dioxide application will be applied and measured for its thickness. Details are in Appendix H.

3.2 Final System and Subsystems

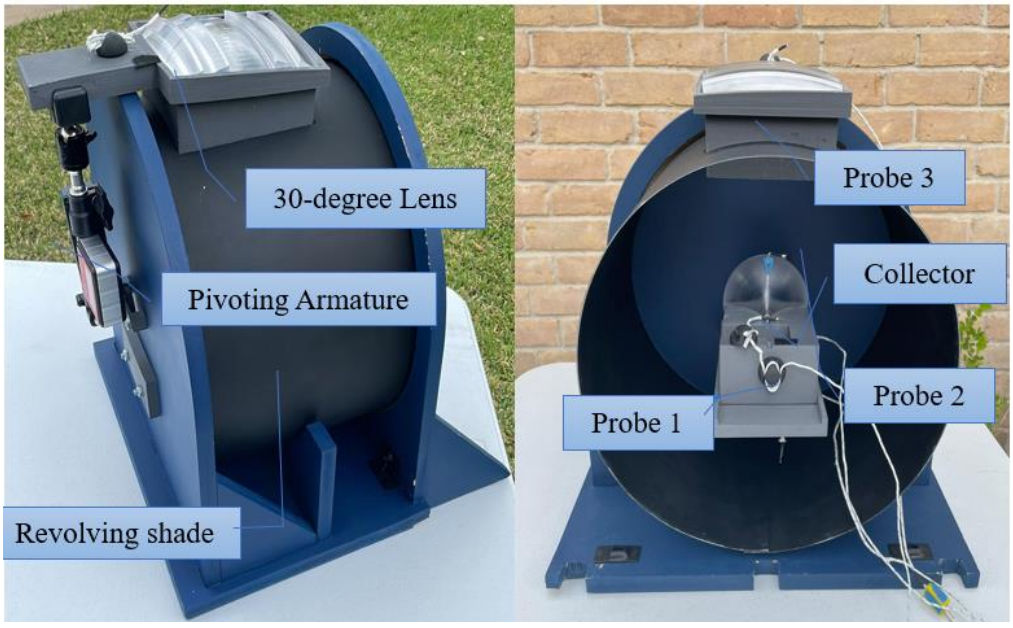


Fig 11. Testing Bench Assembly. The assembly process is in Appendix J.

As shown in Figure 11, the test bench mimics the simulation in terms of the position of the lenses and collectors. Sun-rays will pass through the lens and focus on the collector. The test bench has a Cylindrical Shade that shields the collector from ambient light, which eliminates a factor when assessing the lens performance. The test bench has a pivoted armature that can raise and lower the lens to have its focal point line up with the collectors' center. The pivot armature also rotates with the cylindrical revolving shade to point the lens toward the sun.

Table 4. The Designated Combination set used to Categorize the Lenses and Collector.

Combination set number	**Name of the combination (Lens, Collector)**
1	Acrylic Lens B, Acrylic Collector A
2	Acrylic Lens B, Acrylic Collector B
3	Acrylic Coated Lens A, Acrylic Collector A
4	Acrylic Coated Lens A, Acrylic Collector B
5	Polycarbonate Lens B, Polycarbonate Collector A
6	Polycarbonate Lens B, Polycarbonate Collector B
7	Polycarbonate Coated Lens A, Polycarbonate Collector A
8	Polycarbonate Coated Lens A, Polycarbonate Collector B

4 Results

After going through multiple trials for all eight configurations as shown in Table 4, the data was then logged as shown in appendix #. The trials for each configuration were then averaged and the following graphs below were formed from the average data of each configuration. Each graph has the following datapoints in Celsius over 900 seconds of ambient temperature, Collector Rim temperature, and Collector Port temperature. Each datapoints are formed to a respective curve. The curve then is found to have an exponential function.

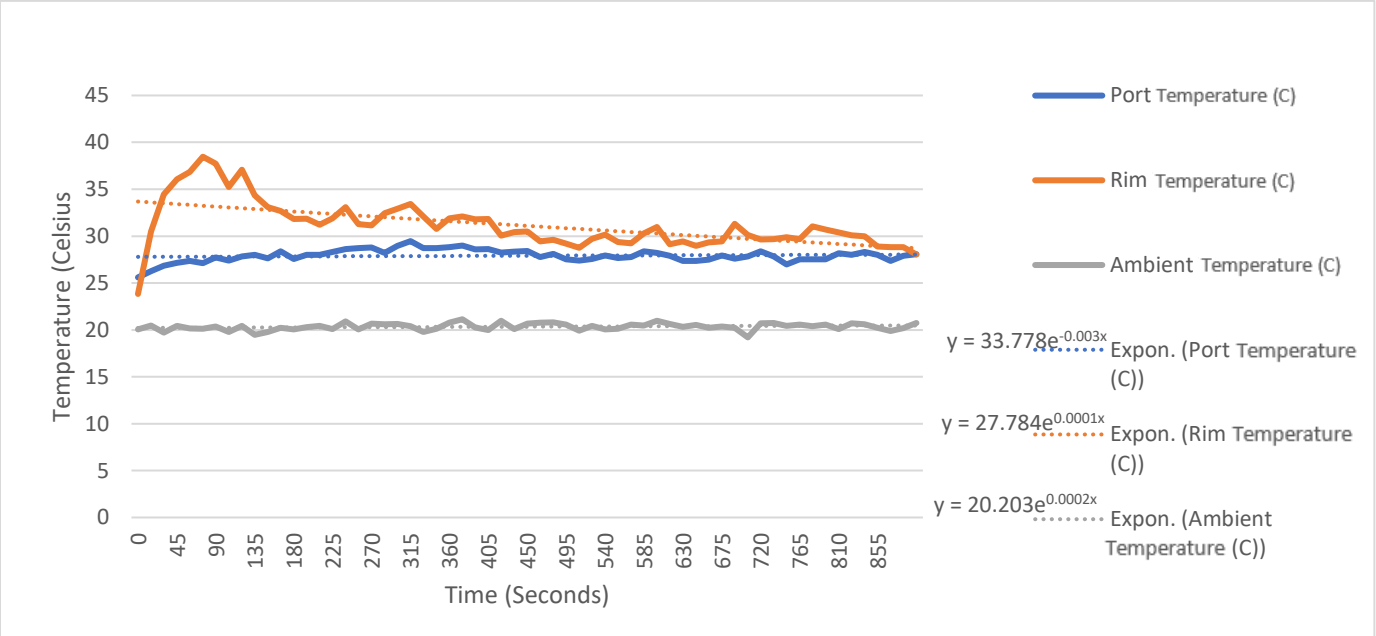


Fig 12. Shows Acrylic Coated Lens A and Acrylic Collector A averaged graph of Temperature readings of the ambient temperature, collector's rim temperature, and collector's port temperature over a 900 second time period.

Figure 12 shows ambient temperature is staying about 20 degrees Celsius for the entire duration. The figure also shows the rim temperature, which peaks at 38.47 Celsius declines, and the port

temperature increases where they converge. This indicates heat traveling along the collector from the rim toward the port.

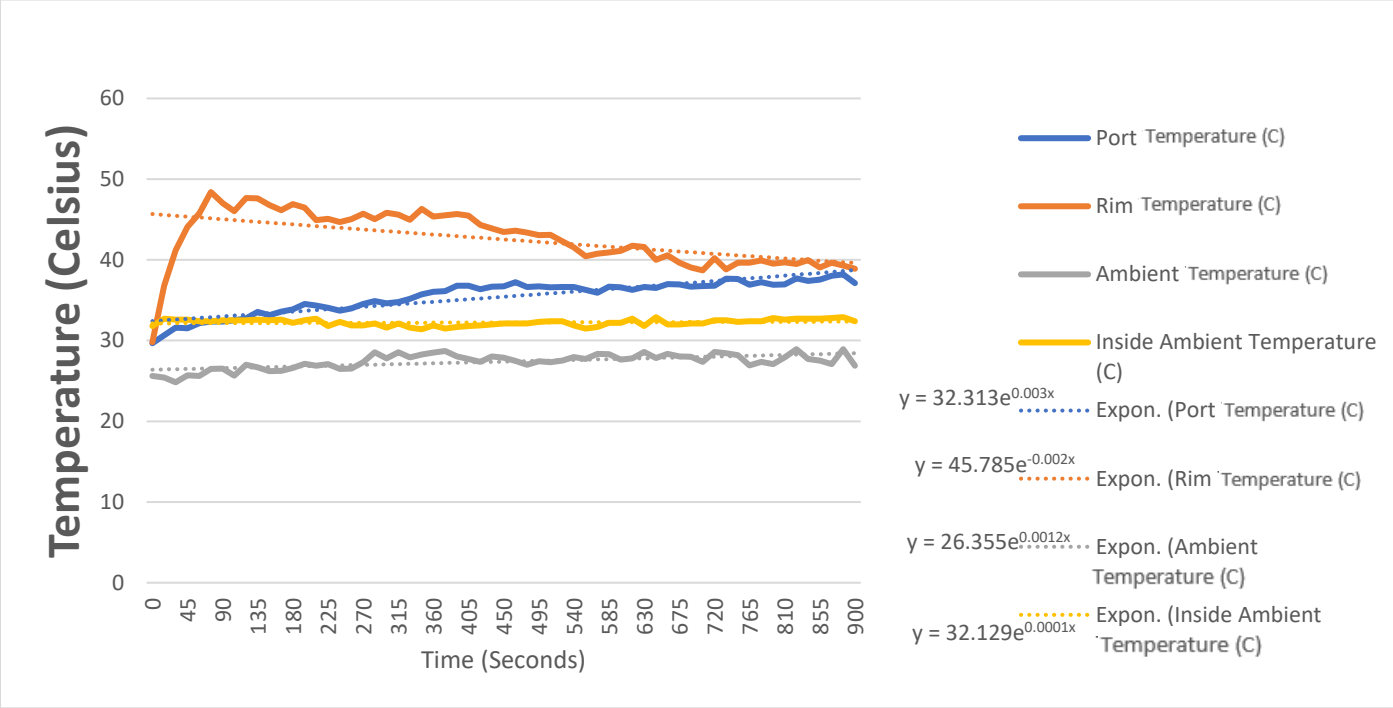


Fig 13. Shows Acrylic Coated Lens A and Acrylic Collector B averaged graph of Temperature readings of the ambient temperature, collector's rim temperature, and collector's port temperature over a 900 second time period.

Figure 13 shows ambient temperature is staying about 26.4 degrees Celsius for the entire duration. The figure also shows the rim temperature, which peaks at 48.4 Celsius declines, and the port temperature increases where they converge. This indicates heat traveling along the collector from the rim toward the port.

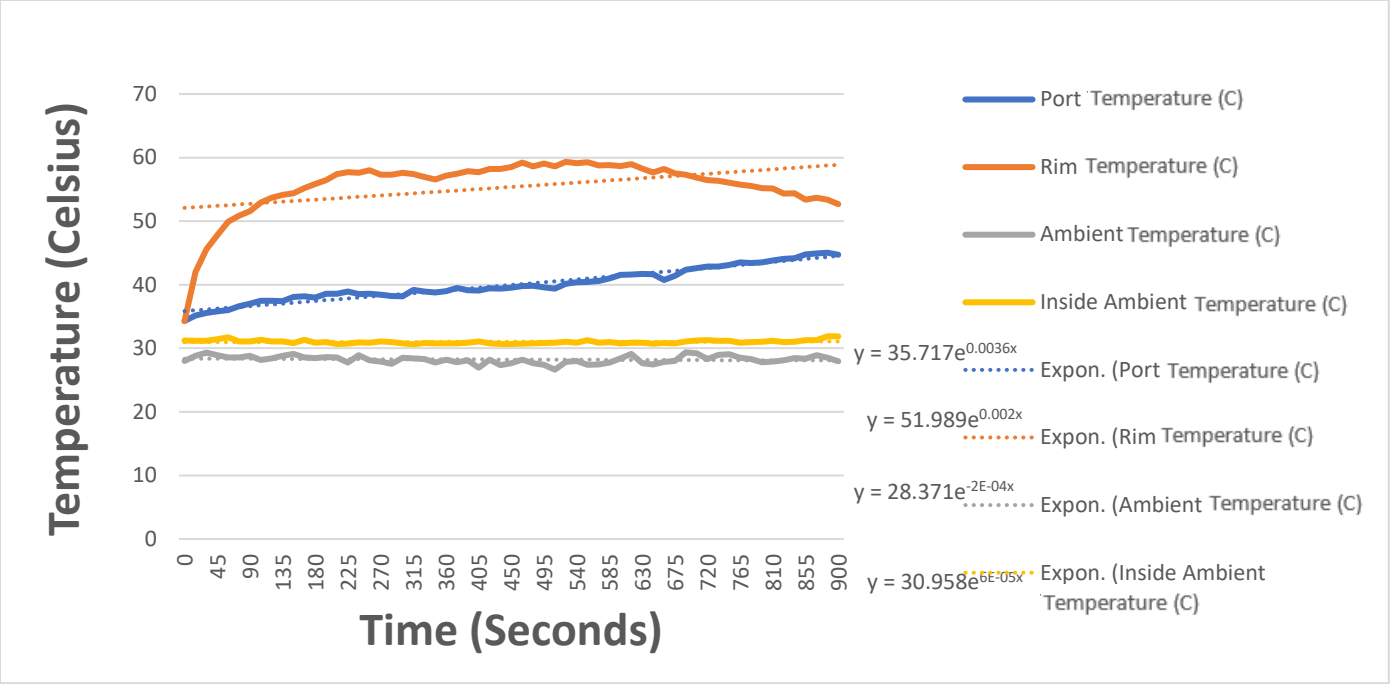


Fig 14. Shows Acrylic Lens B and Acrylic Collector A averaged graph of Temperature readings of the ambient temperature, collector's rim temperature, and collector's port temperature over a 900 second time period.

Figure 14 shows ambient temperature is staying about 28.4 degrees Celsius for the entire duration. The figure also shows the rim temperature, which peaks at 59.3 Celsius declines, and the port temperature increases where they converge. This indicates heat traveling along the collector from the rim toward the port.

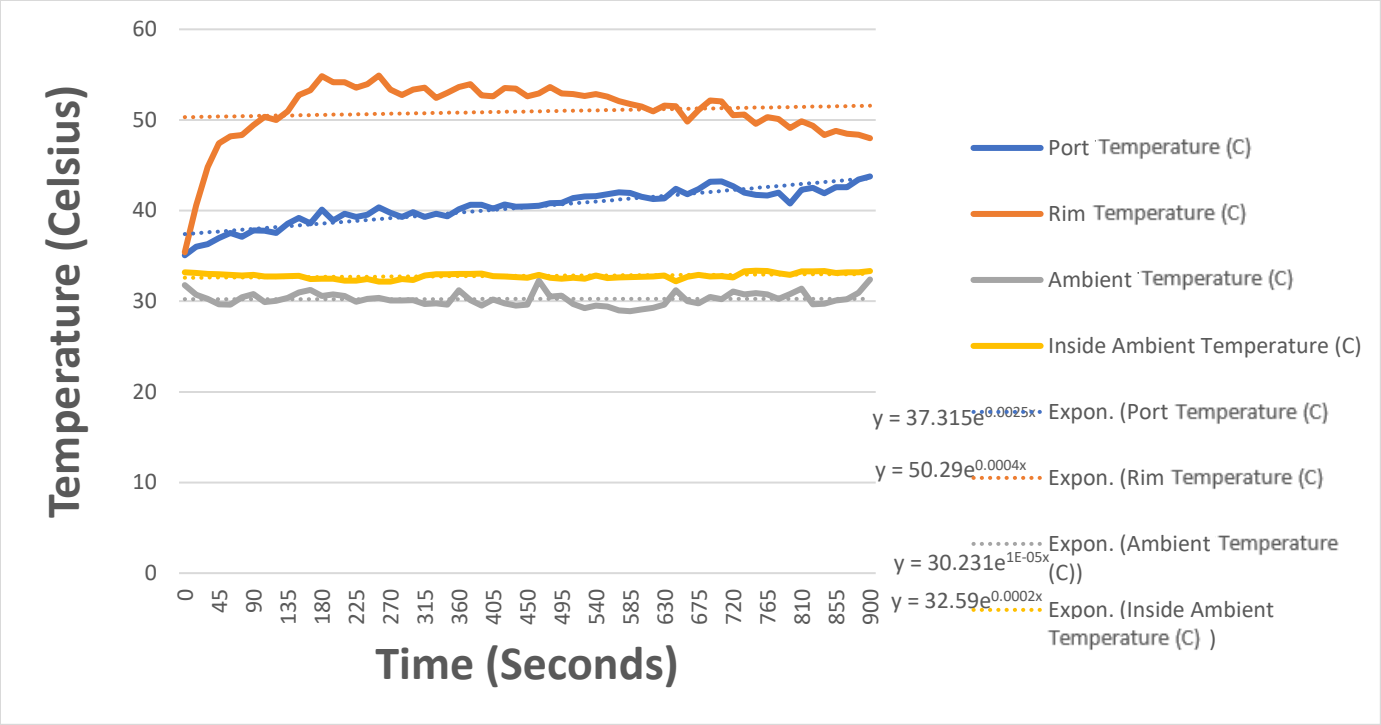


Fig 15. Shows Acrylic Lens B and Acrylic Collector B averaged graph of Temperature readings of the ambient temperature, collector's rim temperature, and collector's port temperature over a 900 second time period.

Figure 15 shows ambient temperature is staying about 30.2 degrees Celsius for the entire duration. The figure also shows the rim temperature, which peaks at 54.9 Celsius declines, and the port temperature increases where they converge. This indicates heat traveling along the collector from the rim toward the port.

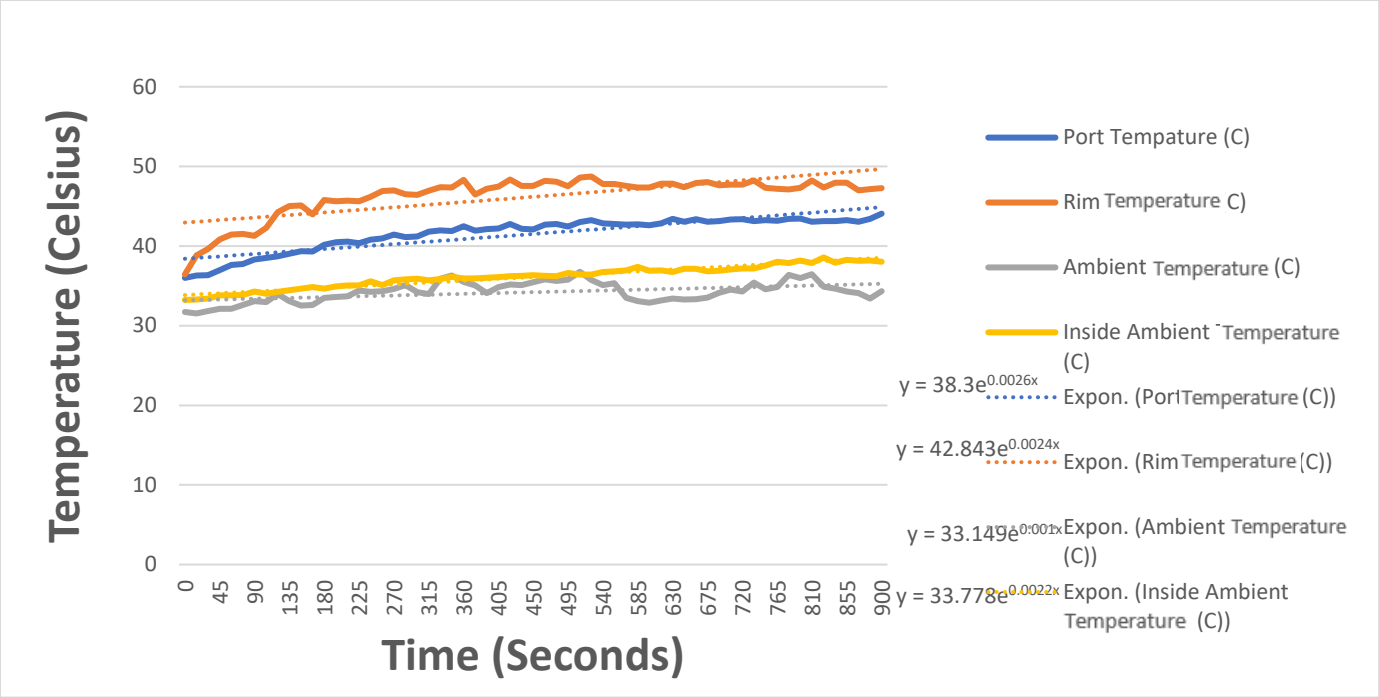


Fig 16. Shows Polycarbonate Coated Lens A and Polycarbonate Collector A averaged graph of Temperature readings of the ambient temperature, collector's rim temperature, and collector's port temperature over a 900 second time period.

Figure 16 shows ambient temperature is staying about 33.1 degrees Celsius for the entire duration. The figure also shows the rim temperature, which peaks at 48.7 Celsius declines, and the port temperature increases where they converge. This indicates heat traveling along the collector from the rim toward the port.

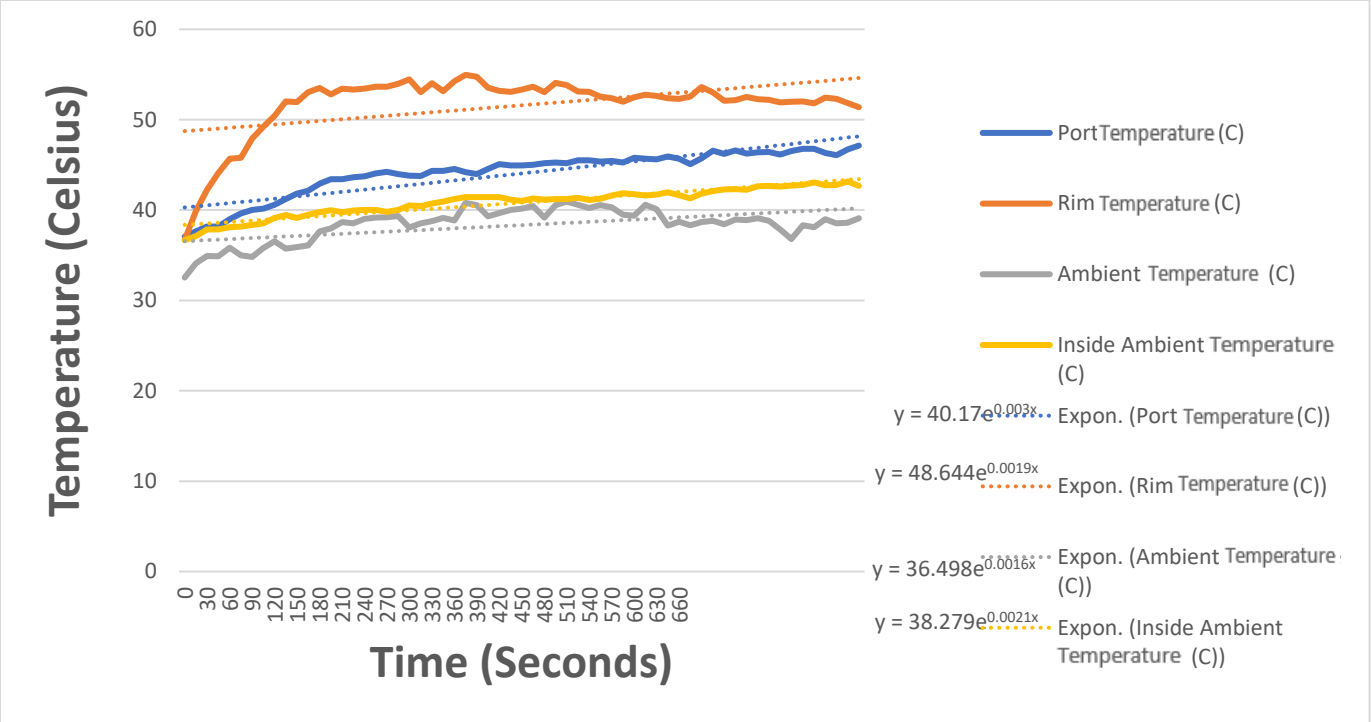


Fig 17. Shows Polycarbonate Coated Lens A and Polycarbonate Collector B averaged graph of Temperature readings of the ambient temperature, collector's rim temperature, and collector's port temperature over a 900 second time period.

Figure 17 shows ambient temperature is staying about 36.5 degrees Celsius for the entire duration. The figure also shows the rim temperature, which peaks at 55 Celsius declines, and the port temperature increases where they converge. This indicates heat traveling along the collector from the rim toward the port.

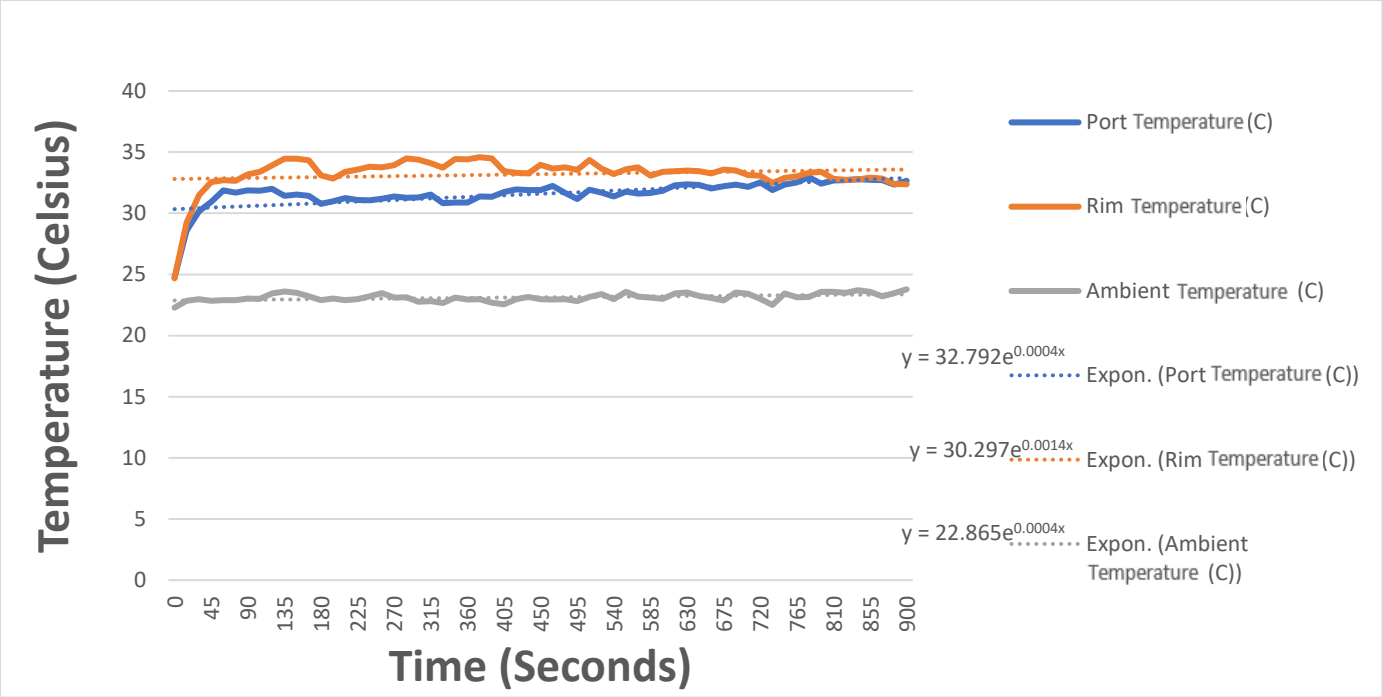


Fig 18. Shows Polycarbonate Lens B and Polycarbonate Collector A averaged graph of Temperature readings of the ambient temperature, collector's rim temperature, and collector's port temperature over a 900 second time period.

Figure 18 shows ambient temperature is staying about 22.9 degrees Celsius for the entire duration. The figure also shows the rim temperature, which peaks at 34.6 Celsius declines, and the port temperature increases where they converge. This indicates heat traveling along the collector from the rim toward the port.

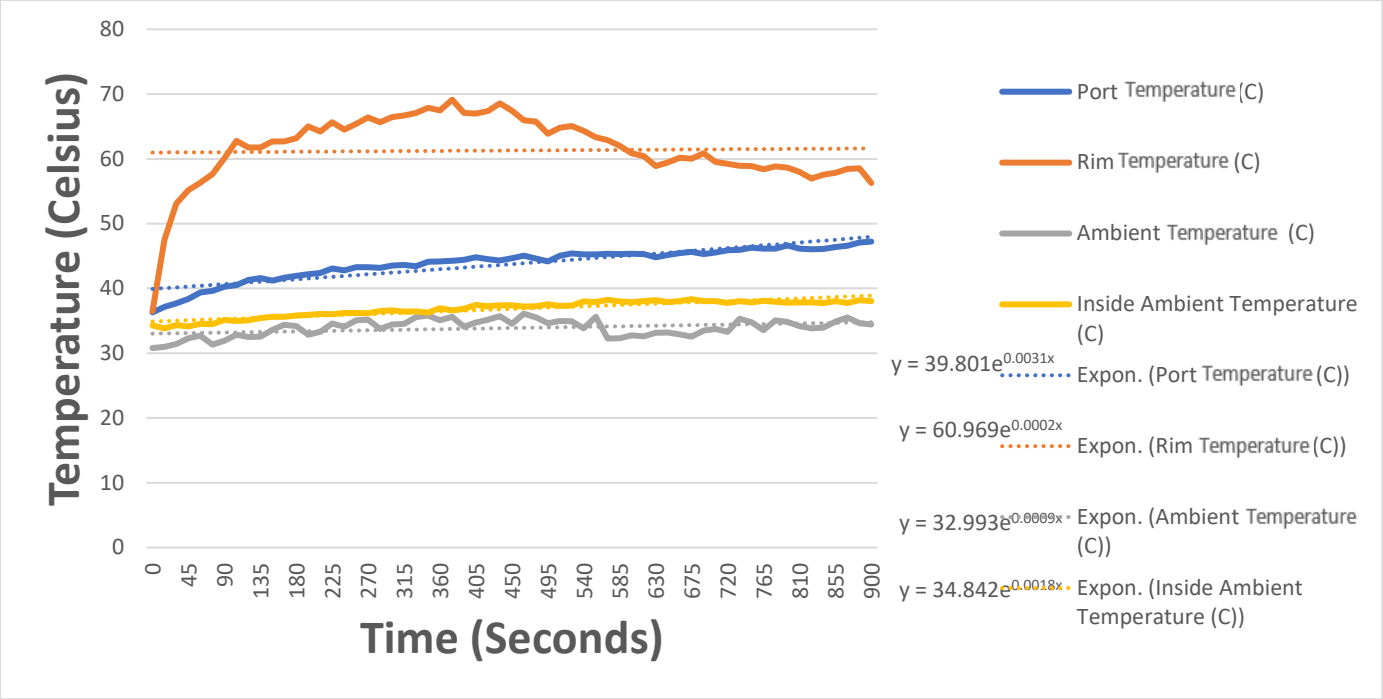


Fig 19. Shows Polycarbonate Coated Lens B and Polycarbonate Collector B averaged graph of Temperature readings of the ambient temperature, collector's rim temperature, and collector's port temperature over a 900 second time period.

Figure 19 shows ambient temperature is staying about 33.0 degrees Celsius for the entire duration. The figure also shows the rim temperature, which peaks at 69.1 Celsius declines, and the port temperature increases where they converge. This indicates heat traveling along the collector from the rim toward the port.

5 Discussion

5.1 CNC

Team SOLIS decided to machine the lens and collector based on the accuracy required and equipment readily available. Based on comments from experienced machinists, feed rate and spindle speed were important in reaching our desired surface finish in a reasonable amount of machine time. Feed rate is the surface speed of the cutting tool in inches per min and spindle speed is the rotational speed of the cutting tool in revolutions per min. There were two different machines used to fabricate our pieces, a Milltronics 7200 which has a feed rate of 510 ipm and a spindle speed of 7,500 rpm. The other was a HAAS VF2, which has a spindle speed of 10,000 rpm and a feed rate of 830 ipm. Both used a 3/8” diameter bit and a 1/4” diameter bit to take away excess material and the final bit used was a 1/8” ball end mill as shown below in Figure 20.

Fig 20. 1/8” Dia. Ball Nose End Mill

These types of tool bits are common and the ball shape on the end allows it to contour easily with curved surfaces leaving a smooth cut face. Using a higher rpm machine gives the lenses

and collector a smoother surface finish, requiring less polishing afterwards. The surface finish in the drawings in Figures E1 and E2 have detailed a 50 RMS (Root mean square) finish. RMS is calculated as the Root Mean Square of the microscopic peaks and valleys on a small sample size of the surface. There are tools that can measure surface finish, one most used is a profilometer. These peaks and valleys will smooth out further when the components start to be polished.

5.2 **Polishing**

The initial manufactured lens and collector which can be seen below in Figure 21 has a semi-nontransparent finish with a few abrasions. Since not a myriad of scuffs is on the lens or collector, no sanding is necessary. To obtain the translucent appearance that is displayed in Figure 22, NOVUS polishing compounds #3, #2, and #1 were used in non-sequential order. All the compound solutions were applied by hand using a microfiber cleaning cloth in a circular motion. Specifically, NOVUS compound #3 was used first to remove any forms of heavy scratches, then NOVUS compound #2 was applied to remove any fine scratches and this was repeated a couple of times before finally applying NOVUS compound #1 to give off a polished finish.

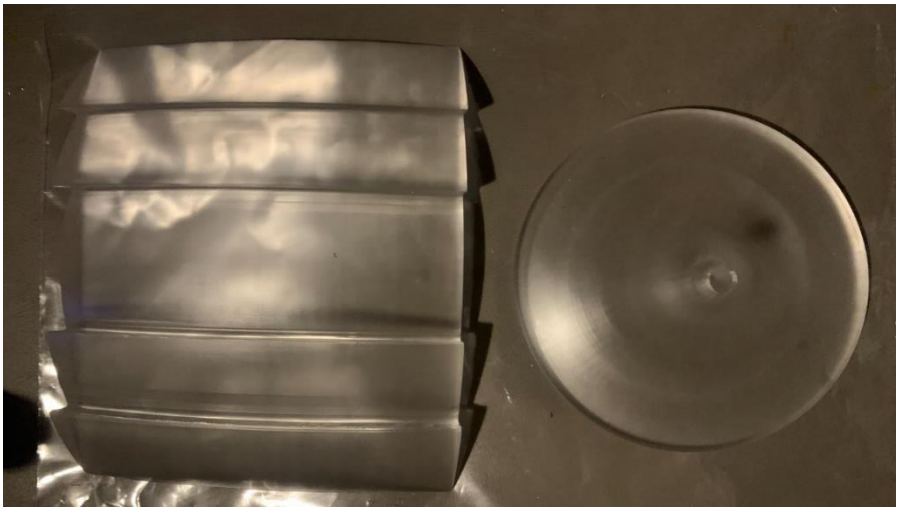


Fig 21. Pre-polished Acrylic Fresnel lens A(left) and Acrylic collector A(right)

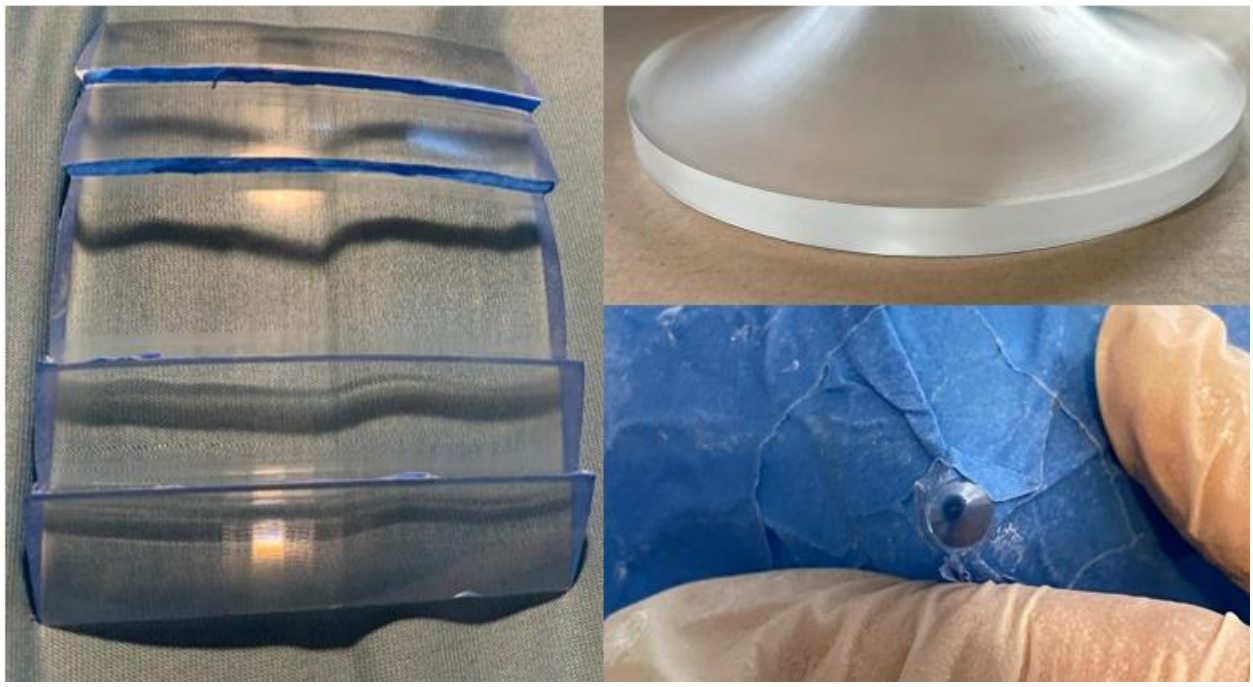


Fig 22. Post-polished Acrylic Fresnel lens A(left) and Acrylic collector A(right)

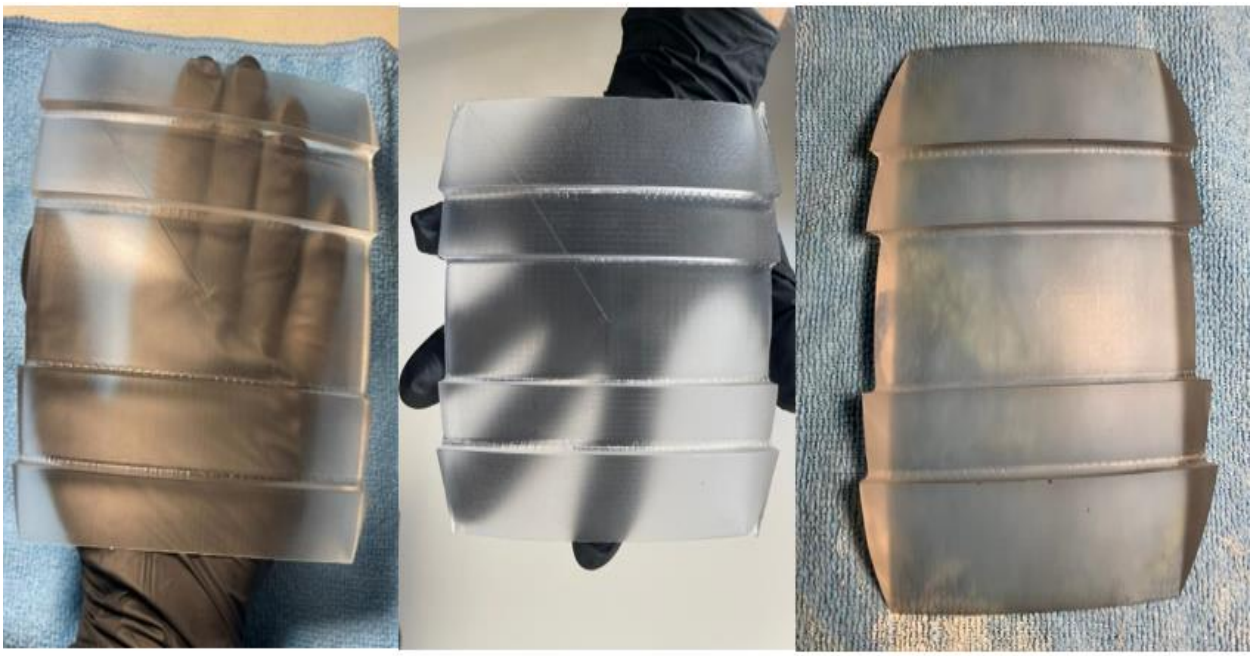


Fig 23. Pre-sanded and Pre-polished Acrylic B(left), Polycarbonate A(Middle) & B(Right) Fresnel lens

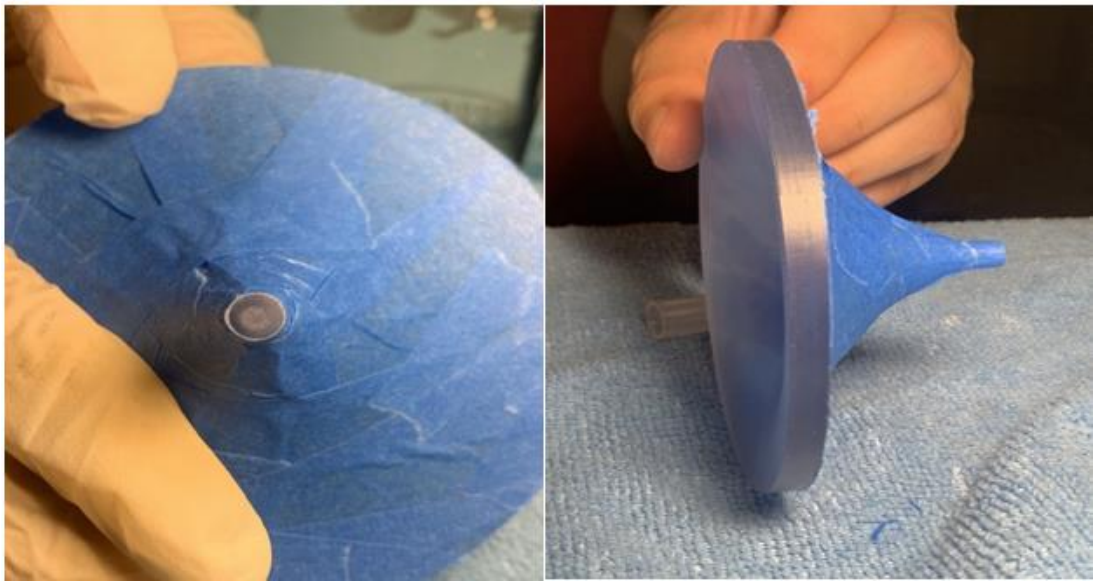


Fig 24. Pre-sanded and Pre-polished Polycarbonate collector

The manufacturing of the lens and collectors using a different CNC machine brought upon imperfections and scratches. The following discussed blemishes can be seen in Figure 23. To alleviate this predicament, Team SOLIS used a combination of sanding, polishing and buffing. The initial procedure of polishing was only altered by the addition of sanding the material first due to a broken bit scratch-made during the manufacturing process, shown above in Figure 23. As a result, different CNC machines being used to produce the rest of the lenses and collectors caused a different response in terms of duration when polishing. Another factor is the different density of polycarbonate versus acrylic which caused a different amount of duration of sanding.

The defining scratch on the lenses required tons of sanding specifically wet sanding as compared to dry sanding, wet sanding provides a smoother finish and reduces the number of imperfections. The process of this type of sanding required using a starting grit of 3000 and gradually going down to a lower grit (2500, 2000, 1500, 1200, 1000), the lowest being 800. Stay at 800 grit till you can no longer feel the scratch and gradually go up grit to eliminate the minor scratches, the highest being 3000. However, it should be mentioned that the use of the grit sizes is

dependent on the type of material. For instance, the acrylic lenses and collectors require a considerably less amount of sanding and use a lower grit compared to the polycarbonate lenses as they are less dense and more transparent. The polycarbonate lenses on the other hand required 10+ hours of sanding as they were quite dense and opaque. In addition, when it came to sanding the polycarbonate lenses, be sure to limit the pressure that is applied as polycarbonate scratches easily.

The polishing method of the lenses and collectors made with the second type of CNC machine was altered to a dual process of manual, and machining labor to help eliminate the minor imperfections that still existed after sanding the material. The machine polishing process used a spiral sewn cotton wheel attached to a power tool that can alter speed (low, medium, high). Each wheel is applied a different compound sparingly to the outside while running the drill and do not mix the different compounds in a wheel. Apply little pressure on the wheel when buffing since applying high pressure with certain speeds (medium/high) can eliminate more material and completely alter the shape. Use Novus compound #3 wheel for 2 minutes on the acrylic lens three times and proceed to finish the fourth time with a microfiber cloth that is applied for about 5 minutes. Use Novus compound #2 wheel and repeat what was done previously, then apply compound 1 and finish with a microfiber cloth. With polycarbonate lens, use compound #3 wheel for 2-5 minutes (depending on severeness of imperfections) once and proceed to finish the 2nd time with a microfiber cloth. Use Novus compound #2 wheel for 2-5 minutes three times and proceed to finish the fourth with a microfiber cloth. Apply compound 1 evenly and finish with a microfiber cloth. The final product will look like Figure 25 shown below.

Fig 25. Post-sanded and Post-polished Acrylic (Left) and Polycarbonate A(Middle) & B(Right) Fresnel Lens

When it came to polishing the collectors, painters' tape, the setup can be noted in Figure 24, was used to make sure only the head and rim of the collector were only polished. The justification for doing this is so the light is concentrated accurately. The combination of wet sanding with 3000 and 2500 grit sandpaper is used for the Polycarbonate collector before polishing to lessen any imperfections. The Novus polishing compound #2 buffing wheel is used for about 2-5 minutes and then finish with a microfiber cloth to obtain the resulting product shown in Figure 26 below. As for the Acrylic Collector, apply wet sanding with 3000 grit to eliminate any imperfection, then start with Novus polishing compound #3 buffing wheel for 2-5 minutes, and finish with a microfiber cloth. Proceed to Novus polishing compound #2 buffing wheel for 2-5 minutes and finish with a microfiber cloth, the resulting product is shown in Figure 27 below.

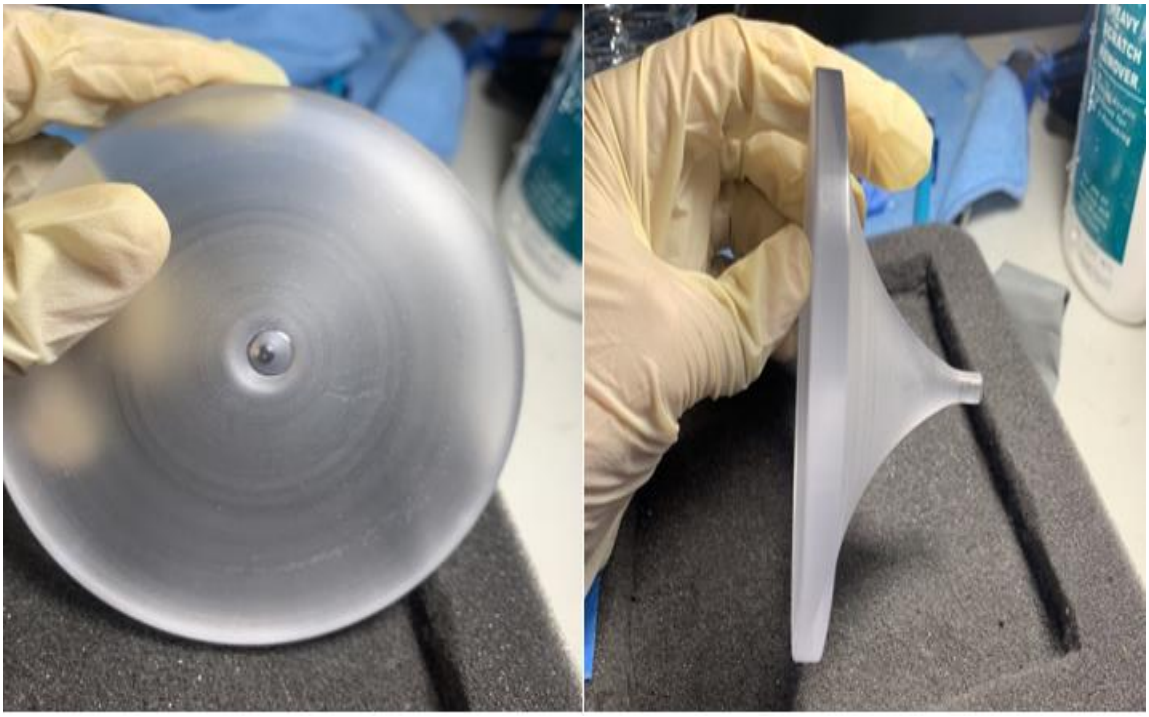


Fig 26. Post-sanded and Post-polished Polycarbonate collector B

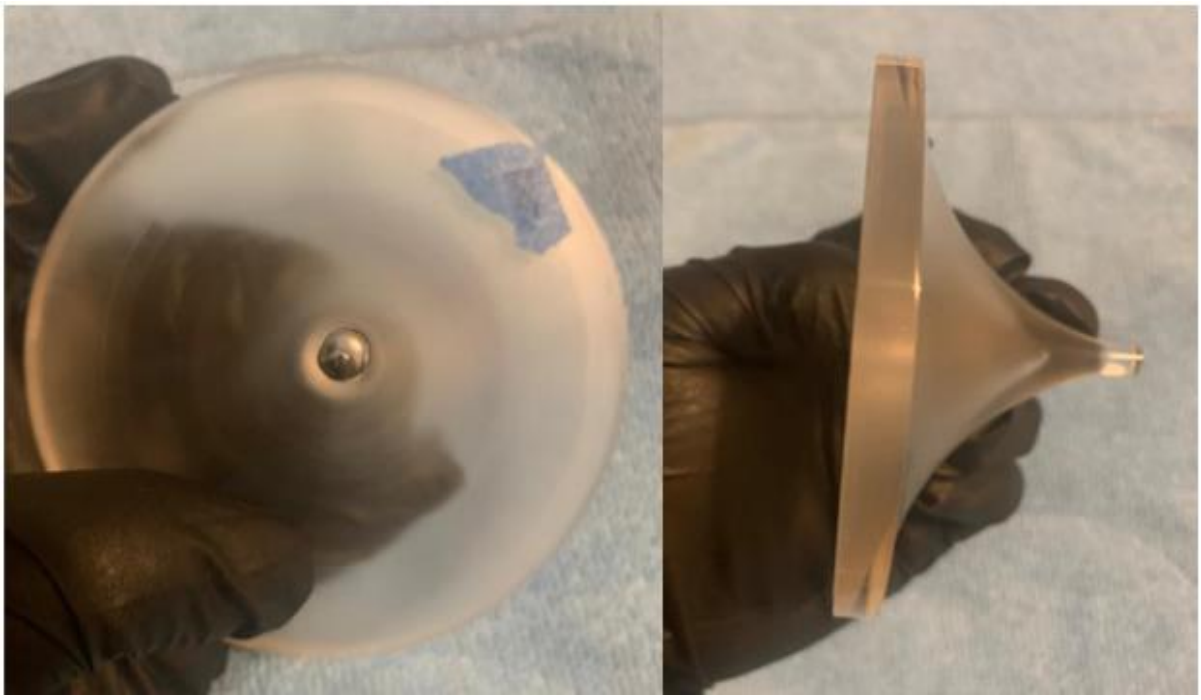


Fig 27. Post-sanded and Post-polished Acrylic collector B

5.3 **C**oating

Silicon Dioxide coating application on selected lenses has given the effect of adding another medium for the sunlight to travel through. However, it may fill small scratches and refine the lens surface to be more even allowing for the sun to travel more easily through the lens.

5.4 **Q**uality Assurance

The quality assurance process as shown in Appendix M was done on all lenses and collectors throughout their fabrication process. For the lenses, the quality assurance process measured the lux at the focal region and took the dimensions of the lens and compared it to the prescribed dimensions at the CNC model stage, polished stage, and coated stage if the lens was to be coated. Similarly, the collector was put through the same process at the CNC model stage and the polished stage. This process helps determine whether the fabrication methods allow for the prescribed lenses and collectors to be produced repeatedly with similar outcomes. In figure 28 the image shows the laser test.

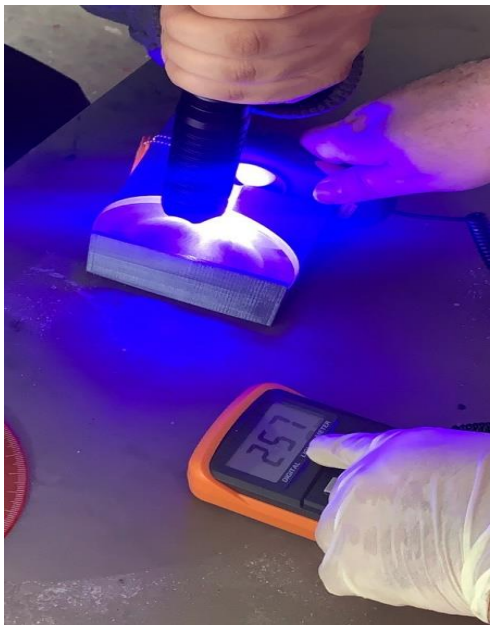


Fig 28. Laser test of Acrylic A collector

For Acrylic Coated Lens A the finished model came within 1.65 % of the prescribed dimensions while the increase in lux was 10.28 %. For Acrylic Lens B the finished model came within 7.97 % of the prescribed dimensions while the increase in lux was 9.59 %. For Polycarbonate Coated Lens A the finished model came within 2.4% of the prescribed dimensions while the increase in lux was 12.4%. For Polycarbonate Lens B the finished model came within 1.91 % of the prescribed dimensions while the increase in lux was 13.5 %. For Acrylic Collector A the finished model came within .84 % of the prescribed dimensions while the increase in lux was 73 %. For Acrylic Collector B the finished model came within 2.29 % of the prescribed dimensions while the increase in lux was 32.3%. For Polycarbonate Collector A the finished model came within 2.90 % of the prescribed dimensions while the increase in lux was 15.2 %. For Polycarbonate Collector B the finished model came within 1.68 % of the prescribed dimensions while the increase in lux was 40%.

5.5 **Tes**t Bench Parameters

One of the biggest influences that can hinder or obstruct the result is the positioning of the probe. Therefore, a consistent and specific probe placement was chosen as shown in figure (28) and figure (29) to ensure that the heat captured from the probe is consistent and accurate. There are three main probes used for the testing bench, where two probes are placed inside of the testing bench and one probe outside of the testing bench to measure the ambient temperature and the temperature on both ends of the collector. A fourth probe was later added to the testing bench during the second day of testing to observe if the inner ambient temperature is imbedding or contributing to the result from the collector probes. All the probes are then guided and inputted into the thermocouple to read the amount of heat that is being exposed onto the testing bench.

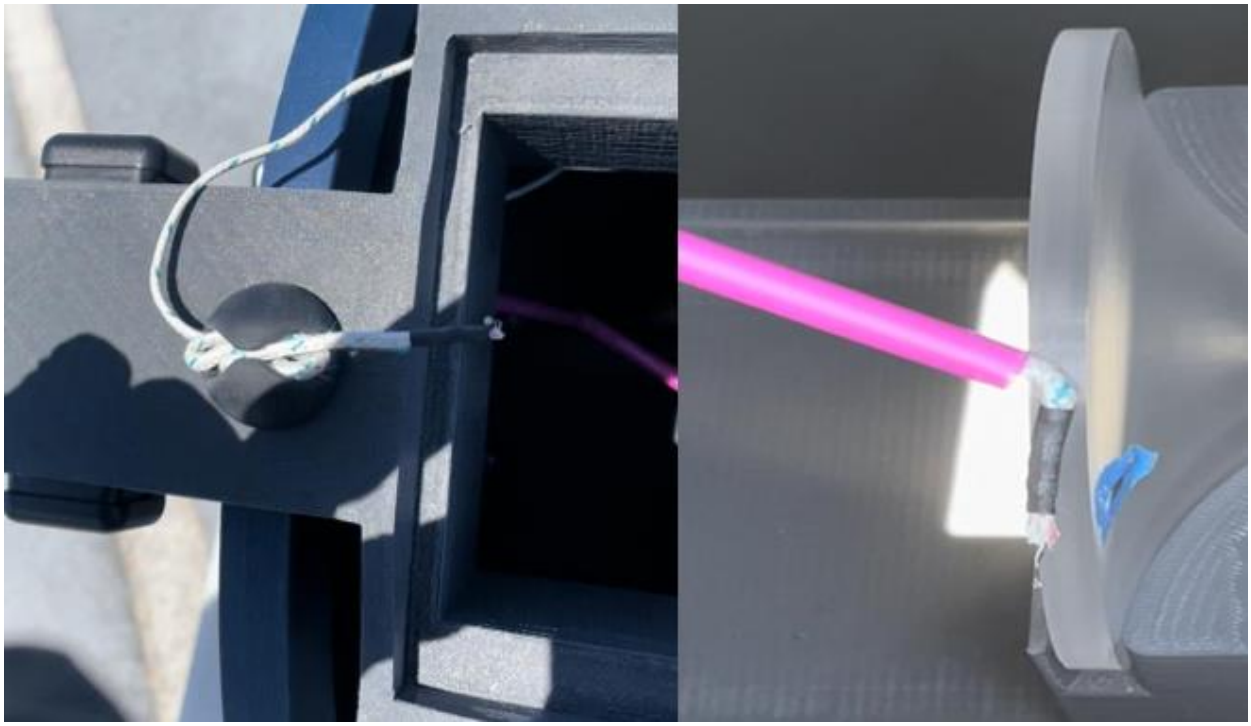


Fig 29. Position of Probe 3 ambient temperature. (Left) and Probe 2 Rim face (Right).

For the third probe of ambient temperature, the probe was placed near the outside of the lens surface as shown on the left side of figure (29). This position was chosen to ensure that the temperature that was entering the lens is being recorded to observe the difference in temperature from the outside environment to the temperatures of the collector. For the second probe of rim face temperature, the probe was placed onto the top faced off the rim surface in the region where the focal point is hitting the rim of the collector. A hollow bending straw is attached to the inside wall of the testing bench and is used to guide and ensure that the probe stays constant within the specific region.

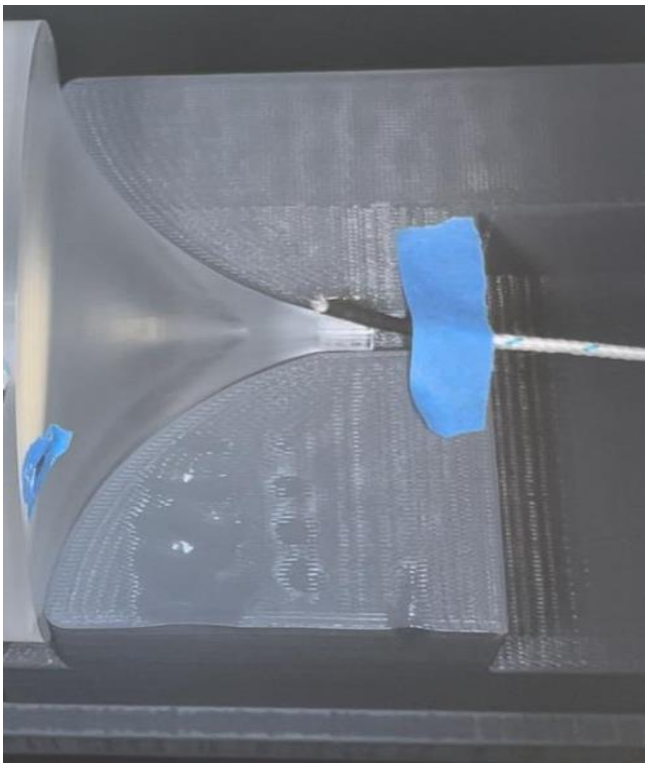


Fig 30. Position of Probe 1 (Port Face)

The first probe was placed near the port side of the collector as shown in figure (30) to measure the heat that is being transferred from the rim of the collector to the port of the collector. It's important to have direct contact with the probe on the flat surface to have a proper heat reading. It is important to cool the collector holder after every trial due to the heat from the PLA collector holding influencing the heat recorded. When testing, it's important that the port side probe is not exposed to the focal point light to ensure that the heat from the port is the only heat that is being observed.

5.6 **Te**sting Parameters

The testing of all the combination lenses and collectors was performed over 4 days. Out of the 4 days, 3 days has been categorized as a weather condition of a category 4 while one day was

considered a mixture of category 2 and 3 as specified in Appendix P. The first day of testing had a mixture of category 3 in the morning and a category 2 in the afternoon as shown in figure (P1) in Appendix P. During the testing in the category 3 weather condition, the temperatures of the lens and collector was affected by two major influences which was the wind or gust that was present and the sky coverage. When comparing category 3 to categories 4 and 5, the ambient temperature, and the heat rate between the rim and port of the collector was observed to be lower in comparison. This can be contributed to the gust of wind cooling the prototype while the testing was being performed. Another influence worth noting was that during category 3 weather, when scatter clouds were present during testing; all the temperatures from the probes can be shown as having temperature drops. These temperature drops can be contributed to the cloud coverage that is blocking solar radiation that is directly affecting the amount of heat that can be focused onto the focal point of the collectors' rim. When performing testing in category 2 during the afternoon; The result shows a dramatic drop in temperature for all ambient, rim, and ports probes. This can be contributed to having heavy cloud coverage that didn't allow very much solar radiation to be transferred through the lens.

Over the next 3 days afterward, the weather conditions were categorized as a category 4 as shown in figure (P2) through (P4) in Appendix P. The weather condition presented no cloud coverage and very little wind to imbed our temperature. These ideal settings allowed for a consistent pattern to be more apparent within this category number than compared to the lower weather category conditions. Therefore, to replicate consistent temperature readings, it is recommended to perform testing in weather conditions that are in category 4 and above to ensure that the transfer of heat presented in the testing can be seen more clearly.

5.7 **Interpreted Results**

Acrylic Coated Lens A and Acrylic Collector A exponential curve based on figure (12) for Ambient Temperature is $y = 20.203e^{0.0002x}$, Collector Rim Temperature $y = 33.778e^{-0.003x}$, and Collector Port Temperature $y = 27.784e^{0.0001x}$. Based on the relationship between the Ambient and Rim temperature the following proportion in Celsius is 60 % increase whereas the temperature difference percentage from the Rim to the Port was 18 % in Celsius.

Acrylic Coated Lens A and Acrylic Collector B exponential curve based on figure (13) for Ambient Temperature is $y = 26.355e^{0.0012x}$, Collector Rim Temperature $y = 45.785e^{-0.002x}$, and Collector Port Temperature $y = 32.313e^{0.003x}$. Based on the relationship between the Ambient and Rim temperature the following proportion in Celsius is a 58 % increase whereas the temperature difference percentage from the Rim to the Port was a 29 % in Celsius.

Acrylic Lens B and Acrylic Collector A exponential curve based on figure (14) for Ambient Temperature is $y = 28.371e^{-2E-04x}$, Collector Rim Temperature $y = 51.989e^{0.002x}$, and Collector Port Temperature $y = 35.717e^{0.0036x}$. Based on the relationship between the Ambient and Rim temperature the following proportion in Celsius is 55 % increase whereas the temperature difference percentage from the Rim to the Port was 31 % in Celsius.

Acrylic Coated Lens B and Acrylic Collector B exponential curve based on figure (15) for Ambient Temperature is $y = 30.231e^{1E-05x}$, Collector Rim Temperature $y = 50.29e^{0.0004x}$, and Collector Port Temperature $y = 37.315e^{0.0025x}$. Based on the relationship between the Ambient and Rim temperature the following proportion in Celsius is 60 % increase whereas the temperature difference percentage from the Rim to the Port was 26 % in Celsius.

Polycarbonate Coated Lens A and Polycarbonate Collector A exponential curve based on figure (16) for Ambient Temperature is $y = 33.778e^{0.0022x}$, Collector Rim Temperature $y = 42.843e^{0.0024x}$, and Collector Port Temperature $y = 38.3e^{0.0026x}$. Based on the relationship between the Ambient and Rim temperature the following proportion in Celsius is 79 % increase whereas the temperature difference percentage from the Rim to the Port was 11 % in Celsius.

Polycarbonate Coated Lens A and Polycarbonate Collector B exponential curve based on figure (17) for Ambient Temperature is $y = 36.498e^{0.0016x}$, Collector Rim Temperature $y = 48.644e^{0.0019x}$, and Collector Port Temperature $y = 40.17e^{0.003x}$. Based on the relationship between the Ambient and Rim temperature the following proportion in Celsius is 75 % increase whereas the temperature difference percentage from the Rim to the Port was 17 % in Celsius.

Polycarbonate Lens B and Polycarbonate Collector A exponential curve based on figure (18) for Ambient Temperature is $y = 22.865e^{0.0004x}$, Collector Rim Temperature $y = 32.792e^{0.0004x}$, and Collector Port Temperature $y = 30.297e^{0.0014x}$. Based on the relationship between the Ambient and Rim temperature the following proportion in Celsius is 70 % increase whereas the temperature difference percentage from the Rim to the Port was 8 % in Celsius.

Polycarbonate Lens B and Polycarbonate Collector B exponential curve based on figure (19) for Ambient Temperature is $y = 32.993e^{0.0009x}$, Collector Rim Temperature $y = 60.969e^{0.0002x}$, and Collector Port Temperature $y = 39.801e^{0.0031x}$. Based on the relationship between the Ambient and Rim temperature the following proportion in Celsius is 85 % increase whereas the temperature difference percentage from the Rim to the Port was 35 % in Celsius.

When analyzing the acrylic set for the coated lens against the uncoated lens there is no discernable difference in the effect on the proportional heat increase percentage from the lens

ambient heat to the rim temperature. Similarly, for polycarbonate, the coated version of the lens and the uncoated lens had no discernable difference in the proportion of heat increase percentage from the lens ambient temperature to the collector rim temperature. Now when comparing the two material sets the best heat transfer in heat transfer percentage increases is shown to be polycarbonate as well as heat transfer from the Collector Rim to the Collector Port is shown that the polycarbonate has the lowest temperature difference percentage.

Experimental Versus Simulation

Analyzing the results and comparing with Team Hyperion's thermal simulation it was found that acrylic came within a 1% difference which helped validate the integrity of the simulation for the acrylic. For polycarbonate it came within 5% of the simulation which also validates the integrity of the simulation.

6 Recommendations

Throughout working on the prototype, the group discovered certain tasks can be completed or done in a different way that will better the accuracy and/or quality of the work. With the CNC of the lens and collector, a machine with a high rpm and ipm for a better surface finish would give a better and closer produced model to the prescribed dimensions. For the polishing section, a better method for polishing polycarbonate will need to be focused on, ideal changes with the polycarbonate were not seen with the Novus compound since the compound is meant for plastics such as Acrylic. Next coating a more controlled output with more precision would allow for a more controlled volume to be sprayed evenly along the lens surface. For quality assurance, a better alternative to measuring using calipers and comparing the results to prescribed dimensions would

be to use a 3-D scan that can determine if the actual lens and collector are made properly relative to the CAD model.

The conditions that the tests were held in can be changed by having a controlled light source in a controlled indoor environment. The light source would simulate the sun and allow for the testing to continue uninterrupted by unforeseen weather patterns. This would also allow for the testing to have a more controlled variable of input for the lenses' ambient temperature and give a more controlled area.

6.1 Future Work

- Creating a thermocouple interfacing with an Arduino board that measures temperature automatically and can input every data point into the graph will allow for a better quality of data.
    - Doing this will require compatible thermocouple probes that can be manipulated in position without losing connection to the Arduino.
    - For the test bench, running multiple sets of tests with each one having three trials takes a lot of time to record data and manually input it into an excel sheet.
- Increasing the size of the acrylic and/or polycarbonate lens from a 30° section cut to a 60° cut.

7 Conclusion

7.1 Concluding Thoughts

Team SOLIS set out to fabricate the Acrylic and Polycarbonate sets of Lenses and collectors to prescribed dimensions, where one lens of each material set would be coated with silicon dioxide. Using the quality assurance procedure Teams SOLIS has determined that it has successfully produced lenses and collectors as prescribed. The next task was to construct a testing bench that would help position the lens and collector to mimic the simulation and allow for instrumentation to log and document the incoming data of optical and thermal data. The testing bench has passed the criteria of allowing the positioning of the lens and collector as the simulation on Optica EM and Simscale have. The results of the thermal testing show the polycarbonate set to transfer more heat from the lens to the collector rim and has shown that the heat loss on the collector was less than the acrylic set. The coating was also determined to show that the effects on heat transfer were negligible.

7.2 Acknowledgments

Team SOLIS would like to express gratitude to Mr. Christopher N. Mendell for pioneering the Fresnel Lens as a solar concentrator for the lunar environment. We would also like to thank Mr. Houston Green and TSGC for sponsoring our project. Team Hyperion for helping design and simulate the prototype lens and collector. Carlos from Custom Precision Sheet Metal for helping in creating the metal shade. J & J Fabricating & Machining Inc for helping in fabricating the lens and collector. Roland Williams Jr from Venturetech in helping to fabricate the lens and collector as well. Finally, we would like to thank San Jacinto College and Dr. Nathaniel Wiggins, the University of Texas Tyler, our advisor Dr. Soren Maloney, and Dr. Andres Garcia, for supporting our project.

8 References

[1] Dunbar, Brian. "Artemis." *NASA*, National Aeronautics and Space Administration, Sept. 2020, www.nasa.gov/specials/artemis/#why.

[2] Sharpe, B. L., & Schrunk, D. G. (2003). Malapert mountain: Gateway to the moon. *Advances in Space Research, 31*(11), 2467-2472. doi:10.1016/s0273-1177(03)00535-0

[3] Smith, D. E., Zuber, M. T., Jackson, G. B., Cavanaugh, J. F., Neumann, G. A., Riris, H., . Zagwodzki, T. W. (2009). The Lunar Orbiter Laser Altimeter Investigation on the Lunar Reconnaissance Orbiter Mission. *Lunar Reconnaissance Orbiter Mission, 150*, 1-4, 209-241. doi:10.1007/978-1-4419-6391-8_10

[4] M. J. Harrell, G. S. Schroeder, and S. A. Daire, "Lunar environment, overview," *Handbook of Life Support Systems for Spacecraft and Extraterrestrial Habitats*, pp. 1–23, 2021.

[5] M. Krueger, D. Guerra, and R. Ehlinger, "Solar Concentrator for the Texas Space Grant Consortium Challenge." Research Paper, San Jacinto College.

[6] 2021, [Online]. Available: https://www.delviesplastics.com/Novus_Directions.html.

[7] US Department of Commerce, NOAA. *National Weather Service*, NOAA's National Weather Service, 2020, www.weather.gov/.

[8] Live, Sky. "Your Guide to the Solar System and the Night Sky." *TheSkyLive*, 2013, theskylive.com/.

9 Appendix

9.1 Appendix A: Poster

UTTyler ENGINEERING Department of Mechanical Engineering

HEC09 - TEAM SOLIS

TDC-73 Novel Non-Tracking Fiber Optic Solar Concentrator for Extraterrestrial Applications

Team Members: **Jonathan Johnston, Christopher Contreras, Mohammed Waheed, Dhaval Patel, Victor Ortiz**
Sponsor: NASA Texas Space Grant Consortium, Jacobs Technology/NASA, JSC
Advisor: Dr. Soren Maloney
Department of Mechanical Engineering, UT-Tyler, Senior Projects 2021 - 2022

Background

The Fresnel Lens and Collector act as a solar concentrator that will be used on a lunar base to power equipment using the sun. The lens allows for the solar rays to be concentrated to the center toward the collector, which can allocate thermal and optical energy to be transfer through a fiber optic cable. The lens must endure the lunar environment regarding varying temperatures and abrasive lunar dust.

Objective

1. Design a solar concentrator that removes the need for solar tracking and can withstand the dusty lunar environment.
2. Fabricate Lenses and Collectors.
3. Fabricate a Testing Bench.
4. Test Lenses and Collectors for thermals and validate thermal simulations.

Specifications

ITEM	SPECIFICATION	VALUE AND LIMIT	UNITS	ACCEPTANCE TEST
1	Melting Point of Selected lens Material and Coating	400	Kelvin	Material Datasheet
2	Refractive Index of selected lens Material and Coating	1.4	No Units	Material Datasheet
3	Transmittance of selected lens Material and Coating	At Least 80	Percent	Material Datasheet

Fabricated Lenses and Collectors

Fig 1. Finished fabricated Lenses (on left) and Collectors (on right) where one lens of each Acrylic and Polycarbonate ls coated with silicon dioxide.

Abstract

The design requirements specified by TSGC have been addressed with the proposed design. The designed lenses are a simplified version of the 360° lens to a 30° lens for fabrication and testing. The testing bench allows for the lenses and collector to mimic a simulation that then can be validated based on thermal results. Polycarbonate was found to concentrate more heat than acrylic. Silicon Dioxide coating had negligible effects on thermal concentration. Acrylic came within 1% of the thermal simulation while the polycarbonate came with in 5%.

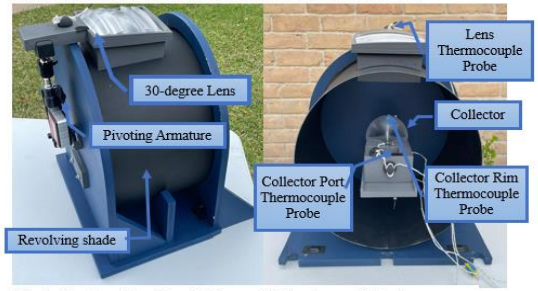
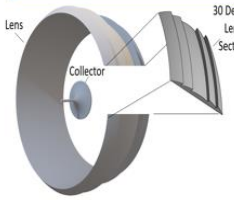


Fig 2. Testing Bench with Lens, Collector, and Probes.

Main Design Features



- Different materials with refractive indexes selected for wider test range.
- To simplify testing, a 30-degree revolved piece of the lens was designed.
- Has a shade to shield from ambient light.
- Can rotate to track sun path.
- Height adjustable.

Fig 3. Section cut of non-tracking Fresnel lens.

Acknowledgements

Team SOLIS would like to express gratitude to

- **Dr. Soren Maloney** – Faculty Advisor
- **Dr. Andres Garcia** - UTT HEC Director
- **Mr. Christopher N. Mendel** - Mentor
- **Mr. Houston Green** – Mentor
- **Dr. Nathanial Wiggins**
- **TSGC**
- **Team Hyperion**
- **Dr. Biswas**

Results and Analysis

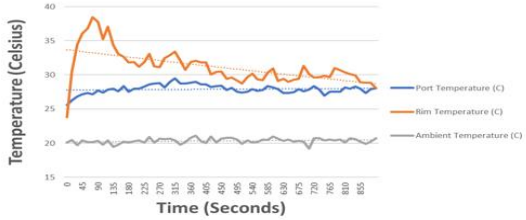


Fig 4. Acrylic results show the temperature from the lens to the collector rim had an increase of about 60 % while the rim transferred 70 % in heat to the port.

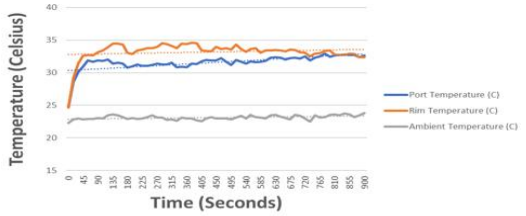


Fig 5. Polycarbonate results show the temperature from the lens to the collector rim had an increase of about 75 % while the rim transferred 85 % in heat to the port. Acrylic experimental results came within 1% of the thermal simulations.

Table 1. Experimental and simulated result.

Acrylic	Port Temp. (°C)	Rim Temp. (°C)	Ambient Temp. (°C)	Weather Conditions / Cloud Fraction	Sun Angle
Experimental	26.3	28.1	21.3	Category 4	59.5°
Simulated	26.4	28.6	21.3	0.1	59.5°

Conclusion

Lenses and Collectors were successfully fabricated to 8.5% of prescribed dimensions. Thermal testing showed the Polycarbonate set transfers more heat from lens to collector's rim and the collector rim to the collector port than the acrylic set. The silicon dioxide coating was shown to have negligible effects on heat transfer for the lenses and collectors.

9.2 Appendix B: Sign Off Sheet

Senior Design Project II

MENG 4216 - Sponsor Review and Sign-off Doc

Project TDC 73: NOVEL NON-TRACKING FIBER OPTIC SOLAR CONCENTRATOR FOR EXTRATERRESTRIAL APPLICATIONS Delivery and Acceptance

Senior design team HEC09-Team SOLIS, from UT-Tyler College of Engineering, has worked with a sponsor: Christopher N. Mendell to design and build a Fresnel lens and testing bench as part of the senior students' academic work during the academic year of 2021-2022. This document includes the sign-off list and Christopher N. Mendell's final approval of the outcome of Project TDC 73: NOVEL NON-TRACKING FIBER OPTIC SOLAR CONCENTRATOR FOR EXTRATERRESTRIAL APPLICATIONS delivered by HEC09-Team SOLIS, based on the previously set and mutually-approved scope and specifications of the project. An authorized signature indicates this approval.

Table 1: Sponsor Sign OFF list for Deliverables of the Senior Project NOVEL NON-TRACKING FIBER OPTIC SOLAR CONCENTRATOR FOR EXTRATERRESTRIAL APPLICATIONS

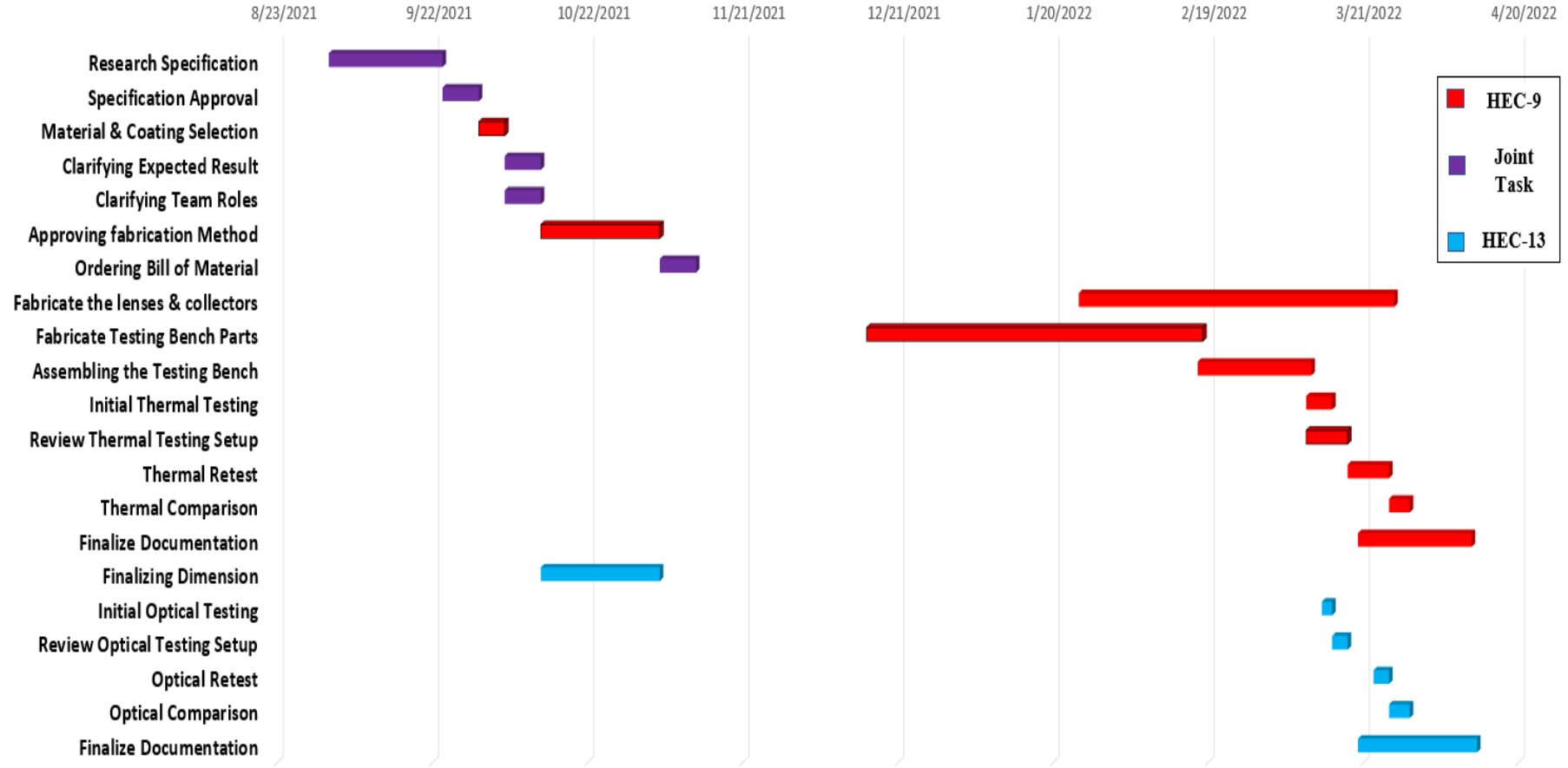
Item No.	Description of Deliverable	Comments:	Sponsor Sign Off: Authorized Initials
Material Selection	Material can withstand the lunar environment and effectively transmit sunrays	Selected Acrylic and Polycarbonate and Fabricated lenses and collectors	
Coating Selection	Coating can withstand the lunar environment and effectively transmit sunrays	Selected Silicon Dioxide as coating to be applied on Lenses	
Testing Bench	Fabricate Testing Bench to hold lens and collector in position to mimic the simulation	Testing Bench allows for lens and collector to be positioned, where lens is directly under the sun	

Production Model Documentation	Technical Documentation	
B.O.M.	Bill of Materials	
Testing		
Testing Thermal Concentration	Measuring temperature in Celsius on Lens and Collector	The temperature is measured by probes positioned on the surface of the lens. rim of the collector, and port of the collector

The following signatures indicate that Christopher N. Mendell approves of the completion ofthis project and deliverables stated above which included all sponsor changes from original design and any consequent changes in the project, as mutually approved by all signing parties.
Also indicated is the acknowledgement by Christopher N. Mendell of reception of the final product of the project.

	4/20/2022
For UT-Tyler Mechanical Engineering : Dr. Nael Barakat / Dr. Andres Garcia, etc…	Date
Christopher N Mendell	4-20-2022
For [ ]:	Date
	4/20/2022
For the Senior Project Students' Team: SOLIS successful *Team Captain*	Date
	4/20/2022
For the Senior Project Students' Team: SOLIS successful *Vice Officer*	Date
	4/20/2022
For the Senior Project Students' Team: SOLIS successful *Communications Officer*	Date
	4/20/2022
For the Senior Project Students' Team: SOLIS successful *Treasurer*	Date
	4/20/2022
For the Senior Project Students' Team: SOLIS successful *Secretary*	Date
	4/20/2022
For UT-Tyler Mechanical Engineering: Advisor	Date

9.3 Appendix C: Gantt Chart.



	Finalize Documentation	Optical Comparison	Optical Retest	Review Optical Testing Setup	Initial Optical Testing	Finalizing Dimension	Finalize Documentation	Thermal Comparison	Thermal Retest	Review Thermal Testing Setup	Initial Thermal Testing	Assembling the Testing Bench	Fabricate Testing Bench Parts	Fabricate the lenses & collectors	Ordering Bill of Material	Approving fabrication Method	Clarifying Team Roles	Clarifying Expected Result	Material & Coating Selection	Specification Approval	Research Specification
Start Date	3/20/2022	3/26/2022	3/23/2022	3/15/2022	3/13/2022	10/13/2021	3/20/2022	3/26/2022	3/18/2022	3/10/2022	3/10/2022	2/17/2022	12/15/2021	1/25/2022	11/5/2021	10/13/2021	10/6/2021	10/6/2021	10/1/2021	9/24/2021	9/2/2021
Duration (Days)	23	4	3	3	2	23	22	4	8	8	5	22	65	61	7	23	7	7	5	7	22

Fig C1. Gantt Chart describing the milestone of both TSGC and Senior Design course.

9.4 Appendix D: Bill of Materials

Table D1. The Bill of Material for the fabrication of the parts and testing setup.

Order time				1-2 days			
Item number	**Quantity**	**Part Number (SKU/ASIN)**	**Description**	**Name**	**Vendor**	**Ship Cost ($)**	**Total Cost ($)**
1	1	SKU: 8574K16	12in x 12in x 2in smooth sheet Color: clear Weight:24.77 lbs.	Polycarbonate Material	McMaster-CARR	0.00	976.90
2	1	SKU:8560K935	12in x 24in x 2in smooth sheet Color: clear Weight:24.78 lbs.	PMMA (Acrylic)	McMaster-CARR	0.00	260.15
3	2	ASIN: B002UCYRZU	Plastic polish kit containing three white 8 oz bottles of different compounds	NOVUS 7100 Plastic Polish	Amazon	0.00	36.58
4	1	ASIN: B07NJXYQBW	SiO_2 Sealant trigger spray Color: blue and white Type: Touchless sealant Brand: 303 Products Weight: 32 Fluid Ounces	SiO_2 Touchless Sealant	303 Products	0.00	19.99
5	1	ASIN: B07HRD6JKK	Six pack of ultrafine green microfiber cloth	Microfiber cloth	Mr. SIGA	0.00	11.99
6	2	ASIN: B00J0GMMP6	Used for 3D printing machine. Color: white Type: PLA (1.75mm) Brand: HATCHBOK Weight:1kilogram	PLA for Lens Holder	Fire Sale Merchant	0.00	46.98
7	1	ASIN: B08KTN7N3V	Color: Black (H) Type: metal Brand: CAOGE Weight: 350grams	Overhead Armature	CAOGE	0.00	19.89
8	1	ASIN:095043724723	3/4-in x 24-in x 6-ft Square	Wooden Panel	Lowe's	0.00	16.99
9	1	ASIN: B07FKN6QJG	Battery-powered Color: Red Type: Iron & copper Brand: TEKCOPLUS Weight: 6.7 ounces	Thermal Couple Device	TEKCOPLUS	0.00	29.90
10	1	ASIN: B00WQLHG2G	Black Aluminum, Self-calibrating +/- 0.2-degree accuracy Color: black Type: Stainless Steel Weight:0.26 lbs.	Digital Angle Gauge	Amazon	0.00	17.50
11	1	ASIN: B005A0ETXY	Battery-powered Color: Orange Brand: Dr. Meter Type: ABS Accuracy: ±3%	Digital Illuminance Light Meter	Thousand shores	0.00	39.99
12	1	ASIN: B01CG97GR2	Battery-powered Color: Blue and black Brand: BOSCH Type: Plastic	Laser measurer	BOSCH	0.00	39.97

			Accuracy: ±1/8 in				
13	1	SKU:1003945225	32 oz Clear Interior Fireproofing Flame Retardant Liquid Spray for Fabric and Raw Wood	Fire retardant spray	Firetect	0.00	18.90
14	1	ASIN: B08Y98BVDM	100 count Synthetic Nitrile-Vinyl Blend Exam Gloves	Exam gloves	MED Pride	0.00	15.99
15	1	ASIN: B000TGSPV6	Black 3 1/2 x 3/4 In	VELCRO Brand Sticky Back Strips	VELCRO Brand	0.00	4.75
16	1	ASIN: B07PNHGPT6	Silicone Non-Slip BBQ Mitt for Grilling	Premium BBQ Gloves	MVZAWINO	0.00	14.99
17	4	SKU: 528531	Combo Round Head Zinc Plated Machine Screw	2-inch screws	Everbilt	0.00	1.28
18	1	-	Galvanized Steel Sheet Size: 29 by 48 inches	Galvanized Steel Sheet	Metal Supermarket	0.00	26.99
19	1	SKU: 448990	Metal paint Color: Flat Black Size: 1quart	Protective Enamel Flat Black Paint	Rust-Oleum Stops Rust	0.00	11.98
20	1	ASIN: B07LFWTQJX	Epoxy Binding Paint Color: Matte Black Size: 16 ounces Fast Drying Material: Solvent Based	Krylon Fusion All-One Spray Paint	Krylon	0.00	18.07
21	1	SKU:364512	Paint Roller Kit 1-roller 1-plastic tray	4-Piece Paint Trim Kit	Unbranded	0.00	7.58
22	1	SKU: 221002	Grade# 0000 12-pack Metal Strand	Super Fine Grit Steel Wool	Homax	0.00	4.97
23	1	ASIN: B098FD6GC3	Material: Aluminum Size: 9.45 x 6.5 x 2.36 in Battery Powered Weight: 1.83 lbs. Power: 500 mw	High Power Purple Blue Beam Pointer	YIJIZE	0.00	85.96
24	1	ASIN: B0928Q3T42	Model: D300 Dual Camera IP67 Water Probe 16.5 ft Semi-rigid Snake Cable Front and Side Camera	Dual Lens Industrial Endoscope Inspection Camera	DEPSTECH	0.00	79.99
					Total Cost ($):		**1807.38**

Team SOLIS and Team Hyperion have received budget funding of $2400.00 from TSGC. The following Table D1 shows the Bill of Materials come within budget.

9.5 Appendix E: ARCI Chart for Team SOLIS Task and Accountability.

Table E1. Legend For Table E2

Definition	Letter Code
Accountable	A
Responsible	R
Consulted	C
Informed	I

Table E2. ARCI Chart for Team SOLIS

Task	Christopher Contreras	Johnathan Johnston	Victor Ortiz	Dhaval Patel	Mohammed Waheed
Concept Designs	R	A	C	I	I
Standard	R	A	C	I	I
Lunar Environment Research	A	C	R	I	I
Material Research	R	I	A	I	C
Coating Research	C	I	R	I	A
Design Development	I	I	C	A	R
Fabrication method	C	I	I	A	R
Coating Application	I	I	R	C	A
Polishing Application	A	I	C	R	I
Simulation research	R	I	I	C	A
Acquisition of components	C	A	I	I	R
Documentation	R	C	I	I	A
Budget	I	R	C	A	I

9.6 Appendix F: Procedure and Diagram of the CNC Machining

Fig F1. Shows Milltronics 7200 CNC machine.

Our team will use Gibbs CAM, as shown in Figure F2, a computer-aided machine software (CAM), to program a CNC machine to make the lens, as shown in Figure F1. CAM software is used to program toolpaths and generate the G-code that controls CNC machines like mills, routers, lathes, and wire EDMs.

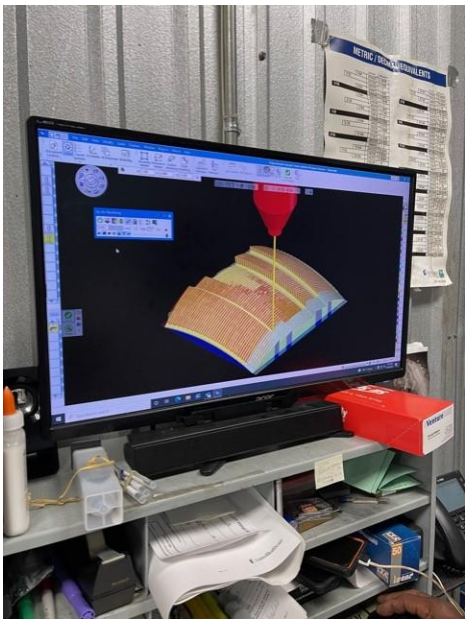


Fig F2. Shows GibbsCAM generating tool path for CNC machine.

9.7 Appendix G: Manufacturing Drawings of Lenses and Collectors

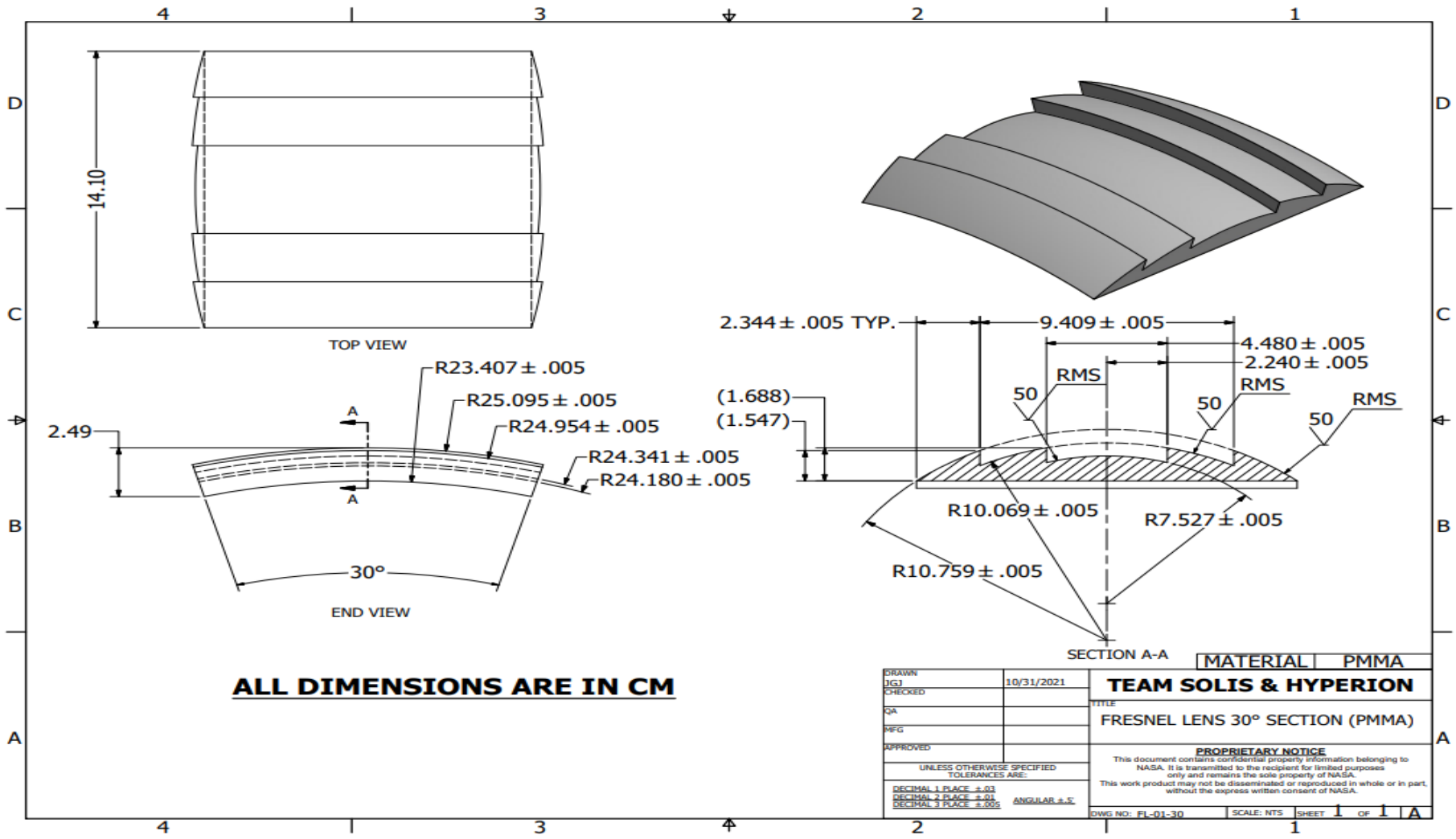


Fig G1. Manufacturing Drawing of PMMA Fresnel Lens 30° Revolve Piece.

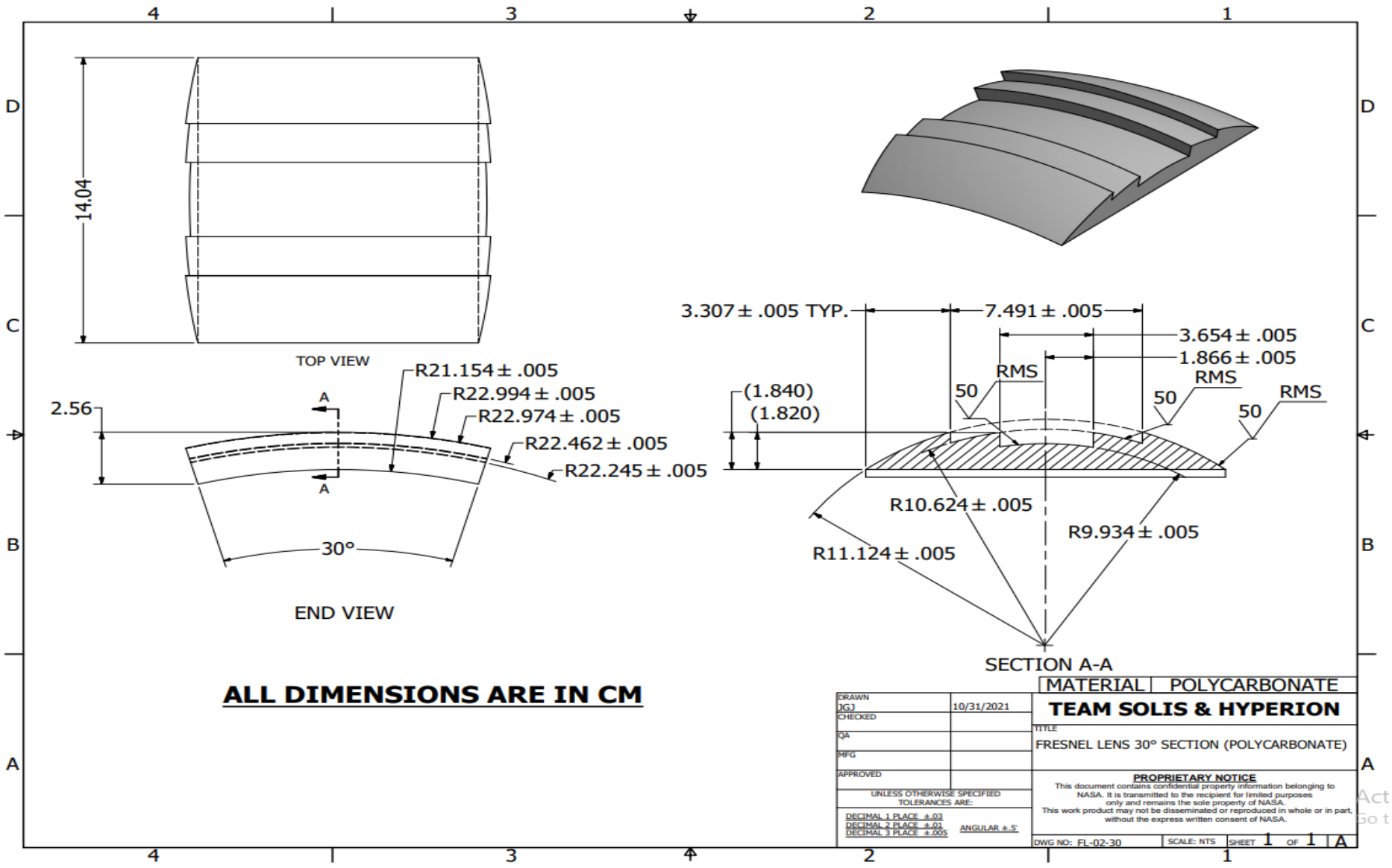


Fig G2. Manufacturing Drawing of Polycarbonate Fresnel Lens 30° Revolve Piece.

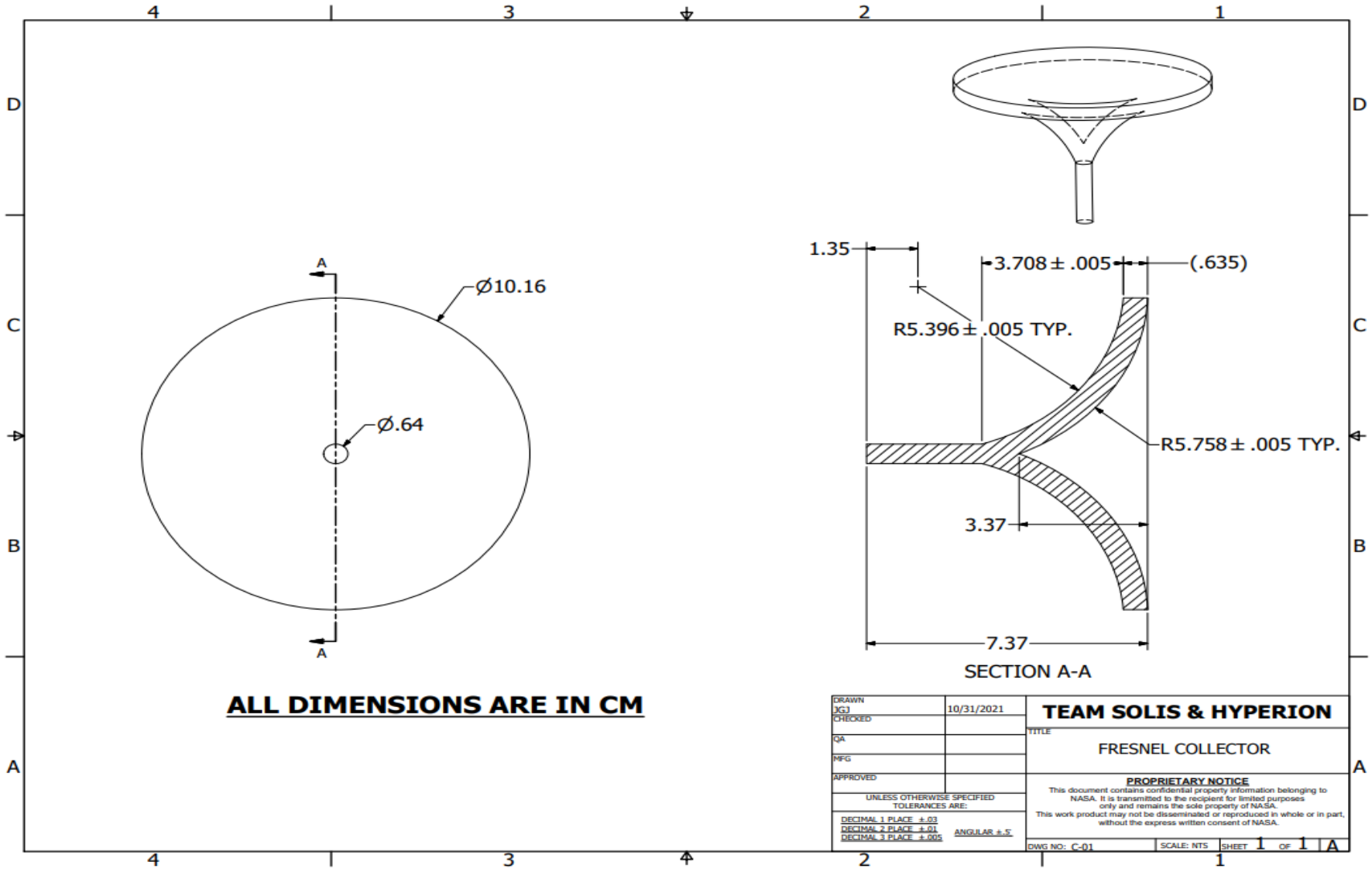


Fig G3. Manufacturing Drawing of PMMA and Polycarbonate Collect

9.8 Appendix H: Polishing Method Details

Once the lens and collector have been fabricated, a polishing method of compound paste must be applied onto both the Fresnel lenses and collector made of PMMA and Polycarbonates. The fabricated material after fabrication will have scratches and deformation that can potentially affect the optical performance. External factors that can affect the performance of the lens and collector must be mitigated to ensure an accurate comparison and validation from the physical model that Team SOLIS is performing to verify the simulated model that Team Hyperion is performing.

A coating method will also be applied to one polycarbonate lens and one PMMA lens to experiment with. The coating can show the effects on the optical and thermal performance of the lens. These coated lenses will be compared and simulated to further validate the simulation and benefits that the coating provides to the lens.

Polishing method

Table H1. Material Safety Data Sheet for Compound Paste Polishing [6].

Types of Plastic used for	Applications
Acrylic	Acrylic Aquariums
Plexiglass	Safety shields & Goggles
Makrolon	Plastic Windows & Skylights
Palsun	Motorcycle Windscreens, Visors
Polycarbonate	Boat Windows & Fiberglass
Lexan	Airplane Windows

The polishing method chosen for this design was the compound paste polishing method that uses a paste compound “Novus” to polish and buffer the lens of PMMA and polycarbonate to

the desired polish. This method was chosen due to the cost and simple application process. This polishing method does not require complicated equipment or a considerable amount of safety parameters to be used, unlike the other polishing methods.

The compound paste polishing method is the most common polishing method used in most industries. These industries include motor vehicles, aviation, building and construction, skylight, and optical industry. This method uses a buffering technique and a special paste to clean and polish the surface of both materials. This method is a lengthy process compared to the other polishing method with repeated steps to ensure quality polished. It is also worth noting that the buffering method only polishes the surface into a glossy finish but does not remove the micro scratches on the lens surface. This polishing method will use a special multi-step paste called “Novus Plastic Cleaners and Polishes” that can be used for PMMA and Polycarbonate, as shown in Table G1. This polisher uses a three-step process to ensure a clean and polished surface [6].

Paste Polishing Method Process:

1) The step is to prepare the lens for the polishing method by using wetted sandpaper to remove large scratches and smooth the surfaces by using coarse wet sandpaper of 600 grit then progressing to fine sandpaper of 2000 grit to have a cleaner surface. Then wipe the surface with a microfiber cloth to clean the lens.
2) Once the lens has been prepared, the first Novus bottle to use is number (3) indicated with a green label called “Heavy scratch remover.” Apply a microfiber cloth and an even pressured spear with a circular motion throughout the lens surface. Wipe the surface with a clean microfiber cloth until no more polish remains.

3) The next step is to apply the second Novus bottle designated with the number (2) on the bottle indicated with a red label called “Fine scratch remover.” Apply an even light pressured speared using a circular motion throughout the lens surface with a microfiber cloth. Then allow the paste to dry into a light haze. Once dried, use a clean microfiber cloth to buffer the surface using short circular strokes until the surface of the lens is no longer hazy.
4) The next step is to repeat the second and third steps until no more scratches are visible and the lens is clean and polished. Once there are no more scratches, the lens can proceed to the last step.
5) The last step is to apply the final Novus bottle designated with the number (1) on the bottle that is also indicated with a blue label called “Plastic clean and shine.” Apply the paste with an even light pressure amount using a microfiber cloth until the lens surface is completely covered. Then with a dry and clean microfiber cloth, buff the lens surface using short circular strokes until the lens becomes completely dried to the desired polished finish.

Polishing Procedure for Lenses and Collectors:

Equipment needed for polishing of all lenses and collectors:

- Novus polishing step (1,2,3) bottles
- Micro-fiber cloths
- Latex gloves
- Painter’s tape (blue tape)

Procedure for PMMA and Polycarbonate Lenses:

1. Use latex gloves and place the lens on a clean protective surface such as a plastic surface to ensure no damage or scratches to the lenses.
2. Starting on the flat surface of the lens as shown in figure (26), remove the surface dust with a clean, soft cloth and shake well the polishing bottle.
3. Apply the blue tap onto the side of the ridges on both sides and ensure that no side surface is exposed as shown in figure (26).
4. While using a clean micro-fiber cloth, apply a moderate amount of "NOVUS No.3 Heavy Scratch Remover onto one side of the cloth.
5. From the top right corner of the flat surface, apply the cloth used in step 3 with firm up-and-downstrokes while moving left to right. Reapply the "NOVUS No. 3" polishing compound as needed. Repeat step 4 until the entire surface has been polished and no large scratches are visible and only fine scratches remain.
6. Using a clean cloth, remove all the remaining polishing from step 4 and ensure that the surface is free from dust. To remove the small scratches from the lens, shake well the bottle called "NOVUS No.2 Fine Scratch Remover" and apply a moderate amount of NOVUS No 2. onto a clean microfiber cloth.
7. Starting on the top right side of the flat surface, apply the cloth described in step 5 with a firm circular clockwise motion while moving from the left to the right of the surface. Reapply the "NOVUS No.2" polishing compound as needed.
8. Once the surface has been covered and dried, buffer the flat surface with a clean cloth until no polishing residue remains on the surface. Repeat steps (5) through (7) until no scratches are visible on the surface.

9. Using a clean cloth, ensure that the flat surface is free from dust and shake well the bottle called “NOVUS No. 1 Plastic Clean and Shine”. Spray the bottle five inches away from the surface and evenly spread it over the entire surface.
10. Using a clean cloth, immediately buffer the surface until the surface is clean and no remaining polishing is visible.
11. Perform the same step from step (3) through step (9) for each of the ridges on the top of the lens
12. Remove the blue tap from the lens's ridges and edges. Once the tape is removed; Polish and remove the residue from the lenses by using the microfiber cloth.

Procedure for PMMA and Polycarbonate collectors:

1. Use latex gloves and place the collector on a clean protective surface such as a plastic surface to ensure no damage or scratches to the collector.
2. Starting on the flat surface of the rim of the collector as shown in figure (27), remove the surface dust with a clean, soft cloth and shake well the polishing bottle.
3. Apply the blue tap onto the side of the rim on both sides and ensure that no side surface is exposed as shown in figure (27).
4. While using a clean micro-fiber cloth, apply a moderate amount of “NOVUS No.3 Heavy Scratch Remover around the rim flat surface.
5. From the side position on the rim facing the port, apply the cloth used in step 3 with firm up-and-downstrokes while moving left to right along the rim. Reapply the “NOVUS No. 3” polishing compound as needed. Repeat step 4 until the entire rim surface has been polished and no large scratches are visible and only fine scratches remain.

6. Using a clean cloth, remove all the remaining polishing from step 4 and ensure that the rim surface is free from dust. To remove the small scratches from the lens, shake well the bottle called “NOVUS No.2 Fine Scratch Remover” and apply a moderate amount of NOVUS No 2. onto a clean microfiber cloth.
7. Starting on the same position chosen in step (5), apply the cloth described in step 5 with a firm circular clockwise motion while moving from the left to the right of the rim surface. Reapply the “NOVUS No.2” polishing compound as needed.
8. Once the surface has been covered and dried, buffer the flat rim surface with a clean cloth until no polishing residue remains on the surface. Repeat steps (5) through (7) until no scratches are visible on the surface.
9. Using a clean cloth, ensure that the flat rim surface is free from dust and shake well the bottle called “NOVUS No. 1 Plastic Clean and Shine”. Spray the bottle five inches away from the surface and evenly spread it over the entire rim surface.
10. Using a clean cloth, immediately buffer the surface until the surface is clean and no remaining polishing is visible.
11. Perform the same step from step (3) through step (9) for the flat surface of the port side of the collector as shown in
12. Remove the blue tape from the side of the collector. Once the tape is removed; Polish and remove the residue from the collector by using the microfiber cloth.

9.9 Appendix I: Coating Method Details

The coating selected as stated is the Silicon Dioxide Spray from 303 Products, chosen following the specifications and availability to be tested along with the lens. For the coating application, both lens materials selected will have two fabricated samples. The coating can be applied to one of each of the samples giving a variation of no coating and with coating.

Guidelines when working with Silicon Dioxide Spray:

Personnel that are participating in coating the selected lenses will have to adhere to the following clothing guidelines. The person applying the coating will have to wear a mask so they may not inhale fumes of the coating during the application; they also will wear gloves not to stain their hands

Procedure:

For our coding application will be using silicon dioxide as shown the source of silicon dioxide will be applied using a hand pump pressurized spray the spray can spray of even coating by Fanning the coating through its nozzle this will first work by placing the solution within the can then hiding the spray you're on the can and I'm pumping the spray so that it may be pressurized the silicon dioxide that now has been pressurized will then be sprayed onto the lens by Fanning it three times over the lens just woke to happen for both models of Poa and polycarbonate as soon as it has been fanned over the water will be then sprayed onto the actual lens until a beating effect occurs this will indicate that the coating has now bonded to the lens

9.10 Appendix J: CAD of Test Bench Components

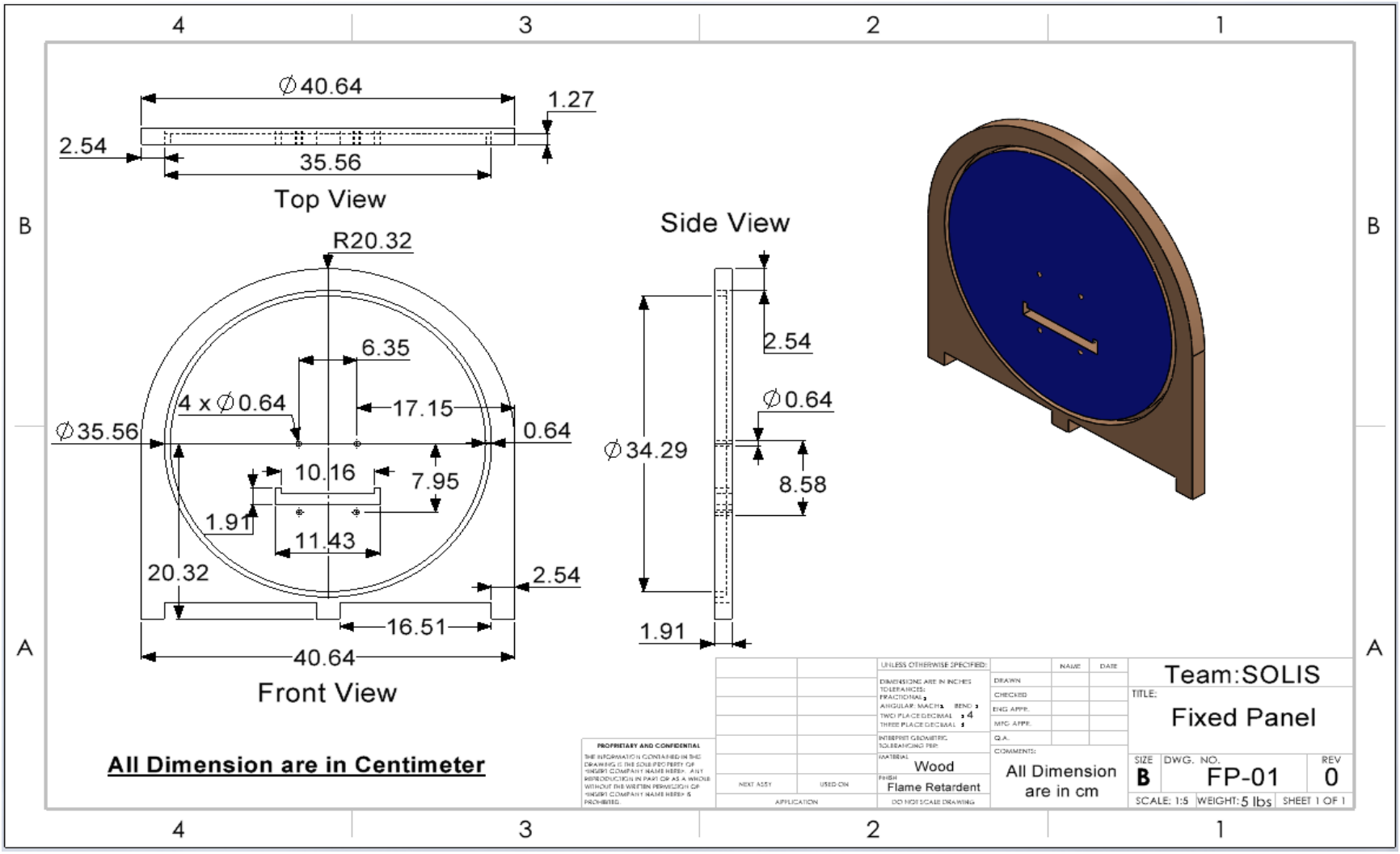


Fig J1. CAD Drawing Sheet of the Fixed Panel.

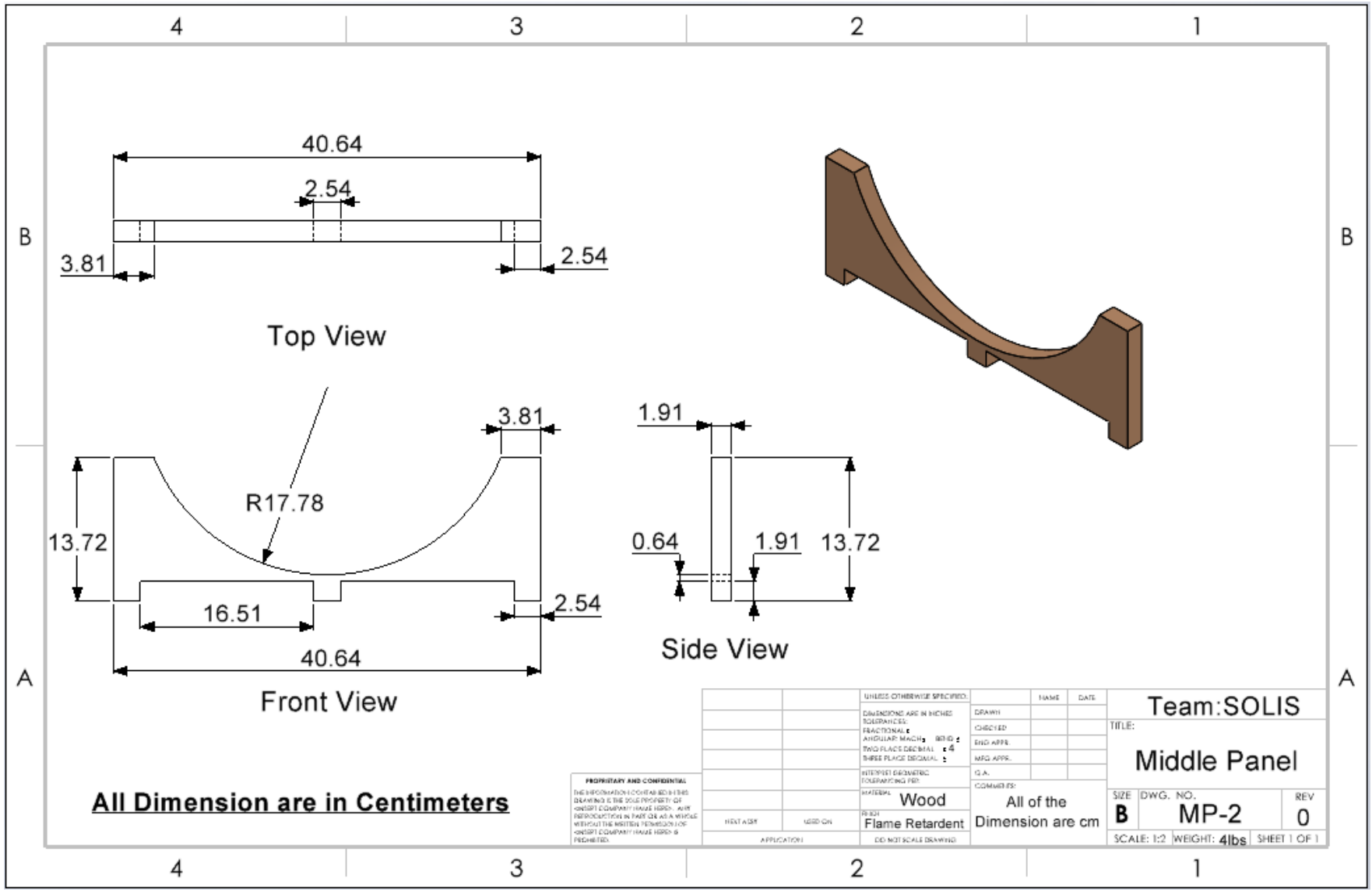


Fig J2. CAD Draft Sheet of the Middle Panel.

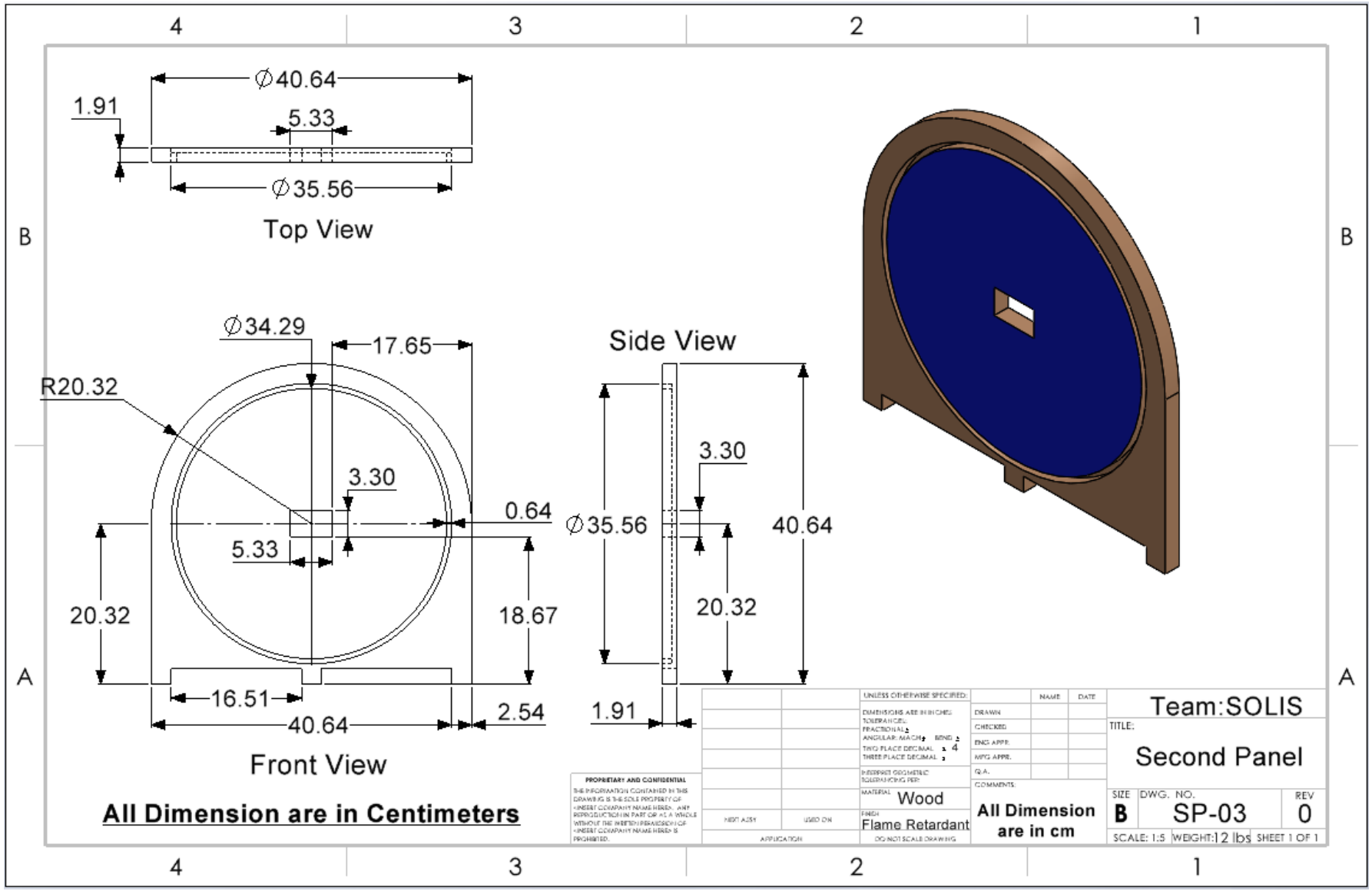


Fig J3. CAD Draft Sheet of the Second Panel.

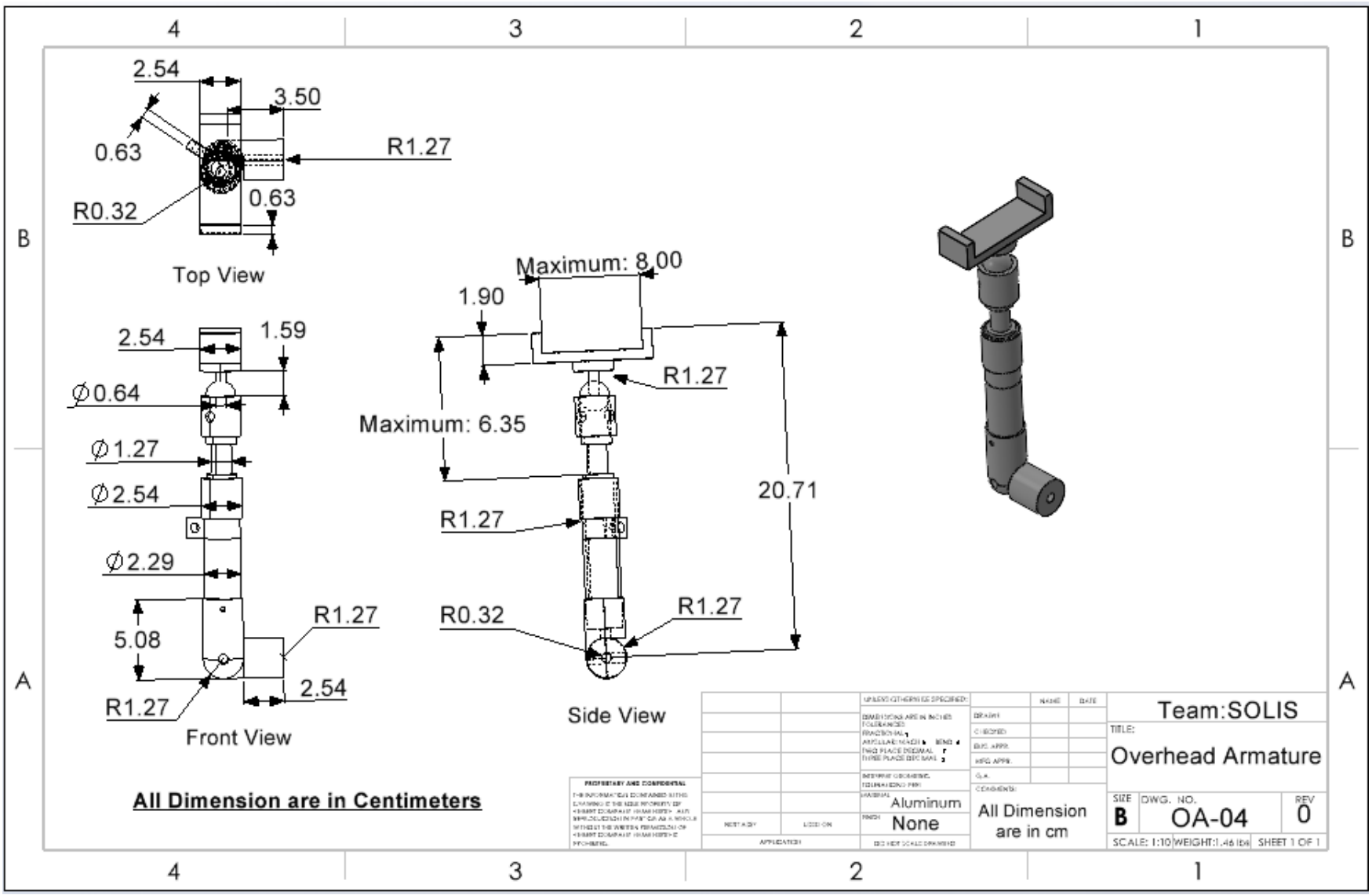


Fig J4. CAD Draft Sheet of the Overhead Armature.

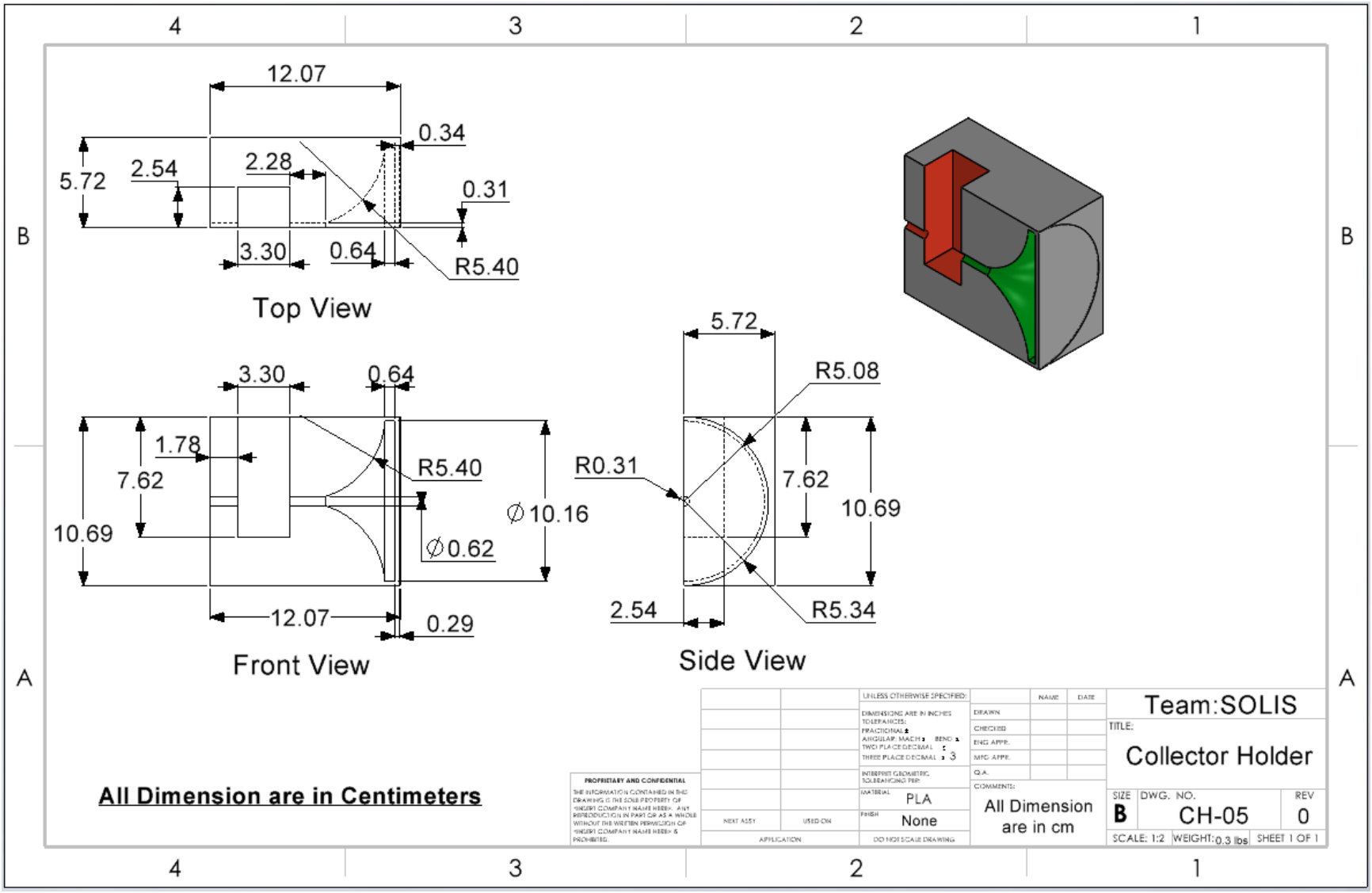


Fig J5. CAD Draft Sheet of the Collector Holder.

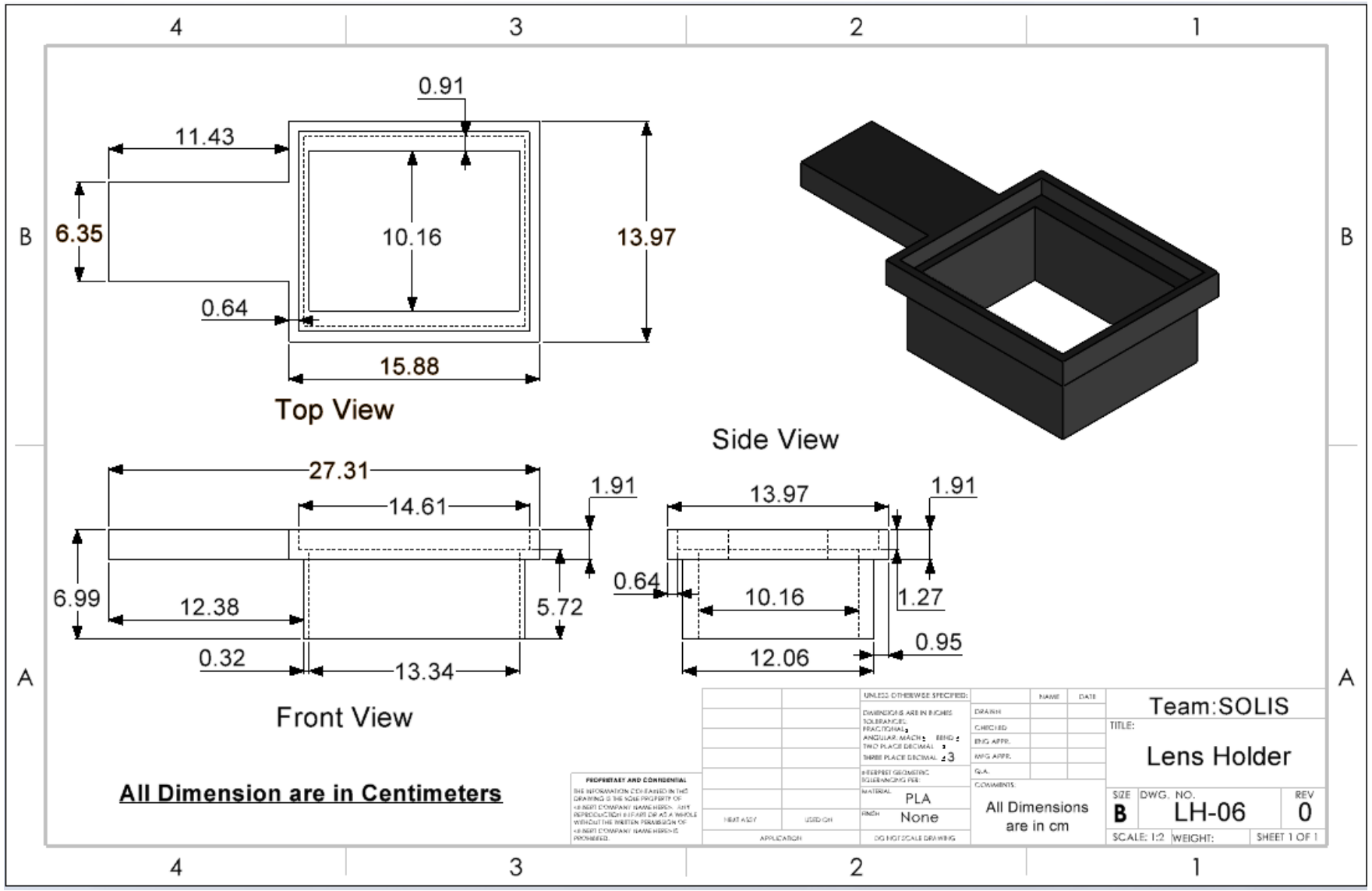


Fig J6. CAD Draft Sheet of the Lens Holder.

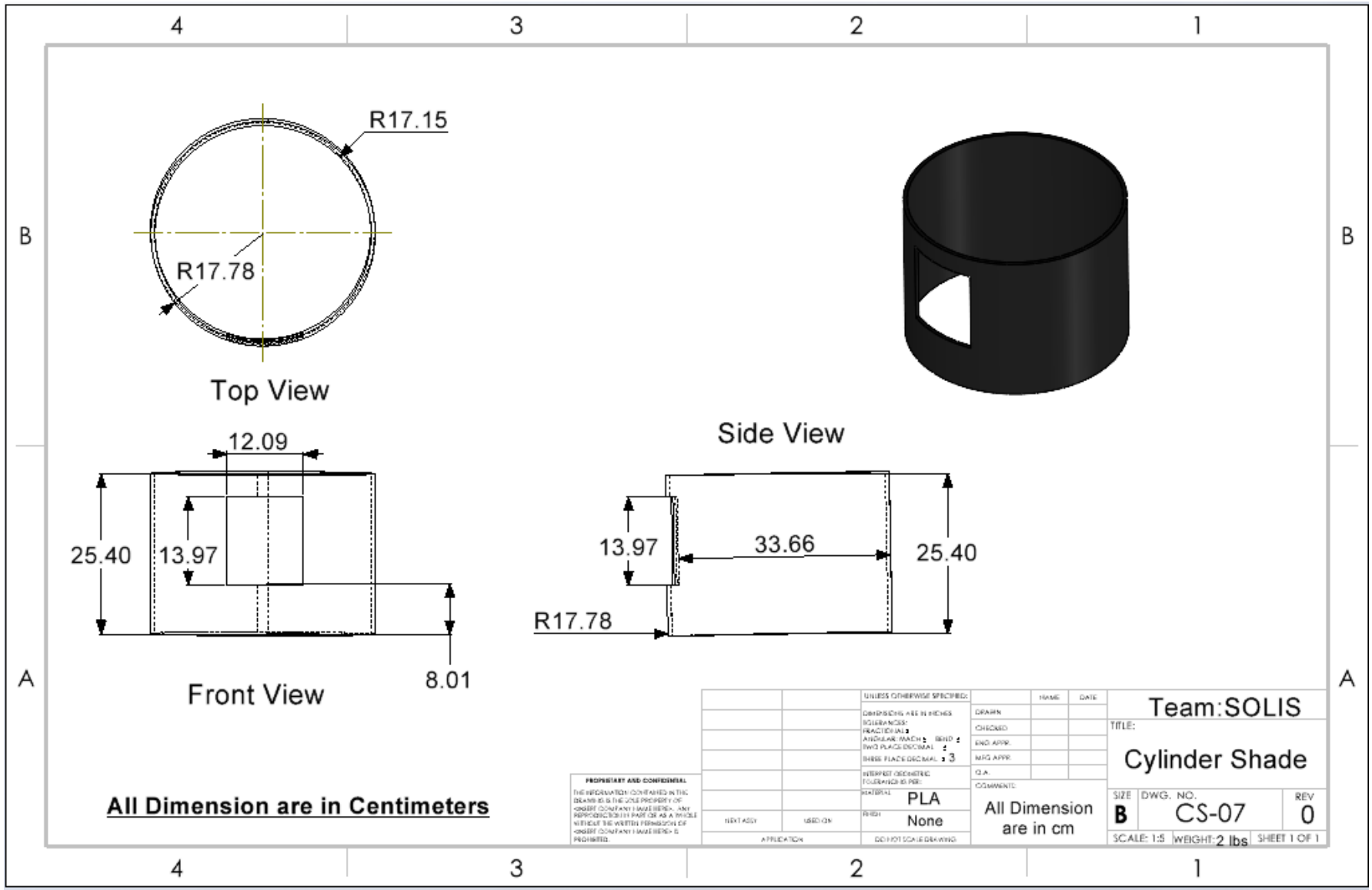


Fig J7. CAD Draft Sheet of the Cylinder Shade.

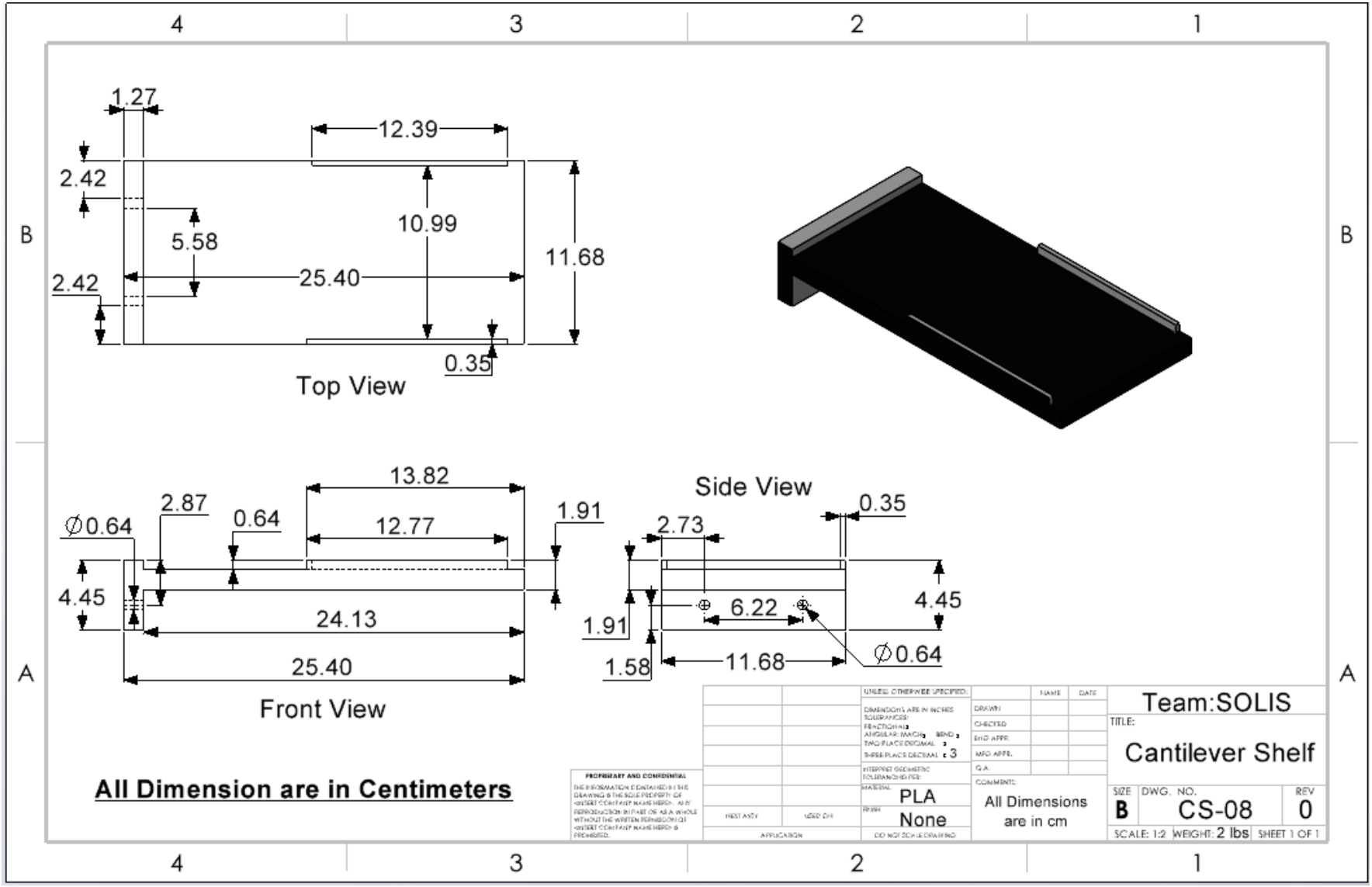


Fig J8. CAD Draft Sheet of the Cantilever Shelf.

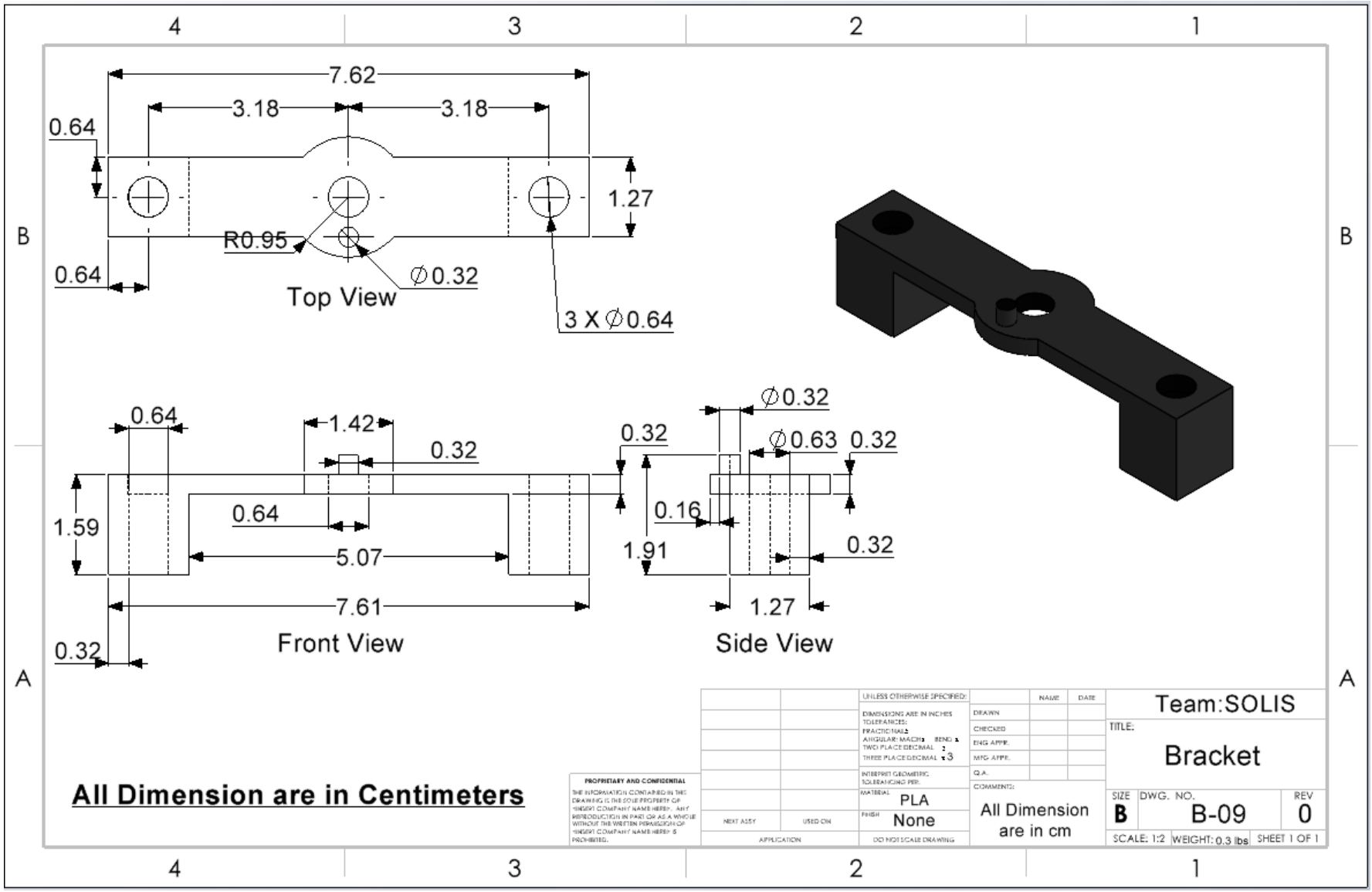


Fig J9. CAD Draft Sheet of the Bracket.

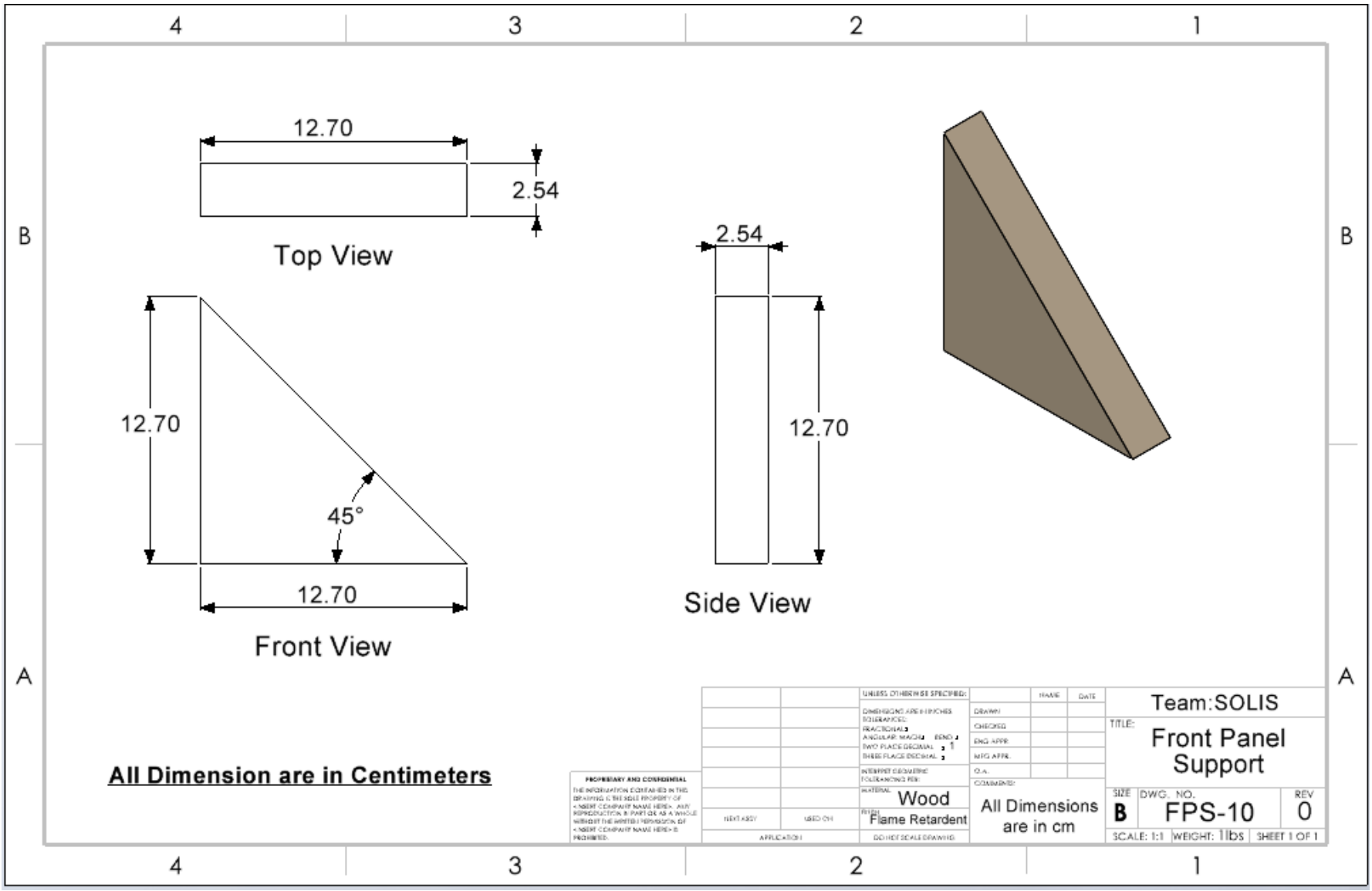


Fig J10. CAD Draft Sheet of the Front Panel Support.

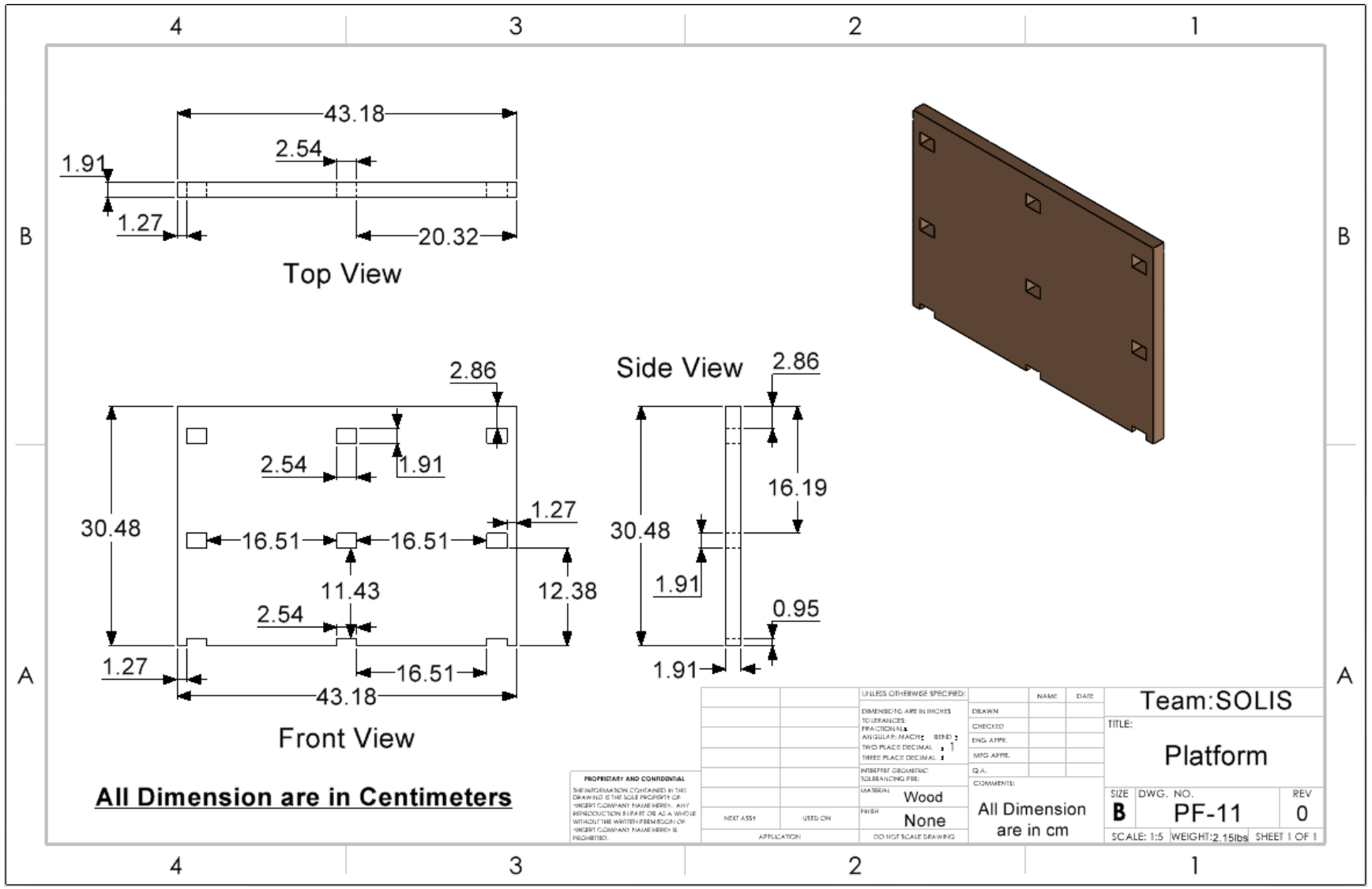


Fig J11. CAD Draft Sheet of the Platform.

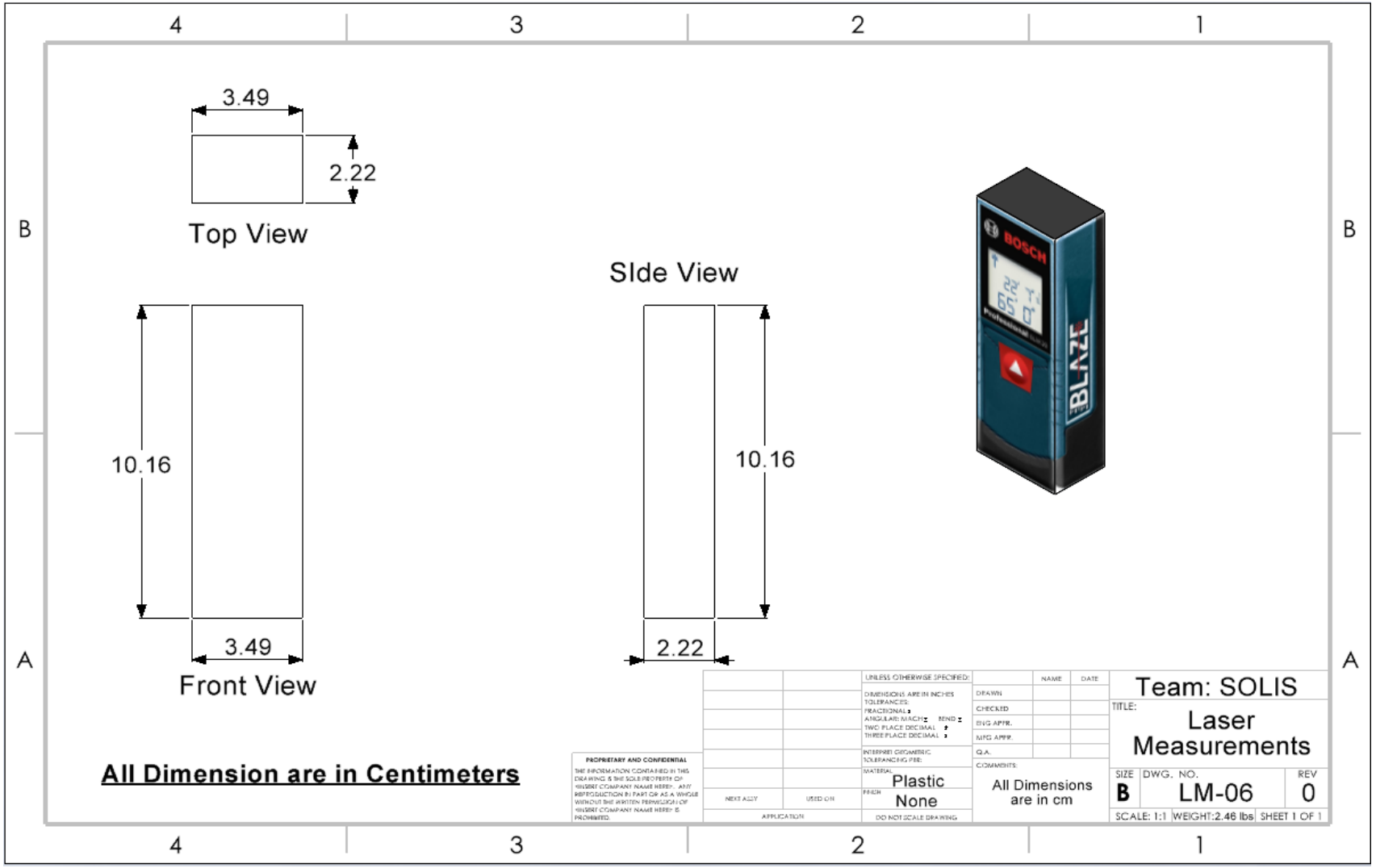


Fig J12. CAD Draft Sheet of the Laser Measurements Device.

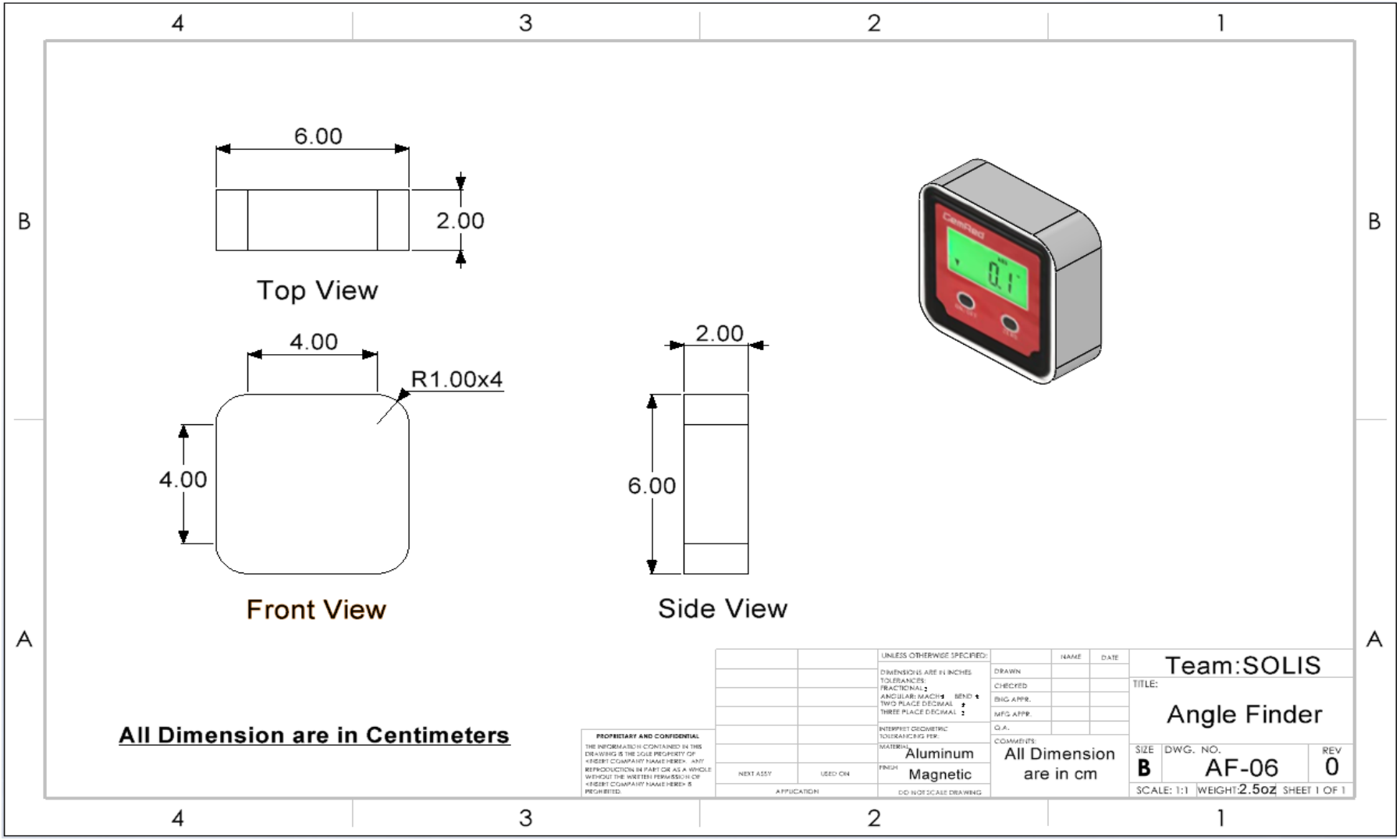


Fig J13. CAD Draft Sheet of the Angle Finder Device.

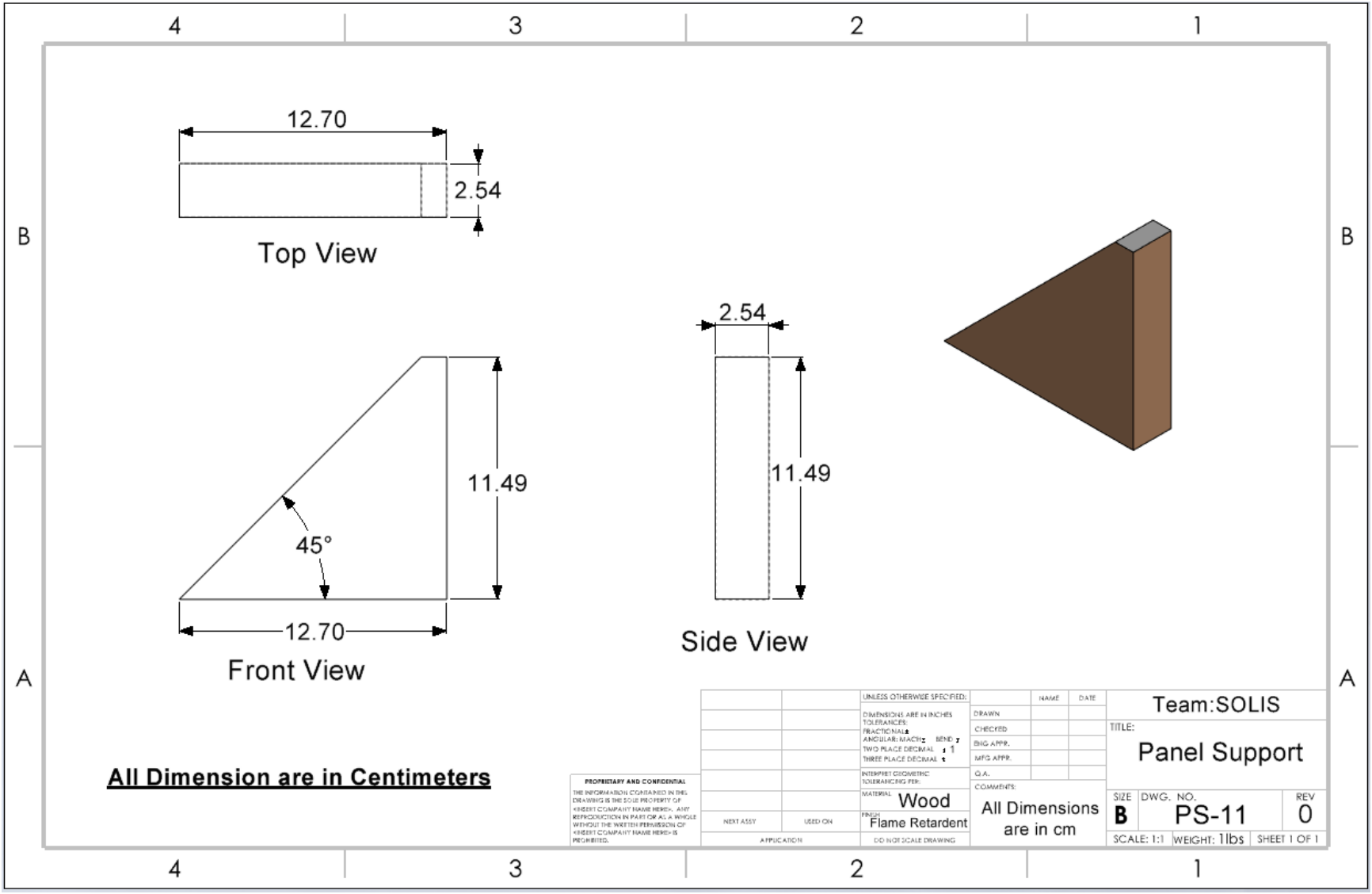


Fig J14. CAD Draft Sheet of the Support Panel.

9.11 Appendix K: Manual Assembly of Test Bench Components

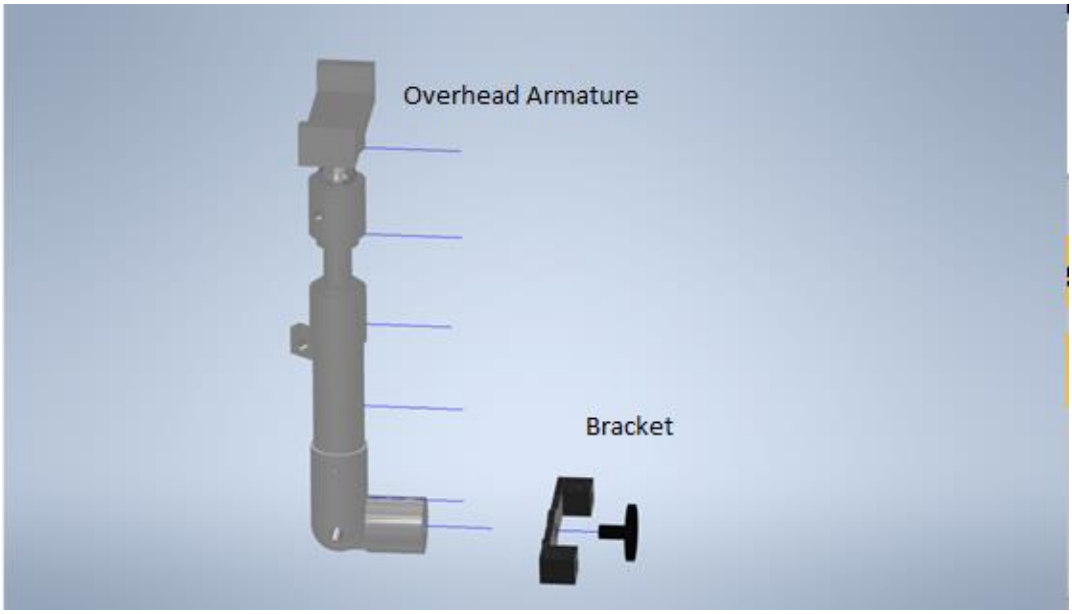


Fig K1. Attach the overhead armature to the bracket.

First, attach the overhead armature to the bracket using the quarter-inch knob. Tightening the following knob will cause the overhead armature to stay fixed and not allow it to rotate. To rotate the armature, the knob must be loosened slightly.

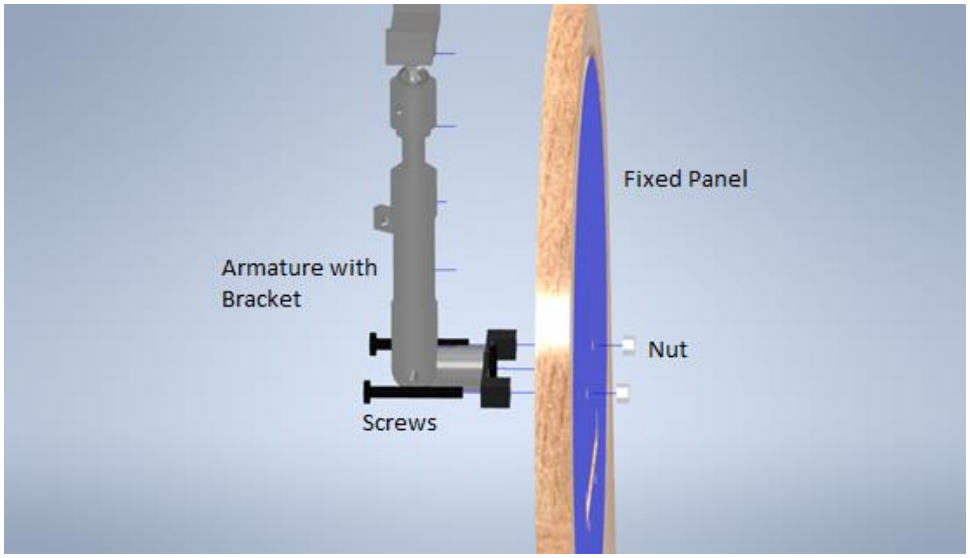


Fig K2. Mount bracket with the overhead armature to the fixed panel.

Mount the bracket, which now has the armature attached, to the fixed panel from the outside with two of the 2-inch machine screws. Next, take the ¼ inch diameter nuts and fasten the machine screws from the other side till the bracket is secured.

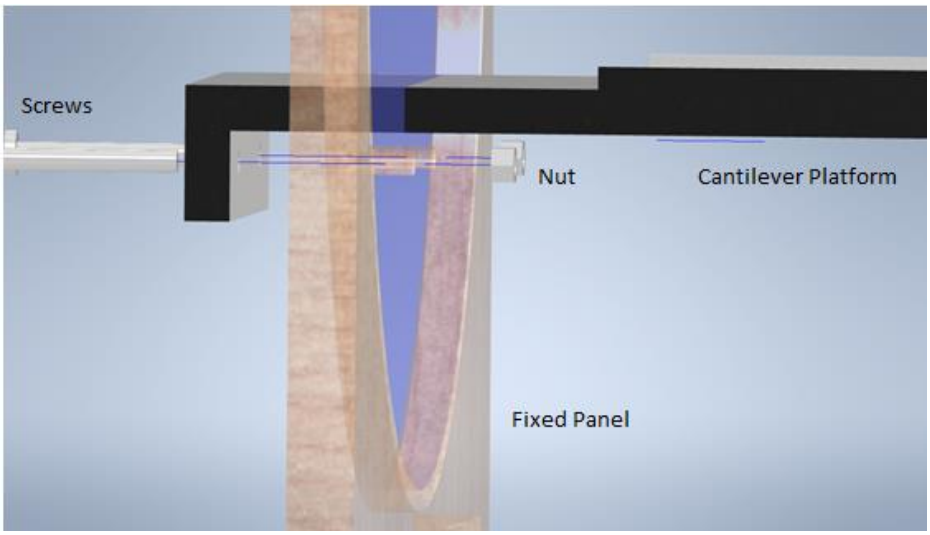


Fig K3. Mount the cantilever platform to the fixed armature.

Slide the cantilever platform through the fixed panel and secure it with two 2-inch machine screws. Next, take the ¼ inch diameter nuts and fasten the machine screws from the other side till the cantilever is secured.

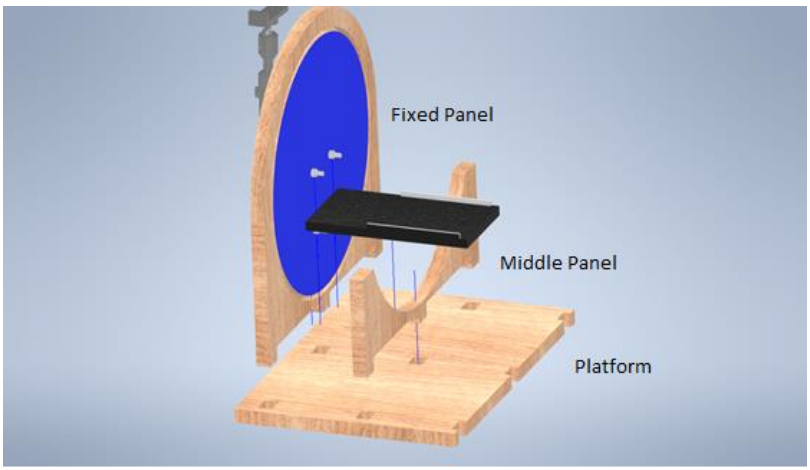


Fig K4. Insert the fixed panel and middle panel in the platform.

attach the fixed panel and middle panel to the platform by placing the legs of each panel in the slots as shown in the above figure.

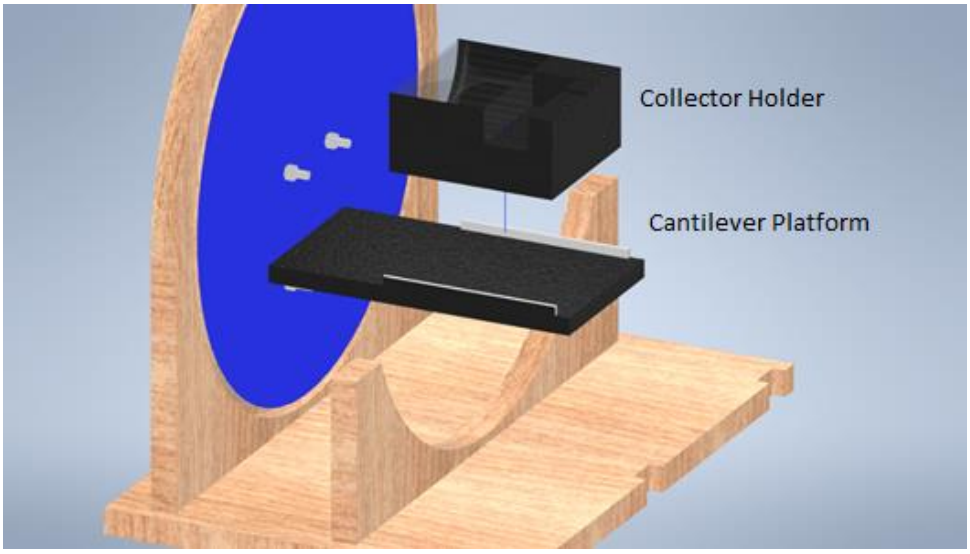


Fig K5. Attach the collector holder to the cantilever platform.

Next, place the collector holder on the cantilever platform and place it within the raised edges. Ensure the velcro strips under the holder are attached to the cantilever platform and secure.

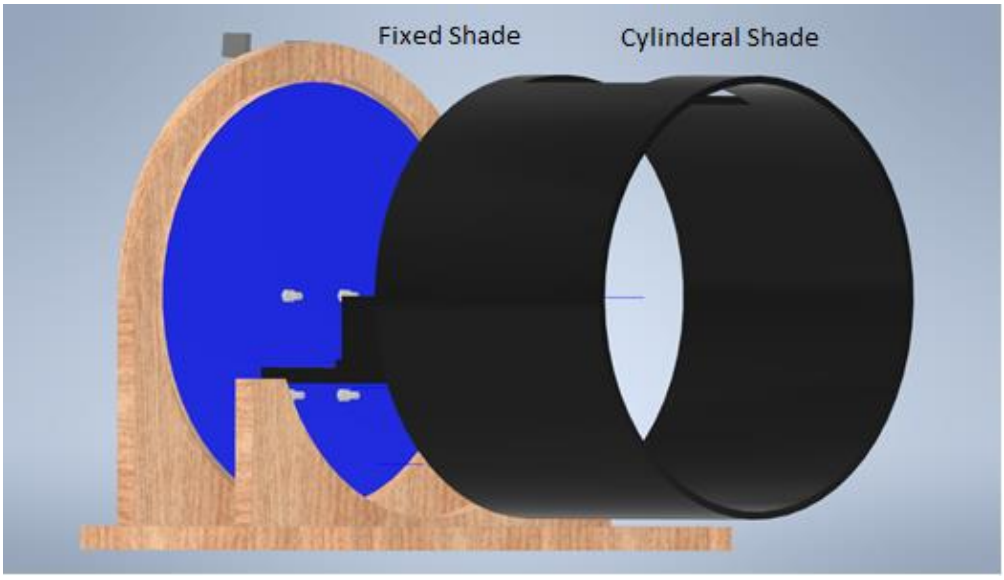


Fig K6. Insert the cylinder light shade in the fixed panel.

Next, place the cylinder light shade by inserting it within the recessed circular edge of the fixed panel. The cylinder shade will rest on the middle panel for additional support.

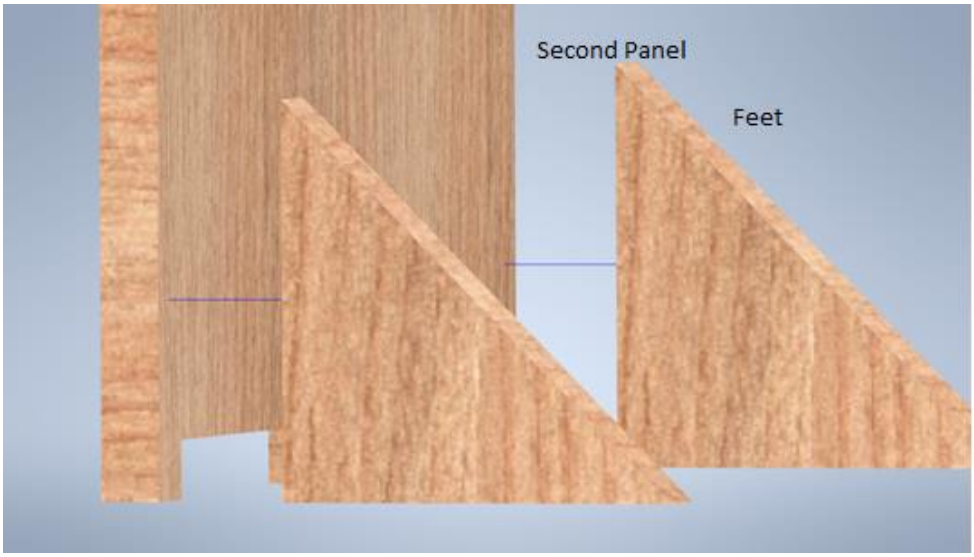


Fig K7. Attach the feet to the second panel.

Attach the following feet to the second panel by using wood glue. The feet are used to keep the panel in place since it will not be fixed on the platform

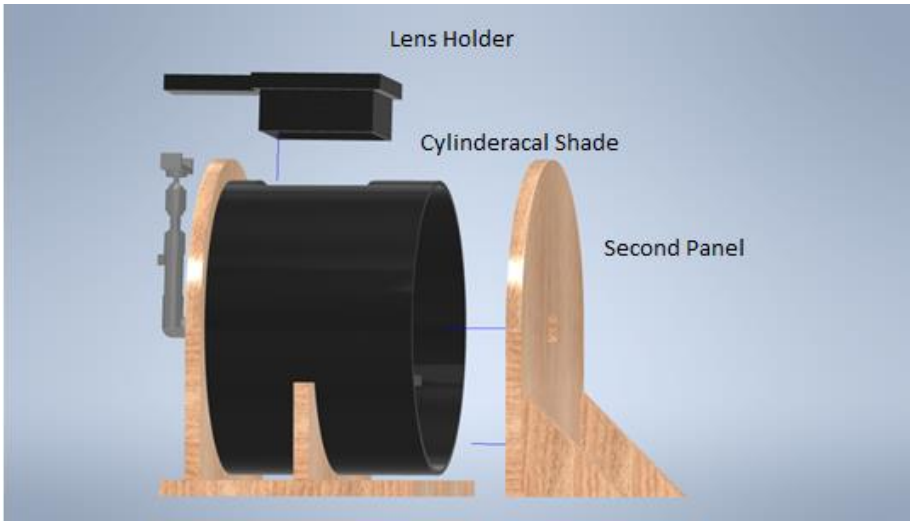


Fig K8. Attach the lens holder to the overhead armature and insert the second panel into the cylinder and platform.

Attach the lens holder to the overhead armature's clamp and the second panel into the plate form by sliding it into the platform opening. The cylinder shade will rest within the circular recessed groove of the second panel.

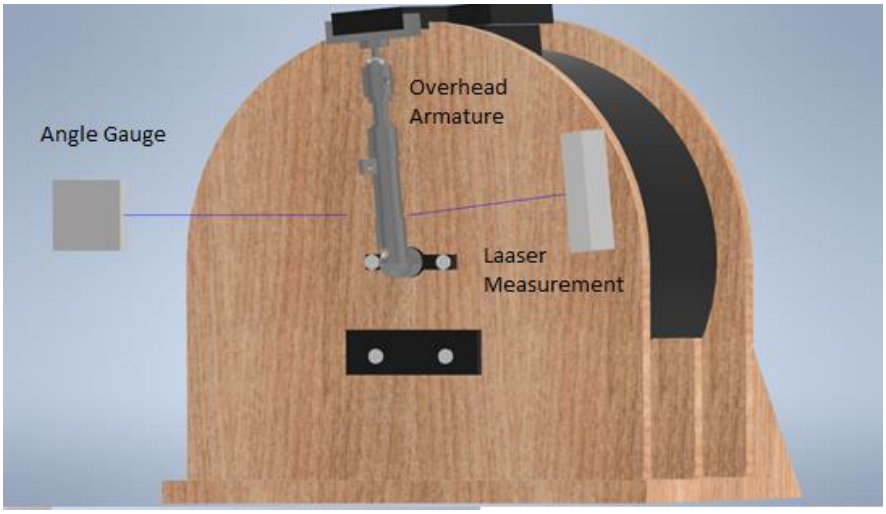


Fig K9. Attach the angle gauge and laser measurement device to the overhead armature.

Finally, attach the angle gauge and laser measurement device to opposing sides of the overhead armature. The angle gauge will attach by a magnet on its bottom to the aluminium of the armature, while the laser measurement device will attach with a velcro strip to the armature.

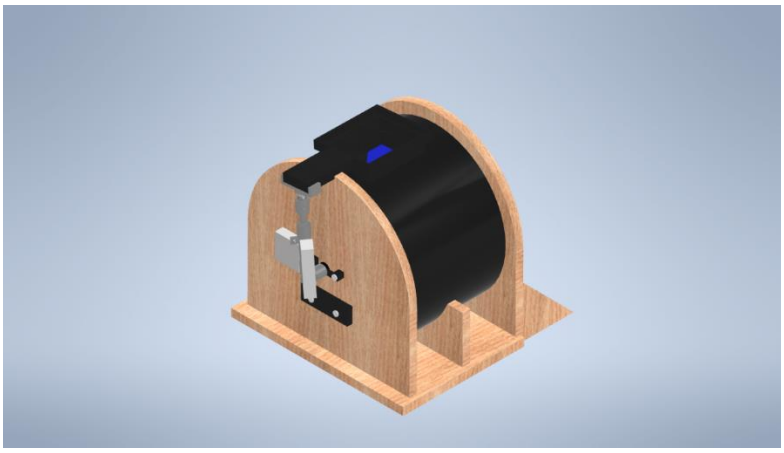


Fig K10. Test Bench fully assembled.

9.12 Appendix L: Design Calculations

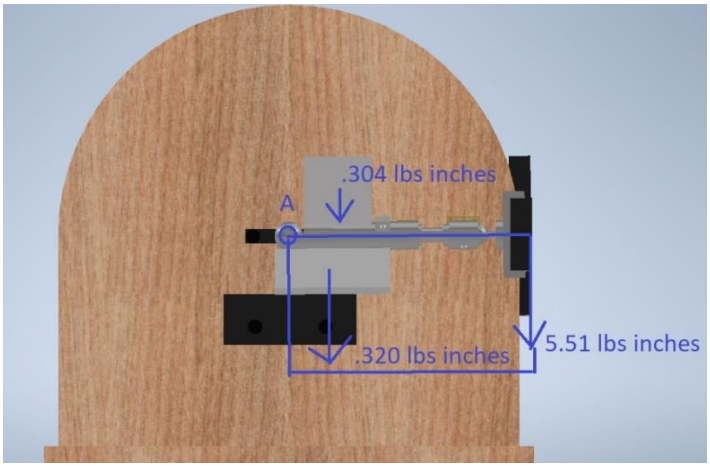


Fig L1. Overlay Diagram of moment impact on the overhead armature.

Using the moment diagram shown in figure J1, the reaction moment at a point can be found.

$$.304\ lbs\ inches\ +\ .320\ lbs\ inches + 5.51\ lbs\ inches = A = 6.13\ lbs\ inches \quad \text{(Equation 1)}$$

As shown in equation 1, the moment at point A is 6.13 lbs. inches or .459 lbs. ft. Since the torque resistance of the screw placed at point A is 7 lbs. ft, which exceeds .459 lbs. ft, it can be justified that the overhead armature will remain at its locked position.

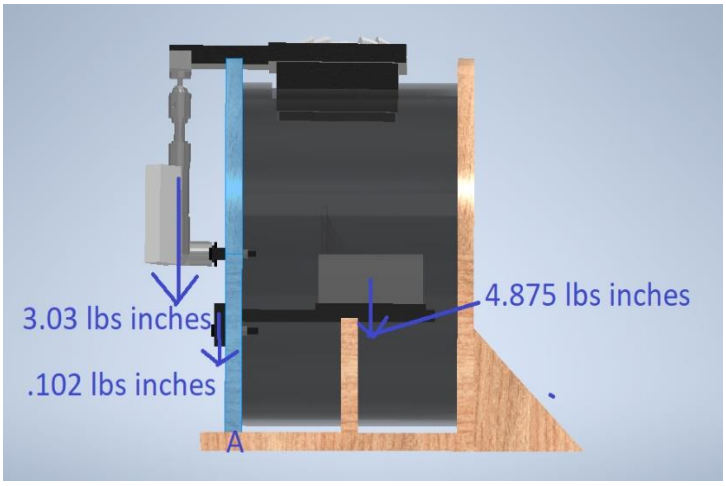


Fig L2. Overlay Diagram of moment impact on Fixed Panel.

$3.03\ lbs\ inches\ +\ .102\ lbs\ inches - 4.875\ lbs\ inches = A = -1.739\ lbs\ inches$ Equation 2

As shown in equation 2, the moment at point A is -1.739 lbs. inches or .145 lbs. ft. Since the torque resistance of the pegged portion of the panel in the platform is 8 lbs. ft placed exceeds point A, it can be justified that the Fixed Panel will remain at its position and will not tilt to either side

9.13 Appendix M: Testing Bench Modifications for As-built Model

The test bench when under three modifications. The first modification was adding the front panel support to either side of the front panel as shown in Figure L1 below.

Figure M1. Shows the test bench assembly with the new addition of front panel supports.

The second modification was the change in material used to construct the cylindrical shade from PLA to galvanized steel. The Shade was constructed by rolling a piece of steel to a cylinder and then welded. Next a cutout was made for the lens holder to be placed in. Finally it was painted with non reflective black paint so it would mitigate the effect internal refraction.

Figure M2. Shows the new cylindrical shade made of galvanized steel that was shaped and painted with non-reflective black paint.

The third modification was the addition of adding hinges at the second panel and platform. This helps the second panel stay in place and maintain the composure of the testing bench device.

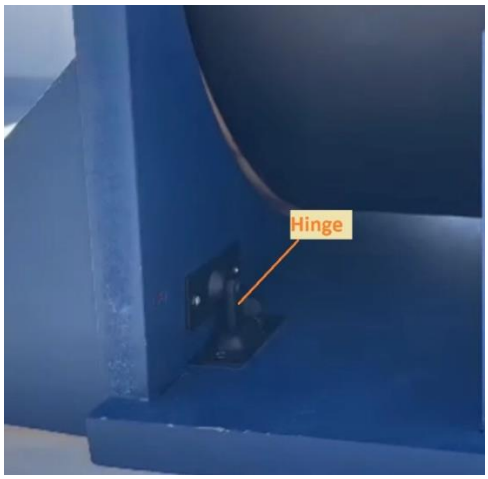


Figure M3. Shows the hinges being used to connect the second panel to the platform on either side of the test bench.

9.14 Appendix N: Quality Assurance Testing

Once the lenses in collectors have been fabricated made of CNC Machining and the test bench has been assembled the next step is to do quality assurance of the lenses and collectors to determine whether the dimensions requirements have been met and the functionality of the lenses and collectors are following as intended

The first step will be to take measurements of the dimensions of the lenses from the highest point of each Ridge perpendicular to the bottom face of the lens as shown in the picture from figure M1.

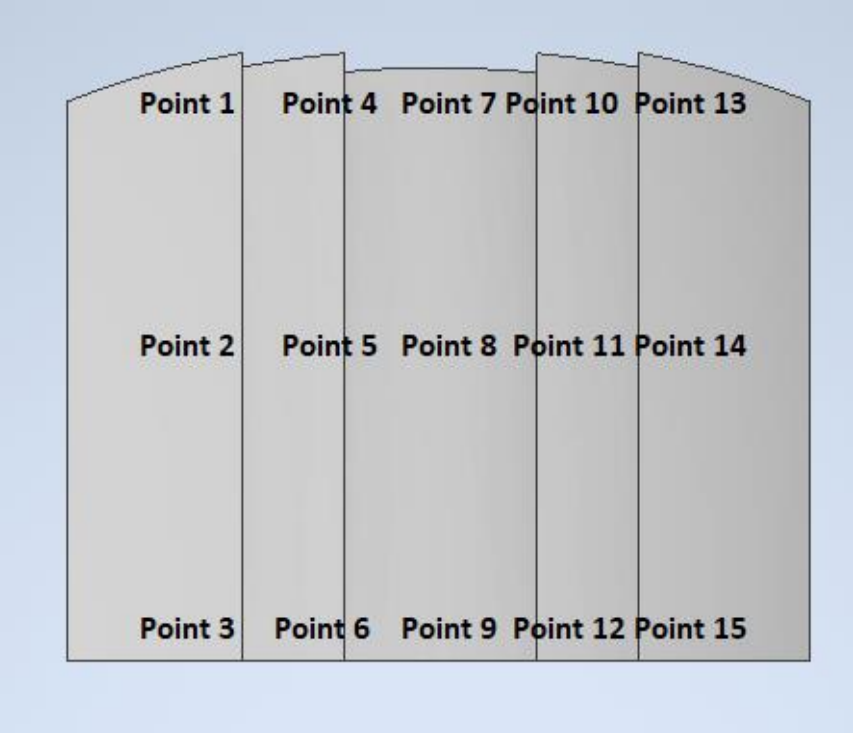


Figure N1. Shows the points for the caliper for the lens

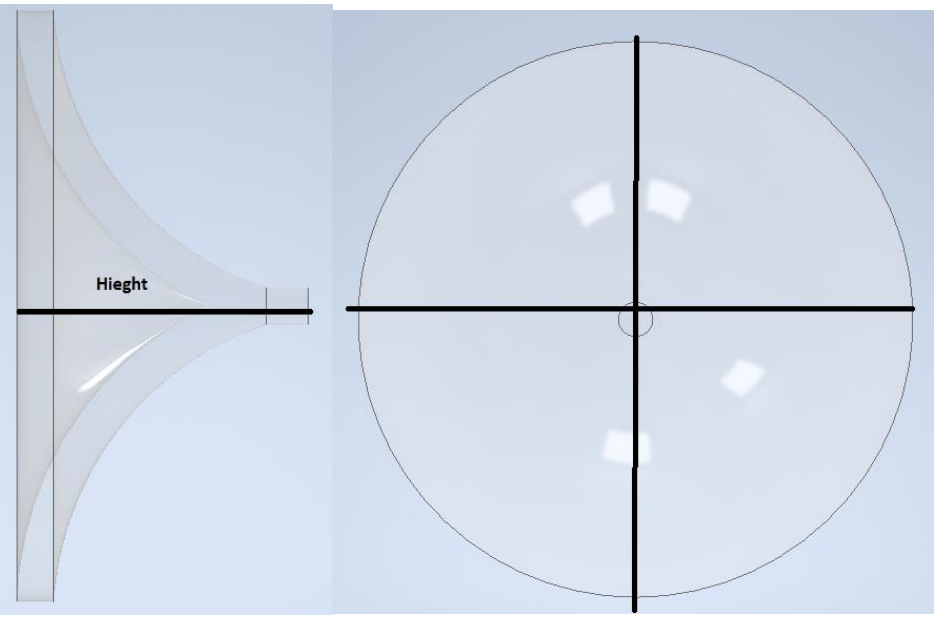


Figure N2. Shows the points for the caliper for the Collector

these measurements will be taken at the CNC model stage and then after polishing the lens another measurement will be taken at the same points. Furthermore, if the lens must be coated the same method will be taken for measurements as well this will help determine if there are any deviations in the processing of the lens during its fabrication process.

The next step will be to test its functionality this will be done by placing a lens in the test bench as intended for its actual procedure and its performance testing.

1. In order to do this, the lenses will be placed in the lens holder and the second panel will be removed from the actual test bench

2. A lux meter will be placed at the center point of the test bench on top of the collector holder this will allow for the Lux meter to be placed at the exact focal region of the lens.

3. The Next Step will be to make sure that this is quality assurance is conducted in a dark room where there is no ambient light

4. A lamp will then be positioned over the lens 4 inches above it and will be directed through the lens towards the focal region

5. Once directed from the focal reason the read then using the Lux meter. This test will be conducted before polishing then after polishing and if a coating is applied to the lens, then after coating.

The Collector after being CNC will be measured along the rim and the exit port of The Collector and the height of the collector will be taken at 90-degree intervals of the rim of the collector and similarly for the exit port and then the height once that is done the polishing method will also occur and then it will be measured again.

Similarly for the quality assurance test in laser testing a similar test will be conducted where the Lux meter will be placed at the exit port of The Collector and they will be no ambient light and a laser will be shined at the rim of the collector and the reading will be taken this will occur at 60-degree intervals next just as mentioned prior The Collector will be polished at the rim and the exit port and the test will be conducted again

9.15 Appendix O: Quality Assurance Specifications Sheet

Acrylic Lens A

CNC Model

Length	Width
125.85	140.63

Trial 1		(mm)			
Length (mm)	15.02	16.93	13.00	16.98	15.65
	15.23	17.39	13.50	17.28	15.87
	14.95	16.75	13.09	17.00	15.48

Polished Model

Length	Width
121.41	140.61

		Width			
Length	15.02	16.47	12.48	16.52	14.59
	15.84	17.49	13.34	17.33	15.23
	15.08	16.32	12.61	16.74	14.93

Coated Model

Length	Width
121.93	140.06

		Width			
Length	15.14	16.69	12.45	16.43	14.38
	16.14	17.82	12.98	17.06	15.08
	15.64	16.57	12.75	16.47	14.74

Lamp Test

Condition	Lux
No lens	876
CNC lens	1129
Polished lens	1233

Acrylic Collector A

CNC

Angle 1-Angle 2 (Degree)	Diameter (mm)
0-180	101.69
90-270	101.69
diameter of stem	6.39
Height	51.62

Polished

Angle 1-Angle 2 (Degree)	Diameter (mm)
0-180	102.55
90-270	101.65
diameter of stem	6.47
Height	51.06

CNC

Angle	Lux (x100)
0	108
60	110
120	125
180	120
240	119
300	116

Polished

Angle	Lux
0	222
60	231
120	225
180*	112
240	180
300	212

Acrylic Lens B

CNC Model

Length	Width
129.56	138.52

Trial 1		(mm)			
Length (mm)	14.78	16.11	12.00	16.25	14.64
	15.28	15.37	10.90	15.30	13.57
	14.88	16.41	11.90	16.15	14.38

Polished Model

Length	Width
129.68	138.30

		Width			
Length	14.76	15.22	12.42	15.55	13.29
	15.58	14.88	11.33	14.33	12.88
	13.50	16.17	12.67	15.21	15.61

Lamp Test

Condition	Lux
No lens	876(+-10)
CNC lens	1136
Polished lens	1245

Acrylic Collector B

CNC

Angle 1-Angle 2 (Degree)	Diameter (mm)
0-180	101.79
90-270	101.93
diameter of stem	6.19
Height	47.69

Polished

Angle 1-Angle 2 (Degree)	Diameter (mm)
0-180	101.79
90-270	101.93
diameter of stem	6.19
Height	47.69

CNC

Angle	Lux (x100)
0	140
60	170
120	213
180	205
240	175
300	123

Polished

Angle	Lux
0	172
60	242
120	225
180*	227
240	230
300	222

Polycarbonate Lens A

CNC Model

Length	Width
118.84	140.75

Lens A		(mm)			
Length (mm)	18.41	18.14	12.94	18.03	18.15
	18.25	17.38	12.46	17.73	17.82
	18.76	17.81	12.95	17.66	18.71

Polished Model

Length	Width
117.01	138.66

Lens A	Width (mm)				
Length (mm)	18.78	18.55	13.15	17.92	19.05
	17.75	18.79	12.35	16.68	18.40
	17.50	18.10	13.07	18.33	18.84

Lamp Test

Condition	Lux
No lens	876(+-10)
CNC lens	855(+-10)
Polished lens	970(+-10)

Coated Model

Length (mm)	Width (mm)
118.84	140.54

	Width (mm)				
Length (mm)	17.96	17.10	12.72	17.24	18.85
	17.54	17.29	12.18	16.72	17.96
	18.10	18.22	13.33	18.05	18.11

Lamp Test

Condition	Lux
No lens	876(+-10)
CNC lens	813(+-5)
Polished lens	1090
Coated Lens	1001

Polycarbonate Collector A

CNC

Angle 1-Angle 2 (Degree)	Diameter (mm)
0-180	101.8
90-270	101.9
diameter of stem	5.78
Height	50.65

Polished

Angle 1-Angle 2 (Degree)	Diameter (mm)
0-180	101.62
90-270	101.57
diameter of stem	5.76
Height	49.66

CNC

Angle	Lux (x100)
0	93
60	117
120	116
180	103
240	121
300	112

Polished

Angle	Lux
0	103
60	123
120	120
180*	162
240	130
300	120

Polycarbonate Lens B

CNC Model

Length	Width
101.54	138.77

Trial 1		(mm)			
Length (mm)	18.18	17.95	13.00	17.88	18.06
	17.85	17.81	12.37	17.91	18.45
	18.03	18.41	13.04	17.67	18.67

Polished Model

Length	Width
101.54	138.77

		Width			
Length	17.96	17.87	12.75	17.24	18.43
	18.00	18.79	11.42	17.54	19.56
	18.21	17.71	12.80	18.10	18.68

Polycarbonate Collector B

CNC

Angle 1-Angle 2 (Degree)	Diameter (mm)
0-180	101.66
90-270	101.76
diameter of stem	6.13
Height	52.35

Polished

Angle 1-Angle 2 (Degree)	Diameter (mm)
0-180	101.78
90-270	101.59
diameter of stem	6.13
Height	52.35

CNC

Angle	Lux (x100)
0	84
60	80
120	78
180	92
240	102
300	83

Polished

Angle	Lux
0	144
60	121
120	112
180*	119
240	120
300	105

9.16 Appendix P: Safety Procedure for Handling the Fresnel Lens and Performing Testing

Safety when polishing and applying the coating

Wearing personal protective equipment is safety glasses and gloves. Use the bottom side of the buffing wheel and apply gentle pressure.

Safety Protocol when performing testing

When performing testing or operating on any system that uses the Fresnel lens, the Fresnel lens concentrates the sunlight by using the groves of the Fresnel lens to bend the light into a focal point. This concentration on the focal point concentrates not only on the light but also on heat. This heat can depend on the type of material, the geometric design, and the sizing of the Fresnel lens. Depending on these parameters, the heat coming from the Fresnel lens focal point can have the potential to cause fire or melt materials. Another critical factor to look at is the glare that the concentrated Fresnel lens emits. This glare can cause blindness from prolonged exposure to the glare. Therefore, a safety parameter or protocol was constructed to ensure the handling and safety use of the Fresnel lens. The protocol is stated as the following:

1. Do not leave the Fresnel lens unattended or directly under the sun when not in use.
2. Unauthorized personnel cannot operate or handle the Fresnel lens testing bench.
3. Unauthorized personnel must be 8 feet away from the testing bench while in use.
4. The Fresnel lens must be stored or transported in a secured casing or box that will not allow light to reach the Fresnel lens.
5. In an emergency such as a fire, cover and remove the Fresnel lens from the testing bench.

6. To protect from glare, dark visor, or anti-glare such as welding, goggles must be worn by everyone around the vicinity of the Fresnel lens.
7. To protect from heat for handling 100 degrees Celsius, the collector must wear heat resistant gloves.
8. Due to the heat being produced, don't focus on the Fresnel lens onto one or anything not meant for its intended purpose.
9. High temperature, high glare, keep distance symbols

9.17 Appendix Q: Testing Environment

The weather condition that the testing bench is performing under can influence the lens performance and the amount of heat that is being transferred. The contributing weather factor that can influence the lens performance is the ambient temperature, the gust or wind present and the sky coverage or the number of clouds that is disrupting the testing. Therefore, classification is needed to group testing data with similar weather conditions that will show how the environment condition is affecting the performance of the lens and collector. The classification is broken down into five categories with category one being less than ideal conditions that can greatly influence the performance of the lens and collector while category 5 is the ideal weather condition that mitigates the environmental factor of the test. The two conditions that have the biggest impact on the besting bench are sky coverage and wind speed. Therefore, either the sky coverage or the wind speed will lower the weather condition category of the test.

For a category 1 weather condition, the weather conditions are consisted of temperature being lower than 50-degree Fahrenheit, wind speed being greater than 30 miles per hour and a sky coverage greater than 60 percent.

For a category 2 weather condition, the weather conditions are consisted of temperature being between 50-to-60-degree Fahrenheit, wind speed being between 10 to 20 miles per hour and sky coverage between 30 to 60 percent.

For a category 3 weather condition, the weather conditions consist of temperature between 60-to-70-degree Fahrenheit, wind speed being between 14 to 20 miles per hour and sky coverage between 10 to 20.

For a category 4 weather condition, the weather conditions are consisted of temperature being 70-to-80-degree Fahrenheit, wind speed being between 6 and 10 miles per hour and sky coverage between 6 to 14 percent.

For a category 5 weather condition, the weather conditions are consisted of temperature being 70-to-80-degree Fahrenheit, wind speed being less than 5 miles per hour and a sky coverage lower than 5 percent.

Weather that involves temperatures higher than 90-degree Fahrenheit or rain will negatively affect the testing result and parameter.

The weather condition for the four days that the testing bench was performed under can be seen in figure (P1) through figure (P4) that is used to organize or group the data set. The weather graph that is provided is an hourly graph that shows the temperature, wind speed, and sky coverage for each of the testing days that was provided by the National Weather Service Forecast for Houston and Galveston Texas [7].

The figure is shown in figure (P5) through (P10) is the weather condition that we observed during the testing days that reflect the different weather category that was followed

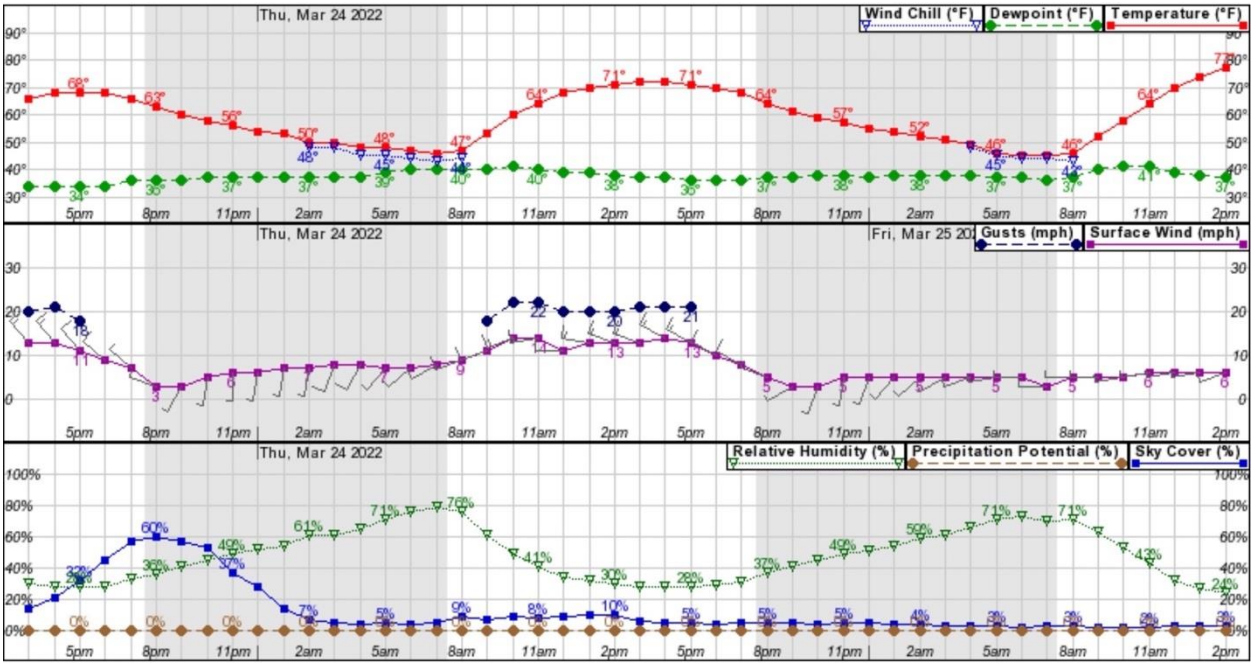


Fig Q1. Hourly Weather Graph Day 1 of Testing for March 23th of 2022.

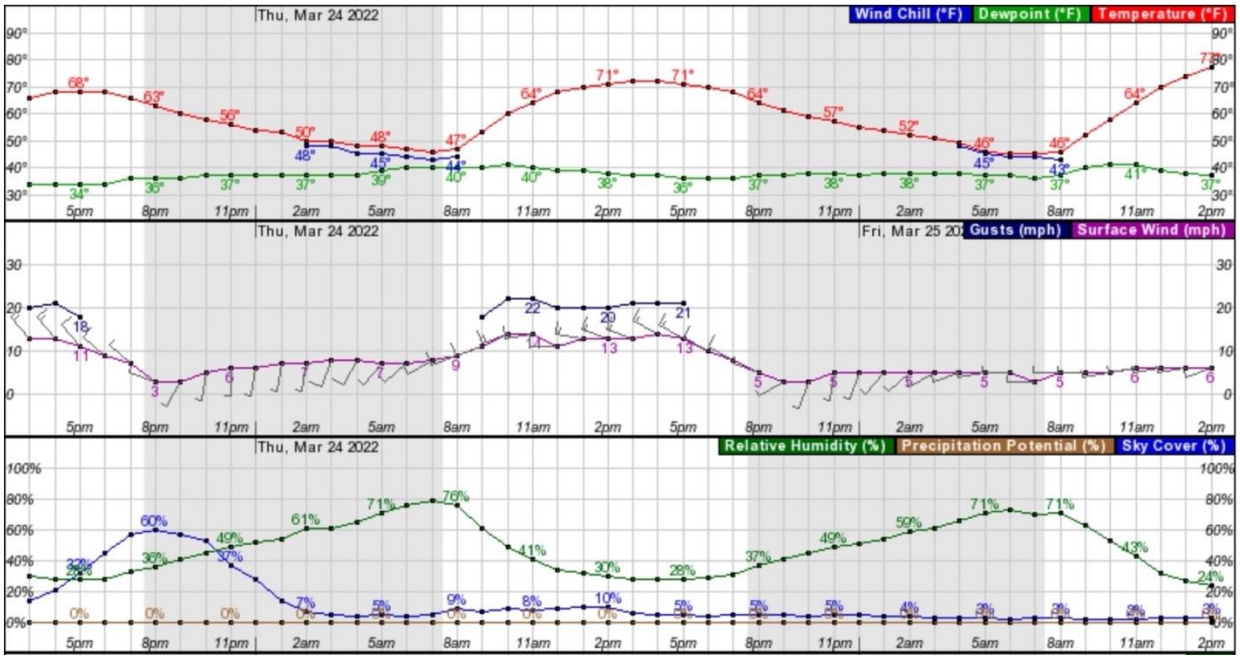


Fig Q2. Hourly Weather Graph Day 2 of Testing for March 24th of 2022.

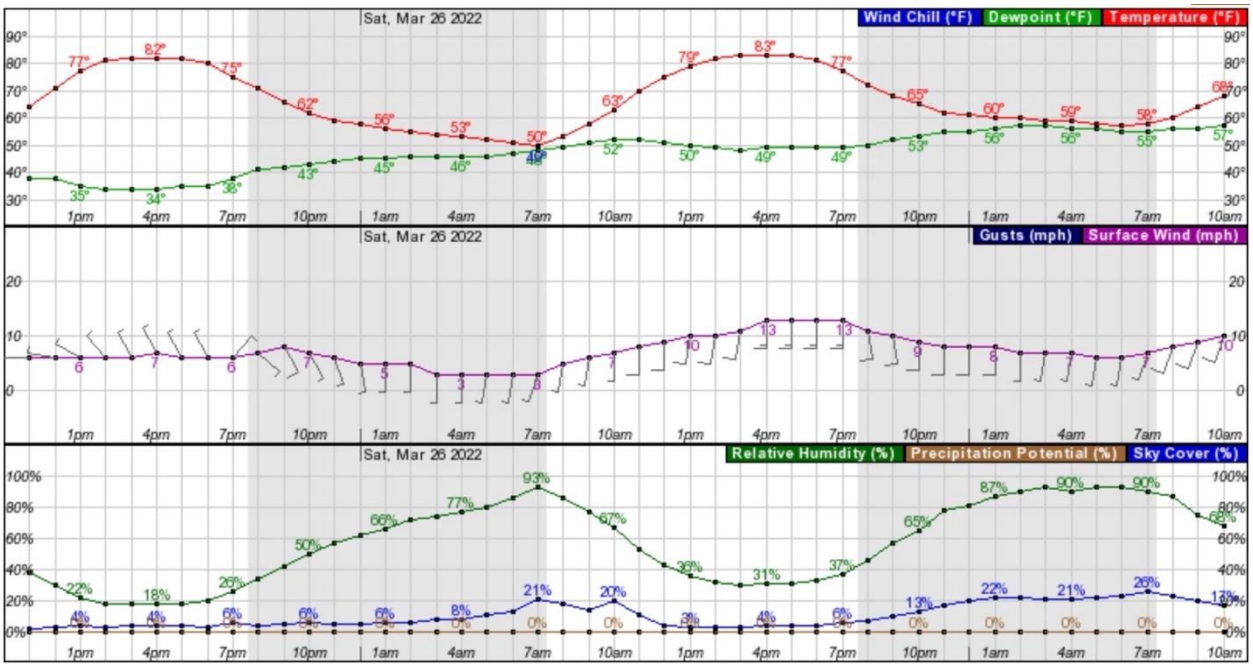


Fig Q3. Hourly Weather Graph Day 3 of Testing for March 25th of 2022.

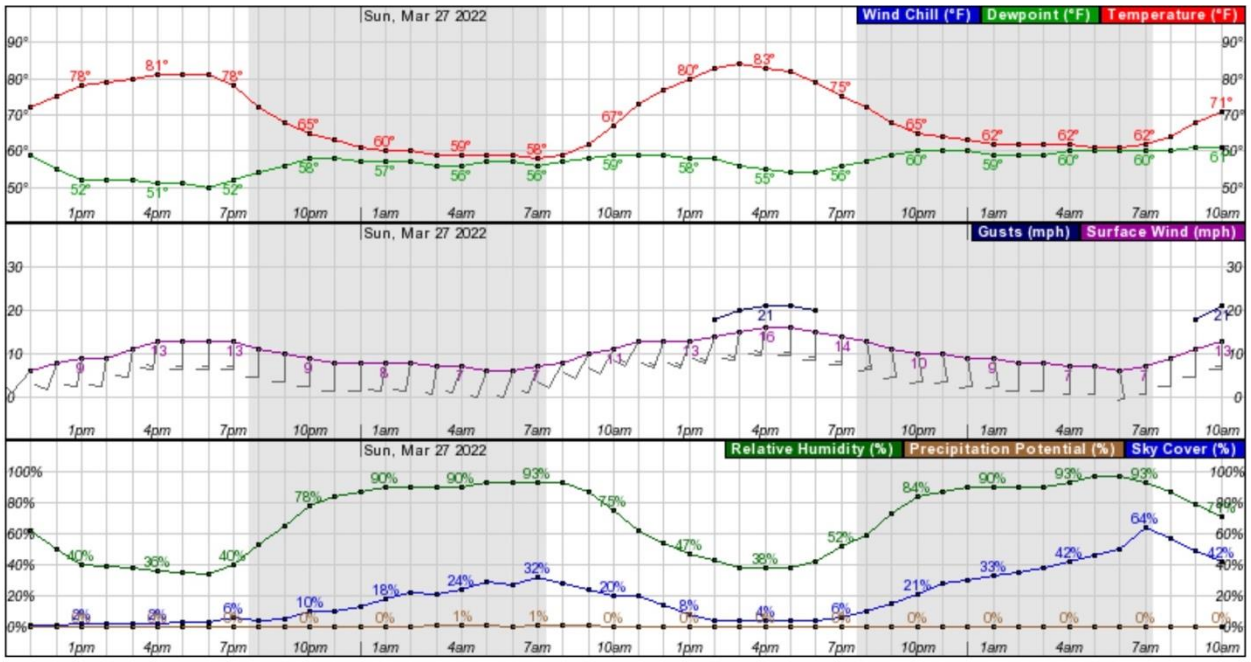


Fig Q4. Hourly Weather Graph Day 4 of testing for March 26th of 2022.

Fig Q5. Category 5 weather conditions

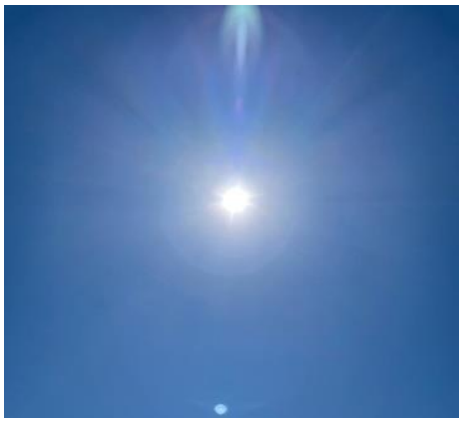


Fig Q6. Category 4 weather conditions

Fig Q7. Category 3 weather conditions

Fig Q8. Category 2 weather conditions

Fig Q9. Category 1 weather conditions

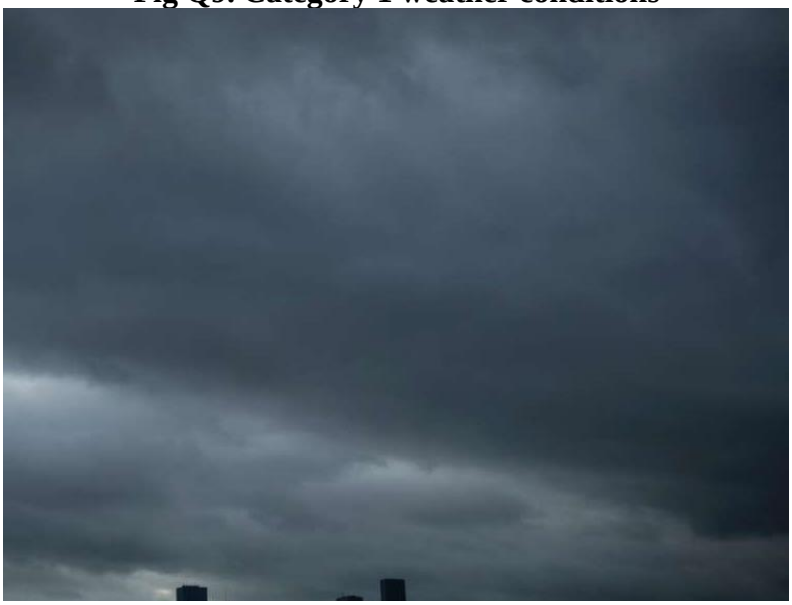
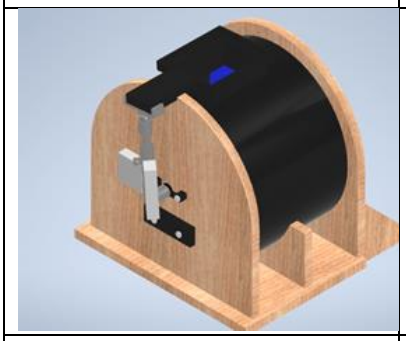
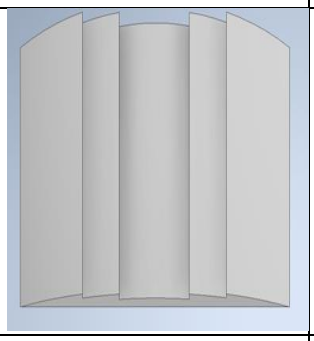
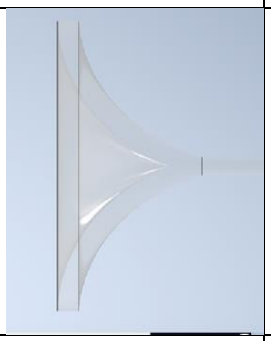


Fig Q10. Category 0 weather condition

9.18 Appendix R: Testing Procedure

Table R1. The Equipment List for Testing the Lenses and Collectors.

Testing Bench	Lenses	Collectors	Thermal Couple Device
			
The test bench mimics the simulation	Fresnel lens will be Testing	Collector will be Testing	Log Temperature Data Points

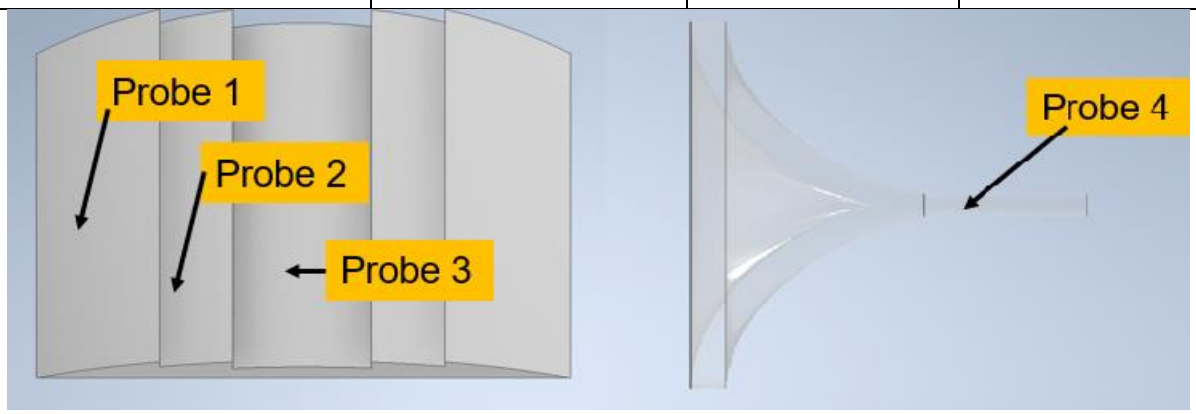


Fig R1. Fabricated lens and collector measurement points for testing.

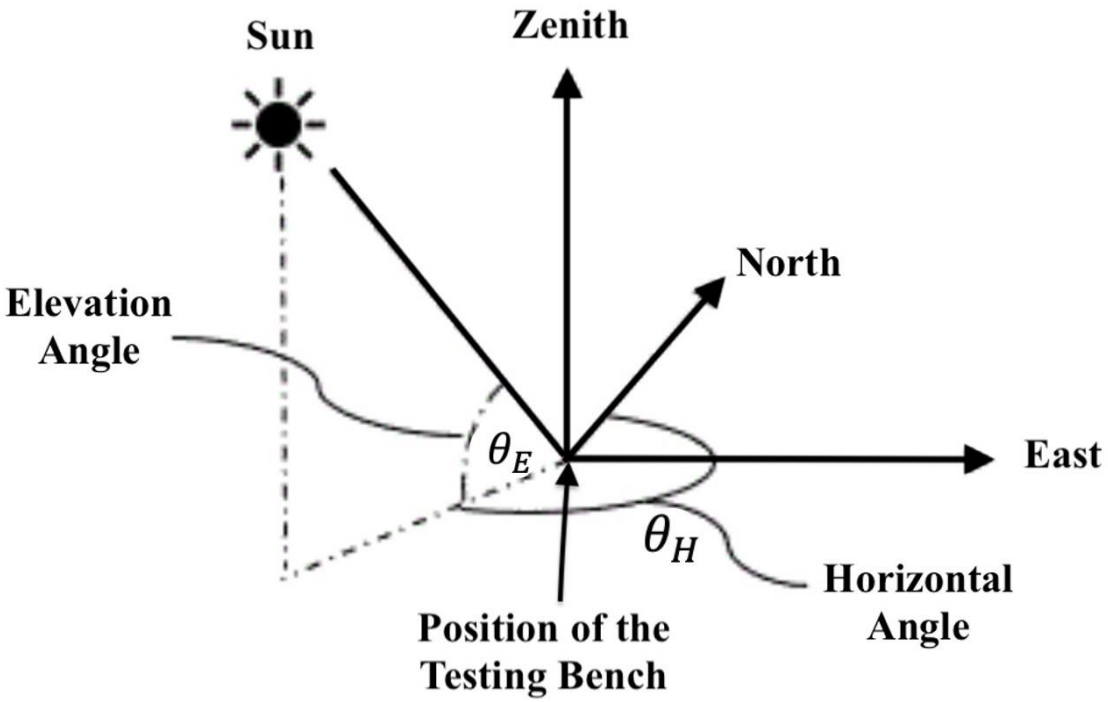


Fig R2. An illustration of the relationship positioning of the Sun and the Testing Bench
Procedure for Testing Thermal Concentration

1) Due to glare and heat that can occur during the testing; When handling the prototype, safety goggles, and heat resistant gloves must be worn by all.
2) Remove the second panel of the testing bench by unlatching the two-safety lock and place the collector inside the collector holder
3) Turn on the multimeter and connect the thermocouple probes to the multimeter and attach the thermocouple device to the second panel outside the surface.
4) Place three thermocouple probes on the lens and collector as shown in Figures 28 and 29.
    - Probe 1- the port of the collector (thermocouple probe)
    - Probe 2- the rim of the collector (thermocouple probe)
    - Probe 3- the other ridge of the lens (thermocouple probe)

5) Re-insert the second panel into the testing bench, so no ambient light comes in and covers the prototype lens holder with a cloth to avoid preheating.
6) Using a compass, rotate the physical prototype to the correct direction of either east or west that corresponds to the sun's direction.
7) By using figure R2 as a reference, stand on one side of the testing bench and face toward the direction of the sun, estimate the horizontal angle (θ_H) at which the sun is located and reposition the testing bench where the lens holder port is directly facing the sun direction. Tilt the lens holder port to the correct elevation angle that corresponds to the sun elevation by using an online sun positioning software [#] and visual estimate at which point the sun is located.
8) Once the prototype is faced and angled to the sun, adjust the collector holder where the rim of the collector is at the center of the opening of the lens holder. To find where the focal point of the lens will be; place both hands face down on top of the lens holder and move both hands toward the center until there is a one inch separate between the index fingers. The light from the one inch will show the focal point region where the collector rim will need to be positioned.
9) Before performing the test, one person will be monitoring and recording the data logging from the thermocouple device by either using a recording device or a cellular phone to record the manual thermocouple data for 15 minutes. The second person will document the date, time, angle of the sun, category of weather, as well as the lens and collector combination that the test was performed. The final person will be handling the prototype and ensure the safety procedure are being followed as well as placing the lens onto the collector when the test is ready to begin.
10) When the lens has been placed into the lens holder, record the thermocouple data, and perform documentation as described in step 9,

11) Once the 15-minute testing has been completed, remove the lens, and collector, and allow the lenses, collector and prototype to be cooled to ambient temperature by placing them in a shaded area. Once all the temperatures are the same as the ambient temperature or probe (3) then repeat step (5) through step (12) for a total of three trials of the lens and collector combination.
12) Once the three trial for the first combination of lenses and collector has been completed; place the unneeded lens and/or collector back into storage before taking a new collector or lens. For the safety and handling of the lens and collector, only one set of collector and lens can be taken out of the storage case at any given moment.
13) The procedure will continue until both lenses for the material sets have been tested with each set having completed three trials as described in table [4].
14) Repeat procedure for other material sets of lenses and collectors until all the temperature has been recorded, place all lenses and collectors back into storage and remove the probes from the prototype. Disassemble the prototype if needed for transportation.

9.19 Appendix S: Raw Results

Table S1. The Raw data set 1 of combination Acrylic Coated Lens A and Acrylic Collector A.

Type of Test	Sun Test		
Test number:	Trial 1		
Date Taken:	23-Mar		
Time of Day:	2:23 PM		
Weather condition:	Category 4		
Sun Angle	59.5		
Lens and Collector	Acrylic Coated Lens A and Acrylic Collector A		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	27.1	25.7	20.2
15	25.8	34.8	19.6
30	26.6	41.1	18.8
45	26.5	47.4	20.1
60	26	50.1	20.1
75	25.6	50.1	20.1
90	26.4	47.3	20.3
105	25.4	44.3	19.8
120	25.8	47.1	19.9
135	26.6	47.1	19.8
150	24.8	43.4	18.9
165	26.5	42	19.7
180	25.6	41.1	19.7
195	25.5	37.7	19.7
210	25.1	37.2	20.5
225	26.3	38.6	19.9
240	25.9	38.6	19.5
255	26.3	36	20
270	25.9	36.8	20.4
285	25.9	37.5	20.4
300	26.3	35.9	20.4
315	27.2	35.9	21.3
330	26.8	37.7	21.3
345	27.2	35	20.9
360	27.4	36.1	21.4
375	27	36.1	21.5
390	26.6	34.3	20.7
405	26.2	33.4	19.8
420	26.4	33.6	19.9

435	26.4	32.8	20
450	27.4	33.7	20.1
465	26.5	32.8	20.1
480	26.5	31.9	20.1
495	27	32.9	21.1
510	26.6	32	19.2
525	26.6	33	20.7
540	26.8	32.1	18.6
555	26.8	32.1	19.8
570	26.8	31.2	20.3
585	26.8	32.1	20.8
600	26.7	31.2	21.3
615	26.8	30.4	20.4
630	26.8	30.4	20.4
645	26.3	29.5	19.9
660	27.2	28.6	19.5
675	27.2	29.5	19.5
690	26.8	29.5	20.4
705	26.3	28.6	19.5
720	28.3	29.5	20.4
735	26.3	29.5	20.4
750	25.8	29.5	20.4
765	27.2	29.5	20.4
780	26.8	29.5	20.4
795	26.8	29.5	20.4
810	26.8	29.5	20.4
825	26.8	28.6	20.4
840	26.8	29	20.4
855	26.8	28.6	20.4
870	25.9	27.7	21.3
885	26.8	29	21.3
900	26.3	28.1	21.3

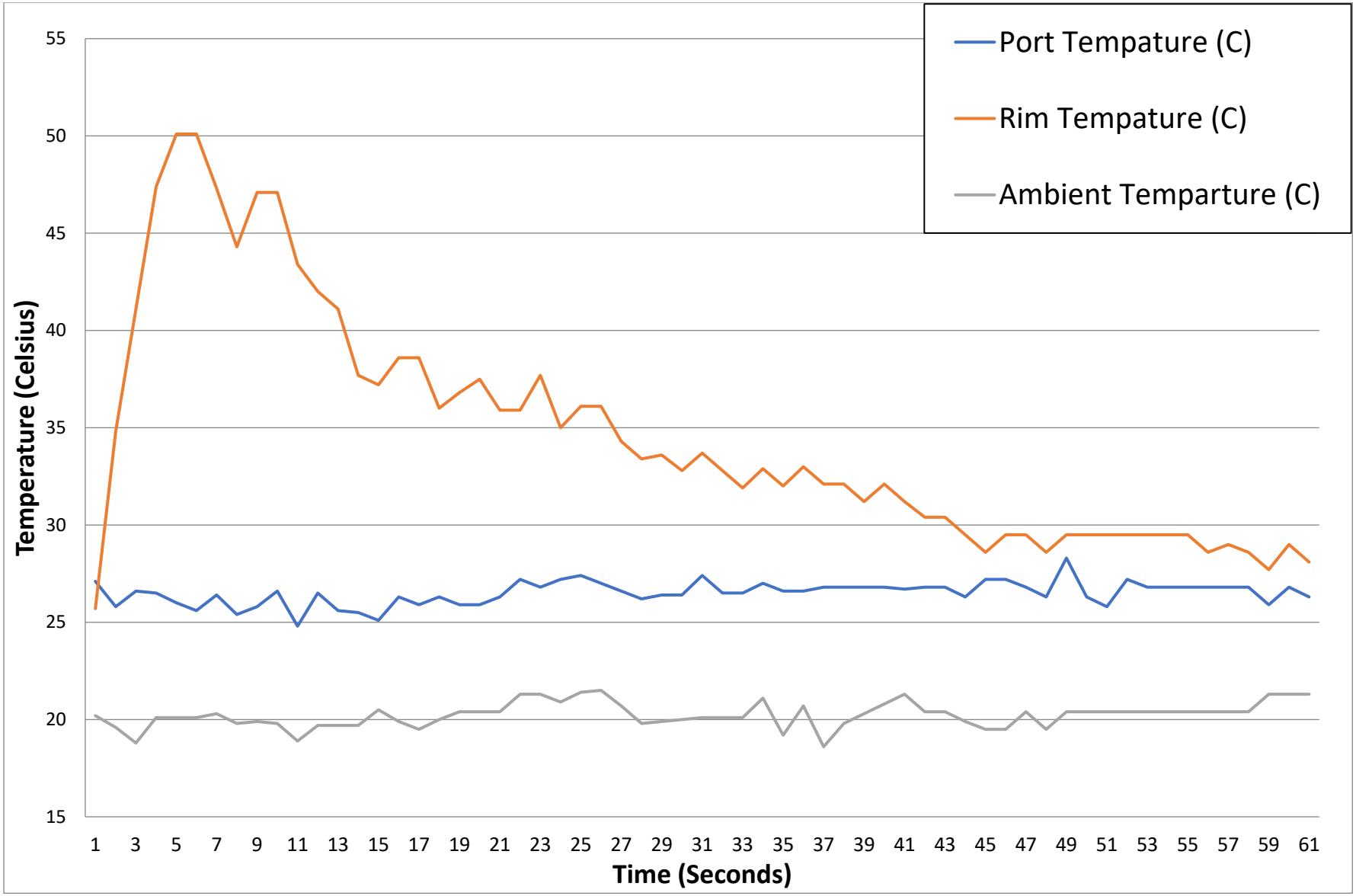


Fig S1. The graph of Acrylic Coated Lens A and Acrylic Collector A for trial 1 at category 4.

Table S2. Raw data of Set 1 combination of Acrylic Lens A and Acrylic Collector A of Trial 2.

Type of Test	Sun Test		
Test number:	Trial 2		
Date Taken:	23-Mar		
Time of Day:	2:49 PM		
Weather condition:	Category 4		
Sun Angle	52		
Lens and Collector	Acrylic Coated Lens A and Collector A		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	25	22	18.5
15	27	31.6	20.2
30	27.9	36.7	19.3
45	28.5	35.2	20.2
60	29.2	34.7	19.3
75	29.2	39.2	19.2
90	29.7	40.1	19.2
105	30.1	35.6	18.7
120	31	38.3	20.1
135	30.6	30.1	19.2
150	30.9	29.1	20
165	31.4	30.1	20.1
180	29.9	28.1	20.1
195	30.8	31	19.9
210	30.8	29.9	19.9
225	30.8	30.1	19.9
240	32.2	33.7	20.8
255	32.4	31.7	20
270	32.2	30.1	20
285	31.4	32.6	19.9
300	33.1	36.4	20.8
315	33.7	37.2	19.1
330	31.8	32.3	17.3
345	31.9	31	18.7
360	31.9	31.9	19.2
375	32.4	33.9	20.2
390	32	34.8	18.4
405	32.1	35.7	18.5
420	31.1	30.2	20.3
435	31.3	32.1	19.4
450	30.4	31.3	20
465	29.5	29.1	20.4

480	30	30.4	20.4
495	28.6	28.1	19.5
510	28.1	27.7	19.5
525	28.6	29.5	19.5
540	29.5	31.8	20.4
555	28.7	30.4	19.5
570	29.1	30.5	19.5
585	30.5	32.3	18.7
600	30.5	35.2	20.6
615	30.1	31.5	19.7
630	28.8	32	19.7
645	29.4	31.6	20.7
660	28.9	33.9	19.8
675	29.4	32.5	19.8
690	29.9	38.1	19
705	30.5	35.5	20
720	30.1	33.7	20
735	30.1	34.2	20.1
750	28.5	33.9	19.4
765	29.3	33.9	19.8
780	29.8	37.5	19.3
795	29.4	37.6	20.2
810	30.3	35.7	19.4
825	29.8	34.8	20.3
840	30.2	33.9	20.8
855	30.2	31.1	19.7
870	29.2	31.9	17.8
885	29.6	31	18.7
900	30	29.1	19.5

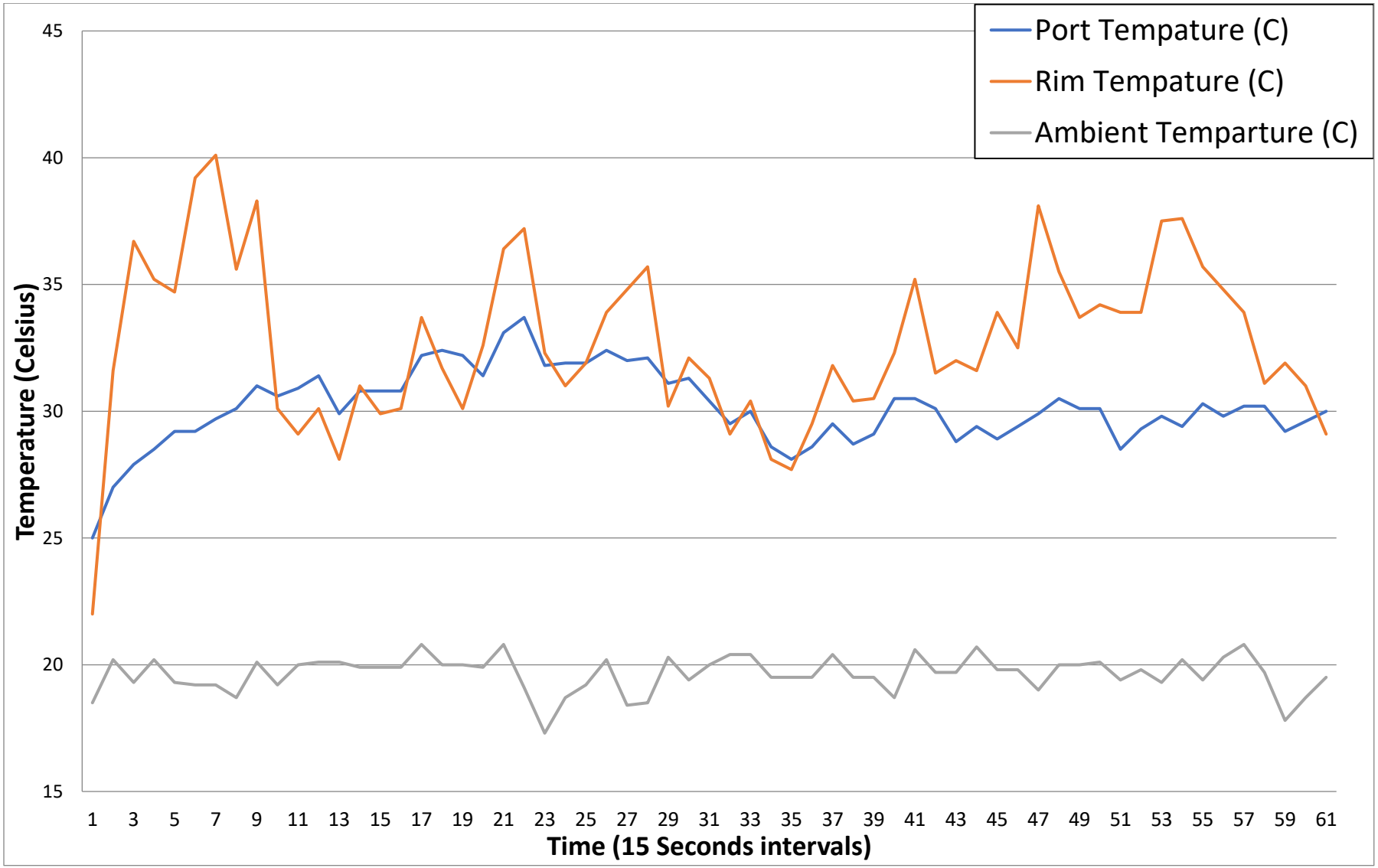


Figure R2. The graph of Acrylic Coated Lens A and Acrylic Collector A for trial 2 at category 4

Table S3. Raw data set 1 of combination Acrylic Lens A and Arclyic collector (A) of Trial 3.

Type of Test apparatus	Sun Test		
Test number:	Trial 3		
Date Taken:	23-Mar		
Time of Day:	3:56 PM		
Weather condition:	Category 2		
Sun Angle	52		
Lens and Collector	Acrylic Coated Lens A and Arclyic Collector A		
Time (Seconds)	Port Tempature (C)	Rim Tempature (C)	Ambient Temparture (C)
0	24.7	23.8	21.5
15	26	25.1	21.6
30	26	25.6	21
45	26.5	25.6	21
60	26.9	25.7	21.1
75	26.6	26.1	21.1
90	27.1	25.8	21.6
105	26.7	25.8	20.8
120	26.7	25.8	21.3
135	26.8	25.9	19.4
150	27.2	26.8	20.4
165	27.2	25.9	20.9
180	27.2	26.3	20.4
195	27.7	26.9	21.3
210	28.1	26.5	20.9
225	27.8	27	20.5
240	27.8	27	22.4
255	27.5	26.1	20.2
270	28.3	26.5	21.6
285	27.3	27.2	21.5
300	27.5	26.5	20.7
315	27.5	27.2	20.8
330	27.6	26.3	20.7
345	27.1	26.3	20.8
360	27.2	27.7	21.7
375	27.6	26.3	21.7
390	27.2	26.3	21.7
405	27.6	26.4	21.7
420	27.2	26.4	22.7
435	27.3	26.4	20.9
450	27.4	26.5	21.9

465	27.3	26.4	21.8
480	27.8	26.5	21.9
495	27	26.6	21.1
510	27.5	26.6	21.1
525	27.5	26.6	21.1
540	27.5	26.6	21.2
555	27.5	25.6	21.1
570	27.4	26	21.9
585	27.8	26.5	21.9
600	27.4	26.5	21
615	26.8	25.5	21.8
630	26.5	25.9	20.9
645	26.4	25.8	21
660	26.4	25.5	21.4
675	27.2	26.3	21.8
690	26.1	26.3	21.3
705	26.7	26.3	18.1
720	26.7	25.7	21.7
735	27.1	25.3	21.7
750	26.6	26.2	21.5
765	26.1	25.6	21.5
780	26	26.1	21.5
795	26.4	25	21.1
810	27.4	26	20.5
825	27.4	26.9	21.4
840	27.9	27	20.6
855	27	27	20.6
870	27	26.9	20.6
885	27.3	26.5	20.6
900	27.9	26.9	21.4

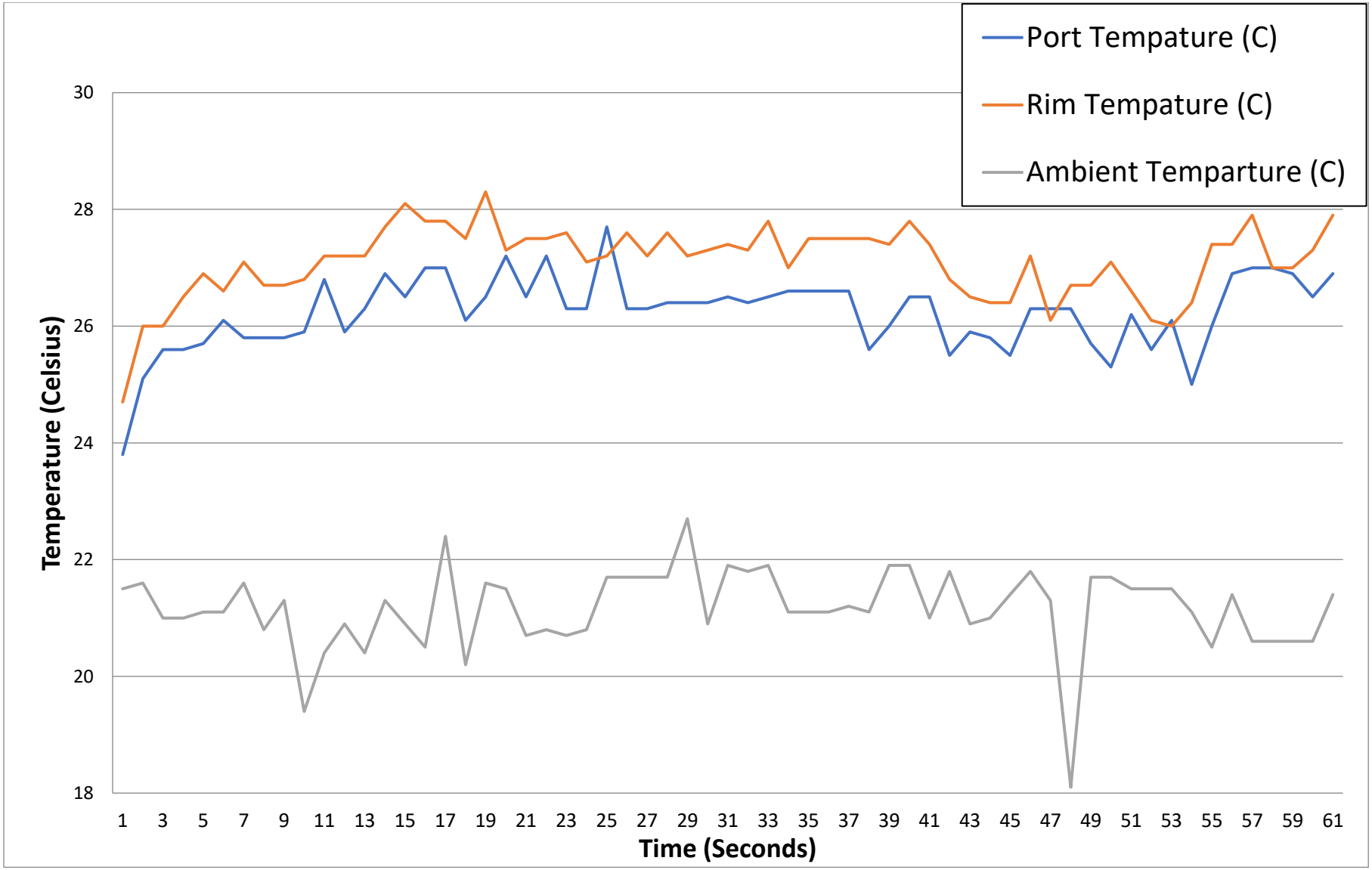


Figure R3. The graph of Acrylic Coated Lens A and Acrylic Collector A of Trial 3 at category 2.

Table S4. Raw data set 1 of combination Acrylic Lens A and Acrylic collector (B) of Trial 1.

Type of Test	Sun Test		
Test number:	Trial 1		
Date Taken:	23-Mar		
Time of Day:	3:32 PM		
Weather condition:	Category 3		
Sun Angle	52		
Lens and Collector	Acrylic coated Lens A and collector B		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	26.6	26.6	20.3
15	25.8	34.8	19.6
30	26.6	41.1	18.8
45	26.5	47.4	20.5
60	26.5	50.1	20.1
75	25.6	50.1	20
90	26.4	47.3	20.3
105	25.8	44.4	19.8
120	24.3	46.7	19.9
135	25.7	47	19.8
150	25.3	43.4	18.9
165	25.3	43	19.8
180	25.2	41.5	18.9
195	25.9	40.6	19.7
210	25.1	37.7	19.6
225	25.1	37.2	20.5
240	25.1	38.6	20.5
255	25.9	38.6	19.5
270	25.9	36.8	18.8
285	26.3	36.3	20.4
300	25.9	37.7	20.9
315	26.3	35.9	20.4
330	26.3	36.6	20.9
345	26.8	37.7	21.3
360	26.8	35	20.9
375	26.8	36	21.3
390	27.1	35.2	20.9
405	27.5	34.2	20.6
420	26.2	33.4	19.8
435	26.8	33.5	20
450	26.5	33.6	20.5
465	27.4	33.7	20.1

480	26.5	32.8	20.1
495	26.5	31.9	20.1
510	26.5	32.8	20.1
525	26.6	31.8	19.2
540	27.1	33	20.3
555	26.8	31.1	19.4
570	26.7	33.1	20.4
585	26.7	32.1	20.3
600	27.1	31.1	20.3
615	26.2	32.1	21.2
630	26.8	31.3	21.3
645	26.3	30.4	20.4
660	26.8	30.4	20.4
675	27.2	30.4	20.4
690	26.8	29.5	20.4
705	26.8	29	19.5
720	26.9	29.9	20.4
735	26.3	28.6	19.5
750	27.2	29.5	20.4
765	25.9	28.6	19.5
780	26.3	29.5	20.4
795	25.8	29.5	19.9
810	25.8	29.5	20.4
825	26.3	29.5	20.4
840	26.8	29.5	20.4
855	27.2	29.5	19.9
870	25.9	29	20.4
885	26.3	28.7	20.4
900	26.3	27.7	20.4

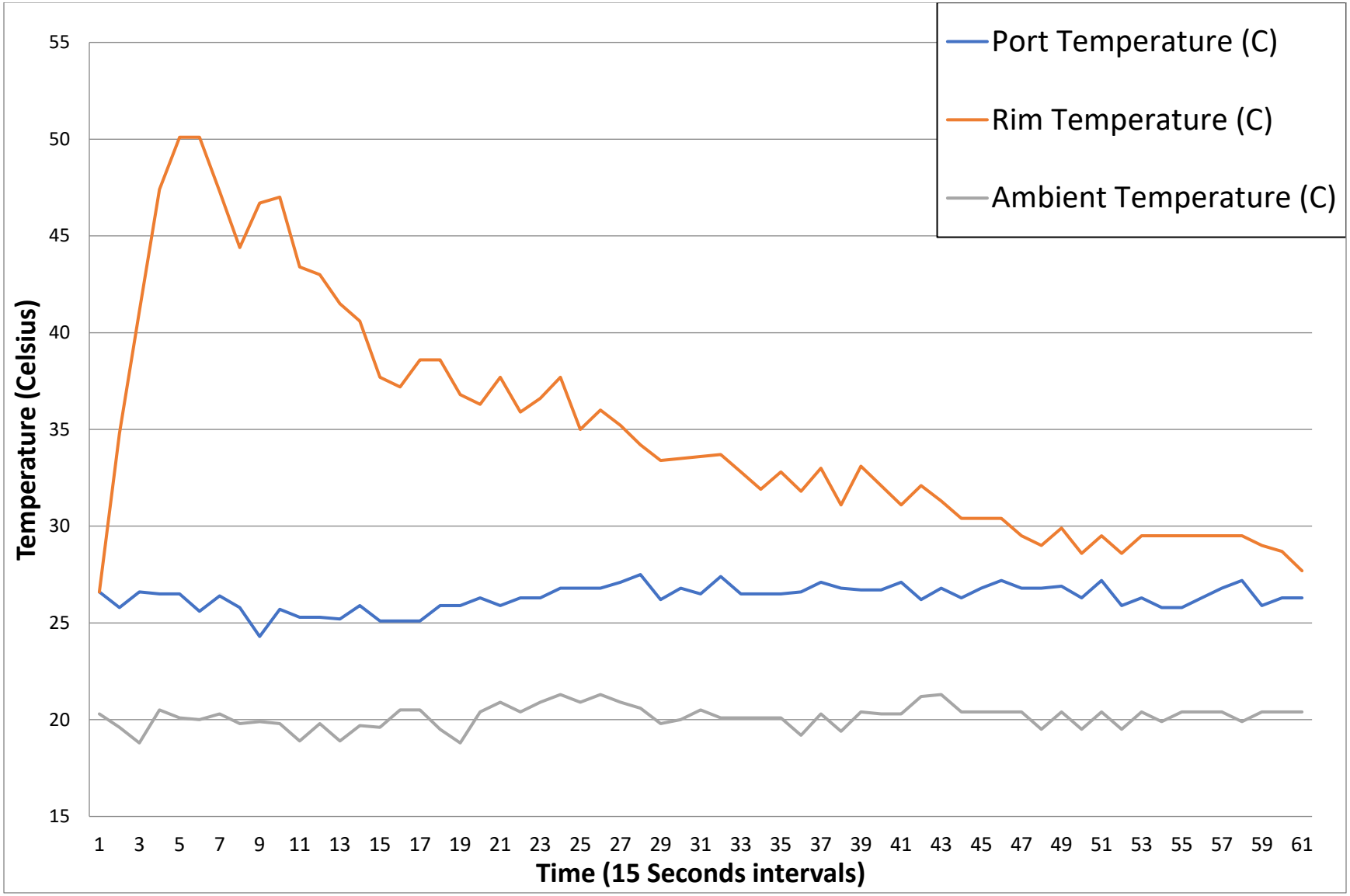


Figure R4. The graph of Acrylic Coated Lens A and Acrylic Collector B of Trial 1 at category 3.

Table S5. Raw data set 1 of combination Acrylic coated Lens A and Acrylic collector (B) of Trial 2.

Type of Test	Sun Test		
Test number:	Trial 2		
Date Taken:	24-Mar		
Time of Day:	4:03 PM		
Weather condition:	Category 4		
Sun Angle	43		
Lens and Collector	Acrylic coated Lens A and collector B		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	25.6	28.3	25.6
15	28	35.6	25.7
30	29.1	39.4	24.8
45	30	39.7	25
60	30.2	42	26.1
75	30.8	44.4	27.1
90	30.8	47.2	29.5
105	31.8	48.4	27.4
120	34.2	48	29.5
135	35.1	48.7	28.7
150	34.9	49	29
165	34.7	47.4	27.4
180	35.7	49.3	29.3
195	35.9	48.6	27.7
210	36.1	46.2	29.8
225	37.1	48.9	28
240	35.9	47.3	28.1
255	36.9	49	29.1
270	37.4	50.1	32.1
285	38.6	50.3	33.1
300	37.7	49.5	29.5
315	37.7	49.6	30.5
330	38	47.1	30.7
345	38.9	49.8	32.1
360	39	50.5	33.1
375	39.2	50	33.3
390	40.8	50.2	33
405	40.3	49.5	31.3
420	41	50.5	32.3
435	41.2	49.8	33.5
450	41.5	49.2	32.8

465	41.2	48.6	31.9
480	40.3	48.6	29.5
495	41.3	48.6	31.7
510	40.4	47.7	31.3
525	40.9	47.2	32.7
540	40.4	44.1	33
555	39.4	42.1	33
570	39.4	43	32.1
585	40.6	42.4	32.8
600	40.9	45.9	32.2
615	40.8	47.7	31.3
630	40.4	47.2	34.1
645	40.4	44.1	33.1
660	40.4	43.1	32.7
675	40.8	42.5	33.5
690	41.1	41.1	32.4
705	40.5	42.3	32.3
720	40.5	44.1	33.3
735	44.5	42.4	34.4
750	42.5	43.4	33.25
765	41.6	43.5	30.7
780	42.1	42.5	30.7
795	41.6	43	31.6
810	41.7	42.6	32.7
825	42.3	41.8	33.7
840	41.8	43.2	32.7
855	41.9	42.7	32.7
870	43.6	43.6	30.9
885	44.5	42.7	33.5
900	41.2	42.5	29.8

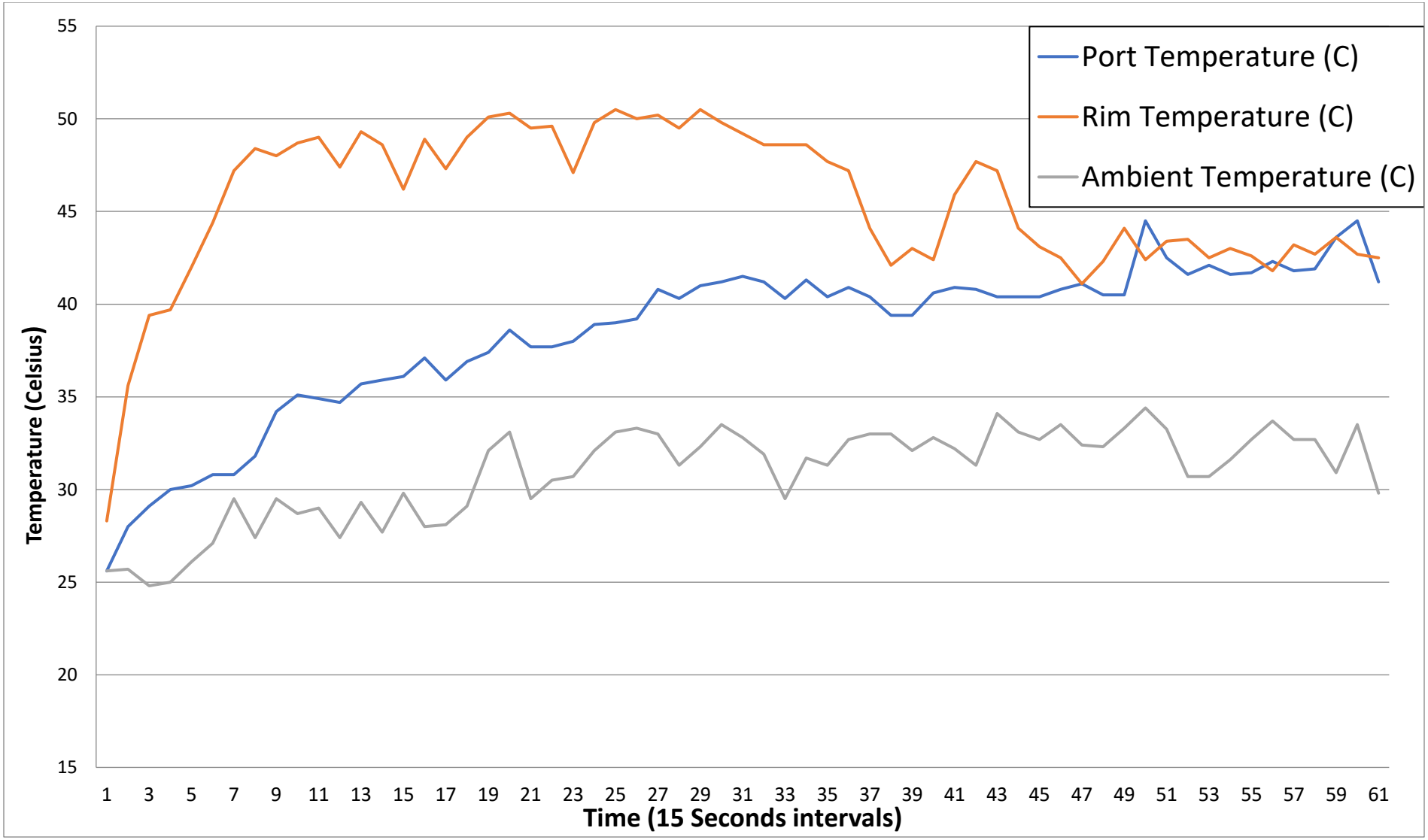


Figure R5. The graph of Acrylic Coated Lens A and Acrylic Collector B of Trial 2 at category 4.

Table S6. Raw data set 1 of combination Acrylic Lens A and Acrylic collector (B) of Trial 3.

Type of Test:	Sun Test			
Test number:	Trial 3			
Date Taken:	26-Mar			
Time of Day:	3.54 PM			
Weather condition:	Category 4			
Sun Angle	37			
Lens and Collector	Acrylic Lens A and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	36.8	34.5	30.9	31.8
15	38.2	40	30.9	32.7
30	39.1	43.1	30.9	32.6
45	38.1	45.2	31.6	32.6
60	39.8	45.2	30.7	32.4
75	40.7	50.7	32.4	32.4
90	39.9	46.6	29.8	32.5
105	39.9	45.3	29.8	32.5
120	39.8	48.3	31.6	32.5
135	39.8	47.1	31.6	32.6
150	39.3	48	30.7	32.5
165	40.7	48	31.6	32.6
180	40.7	49.9	31.6	32.2
195	41.8	50.2	34	32.5
210	41.8	50.9	31.3	32.7
225	40	49.1	32.7	31.8
240	40.1	48.2	30.9	32.3
255	39.2	47.5	31	31.9
270	40.3	50.2	31.1	31.9
285	39.8	48.5	32.1	32.1
300	40.3	50.3	33	31.6
315	40.3	51.3	34.8	32.1
330	41.2	51.2	32.1	31.6
345	41.5	51.4	31.4	31.4
360	42.3	50.6	31.5	31.9
375	42.4	50.6	31.5	31.5
390	42.5	51.6	30.2	31.7
405	42.6	52.7	31.3	31.8
420	41.9	49.1	30	31.9
435	42	48.4	30.6	32

450	42.1	47.6	30.3	32.1
465	43.1	48.5	30.4	32.1
480	43.1	48.7	31.4	32.1
495	42.4	48.7	30.5	32.3
510	42.9	48.8	30.6	32.4
525	42.4	47.9	30.6	32.4
540	42.4	47.6	30.6	31.9
555	42.6	48.1	30.8	31.5
570	41.7	46.2	32.6	31.7
585	42.7	48.2	31.8	32.2
600	41.8	46.3	30.4	32.2
615	41.8	45.4	30.9	32.7
630	42.7	46.3	30.4	31.8
645	42.8	45.5	30	32.9
660	43.8	48.2	32	32
675	42.9	46.1	30.2	32
690	42.1	46.6	31.2	32.1
705	43	44.8	30.3	32.1
720	43	46.6	32.1	32.5
735	42.2	45.5	31.4	32.5
750	43.2	46	30.9	32.3
765	43.3	46.9	30.6	32.4
780	43.3	47.8	31	32.4
795	43.4	46.1	29.8	32.8
810	43.4	47	30.7	32.6
825	44.5	47.2	32.7	32.7
840	43.6	47.2	30	32.7
855	43.6	45	30	32.7
870	44.6	46.4	30	32.8
885	43.8	46.5	32.9	32.9
900	43.8	46.5	30.5	32.4

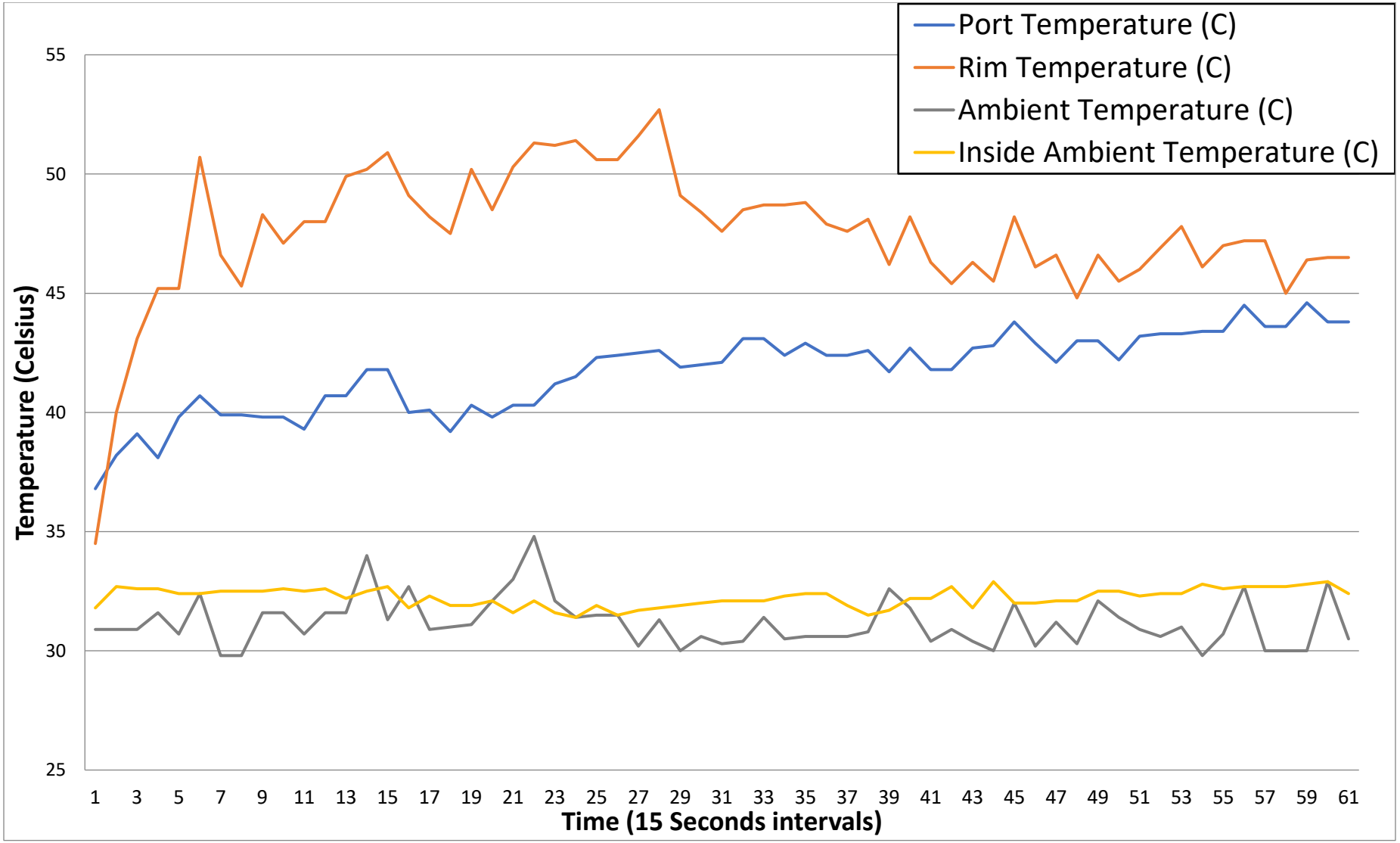


Figure R6. The graph of Acrylic Lens A and Acrylic Collector B of Trial 3 at category 4

Table S7. Raw data set 1 of combination Acrylic Lens B and Acrylic collector (A) of Trial 1.

Type of Test	Sun Test			
Test number:	Trial 1			
Date Taken:	26-Mar			
Time of Day:	12:14 PM			
Weather condition:	Category 4			
Sun Angle	54			
Lens and Collector	Acrylic Lens B and Collector A			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	34.1	33.2	27.7	30.5
15	35	38.6	27.7	30.4
30	35.9	40	28.6	30.4
45	35.9	41.2	27.6	30.3
60	35.9	43	27.6	31.2
75	35.8	43.9	27.6	30.1
90	37	44.7	28.5	30.1
105	37.4	45.6	27.8	31
120	37.4	46	27.4	30.1
135	36.5	46.5	27.4	30.1
150	37.3	46.7	29.5	30.2
165	38.3	49.2	27.4	31.6
180	37.6	50.1	27.5	31
195	37.5	51	28.4	31
210	37.4	51.9	27.4	30.1
225	38.8	52.9	27.5	30.1
240	37.9	52.9	27.4	30.6
255	38.3	54.3	27.5	30.6
270	37.4	53	26.6	30.8
285	37.5	54.8	26.6	30.7
300	38.3	55.7	27.4	30.6
315	39.4	55.1	27.6	30.1
330	38.5	55.7	27.6	30.6
345	39	55.8	26.7	30.4
360	38.5	56.7	28	30.4
375	39.1	57.6	26.8	30.3
390	39.5	58.6	27.7	30.4
405	39.5	60	25.9	30.9

420	39.5	59.5	26.8	30.4
435	39.3	60.4	25.9	30.6
450	38.8	61.4	26.8	30.4
465	38.8	62.4	26.9	30.6
480	39.7	61.5	27	30.6
495	39.7	62.1	27.5	30.6
510	38.4	60.6	26.5	30.7
525	38.8	62.4	27	30.6
540	40.7	63.4	27	30.6
555	40.7	63.4	27.1	30.7
570	41.1	63	27.1	30.3
585	42.3	61.6	27.1	30.7
600	42.1	61.6	26.2	30.7
615	42.1	63.4	27.2	30.8
630	43.2	62.1	26.3	30.8
645	42.9	61.3	26.4	30.5
660	40.9	63.6	27.7	30.8
675	42.4	62.2	28.7	30.1
690	43.5	61.2	29.2	30.1
705	44.2	60.5	27.4	30.9
720	44.5	60.2	27.5	31.1
735	44.9	59.8	27.6	30.7
750	45.1	58.7	26.8	30.4
765	45.7	58.2	26.8	30.4
780	45.6	57.8	26.9	30.5
795	45.6	57.4	27	30.8
810	46	56.7	25.9	30.7
825	46.2	56.2	27	30.6
840	47.2	56.2	27.1	30.7
855	47.6	55.8	28	31.4
870	48.7	55.6	27.6	31.3
885	48.7	55.6	28	32.1
900	48.5	54.9	28	31.8

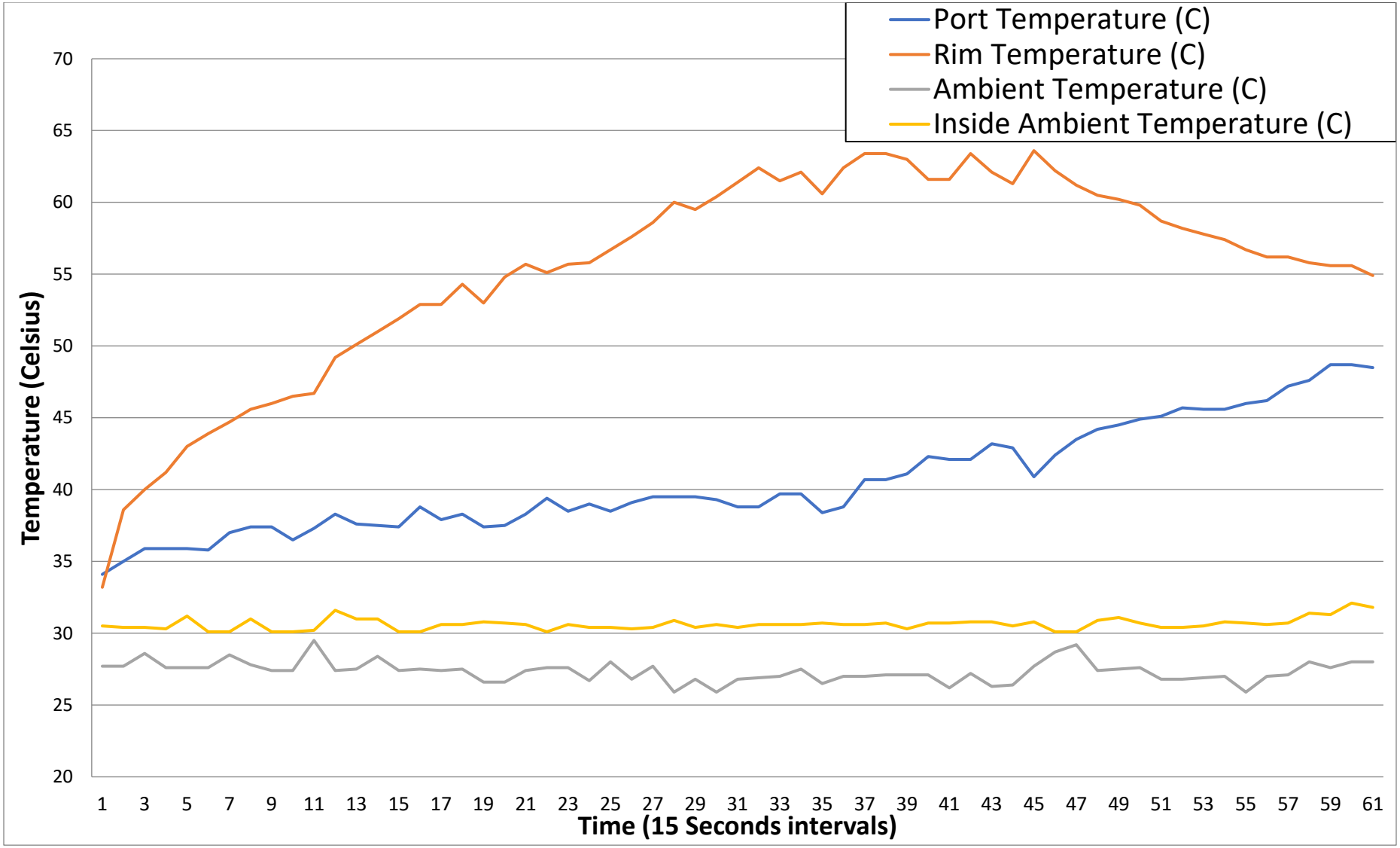


Fig S7. The graph of Acrylic Lens B and Acrylic Collector B of Trial 1 at category 4

Table S8. Raw data set 1 of combination Acrylic Lens B and Acrylic collector (A) of Trial 2.

Type of Test	Sun Test			
Test number:	Trial 2			
Date Taken:	26-Mar			
Time of Day:	12:38 PM			
Weather condition:	category 4			
Sun Angle	59			
Lens and Collector	Acrylic Lens B and Collector A			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	33.8	35.1	28.2	31.9
15	34.6	43.8	28.3	31.8
30	34.6	48.2	28.2	31.8
45	35.4	50	27.3	32.7
60	35.4	52.7	29.1	32.7
75	36.3	53.7	29.5	31.8
90	36.4	54.1	29.1	31.8
105	36.4	54.6	27.2	31.7
120	36.4	55.5	28.2	31.8
135	36.6	55.5	29.1	31.8
150	37.4	55.1	29.2	31.9
165	36.5	55.1	28.3	31
180	36.8	54.2	28.4	31.1
195	37.6	54.9	28.5	31.2
210	37.6	55	29.4	31.3
225	37.7	55	27.7	31.3
240	37.8	54.5	30.4	31.4
255	37.9	55.2	27.8	31.1
270	38	55.2	28.9	31.6
285	38	54.4	28	31.2
300	37.1	54.4	29.8	30.7
315	38	54.5	29	30.8
330	38.2	54.6	29.6	30.9
345	38.2	53.8	28.3	30.9
360	38.3	53.8	27.4	31
375	38.3	53.8	27.4	31.1
390	37.8	54	27.5	31.2
405	37.6	53	26.7	31.2
420	38.1	54.1	28.6	31.3
435	38.6	53.1	27.7	31.3

450	38.6	53.1	27.7	31.3
465	39.5	53.1	28.7	31.3
480	39.5	52.2	27.5	31.3
495	38.7	52.4	27	31.5
510	38.8	52.1	26.6	31.6
525	39.4	51.6	28.9	31.6
540	38.9	50.7	29.3	31.6
555	39.1	50.6	27.2	31.7
570	39.2	50.1	27.4	31.8
585	39.2	50.1	27.4	31.5
600	40.1	50.1	30.1	31
615	40.2	50.1	30.2	31.1
630	39.4	49.3	27.7	31.1
645	39.4	49	27.7	31.3
660	39.5	48.6	27.7	31.3
675	39.5	48.6	27.2	31.8
690	40.5	48.8	28.6	31.9
705	40.7	47.9	29.6	31.6
720	40.7	48	28	31.6
735	40.7	47.1	28.9	31.6
750	40.7	47.1	29.8	31.6
765	40.8	46.7	28.1	30.8
780	40.5	46.4	29.1	31.8
795	40.9	46.4	27.3	31.4
810	41	45.9	27.3	31
825	41.7	45.6	27.6	31.2
840	41.2	45.8	28	31.2
855	42.1	45.8	28.5	31.2
870	41.2	45.8	28.6	31.2
885	41.3	44.9	27.8	31.9
900	40.5	45.1	27.9	32.33

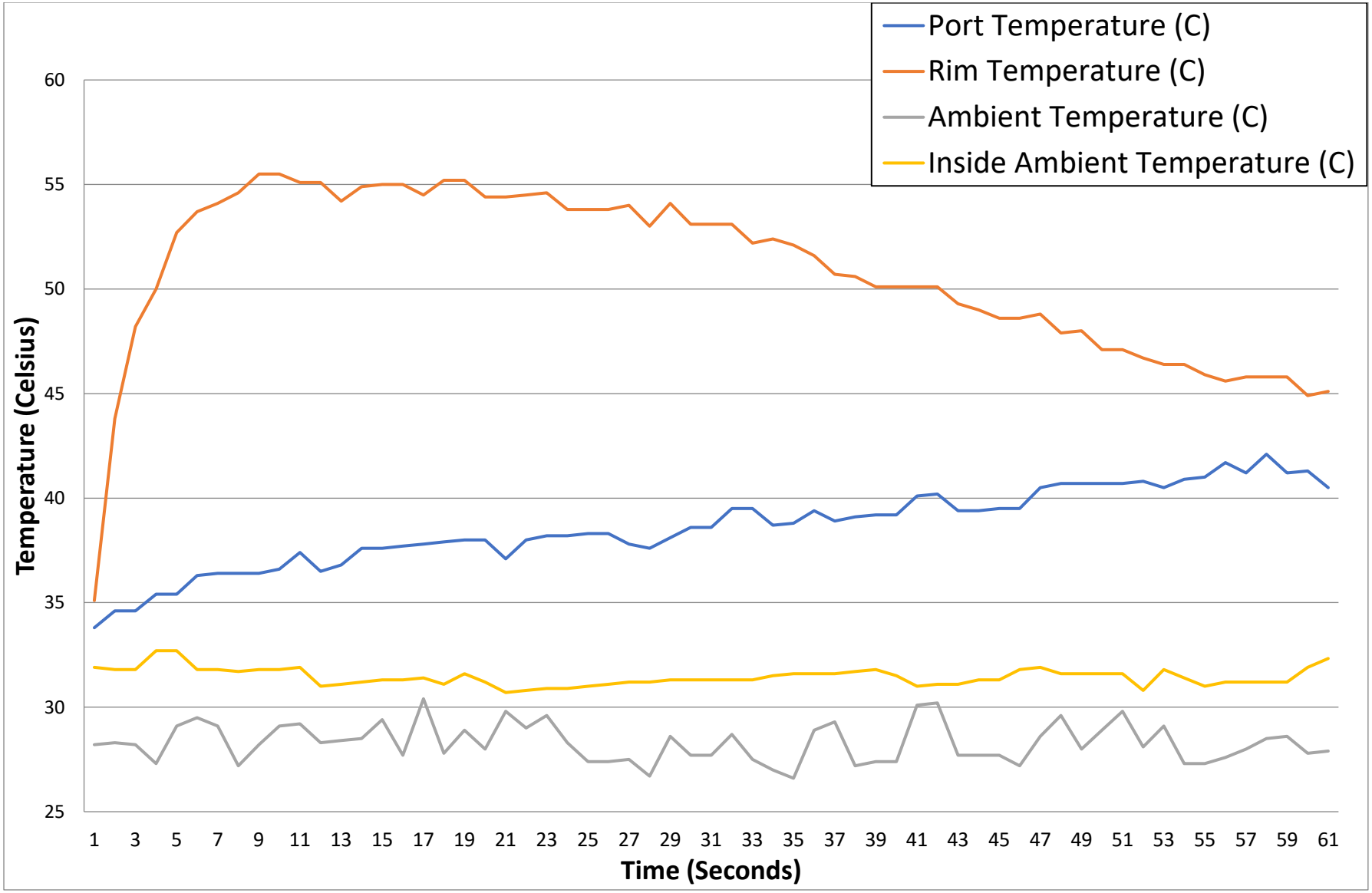


Fig S8. The graph of Acrylic Lens B and Acrylic Collector A of Trial 2 at category 4

Table S9. Raw data set 1 of combination Acrylic Lens B and Acrylic collector (A) of Trial 3.

Type of Test	Sun Test			
Test number:	Trial 3			
Date Taken:	26-Mar			
Time of Day:	1:13 PM			
Weather condition:	Category 4			
Sun Angle	62			
Lens and Collector	Acrylic Lens B and Collector A			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	35	34.5	28.1	31.3
15	35.9	43.6	30.4	31.3
30	36.2	48.6	31.2	31.3
45	36.2	52.2	31.8	31.3
60	36.8	54.1	29	31.3
75	37.7	55	28.6	31.3
90	37.7	55.9	28.9	31.3
105	38.6	58.6	29.5	31.3
120	38.6	59.5	29.6	31.3
135	39.1	60.4	30	31.3
150	39.5	61.3	28.6	30.4
165	39.7	61.3	30	31.4
180	39.5	63.3	29.5	30.6
195	40.6	63.4	28.9	30.7
210	40.7	65.3	28.9	30.7
225	40.3	65.3	28	30.8
240	39.9	65.4	29	30.8
255	39.6	64.5	29.1	30.9
270	39.9	63.7	28.2	30.9
285	39.2	62.8	28.13	31
300	39.2	62.8	28.3	31
315	40.1	62.7	28.7	31
330	40.1	60.6	27.8	31
345	39.2	60.1	28.3	31
360	40.1	61	29.2	31
375	41	61	29.2	31
390	40.1	61	29.2	31
405	40.1	60.1	28.3	31.1
420	40.7	61.1	29.3	30.6
435	40.3	61.1	28.4	30.2
450	41.2	61.1	28.5	30.3

465	41.1	62.2	29	30.3
480	40.3	62.2	28.5	30.4
495	40.4	62.7	27.7	30.4
510	40.9	63.1	26.8	30.3
525	42.2	64	27.7	30.9
540	41.6	63.2	27.7	30.5
555	41.5	63.8	27.9	31.4
570	41.5	63.2	27.9	30.6
585	41.5	64.7	28.8	30.7
600	42.5	64.3	28.9	30.7
615	42.5	63.4	29.9	30.7
630	42.5	63.4	29	30.7
645	42.7	62.7	28.2	30.4
660	41.8	62.4	28.2	30.4
675	42.3	61.8	28.2	30.5
690	43	62	30.3	31.2
705	43	62.1	30.7	31.2
720	43.4	61.2	29.4	31.2
735	43	62.2	30.4	31.3
750	43.6	62.4	30.6	31.5
765	44	62.4	30.6	31.5
780	44.1	62.5	28.9	30.7
795	44	61.8	29.1	30.9
810	44.4	62.8	30.5	31.9
825	44.3	61.2	29.8	31.2
840	44.1	61.2	30.3	31.2
855	44.6	58.6	28.6	31.3
870	44.8	59.7	30.6	31.4
885	45.1	59.7	29.7	31.6
900	45.1	58	28	31.5

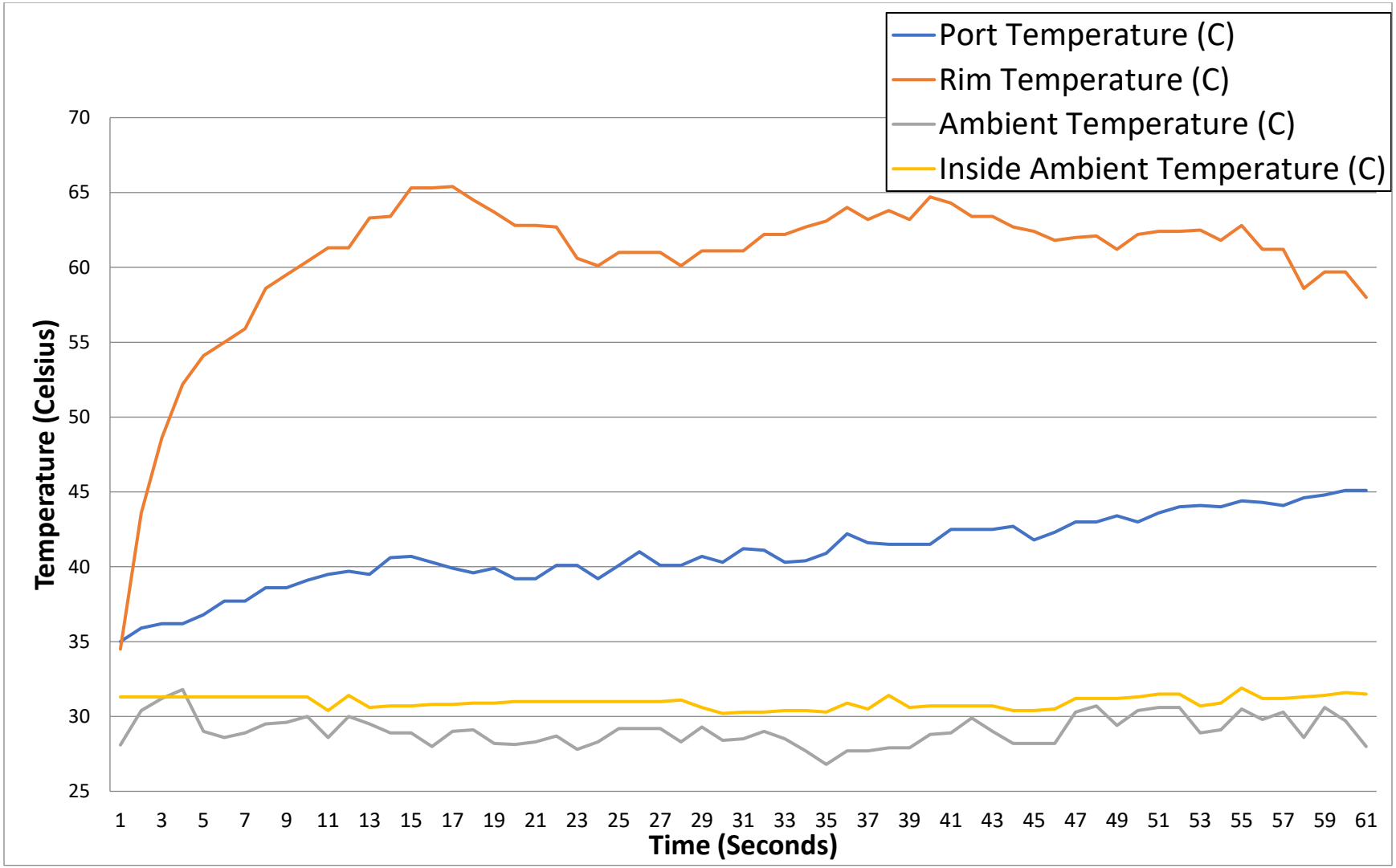


Fig S9. The graph of Acrylic Lens B and Acrylic Collector A of Trial 3 at category 4.

Table R10. Raw data set 1 of combination Acrylic Lens B and Acrylic collector (B) of Trial 1.

Type of Test:	Sun Test			
Test number:	Trial 1			
Date Taken:	26-Mar			
Time of Day:	2:21 PM			
Weather condition:	Category 4			
Sun Angle	60			
Lens and Collector	Acrylic Lens B and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	35	35	35	33.9
15	36.5	44.8	31.2	33.9
30	37.2	49.1	30	33.6
45	38.2	50.9	30	33.6
60	39.1	51.8	30	33.5
75	39	51.7	29.9	33.4
90	38.3	51.5	31.9	33.3
105	37.8	51.5	30.1	33.3
120	38.3	52.2	29.6	33.2
135	39.6	54.1	31.4	33.1
150	40.5	53.1	30.4	33.1
165	39.5	53.1	30.4	33
180	40.3	53.6	32.2	33
195	38.5	53	30.4	33
210	40.4	53	31.2	33.1
225	39.6	52.2	29.5	33.1
240	39.6	52.2	30.4	33.2
255	40.5	52.3	30.5	32.8
270	39.6	52.3	29.6	32.3
285	38.7	51.4	30.1	33.2
300	38.8	51	30.5	32.7
315	38.8	52.4	30.1	33.2
330	39.7	52.3	30.6	33.3
345	38.8	50.6	28.8	32.8
360	39.7	52.4	30.6	33.3
375	41.6	53.3	29.7	33.3
390	41.5	53.3	29.7	33.3
405	41.5	53.3	29.2	33.3
420	41	53.3	29.7	33.3
435	40.6	53.3	29.8	33.3

450	40.6	53.3	28.9	33.3
465	40.7	53.4	36.8	33.3
480	42.4	53.6	29.3	33.3
495	41.5	54.2	29.8	33.5
510	41.6	53.3	29	33.5
525	41.7	53.4	29.9	33.5
540	41.5	53.5	30.8	34
555	42.6	53.4	30.8	33.4
570	43.5	53.5	29.8	33.5
585	42.1	53.5	29	33.5
600	41.7	52.6	29.9	33.5
615	40.8	52.7	29.5	33.5
630	40.9	52.7	30	33.6
645	42.7	52.7	33.6	32.7
660	42.7	52.7	30	33.6
675	42.9	52.7	30	33.6
690	43.4	52.9	31	32.9
705	43.8	52.9	30.3	32.9
720	44.4	52.5	33	33
735	43	52.5	29.4	33.4
750	42.1	52.1	29.4	33.4
765	42.3	52.3	31.4	34.1
780	41.5	51.5	29.7	34.1
795	41.4	51.9	31.5	34.2
810	43.3	51.5	31.5	34.3
825	44.4	51.5	29.7	34.2
840	43.4	51.5	29.2	34.2
855	43.4	51.5	29.7	34.2
870	44.2	51.5	29.8	34.2
885	45.8	51.5	30.6	34.2
900	45.6	49.8	29.7	34.2

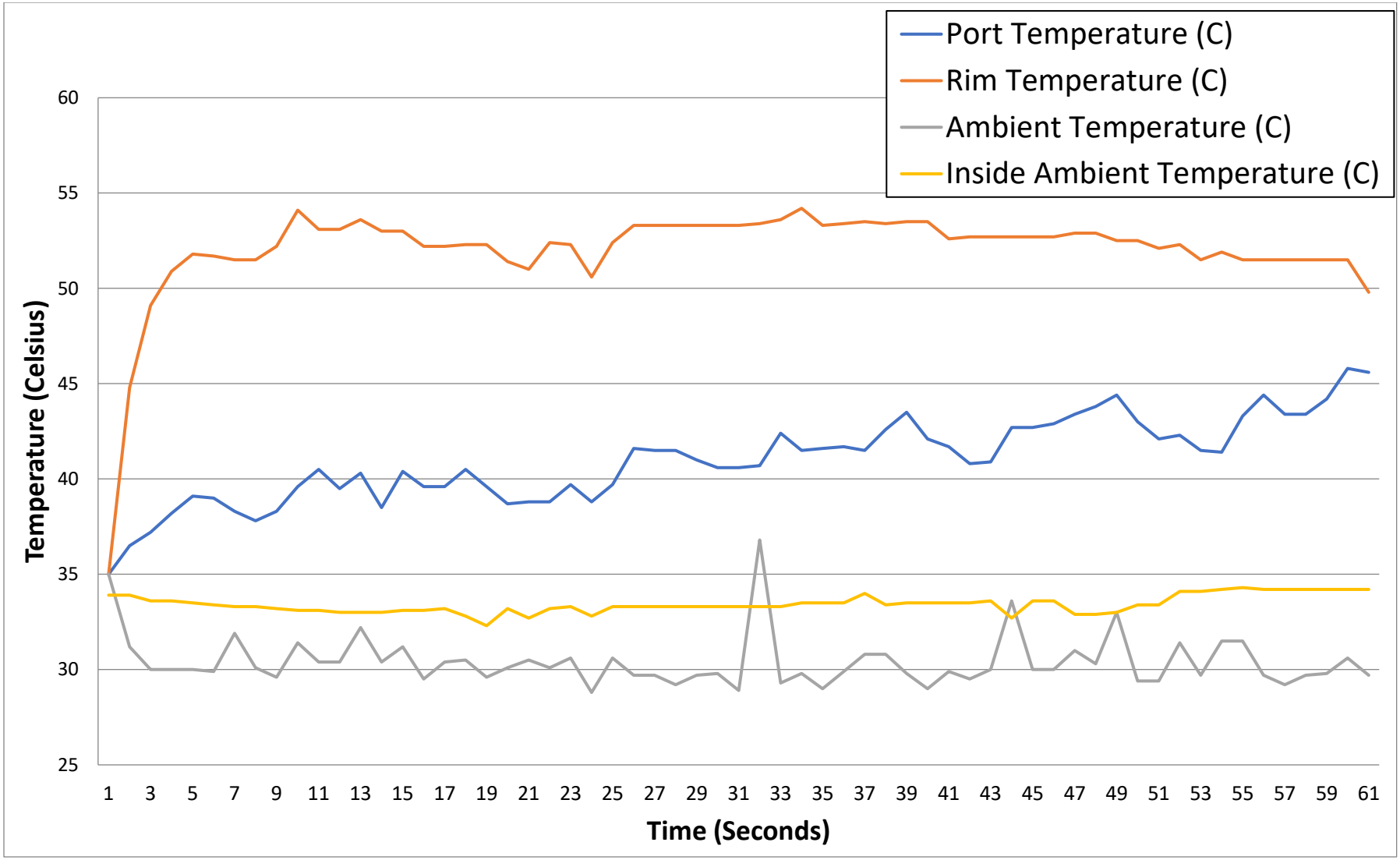


Fig S10. The graph of Acrylic Lens B and Acrylic Collector B of Trial 1 at category 4.

Table S11. Raw data set 1 of combination Acrylic Lens B and Acrylic collector (B) of Trial 2.

Type of Test:	Sun Test			
Test number:	Trial 2			
Date Taken:	26-Mar			
Time of Day:	2:46 PM			
Weather condition:	Category 4			
Sun Angle	57			
Lens and Collector	Acrylic Lens B and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	35.1	36.1	29.7	32.4
15	35.6	35.1	30.6	32.4
30	35	40.5	31.4	32.4
45	36	45.7	29.6	32.3
60	36	44.8	29.6	32.3
75	34.9	45	31.3	32.2
90	36.9	48.1	30.4	32.1
105	37.2	49.5	29.5	32.2
120	36.9	49.5	30.5	32.2
135	37	48.7	29.7	32.4
150	37.9	53.3	29.7	32.4
165	37.9	55.6	29.7	31.5
180	39.7	58.8	30.1	32.4
195	38.8	59.2	29.8	32.4
210	39.2	58.3	30.2	31.6
225	38.9	59	29.9	31.6
240	39.1	59.1	30	31.8
255	40	60.9	30	31.3
270	40	60.4	30	31.8
285	39.1	57.2	30	31.8
300	40.1	58.3	29.2	31.9
315	39.3	58.5	29.2	31.9
330	39.4	56.1	29.3	32.1
345	39.4	59.4	31.1	32.1
360	40.3	58.5	31.2	32.1
375	40.3	58.5	31.2	32.1
390	40.3	55.7	29.4	32.1
405	39.4	56.2	31.2	32.2
420	40.4	57.1	30.4	32.1
435	40.5	59.6	29.5	31.8
450	40.5	57	29.7	31.5

465	40.6	56	28.8	31.5
480	39.7	57.9	29.2	31.5
495	39.7	55.1	29.8	31.5
510	40.2	54.8	28.8	31.6
525	40.7	54.9	29	31.6
540	40.9	55.4	28.1	31.7
555	40.9	55.4	28.2	31.8
570	40.9	52.7	28.2	31.8
585	41	52.7	28.2	31.8
600	41	53.6	28.3	31.9
615	41	52	29.2	31.9
630	42	53.7	29.2	32
645	42	52.9	30.2	31.9
660	40.2	49.3	30.2	31.5
675	42	52.9	29.8	32
690	43	54.8	30.4	32.1
705	42.1	54.4	30.7	32.1
720	41.3	52.2	30.5	31.6
735	41.4	52.3	33.2	31.8
750	41.5	50.6	33.8	31.5
765	40.6	51.5	31	31.5
780	41.7	51.7	30.8	30.8
795	40	50	30	30.9
810	41.8	51.8	30.9	31.1
825	41.1	50.2	30.2	31.2
840	39.4	46.2	29.8	31.2
855	42.3	47.5	30.3	31.4
870	41.4	47.3	30.6	31.5
885	42.4	47	30.6	31.5
900	43.6	47	34.5	31.8

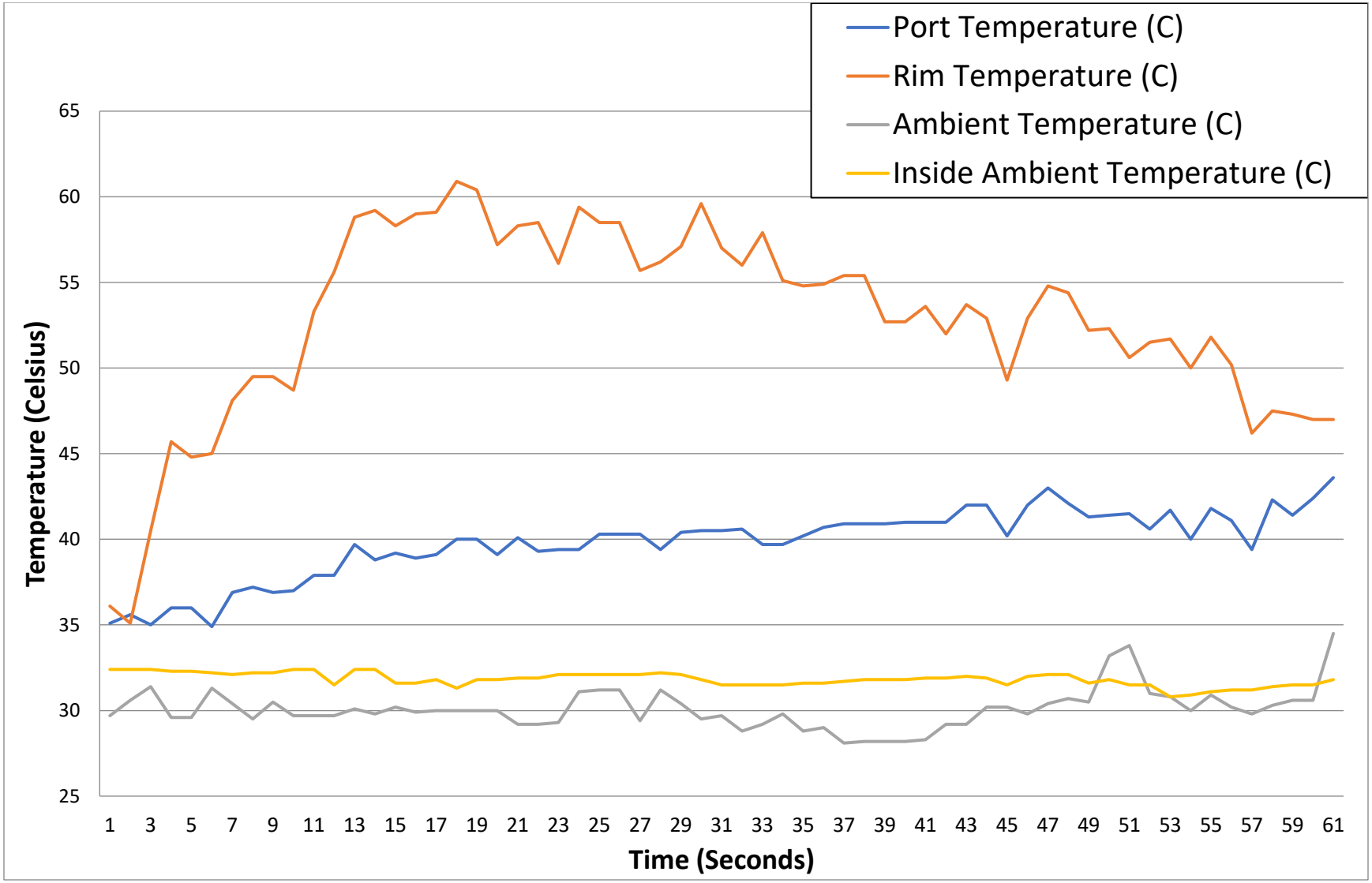


Fig S11. The graph of Acrylic Lens B and Acrylic Collector B of Trial 2 at category 4.

Table S12. Raw data set 1 of combination Acrylic Lens B and Acrylic collector (B) of Trial 3.

Type of Test:	Sun Test			
Test number:	Trial 3			
Date Taken:	26-Mar			
Time of Day:	3:13 PM			
Weather condition:	Category 4			
Sun Angle	50.4			
Lens and Collector	Acrylic Lens B and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	35.1	35.1	30.6	33.3
15	35.9	41.8	30.4	33.1
30	36.7	44.8	29.4	33
45	36.7	45.7	29.4	33
60	37.5	48	29.3	32.9
75	37.4	48.3	30.1	32.9
90	38.2	48.7	30.1	33.3
105	38.3	50	30.1	32.7
120	37.4	48.3	30	32.8
135	39.1	50.1	30	32.8
150	39.2	51.9	32.8	32.9
165	38.4	51.1	33.7	32.9
180	40.3	52.1	29.4	32.1
195	39.4	50.3	32.1	32.1
210	39.4	51.2	30.3	32.1
225	39.4	49.5	30.4	32.1
240	39.9	50.5	30.4	32.3
255	40.6	51.5	30.6	32.4
270	39.7	47.4	30.6	32.4
285	40.1	49.7	30.1	32.4
300	40.6	50.7	30.7	32.4
315	39.8	49.8	29.8	33.4
330	39.9	48.9	29.4	33.5
345	39.9	49	29	34
360	40.4	50	31.8	33.6
375	40	50	29.5	33.6
390	40.1	49.1	29.5	33.7
405	39.7	48.3	30.2	32.8
420	40.6	50.2	29.2	32.8
435	40.2	47.5	29.3	32.9
450	40.3	47.5	30.3	33

465	40.3	49.4	31.2	33.9
480	40.3	49.4	33	33
495	41.4	49.5	32.2	32.5
510	42.3	50.5	31.3	32.7
525	42.3	49.6	28.8	32.4
540	42.4	49.7	29.7	32.8
555	41.9	48.9	29.2	32.5
570	41.7	50	29	32.6
585	42.7	49.1	29.5	32.7
600	41.9	48.2	29.1	32.7
615	42	48.2	29.1	32.8
630	41.1	48.4	29.7	32.9
645	42.5	48.9	29.8	32
660	42.5	47.5	29.8	33
675	42.2	47.7	29.5	33.1
690	43.2	48.7	30	33.2
705	43.8	48.8	29.7	33.3
720	42.4	46.9	29.7	33.3
735	41.5	47	29.7	34.7
750	41.6	46	29.5	35.2
765	42.1	47.1	29.9	34.4
780	42.7	47.1	30.3	34.4
795	40.9	45.4	30.9	33.6
810	41.8	46.3	31.8	34.5
825	42	46.4	29.1	34.5
840	42.9	47.3	30.2	34.6
855	42	47.4	30.2	33.8
870	42.1	46.6	30.3	33.9
885	42.1	46.6	31.6	33.9
900	42.1	47.1	33	34

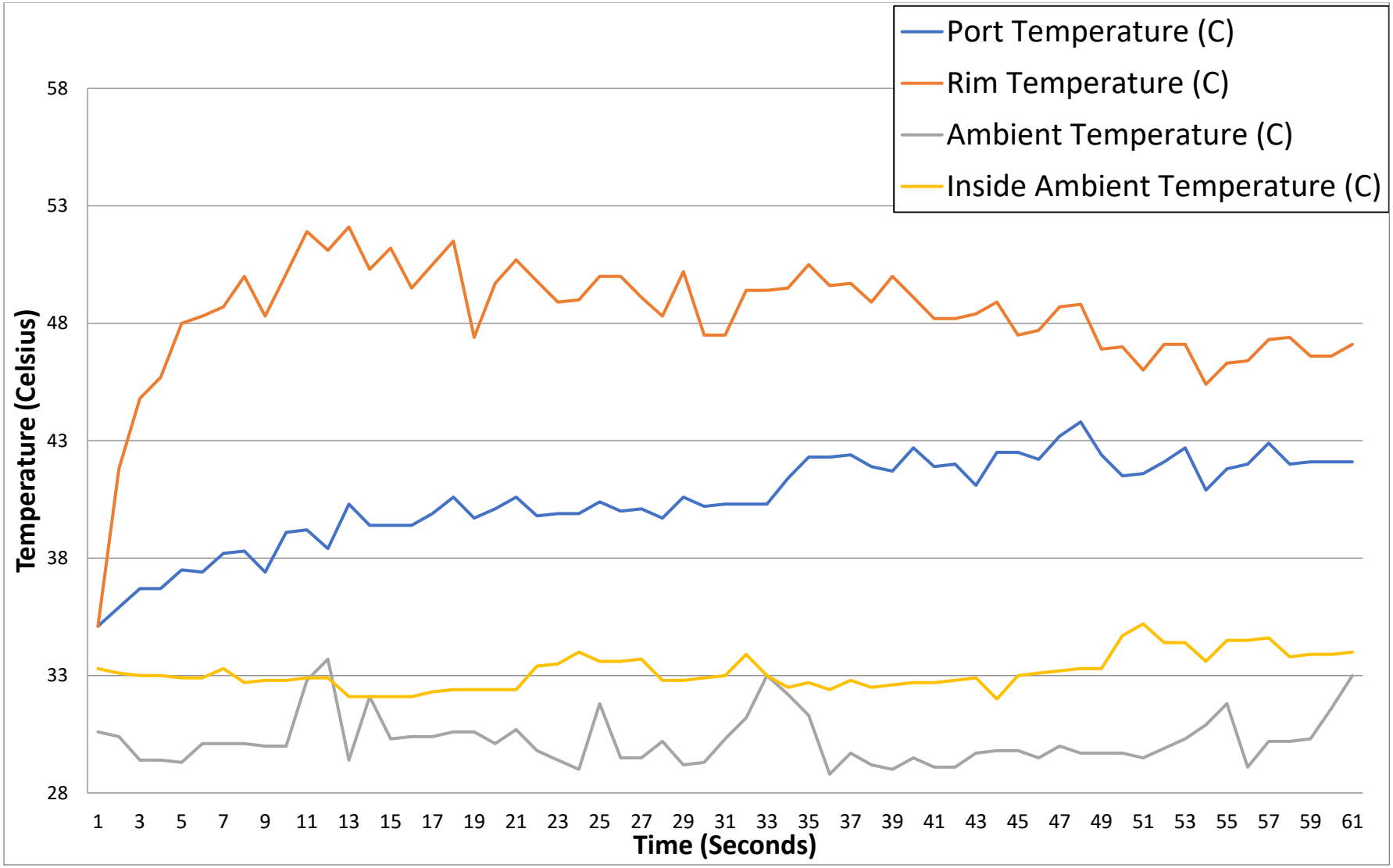


Fig S12. The graph of Acrylic Lens B and Acrylic Collector B of Trial 3 at category 4.

.

Table S13. Raw data set 1 of combination Polycarbonate Coated Lens A and collector (A) of Trial 1.

Type of Test:	Sun Test			
Test number:	Trial 1			
Date Taken:	25-Mar			
Time of Day:	4:40 PM			
Weather condition:	Category 4			
Sun Angle	24			
Lens and Collector	Polycarbonate Coated Lens A and Collector A			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	36.6	37.5	33.9	35.7
15	36.6	37.4	33	35.6
30	37.3	40	34.5	35.4
45	37.4	41.1	34.7	36.5
60	38.5	42.1	35.8	36.6
75	37.8	42.4	36.5	36.3
90	39.1	41.8	37.2	37.2
105	38.7	42.9	37.3	37.3
120	39.4	47.1	38.4	37.5
135	39.5	48.5	38.1	37.6
150	40.5	49.6	37.3	38.2
165	41.2	48.9	38	38
180	42	50.2	38.3	38.2
195	43.8	51.1	40.1	39.2
210	44.1	51.4	39.5	39.5
225	43.5	52.1	41.7	39.8
240	43.8	52	41	40.1
255	44.1	52.3	42.2	40.4
270	44.4	52.5	41.6	40.6
285	44.6	52.8	44.1	40.9
300	44.8	53	41.2	41.1
315	45.9	53.2	40.4	40.9
330	45.3	53.5	43.5	41.6
345	45.6	53.8	45.6	41.9
360	46	54.2	44.1	42.2
375	46.1	53.3	44.4	42.6
390	46.6	54.6	40.6	42.3
405	46.7	54.4	42.1	43
420	46.5	54.2	43.3	43.3

435	46.5	54.3	44.3	43.4
450	46.2	54.5	44.9	43.5
465	46.4	54.5	46.4	43.6
480	46.5	54.7	46.5	43.8
495	46.7	54.8	46.7	43.9
510	46.5	54.7	47	44.2
525	47.2	54.4	45.4	44.4
540	47.5	55.2	44.8	43.8
555	47.2	55	43.9	44.1
570	47	55.1	39.7	45.1
585	46.1	55.1	38.9	45.6
600	45.6	54.2	38.3	46
615	46.9	55	39.6	45.8
630	47.9	55.3	40.6	45.2
645	48.2	55.4	40.8	45.4
660	48.2	55.4	40.4	45.4
675	48.2	55.4	40	45.4
690	48.4	55.5	43.6	45.6
705	48.5	55.3	42.1	45.7
720	48.5	55.7	43.1	46.2
735	47.8	55	45.5	45.9
750	49	55.7	44.3	46.1
765	49.1	55.4	45.4	46.8
780	49.2	55.4	48.3	47.2
795	49.3	55.6	46.5	47.4
810	47.4	55.6	47.4	47.4
825	47.4	55.6	44.7	48.4
840	47.4	55.6	43.8	47.3
855	47.8	55.5	42.8	47.4
870	48.2	55.4	42.7	47.2
885	49.1	55.4	41.8	47.2
900	50.3	54.4	41.5	47.3

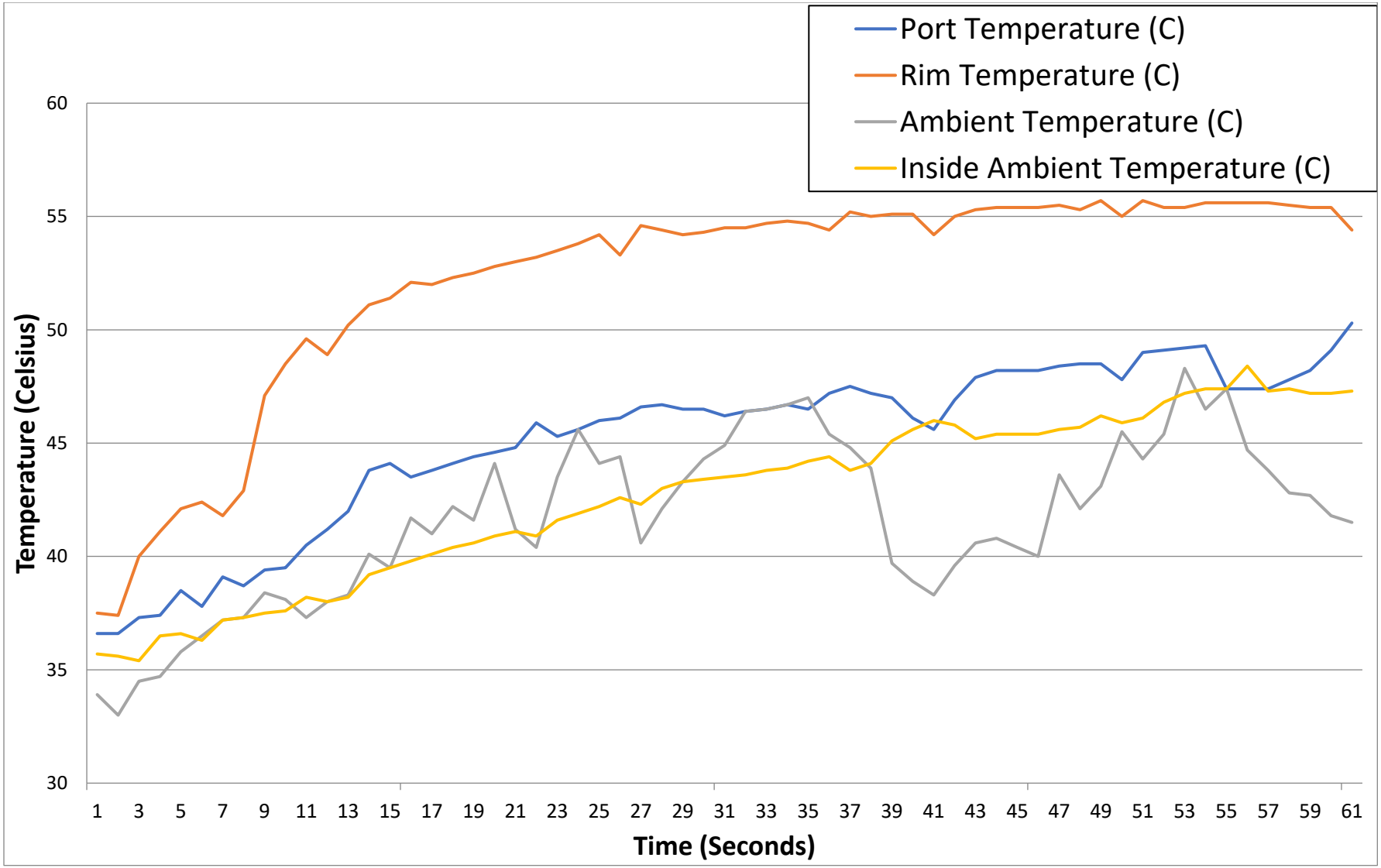


Fig S13. The graph of Polycarbonate Lens A and Collector A of Trail 1 at category 4

Table S14. Raw data set 1 of combination Polycarbonate Lens A and collector (A).

Type of Test:	Sun Test			
Test number:	Trial 2			
Date Taken:	26-Mar			
Time of Day:	4:22 PM			
Weather condition:	Category 4			
Sun Angle	39			
Lens and Collector	Polycarbonate Lens A and Collector A			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	34.2	34.5	30.9	32.7
15	34.5	40	31.7	32.6
30	34.5	39.9	30.2	33.1
45	35.6	40.7	31	33.4
60	36.4	41.5	30.5	33.3
75	37.4	42.4	30.6	33.3
90	37.9	42.4	32.4	33.3
105	38.8	43.3	31.5	33.3
120	38.8	45.1	32.9	33.3
135	39.7	45.1	31.5	33.3
150	39.7	44.2	30.6	33.3
165	38.8	43.3	30.6	34.2
180	39.7	44.7	31.5	34.2
195	38.8	43.4	30.1	34.2
210	38.9	42.4	30.6	34.2
225	38	41.6	30.7	33.9
240	39	43.4	31.7	34.3
255	40.2	46.1	30.7	33.4
270	40.8	47.1	31.7	34.3
285	39.9	44.5	30.8	34.3
300	40	44	30.9	34.4
315	39.9	44.5	30.9	34.5
330	40.9	46.3	32.7	33.6
345	40.4	45.4	31.8	34.1
360	41.8	47.4	30.9	33.2
375	40	43.7	30.1	32.8
390	40.1	43.7	30.2	33.8
405	40.2	44.7	30.1	33.8
420	41.1	46.5	31.2	33.8
435	40.3	45.3	30.3	33

450	40.3	44.8	30.7	33
465	41.3	45.7	30.3	33.1
480	40.9	45	30.5	33.2
495	40.6	45	30.6	33.3
510	42.4	47.4	31.5	33.3
525	42.4	48	31.6	32.4
540	41.7	46.2	30.4	33.5
555	41.8	46.3	31.8	33.5
570	41.8	46.3	30.4	32.7
585	41.8	45.4	30	33.6
600	41.9	45.4	30	32.7
615	41.3	45.5	30.1	32.9
630	42	45.6	30.2	32.9
645	40.7	43.8	29.3	33.9
660	41.6	45.7	30.2	33
675	41.6	46.6	30.3	33
690	41.2	44.4	29.4	33
705	42.1	45.7	31.7	33.4
720	42.1	45.7	30.3	33.2
735	42.1	47.5	31.3	33
750	41.3	44.9	29.9	33.9
765	40.4	44	29.5	34.1
780	40.5	43.1	30.4	34.1
795	41.4	44	31.4	34
810	41.3	45.9	31.4	33.5
825	41.4	44.1	30	34.1
840	41.4	45	29.6	34.1
855	41.4	46	30.5	34.1
870	41.4	44.1	30.5	34
885	41.4	43.7	29.7	34.1
900	41.4	45.1	30.5	34.1

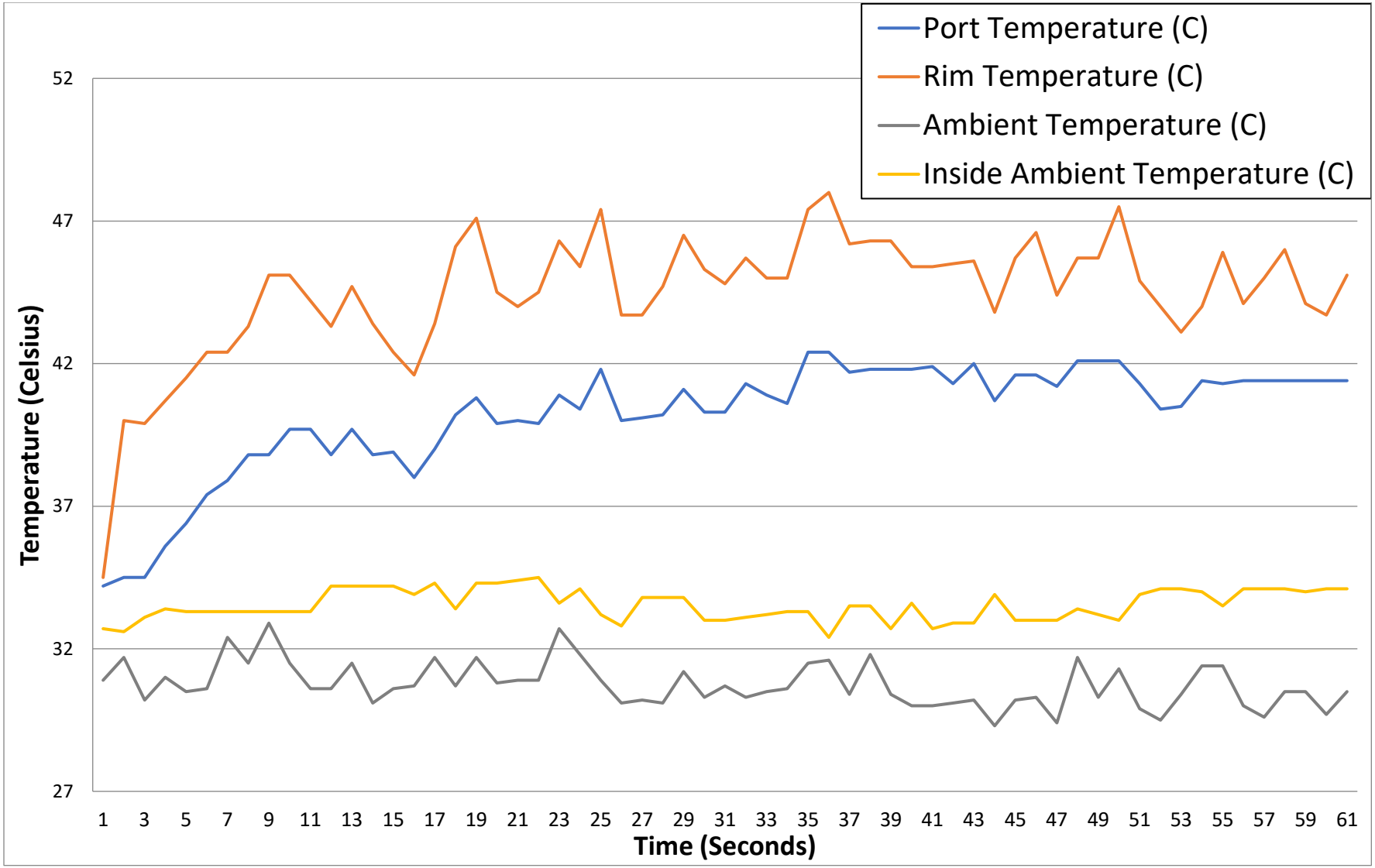


Fig S14. The graph of Polycarbonate Lens A and Collector A of Trial 2 at category 4.

Table S15. Raw data set 1 of combination Polycarbonate Lens A and collector (A)

Type of Test:	Sun Test			
Test number:	Test 3			
Date Taken:	26-Mar			
Time of Day:	5:00 PM			
Weather condition:	Category 4			
Sun Angle	39			
Lens and Collector	Polycarbonate Lens A and Collector A			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	37.2	37.3	30.3	31.3
15	37.8	39.1	29.9	31.7
30	37.2	39	30.8	31.7
45	38	40.7	30.7	31.5
60	38	40.7	30.1	31.5
75	38	39.8	30.7	31.9
90	37.9	39.7	29.7	32.4
105	38	40.6	30.1	31.4
120	37.9	40.6	30.6	31.9
135	37.9	41.5	29.7	32.4
150	37.9	41.5	29.7	32.4
165	37.9	39.7	29.2	32.4
180	38.8	42.4	30.6	31.5
195	38.8	42.3	30.6	31.4
210	38.7	43.3	31	31.4
225	39.6	43.2	30.8	31.5
240	39.6	43.2	30	32.3
255	38.6	42.3	30.1	31.5
270	39.1	41.3	30.5	32.2
285	38.8	42.2	30.4	32.2
300	38.8	42.3	30.5	32.2
315	39.6	43.1	30.6	31.7
330	39.7	42.4	31.5	32.4
345	39.7	42.9	31.5	32.4
360	39.7	43.3	31.5	32.4
375	39.7	42.4	30.6	32.4
390	39.7	43.3	31.5	31.9
405	39.7	43.3	32.4	31.5
420	40.7	44.3	31	31.5
435	39.7	43	30.7	32.4
450	39.8	43.4	30.7	32.5

465	40.3	44.4	30.8	32.1
480	40.9	44.5	29.9	31.7
495	40	42.7	30	32.7
510	40.1	43.7	31.8	31.8
525	40.2	43.8	30.2	32.4
540	39.3	42	30.1	32.9
555	39.3	42.1	30.3	32.9
570	39.3	41.2	30.3	33
585	40.3	41.6	30.3	33
600	40.3	42.5	30.3	32
615	40.3	43	29.8	32.1
630	40.3	42.6	29.4	32.1
645	40.3	43	29.8	32.1
660	40.3	42.6	29.4	33
675	39.4	42.1	30.3	32.1
690	39.8	43	29.4	32.1
705	39.4	42.1	29.8	32.1
720	39.5	41.7	29.5	32.2
735	39.5	42.2	29.4	32.6
750	39.5	41.3	29.5	32.6
765	40	42.2	29.6	33.2
780	40.5	42.8	30.4	32.3
795	39.6	42.3	30	33.2
810	40.4	43.2	30.6	32.7
825	40.6	42.3	30	33.2
840	40.6	43.2	30.6	32.3
855	40.6	42.4	29.6	33.3
870	39.6	41.5	29.1	33.2
885	39.7	42.4	28.7	33.3
900	40.5	42.3	31	32.7

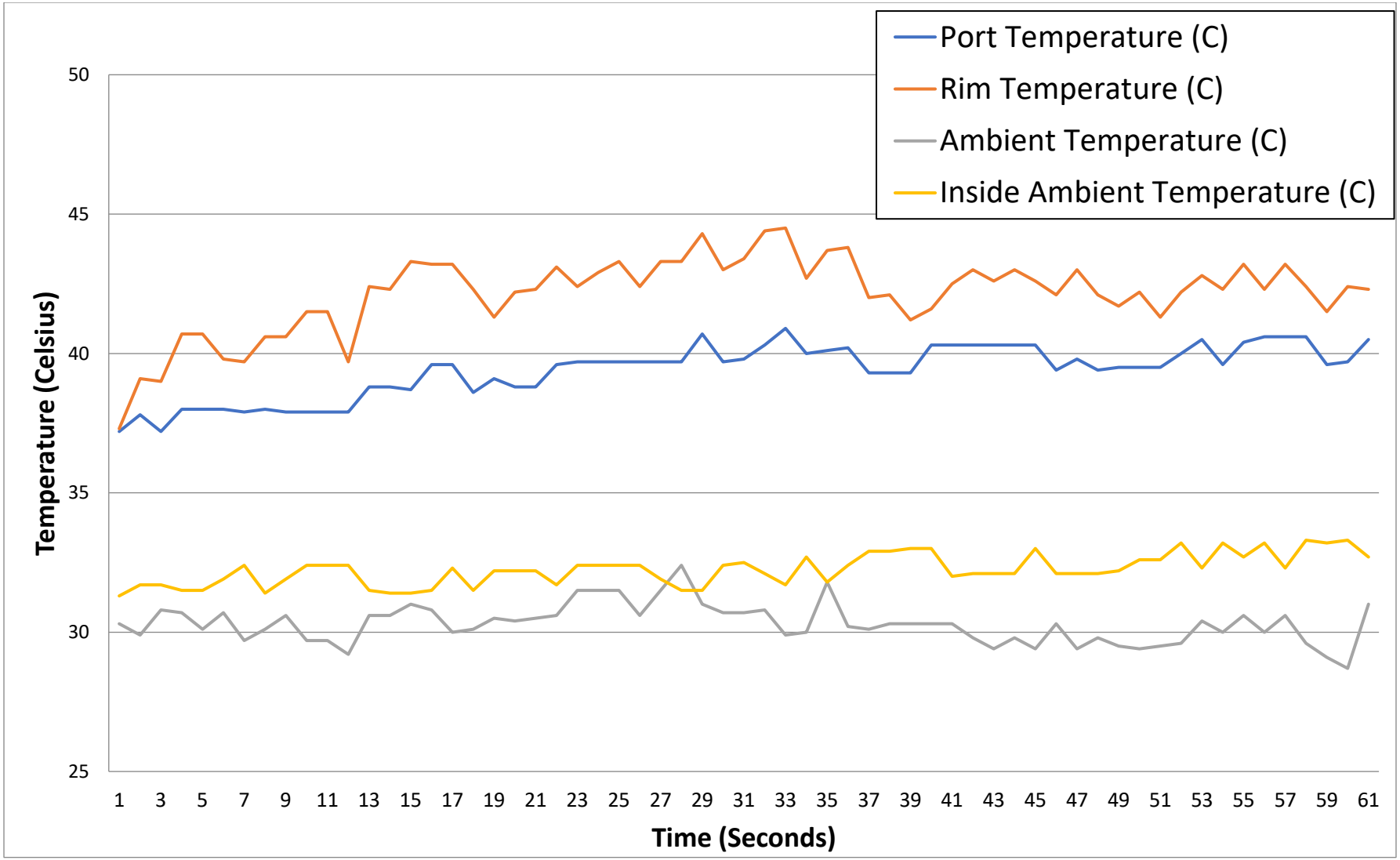


Fig S15. The graph of Polycarbonate Coated Lens A and Collector A of Trial 3 at category 4.

Table S16. Raw data set 1 of combination Polycarbonate Coated Lens A and collector (B) of Trial 1.

Type of Test:	Sun Test			
Test number:	Trial 1			
Date Taken:	25-Mar			
Time of Day:	2:30 PM			
Weather condition:	Category 4			
Sun Angle	58			
Lens and Collector	Polycarbonate Coated Lens A and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	37.5	34.7	30.2	35.5
15	38.3	41.9	33.7	37.4
30	39.4	44.8	33.5	38.5
45	39.4	49	34.9	38.6
60	40.6	52.4	34.2	38.8
75	40.9	53.1	33.6	39.1
90	41.1	55.6	33.8	39.3
105	41.3	54.8	34.8	39.4
120	42.4	55.1	36	40.6
135	42.6	56.2	35.4	40.8
150	42.7	56.4	35.4	40
165	43	56.6	35.7	40.7
180	43.2	56.8	35.9	40.3
195	44.2	56	36.5	40.6
210	44.5	55.3	37.1	40.2
225	44.5	56.4	37.2	40.4
240	44.7	55.7	36.5	40.2
255	44.8	54.4	36.6	40.2
270	44.9	55.9	36.7	40.3
285	45	55	36.8	40.4
300	44.3	55.3	36.2	41.7
315	44.4	54.9	37.6	41.7
330	45.6	54.7	36.5	42
345	45.6	54.7	36.5	42
360	45.9	54.1	36.8	42.3
375	45.5	55	39.1	42.3
390	45	54.5	37.7	42.4
405	45.3	55.1	38.9	42.5
420	46.2	55.3	38.5	41.7

435	46.9	54.7	38.2	40.9
450	46.5	54.3	38.8	40
465	46.8	54.5	38.6	40.7
480	47.1	54.3	38.9	40.4
495	47.1	54.5	40.3	40.7
510	47.4	53.3	40.1	40.3
525	47.2	53.2	39.3	40.5
540	47.3	53.2	37.7	40.1
555	46.8	52.3	38.6	40.1
570	46.8	52.3	37.7	40.8
585	45.9	51.8	38.1	41.2
600	46.7	52.2	37.7	41.5
615	46.7	52.2	38.5	41.4
630	46.7	52.7	39.4	41.6
645	47.7	52.7	38.6	42
660	47.9	52.5	39.7	42.3
675	48	53.4	38.4	42.4
690	48	53.5	38	42.6
705	48.1	52.1	38	43.6
720	48	52.1	38	43.5
735	48	51.6	38.9	43.2
750	48	52.6	38	43.5
765	48.2	52.6	38	43.9
780	48	51.8	37.5	43.6
795	47.1	50.7	37.3	44.1
810	47.1	51.6	37.1	44
825	48	51.6	38.9	44.4
840	48	50.8	38.2	44.4
855	48	51.4	38.9	43.7
870	47.1	51	37.2	43.6
885	48.5	50.7	37.1	42.5
900	48.6	51.1	37.5	42.7

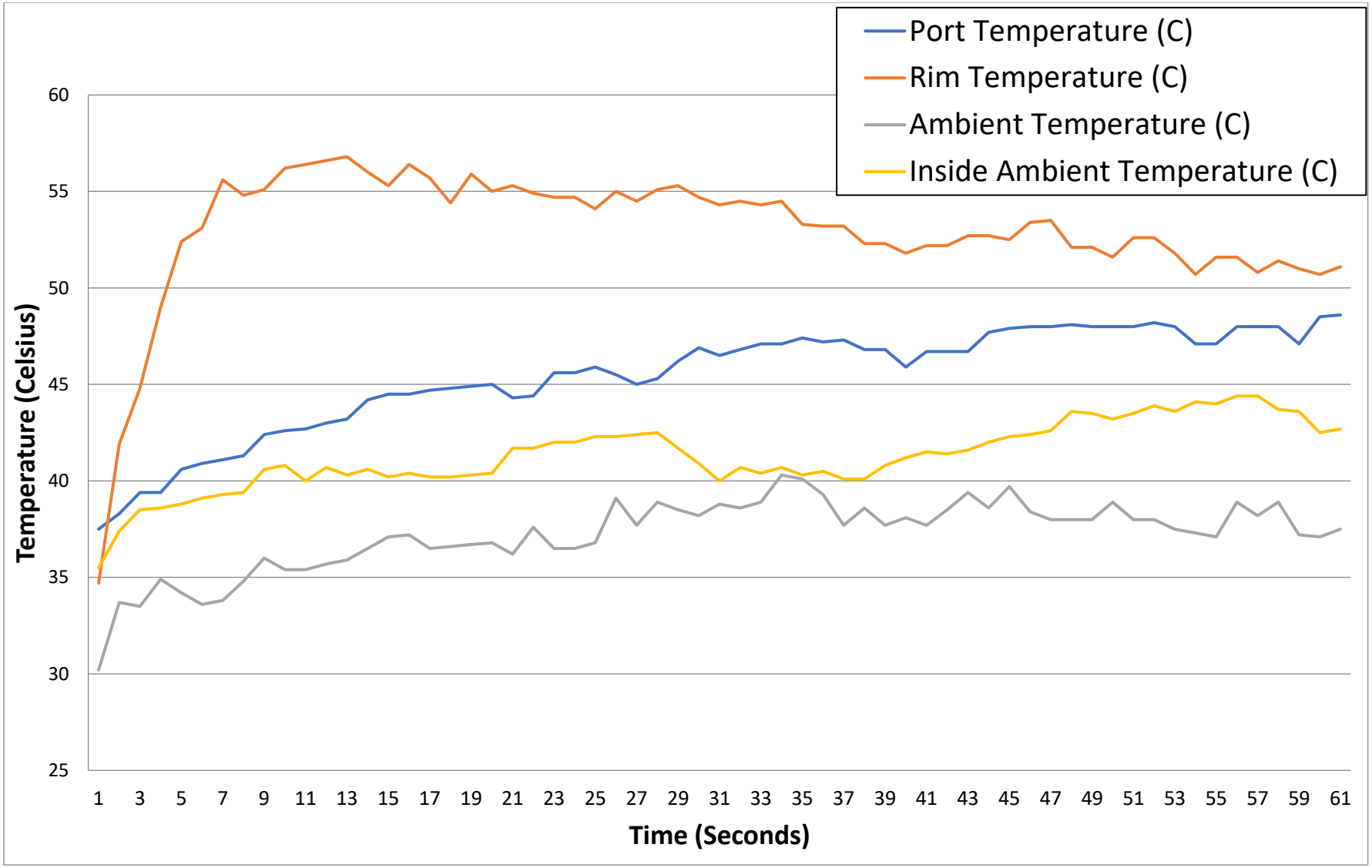


Fig S16. The graph of Polycarbonate Coated Lens A and Collector B of Trial 1 at category 4

Table S17. Raw data set 1 of combination Polycarbonate Lens A and collector (B) of Trial 2.

Type of Test:	Sun Test			
Test number:	Trial 2			
Date Taken:	25-Mar			
Time of Day:	4:40 PM			
Weather condition:	Category 4			
Sun Angle	36			
Lens and Collector	Polycarbonate Coated Lens A and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	36.6	37.4	33	35.6
15	37.3	40	34.5	35.4
30	37.4	41.5	35.5	36.5
45	37.5	42.1	34.8	36.6
60	37.8	42.4	36.5	36.9
75	39.1	41.8	37.2	37.2
90	39.2	43.6	37.4	37.5
105	39.4	47.1	38.4	37.5
120	39.4	48.5	38.1	37.6
135	40.4	49.6	37.3	38.2
150	41.7	49.4	38	38
165	42	50.2	38.3	38.2
180	43.8	51.1	39.3	39.2
195	44.1	51.4	39.5	39.5
210	43.5	51.7	41.7	39.8
225	43.8	52	41	40.1
240	44.1	52.3	42.2	40.4
255	44.4	52.5	42.5	40.3
270	44.4	52.6	43.5	40.7
285	44.7	52.9	43.7	40.9
300	44.8	53.1	40.6	41.1
315	45	53.2	39.6	40.4
330	45.3	53.5	42.5	41.5
345	45.3	53.5	43.5	41.5
360	45.6	53.8	41.6	41.9
375	46	54.2	44.1	42.2
390	46.1	53.3	44.4	42.6
405	46.6	54.6	40.6	42.3
420	46.7	54.4	42.1	43
435	46.1	54.2	43.3	42.9
450	46.5	54.3	44.3	43.4

465	46.2	54.5	45.3	43.5
480	46.4	54.5	41.1	43.6
495	46.6	54.7	43.5	43.8
510	46.7	54.8	45.1	43.9
525	46.9	54.7	44.1	44.1
540	46.4	54.5	44.4	43.6
555	46.5	54.7	44.5	43.8
570	46.7	54.8	44.7	43.9
585	47	55.1	41.5	44.2
600	47.2	54.4	42	44.4
615	47.5	55.2	44.8	43.8
630	47.2	55	43.9	44.1
645	47.1	55.1	39	44.1
660	46.1	55.1	38.9	43
675	45.1	54.2	38.8	42
690	46.8	55	39.6	43.2
705	48.2	55.4	39.7	43.4
720	48.2	55.4	40	43.4
735	48.3	55.6	39.4	43.6
750	48.5	55.3	40.1	43.7
765	48.5	54.8	39.8	43.7
780	48.8	55.9	40.2	43.9
795	48.8	55.2	38.9	43.6
810	49.1	55.4	35.7	43.8
825	48.7	55.5	38.4	44.2
840	49.2	55.6	38.3	44.7
855	47.4	55.6	40.2	43.2
870	48.4	55.2	39.8	43.1
885	48.9	54.8	40.2	45.4

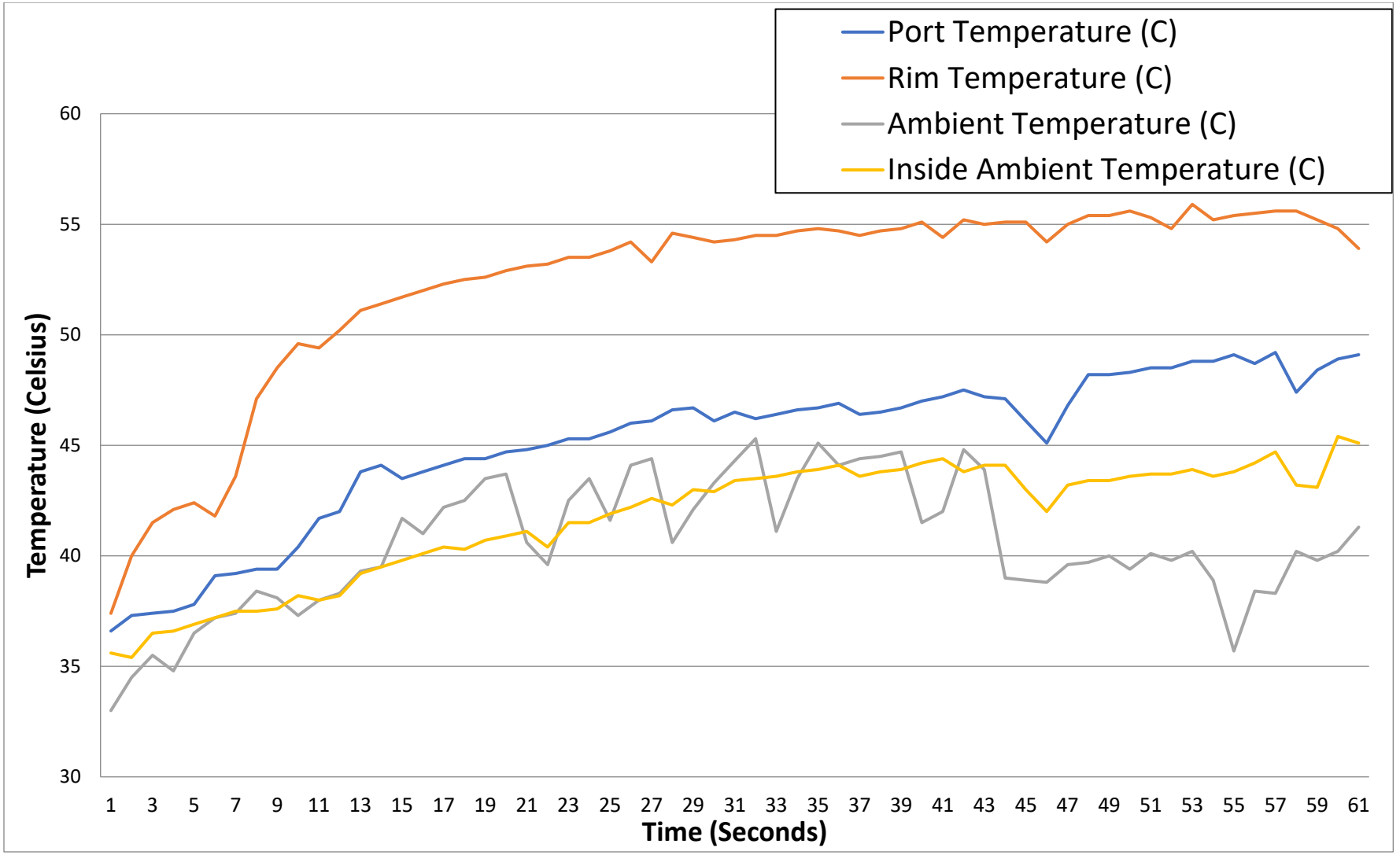


Fig S17. The graph of Polycarbonate Coated Lens A and Collector B of Trial 2 at category 4.

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Table S18. Raw data set 1 of combination Polycarbonate Lens A and collector (B) of Trial 3.

Type of Test:	Sun Test			
Test number:	Trial 3			
Date Taken:	25-Mar			
Time of Day:	5:00 PM			
Weather condition:	Category 4			
Sun Angle	27			
Lens and Collector	Polycarbonate Coated Lens A and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	37.1	38	34.4	38.9
15	37.3	37.7	34.1	38.5
30	37.7	40.4	35.8	38.6
45	37.6	41.2	34.9	38.4
60	38.6	42.3	36.8	38.6
75	38.9	42.5	34.2	38.2
90	39.8	44.5	33.2	38.3
105	39.8	45.8	34.2	38.7
120	40	47.7	35.5	39.2
135	40.7	50.3	34.5	39.4
150	41.1	50.1	34.3	39.4
165	41.4	52.3	34.3	39.6
180	41.8	52.6	37.7	39.8
195	42	51	37.9	39.8
210	42.3	53.3	37.2	39.3
225	42.6	51.6	37.4	39.3
240	42.4	52.3	38.4	39.5
255	43	54	38.4	39.5
270	43.4	52.4	37.4	38.4
285	42.3	54	37.5	38.7
300	42.3	55	37.4	38.7
315	41.9	51	38.4	39.2
330	42.1	53.9	37.3	38.7
345	42.1	51.3	37.4	39.3
360	42.2	54.9	38.1	39.5
375	41.1	55.7	39.2	39.8
390	40.9	56.4	39.5	39.3
405	41.8	50.9	38.4	39.5
420	42.3	49.9	38.4	39.6
435	41.8	50.4	38.6	39.6
450	41.8	51.4	37.4	39.6

465	42	52	37.4	39.7
480	42.1	50.3	37.5	39.5
495	42.1	53	37.8	39.2
510	41.5	53.4	37.6	39.5
525	42.4	51.5	38.4	39.5
540	42.8	51.6	38.6	39.6
555	42.8	50.7	38.5	39.9
570	42.8	50	38.5	40.1
585	42.9	49.1	38.9	40.2
600	43.5	50.8	38.4	39.4
615	42.9	50.9	38.5	39.6
630	42.9	50.2	37	39.4
645	43	49.3	37.2	39.8
660	43	49.3	37.5	39.6
675	42.1	50.1	37.8	39.5
690	42.4	52.3	38.4	39.7
705	43.4	51.5	38.7	39.3
720	42.4	48.8	37.3	40
735	43.5	49.3	38.6	40.2
750	42.3	49.6	38.5	39.5
765	42.5	49.4	39.5	40.3
780	42.5	48.9	38.7	40.5
795	42.5	49.8	37.4	40.1
810	43.4	49	37.6	40.3
825	43.6	49	37.6	39.7
840	43.1	49	37.8	40.1
855	43.6	50.3	37.9	41.3
870	42.7	50.7	38.6	41.6
885	42.7	50	38.5	41.6
900	43.7	49.2	38.5	40.2

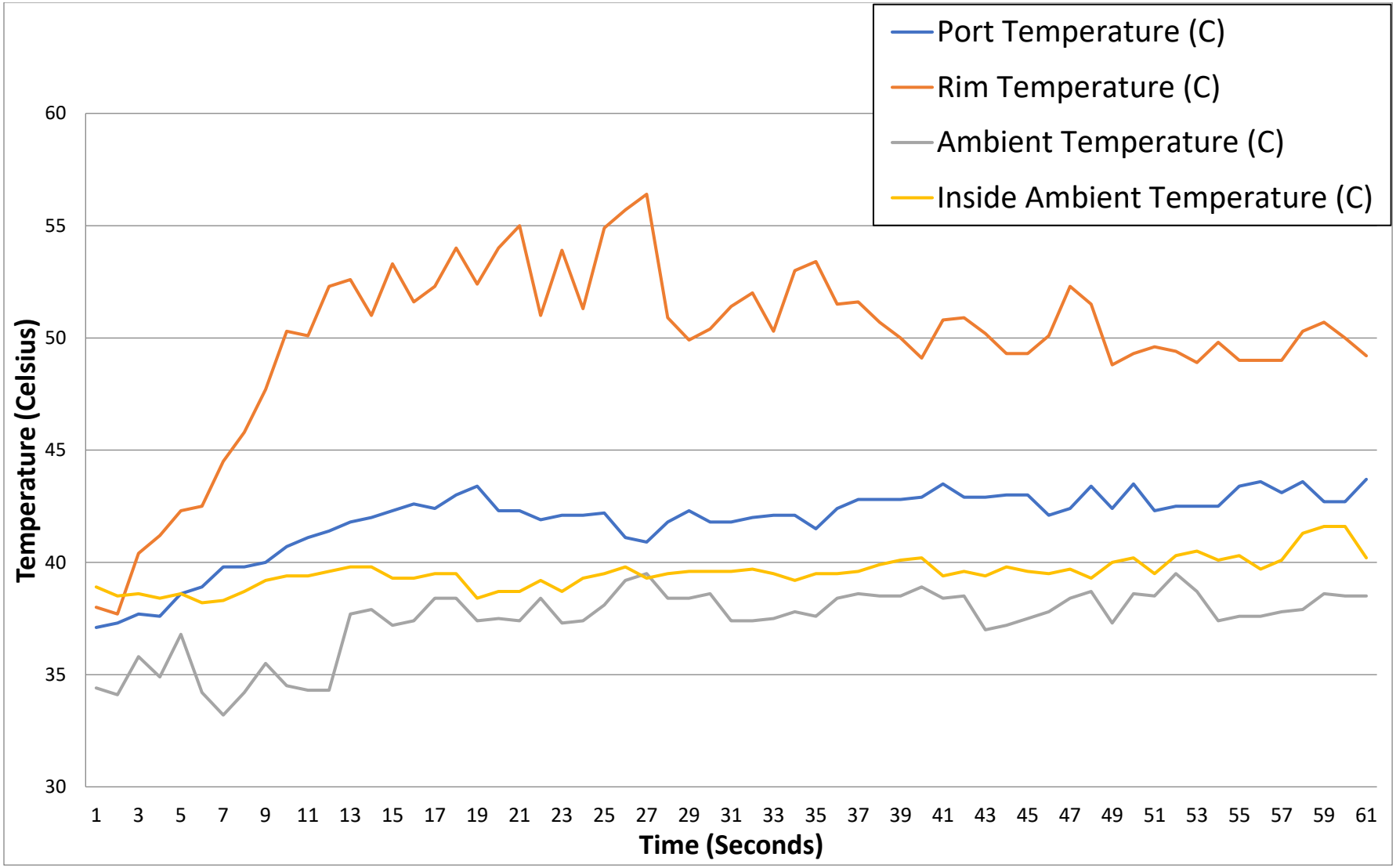

Fig S18. The graph of Polycarbonate Coated Lens A and Collector B of Trial 3 at category 4.

Table S19. Raw data set 1 of combination Polycarbonate Lens B and collector (A) of Trial 1.

Type of Test	Sun Test		
Test number:	Trial 1		
Date Taken:	23-Mar		
Time of Day:	4:03 PM		
Weather condition:	Category 2		
Sun Angle	52		
Lens and Collector	Polycarbonate Lens B and Collector A		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	25	24.5	22.2
15	25	25	21.8
30	26	25	22.2
45	25.5	25	21.4
60	26.5	25.1	21.4
75	26.4	26.1	21.4
90	26.1	25.6	22
105	26.3	25.7	21.6
120	26.7	25.4	21.7
135	26.3	26.3	22.7
150	26.5	26	22.7
165	26.6	25.7	22
180	26.7	26.6	22
195	27.1	26.2	22.2
210	27.2	25.9	22.2
225	27	26	22.4
240	27.4	27.1	22.5
255	27.1	27.1	23
270	27.3	27.3	22.7
285	27.4	27.4	21.9
300	27.9	27.5	21.5
315	27.7	27.7	21.3
330	27.7	27.2	21.3
345	27.7	27.2	21.3
360	27.8	26.8	21.9
375	28.1	26.9	22.3
390	27.8	26.5	22.3
405	27.8	26.8	22.3
420	28.2	26.9	22.2
435	27.7	26.8	22.3
450	28.1	26.8	22.2
465	27.7	26.8	22.7

480	27.7	26.8	21.2
495	28.1	26.8	22.2
510	27.2	26.8	22.2
525	27.7	26.3	22.2
540	27.6	26.3	21.3
555	27.7	26.3	21.8
570	27.1	26.8	21.2
585	27	25.7	22.1
600	26.5	26.1	21.9
615	27.8	26.4	21.9
630	27.3	25.9	21.8
645	27.5	26.4	21.8
660	26.7	26.2	20.7
675	26.2	26.2	21.2
690	27.5	27.1	22.5
705	27.1	26.2	21.6
720	27.1	26.2	21.6
735	27.1	26.2	21.6
750	27.5	26.2	21.6
765	26.6	26.2	21.6
780	27.1	27.1	22.1
795	27.1	27.2	22.5
810	27.1	26.2	21.8
825	27.5	26.3	21.6
840	27.6	26.2	21.6
855	27.7	27.1	22.6
870	27.5	27.1	21.5
885	27.2	26.4	21.6
900	27.2	26.4	22.2

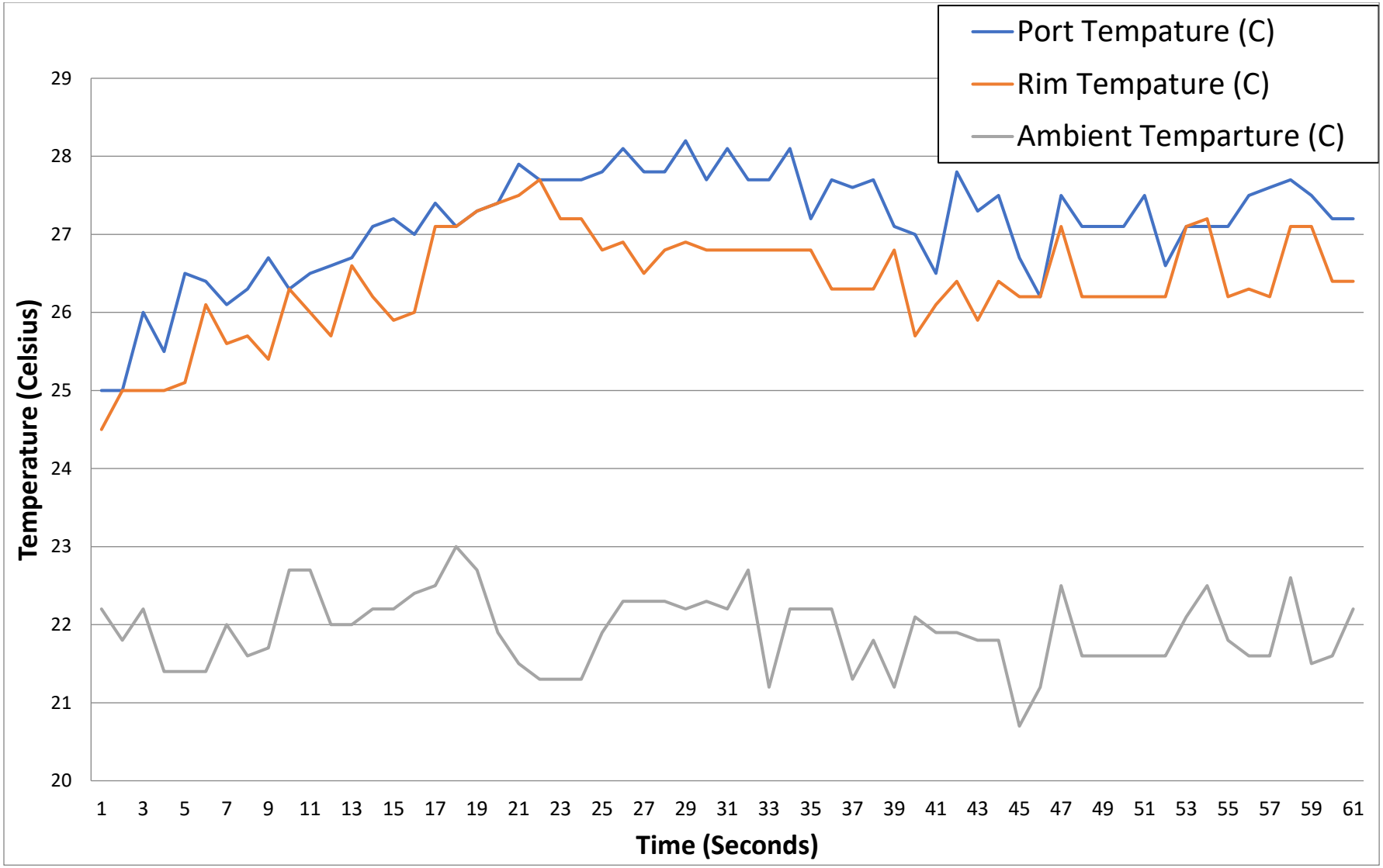

Fig S19. The graph of Polycarbonate Coated Lens B and Collector A of Trial 1 at category 2

Table S20. Raw data set 1 of combination Polycarbonate Lens B and collector (A) of Trial 2.

Type of Test apparatus	Sun Test		
Test number:	Trial 2		
Date Taken:	23-Mar		
Time of Day:	4:26 PM		
Weather condition:	Category 2		
Sun Angle	38		
Lens and Collector	Polycarbonate Lens B and Collector A		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	27	25.7	22.9
15	27.5	26.6	22
30	25.5	26.5	22
45	27	27.6	21.5
60	26.6	26.6	21.1
75	27.6	26.6	22.1
90	27.9	26.5	22
105	27.5	26.6	21.5
120	27.6	25.5	23
135	26.9	25.6	22.5
150	26.6	25.5	22.8
165	26.5	24.6	22.8
180	25.5	25.5	22.8
195	26.9	25.4	22.7
210	26.3	24.4	21.6
225	26.3	24.9	22.6
240	26.6	25.2	21.6
255	25.6	24.1	22
270	25.5	24.5	21.3
285	25.4	24	21.2
300	25.7	23.8	22
315	25.6	24.6	21.1
330	25.6	24.2	21
345	25.5	24.5	21.8
360	25.3	24.3	21.7
375	26.2	25.3	22.4
390	25.6	25.2	21.5
405	25.9	24	21.4
420	25.4	24	22.2

435	25.3	23.9	21.3
450	26.1	23.8	22
465	25.6	23.7	21
480	25.1	22.8	21.9
495	24.6	23.6	20.9
510	25.4	23.6	20.8
525	25.3	23.5	21.6
540	25.3	23.4	21.6
555	25.1	24.3	21.5
570	25.5	24.2	20.5
585	25.3	24.1	21.3
600	25.9	24.1	21.3
615	25.3	24.1	21.8
630	25.8	24.9	21.1
645	25.7	23.9	21.2
660	26.1	23.3	20.2
675	26.5	25.7	21
690	26	25.6	21
705	26	24.7	21.9
720	26.5	24.7	21.9
735	25.6	24.7	21
750	25.6	23.8	21.9
765	26	24.7	21.5
780	26	24.6	21.8
795	25.8	24.9	21.7
810	26	24.5	21.7
825	25.4	24.6	20.8
840	26.7	24.5	21.7
855	25.8	24.5	20.8
870	26.3	25.4	21.9
885	26.7	25.4	21.8
900	26.4	25.4	21.8

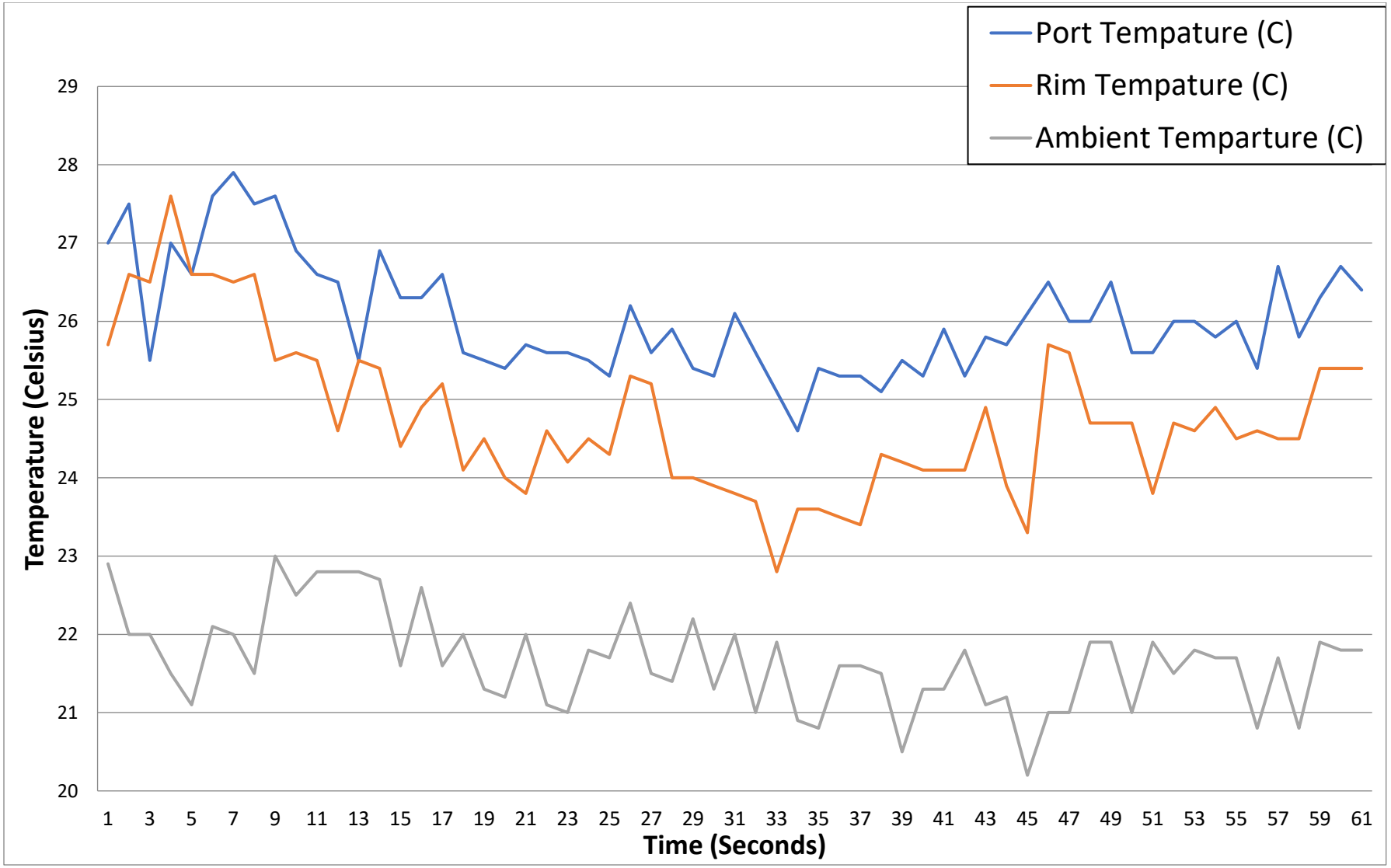

Fig S20. The graph of Polycarbonate Coated Lens B and Collector A of Trial 2 at category 2.

Table S21. Raw data set 1 of combination Polycarbonate Lens B and collector (A) of Trial 3.

Type of Test	Sun Test		
Test number:	Trial 3		
Date Taken:	23-Mar		
Time of Day:	4:45 AM		
Weather condition:	Category 2		
Sun Angle	34		
Lens and Collector	Uncoated Polycarbonate B and Collector A		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	25.2	23.4	21
15	26	24.7	20.1
30	27	24.7	21
45	28.8	25.6	21.6
60	29.7	26	21
75	30.6	26.5	21
90	30.1	26.5	21
105	29.7	25.6	21
120	29.2	25.6	20.7
135	28.8	25.6	21
150	29	25.4	19.5
165	28.1	25.4	20.8
180	27.1	24.5	19.8
195	27.1	25.3	20.3
210	27.1	24.8	20.3
225	27.5	24.3	19.8
240	26.6	24.4	20.3
255	26.6	24.3	20.6
270	26.9	25.2	19.7
285	25.5	25.1	20.6
300	25.9	25.1	21.4
315	27.8	26	19.6
330	27.3	26	20.1
345	26.9	26	19.5
360	27.3	26.4	19.6
375	27.3	26.9	19.6
390	27.8	26.9	20.5
405	28.3	26.9	20.6
420	29.2	27	20.5
435	28.7	26.9	20.5
450	28.8	27	20.7

465	29.8	26.9	20.3
480	28.5	26.1	21.5
495	28.7	26.5	21.2
510	28.4	26	20.5
525	28.9	26.1	20.5
540	27.3	25.5	20.5
555	27.9	25.7	20.5
570	27.8	26	21.4
585	28.3	25.9	21.4
600	28.2	25.9	20.5
615	27.7	25.9	21
630	28.2	25.9	21.3
645	28.2	26.3	20.4
660	27.7	26.9	20.5
675	29.1	27.9	20.5
690	28.6	26.9	20.4
705	29.7	27.3	20.5
720	28.7	26.9	21.4
735	28.9	27.3	20.5
750	29.4	26.9	20.2
765	28.9	27.1	19.8
780	29.4	27.5	19.8
795	28.9	27.1	19.8
810	28.1	26.3	20.7
825	28.6	26.6	20.8
840	29	27.1	21.7
855	29	27.6	20.4
870	29	27.2	21.7
885	28.3	25.9	20.8
900	28.7	25.6	20.8

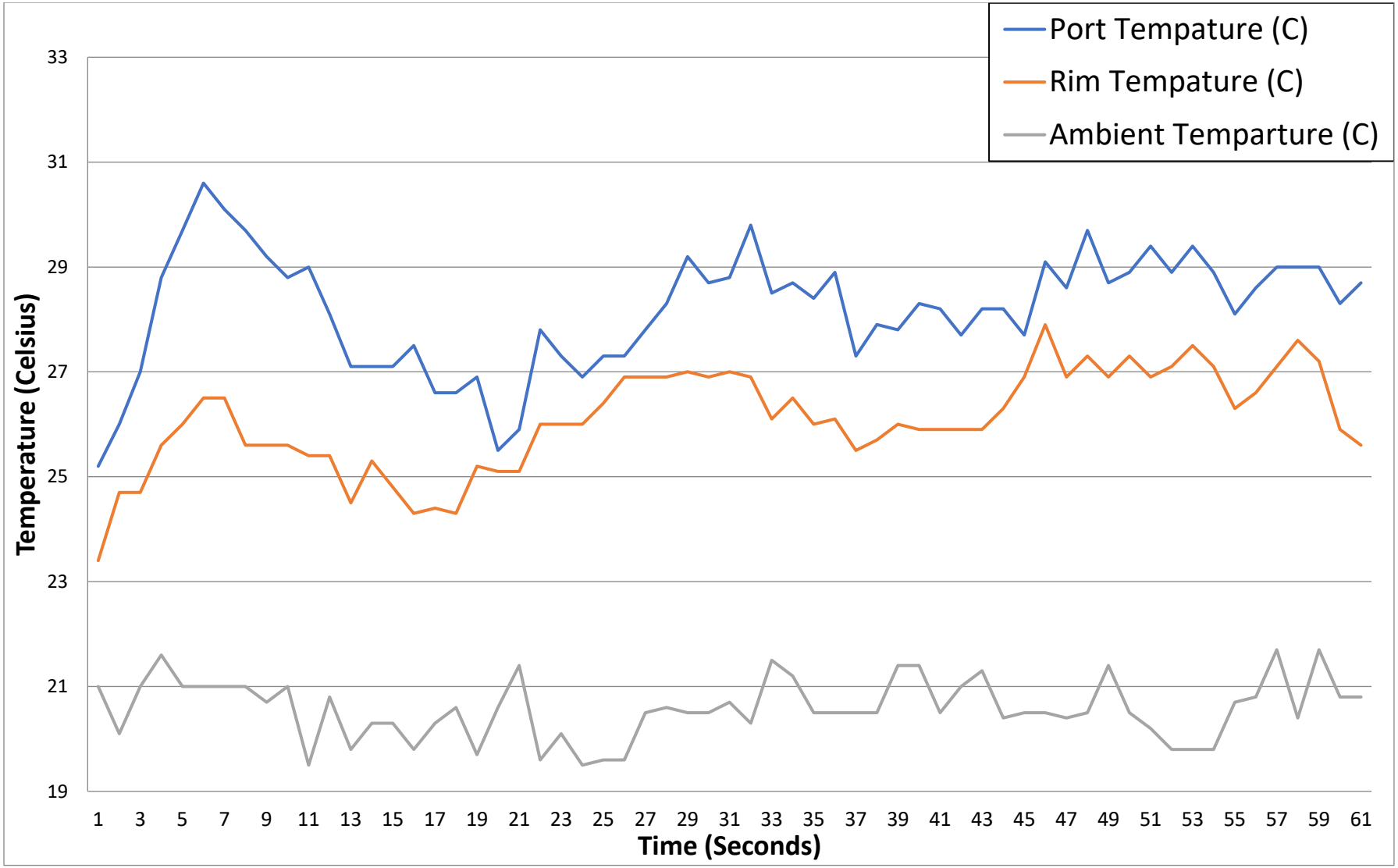

Fig S21. The graph of Polycarbonate Coated Lens B and Collector A of Trial 3 at category 2

Table S22. Raw data set 1 of combination Polycarbonate Lens B and collector (A) of Trial 4.

Type of Test	Sun Test		
Test number:	Trial 4		
Date Taken:	24-Mar		
Time of Day:	1:27 PM		
Weather condition:	Category 4		
Sun Angle	60		
Lens and Collector	Uncoated Polycarbonate B and Collector A		
Time (Seconds)	Port Tempature (C)	Rim Tempature (C)	Ambient Temparture (C)
0	25.1	26.1	24.2
15	36.2	28.2	26.3
30	41.9	29.7	25.5
45	42.9	29.8	24.7
60	44.8	29.8	25.7
75	44	29.9	26
90	43.3	30.6	26
105	43.5	30.7	24.8
120	42.7	30.7	25
135	40	30.9	25.4
150	40.4	30.9	25.4
165	40.9	31.3	25
180	40	31.2	25.4
195	40	30.9	25.4
210	41.3	31.9	26.3
225	39.6	32.9	26.4
240	38.7	31.3	26.5
255	41	32.9	26.4
270	40.3	32.4	27.5
285	39.5	32.2	26.7
300	39.6	34.1	24
315	39.6	34.2	26.8
330	37.7	34.1	25.9
345	37.6	34.2	25.9
360	35.9	32.4	25.9
375	36.8	32.6	24.1
390	35.9	32.3	23.1
405	37.2	32.3	24
420	38.6	33.1	25
435	37.7	33.2	26.5
450	36.9	33.8	24.2

465	37.9	33.3	25.7
480	35.2	34.3	24.4
495	36.1	34.4	25.3
510	37.9	36.1	26.2
525	37.1	35.3	26.3
540	35.4	35.4	24.5
555	38.1	36.8	27.2
570	36.5	35.5	26.5
585	36.6	35.6	23.8
600	37.4	36.5	24.8
615	38.4	36.6	25.7
630	38.6	37.6	27.5
645	37.8	37.4	27.8
660	37.1	36.7	26.9
675	36.8	36.3	26.7
690	35.4	36.3	26.3
705	34.4	36.8	26.3
720	37.7	37.7	26.3
735	37.2	37.3	25.4
750	37	38.3	26.4
765	37.9	38	24.7
780	38.4	39.3	25.7
795	37.5	39.8	28
810	38.6	39.9	27
825	38.2	39.5	29.4
840	37.3	40.1	27.4
855	38.7	40.6	29.2
870	37	39.4	25.7
885	34.4	38.9	27.1
900	37.2	38.9	27.1

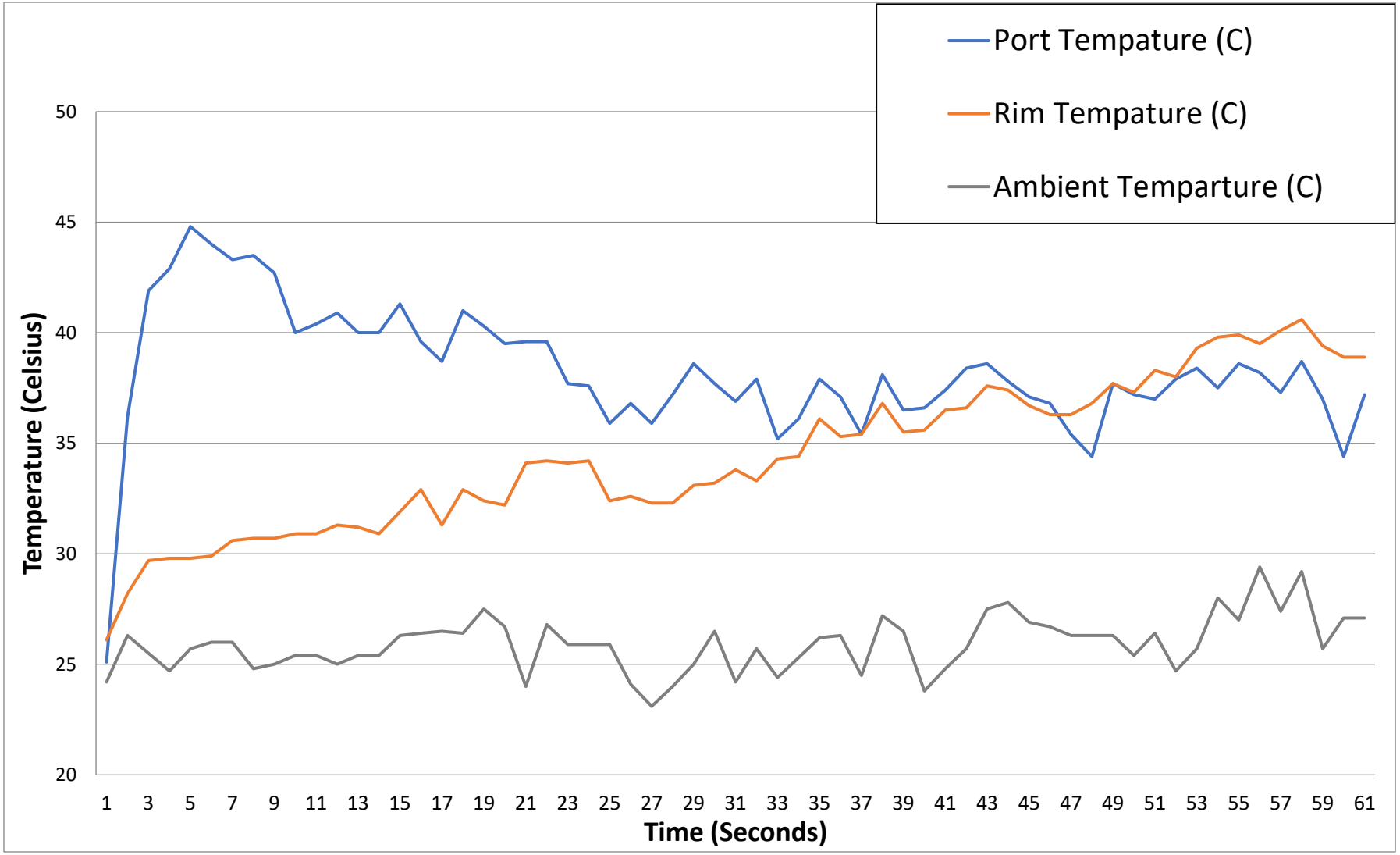

Fig S22. The graph of Polycarbonate Coated Lens B and Collector A of Trial 4 at category 4

Table S23. Raw data set 1 of combination Polycarbonate Lens B and collector (A) of Trial 5.

Type of Test	Sun Test		
Test number:	Trial 5		
Date Taken:	24-Mar		
Time of Day:	1:58 AM		
Weather condition:	Category 4		
Sun Angle	61		
Lens and Collector	Uncoated Polycarbonate B and Collector A		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	23	23.8	21.2
15	28.9	33.9	23
30	30.4	38.6	22.1
45	30.9	41.9	22.8
60	32.7	42.4	23.3
75	31.5	44.2	23.3
90	32.5	46.2	24
105	32.7	46.3	25.4
120	33.9	47.9	23.9
135	34	48.6	23.9
150	33.8	48.8	25.1
165	33.6	47	23.5
180	33.2	44.5	23.1
195	33.6	44.5	23.6
210	32.6	46.8	22.6
225	33.6	47.2	23.6
240	34.5	49.1	24.5
255	34.8	48	25
270	36.3	50	23.6
285	36.4	50.9	23.6
300	35.7	49.3	23.8
315	34.7	47	23.8
330	33.9	45.7	22.9
345	33.4	47.4	24.7
360	35.2	50.2	23.8
375	35.7	49.4	24.8
390	35.4	48.6	24
405	36.4	46.9	23.2
420	36	46	24.2
435	36.9	46	24.7
450	36	45.1	23.3

465	36.9	44.2	22.4
480	37.3	45.1	23.2
495	35.9	45.1	23.3
510	37.7	46.8	24.2
525	36	44.7	24.6
540	36.8	43.3	24.2
555	36.9	44.1	25.1
570	36.9	43.7	24.1
585	37.3	42.7	23.6
600	36.7	43.2	23.2
615	38.6	44.1	24
630	37.6	42.2	23.1
645	38.5	42.2	23
660	37.5	42	23.9
675	37.9	42.9	22.9
690	39.3	42.8	24.6
705	38.7	42.8	24.6
720	38.1	41.9	22
735	38	40.2	22.9
750	37.5	41.2	25.6
765	39.8	41.2	25.3
780	40.4	42.2	24.8
795	39.9	41.3	25
810	40.5	40.9	25.9
825	40.4	40.5	24
840	39.1	38.8	24.2
855	39.1	38.8	23.3
870	39.6	40.6	23.3
885	40.5	39.7	24.2
900	39.1	40.1	25.1

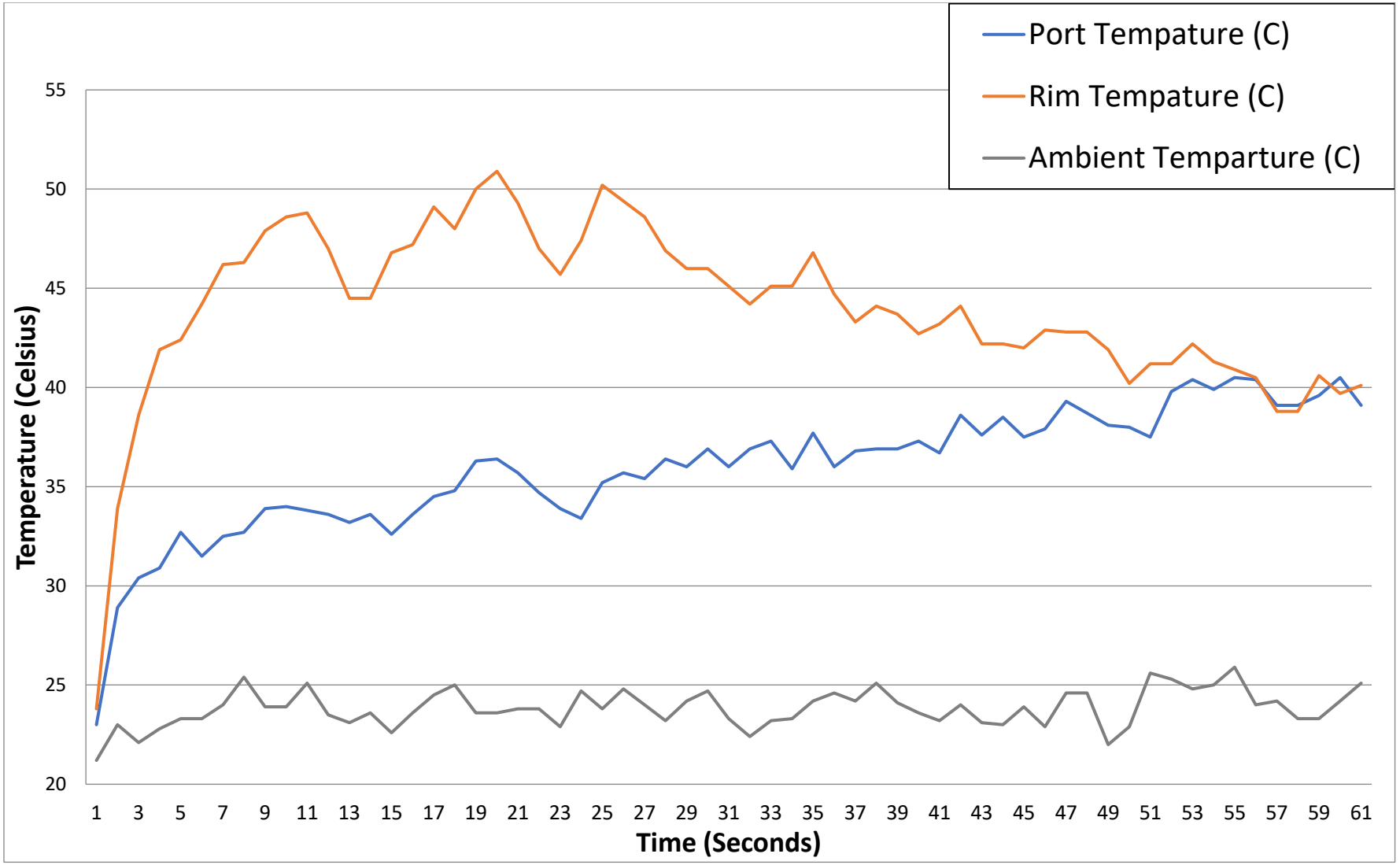

Fig S23. The graph of Polycarbonate Coated Lens B and Collector A of Trial 5 at category 4

Table S24. Raw data set 1 of combination Polycarbonate Lens B and collector (A) of Trial 6.

Type of Test	Sun Test		
Test number:	Trial 6		
Date Taken:	23-Mar		
Time of Day:	2:25 PM		
Weather condition:	Category 4		
Sun Angle	62		
Lens and Collector	Uncoated Polycarbonate B and Collector A		
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)
0	23.1	24.6	22.2
15	27.9	36.9	23.8
30	30.2	44.3	25.1
45	30.4	45.4	25
60	30.9	46.3	24.9
75	30	42.7	23.6
90	31.3	43.6	23.1
105	31.4	45.5	23.7
120	31.9	48.4	26.4
135	32.5	49.7	26.1
150	32.9	50.1	25.5
165	32.9	52	25.2
180	32.1	46.3	24.3
195	31.2	44.8	23.9
210	33	46.6	24.4
225	32.5	46.1	23
240	32.5	45.7	23.9
255	32	46.1	23.9
270	32	44.3	23.8
285	33.4	47.4	24.8
300	32.9	46.5	23.9
315	33.8	45.1	24.3
330	32.8	45.2	24.7
345	34.2	47.3	25.5
360	33.7	46.4	24.8
375	34.2	46.4	24.6
390	35.6	47.5	24.7
405	34.8	43.8	23.8
420	34.3	42.9	23.8
435	35.1	42.8	23.7
450	35.5	47.3	25.5
465	35.6	47	25.6

480	36.2	47.5	25.6
495	33.6	44.9	24
510	35	46.8	25
525	35.2	46	25.1
540	35.8	45.3	25.8
555	34.9	44.4	25.3
570	35.8	46.3	25.4
585	35.4	44.5	26.4
600	36.3	44.5	26.3
615	35.9	43.6	26.3
630	36.7	44.4	26.3
645	36.2	44.4	25.2
660	37.1	44.4	26.2
675	36.7	42.5	24.9
690	37.2	42.2	26.4
705	37	41	25.6
720	37	41	24.8
735	34.6	39.2	23.7
750	37	41	24.9
765	36	41	25.9
780	36.4	39.2	24.8
795	35.3	40	24.4
810	35.8	39	24.4
825	36.2	38.9	24.4
840	37	39.8	25.7
855	36.1	38.9	25.2
870	36.9	37.4	25.1
885	37	38	25.3
900	37.4	37.8	25.7

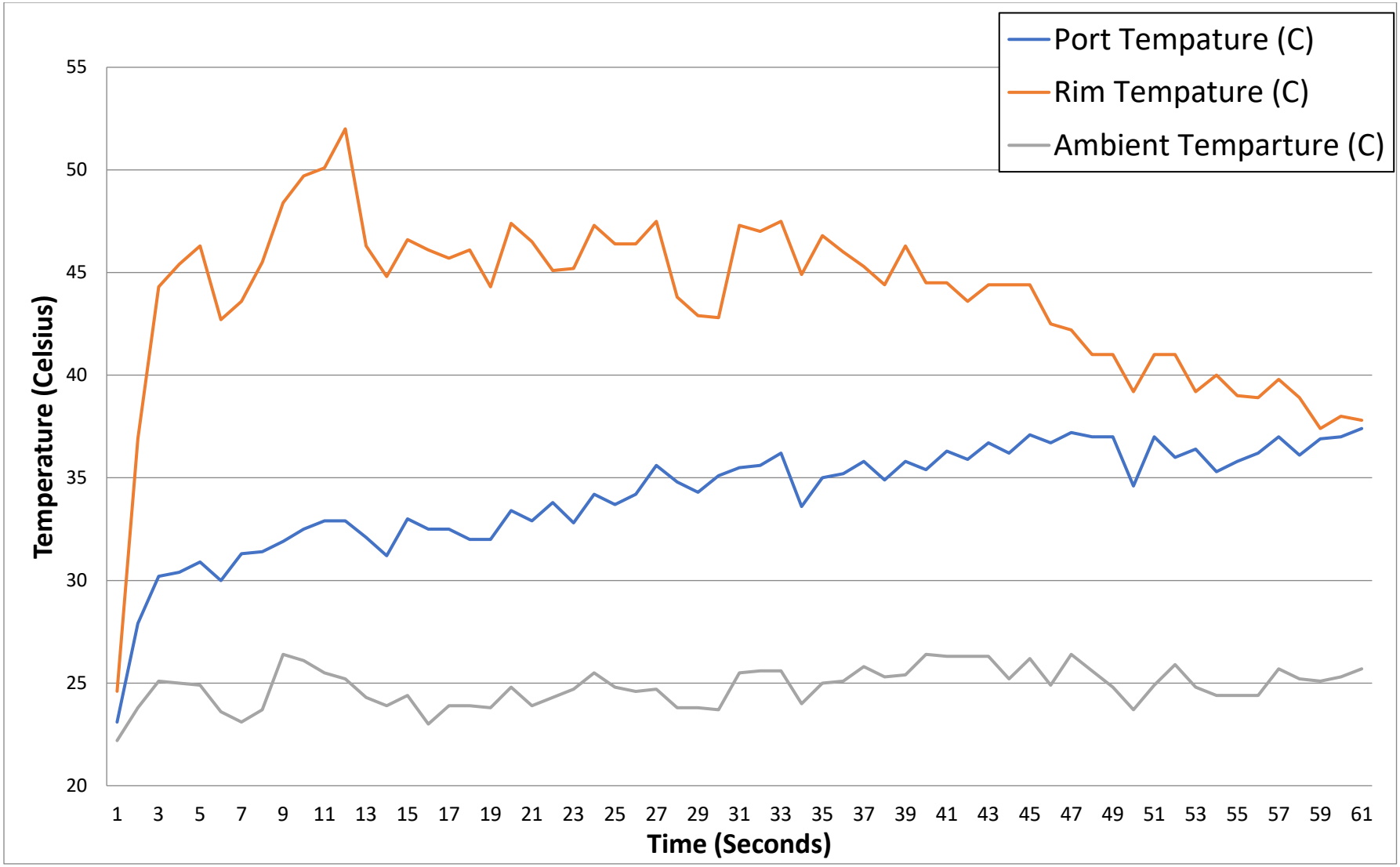

Fig S24. The graph of Polycarbonate Coated Lens B and Collector A of Trial 6 at category 4

Table S25. Raw data set 1 of combination Polycarbonate Lens B and collector (B) of Trial 1.

Type of Test:	Sun Test			
Test number:	Trial 1			
Date Taken:	25-Mar			
Time of Day:	11:50 PM			
Weather condition:	Category 5			
Sun Angle	54			
Lens and Collector	Polycarbonate Lens B and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	35	36.5	29.5	34.1
15	35.8	57.6	29.4	34
30	36.8	61.3	29	35
45	37.7	62.2	30.4	34.1
60	38.8	61.5	31.5	34.3
75	38.9	61.7	29.9	34.5
90	40.1	61.4	28.3	35.6
105	40.3	62.9	29.3	35.8
120	40.9	62.2	29.5	35.9
135	41.4	62.4	29.7	36.1
150	40.7	61.6	29.8	36.2
165	41.7	58.9	31.7	36.3
180	41.8	57.3	32.7	36.4
195	42.4	57.4	32.8	36.5
210	42.6	56.7	33	36.7
225	43	57.6	33.9	36.7
240	43	56.2	33.1	36.7
255	43.2	56	34.1	37
270	44	56.2	35.1	37
285	43.8	56.1	33.3	37
300	44.3	57.1	35.2	37.1
315	44.4	56.2	34.3	37.3
330	44.5	55.4	35.4	37.3
345	44.5	57.7	34.5	37.3
360	45.5	55.4	34.6	38.4
375	44.8	56.6	36.1	37.6
390	44.8	55.3	33.9	38.5
405	45.8	55.7	34.9	38.6
420	45.4	58.6	35.8	38.6
435	45.9	55.9	36	38.8

450	46	57	33.3	38.7
465	46	55.2	37.9	38.8
480	46	54.2	36	38.8
495	46	54.2	34.7	38.8
510	47	55.1	33.8	38.8
525	47	54.2	37	38.8
540	47	54.2	36	39.7
555	47	54.7	37.1	38.9
570	47	54.7	33.4	39.7
585	47	55.2	32.4	39.7
600	47	55.1	33.8	39.8
615	47	55.1	34.3	39.7
630	47	54.2	33.3	39.7
645	47.5	55.2	33.4	39.8
660	47.5	55.2	33.4	39.8
675	48	57.1	32	39.7
690	47	61.5	33.4	39.7
705	47.4	56	33.4	39.7
720	47.9	56.5	32.4	39.7
735	47.9	55.1	37	39.7
750	48	54.3	37.9	39.8
765	48	55.1	37.1	39.7
780	47.9	55.2	37	39.7
795	47.9	55.1	37.1	39.7
810	47.9	53.8	35.1	39.7
825	47.9	53.3	35.1	39.7
840	47.9	53.3	35.1	39.7
855	48.8	55.1	32.4	40.1
870	48.8	55.2	37	40.1
885	48.8	55.1	35.1	40.6
900	48.8	54.2	33.3	40.6

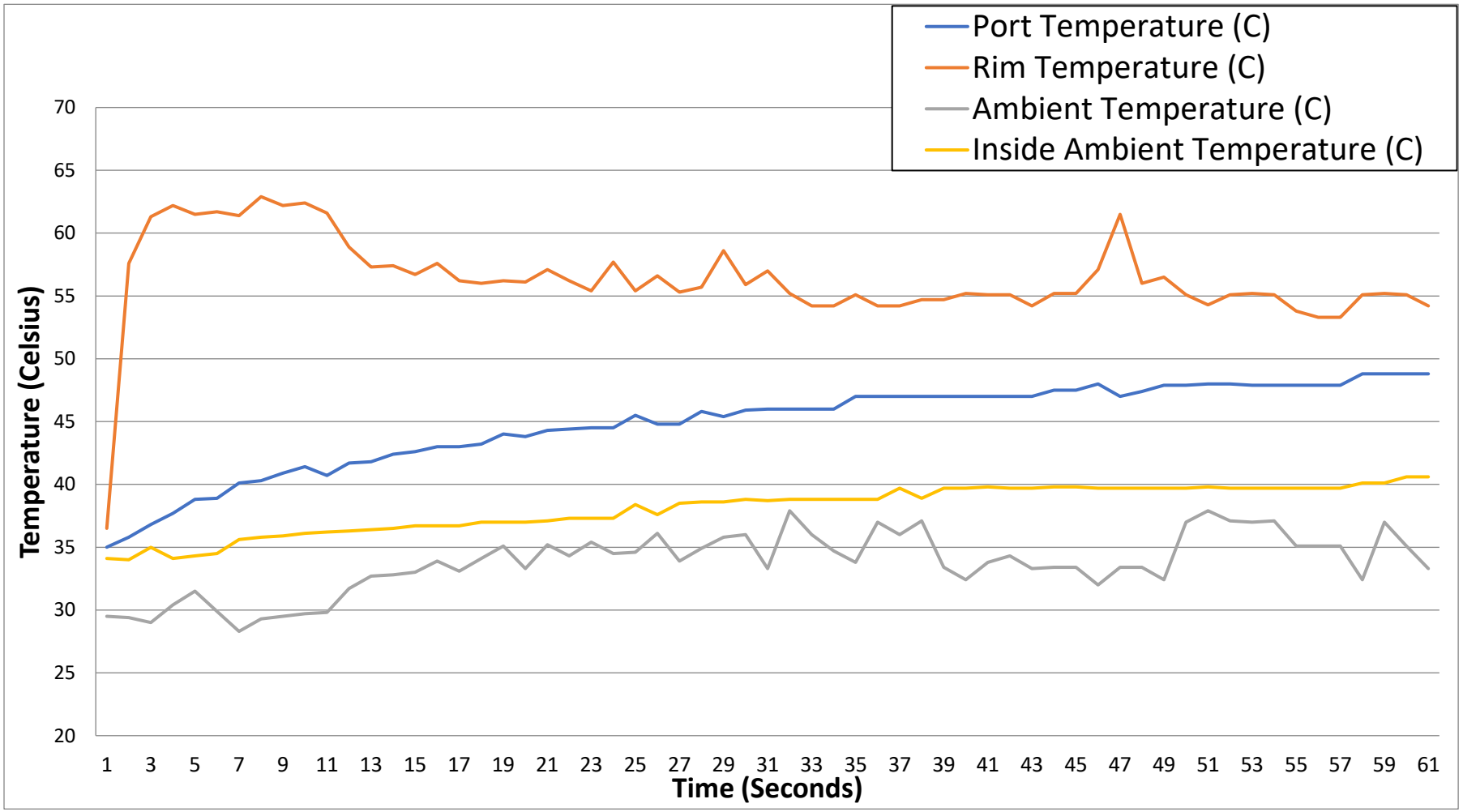

Fig S25. The graph of Polycarbonate Coated Lens B and Collector B of Trial 1 at category 5

Table S26. Raw data set 1 of combination Polycarbonate Lens B and collector (B) of Trial 2.

Type of Test:	Sun Test			
Test number:	Trial 2			
Date Taken:	25-Mar			
Time of Day:	12:40 PM			
Weather condition:	Category 4			
Sun Angle	60			
Lens and Collector	Polycarbonate Lens B and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	38.3	38.4	31.9	36
15	39	43.1	32.6	35.4
30	39	52.6	34	35.3
45	40.1	57.5	35.6	35.6
60	40.8	59.3	34.8	36.6
75	40.9	63.1	32.2	36.3
90	41.6	65.3	35.7	37.1
105	41.8	66.4	37.4	36.4
120	43	67.6	36.7	36.7
135	43.3	69.2	36.2	37.5
150	42.8	71.9	40.1	37.8
165	43.1	73.2	39.5	37.7
180	43.4	75.7	38	38.1
195	43.6	76.4	34.5	38.2
210	43.8	76.6	34.8	38.5
225	45	78.7	38.7	38.7
240	44.2	80.6	37.9	39
255	45.4	80	40	39.1
270	44.7	81.8	38.3	39.4
285	44.5	82.3	36.8	39.6
300	45.1	82.9	36.9	39.7
315	45.3	83.6	38.1	39.9
330	44.6	83.7	39.2	40
345	45.7	84.8	39.4	39.4
360	45.8	84.9	40.4	40.5
375	45.9	84.1	38.6	40
390	46.2	85.2	38	39.8
405	46.2	83.9	38.9	40.8
420	45.7	78	39.1	40.8

435	44.6	80.1	40.1	41
450	45.1	81.1	37.9	41.1
465	46.7	82	39.8	40.4
480	46.8	81.4	40.5	40.5
495	45.9	76.8	38.6	40.9
510	46.5	77.8	39.6	40.6
525	47.1	78.9	37.1	40.8
540	47.1	77.1	35.3	41.2
555	47.1	75.3	38.9	41.7
570	47.2	74.4	33.5	41.8
585	47.1	69	34.5	41.7
600	47.2	69.8	34.5	41.7
615	47.1	67.1	33.5	41.7
630	47.1	67.1	37.1	41.7
645	47.1	66.3	36.2	40.8
660	48	66.2	35.3	41.7
675	48	65.3	36.2	41.7
690	48	63.9	37.1	40.8
705	48	63.5	38	40.8
720	48	62.6	38	40.8
735	48.2	62.7	39.1	40.9
750	48.7	62.4	36.5	41
765	48.8	62	34.2	41.1
780	48.8	62	38.3	41.1
795	49.3	61.5	37.5	41.1
810	48.9	61.2	37.5	41.2
825	48.5	61.4	36.6	41.2
840	48.6	61.4	36.8	40.9
855	48.7	60.4	42.4	41.5
870	49.2	60.2	39.7	40.6
885	49.7	59.7	38.9	41.2
900	50.2	58.4	40	40.9

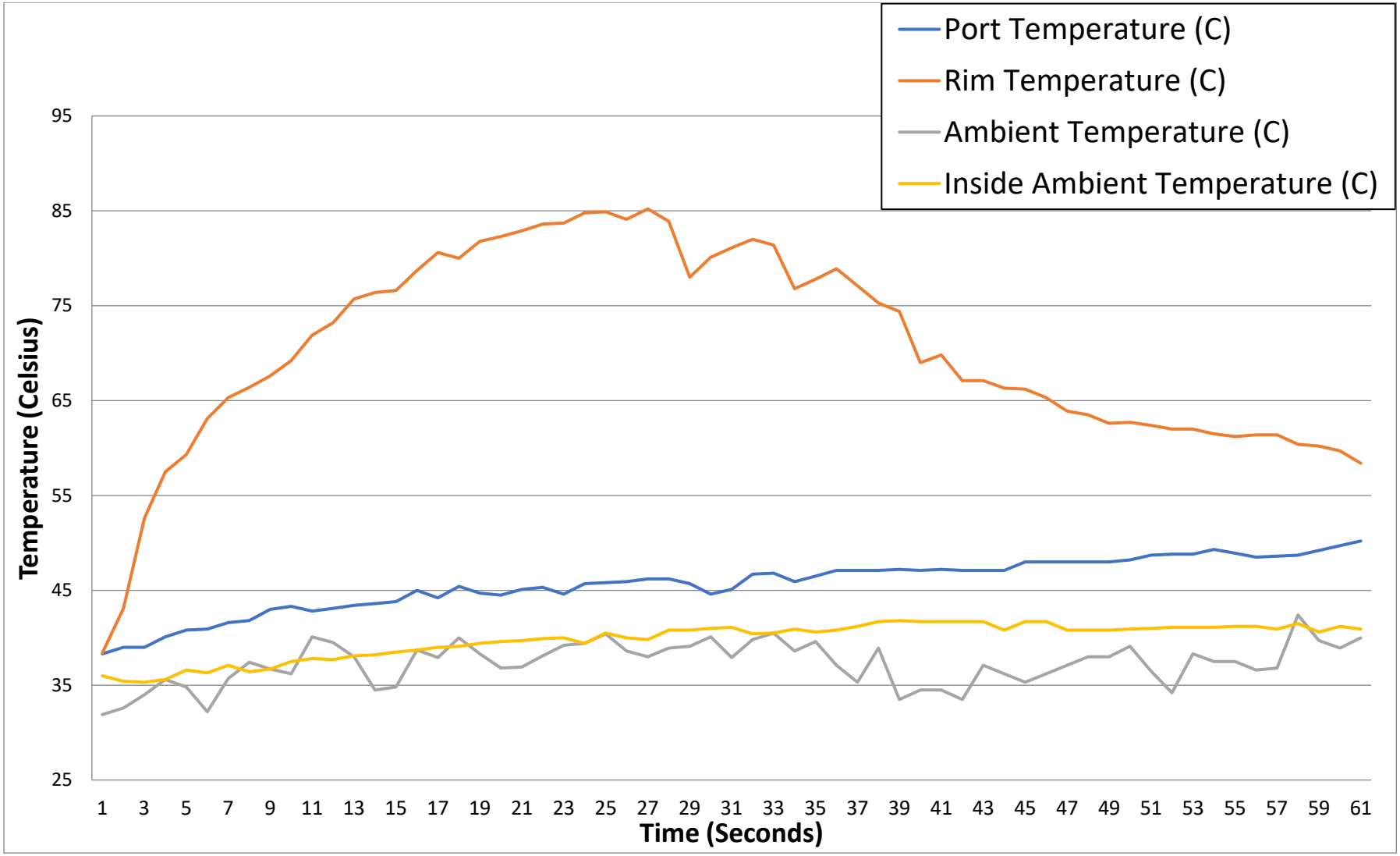

Fig S26. The graph of Polycarbonate Coated Lens B and Collector B of Trial 2 at category 4

Table S27. Raw data set 1 of combination Polycarbonate Lens B and collector (B) of Trial 3.

Type of Test:	Sun Test			
Test number:	Trial 3			
Date Taken:	26-Mar			
Time of Day:	5:23 PM			
Weather condition:	Category 4			
Sun Angle	27			
Lens and Collector	Polycarbonate Lens B and Collector B			
Time (Seconds)	Port Temperature (C)	Rim Temperature (C)	Ambient Temperature (C)	Inside Ambient Temperature (C)
0	35.6	34.6	31	32.8
15	36.6	41.9	30.9	32.1
30	37.3	45.4	31.3	32.7
45	37.3	45.9	30.9	32.7
60	38.6	48.2	31.8	32.7
75	39.1	48.2	31.9	32.7
90	39.1	53.6	31.8	32.7
105	39.5	59.1	31.8	32.7
120	40	55.4	31.3	32.7
135	40.1	53.6	31.8	32.7
150	40.1	54.6	30.9	32.8
165	40.1	56	31.9	32.9
180	40.7	56.5	31.9	33
195	40.6	61.2	31.2	33
210	40.7	59.4	32.1	33
225	41.2	60.7	31.2	32.6
240	41.2	56.7	31.2	33
255	41.2	60.3	31.2	32.6
270	41.2	61.2	32.1	32.1
285	41.2	58.5	31.2	33
300	41.2	59.4	31.2	33
315	41.2	60.3	31.2	32.1
330	41.2	62.1	32.1	32.1
345	42.1	61.2	33.5	32.1
360	41.2	62.1	30.3	32
375	42.1	66.7	32.1	32.2
390	42.2	60.8	30.4	32.2
405	42.4	61.3	30.4	32.9
420	42.4	65.6	30.6	32.3
435	42.4	69.7	31	32.4

450	42.9	64.2	32.4	32.4
465	42.4	60.6	30.6	32.4
480	41	61.6	30.1	32.5
495	40.6	60.6	30.6	32.9
510	41.6	61.6	31.6	32.5
525	42.1	62.1	30.7	32.5
540	41.6	61.7	30.3	33.1
555	41.7	60	30.8	33.1
570	41.8	59.5	29.9	33.2
585	41.8	61.8	30	32.6
600	41.8	57.7	30	32.2
615	41.8	59.1	30	32.7
630	40.4	55.4	29.1	33.2
645	40.8	56.8	30	33.1
660	40.9	59.1	30	32.7
675	40.9	57.7	29.5	33.6
690	40.9	57.2	30	33.6
705	41.3	59.1	29.9	33.6
720	41.8	58.6	29.5	32.7
735	41.7	59	29.9	33.5
750	42.2	60	30	32.7
765	41.6	58.1	29.4	33.5
780	41.8	59.3	30	33.1
795	42.7	59.4	29.9	32.6
810	41.7	59	29.9	32.6
825	41.7	56.2	29.9	32.7
840	41.8	58	29.9	32.6
855	41.7	58.1	29.9	32.6
870	41.7	59.9	29.9	32.6
885	42.7	60.8	29.9	32.7

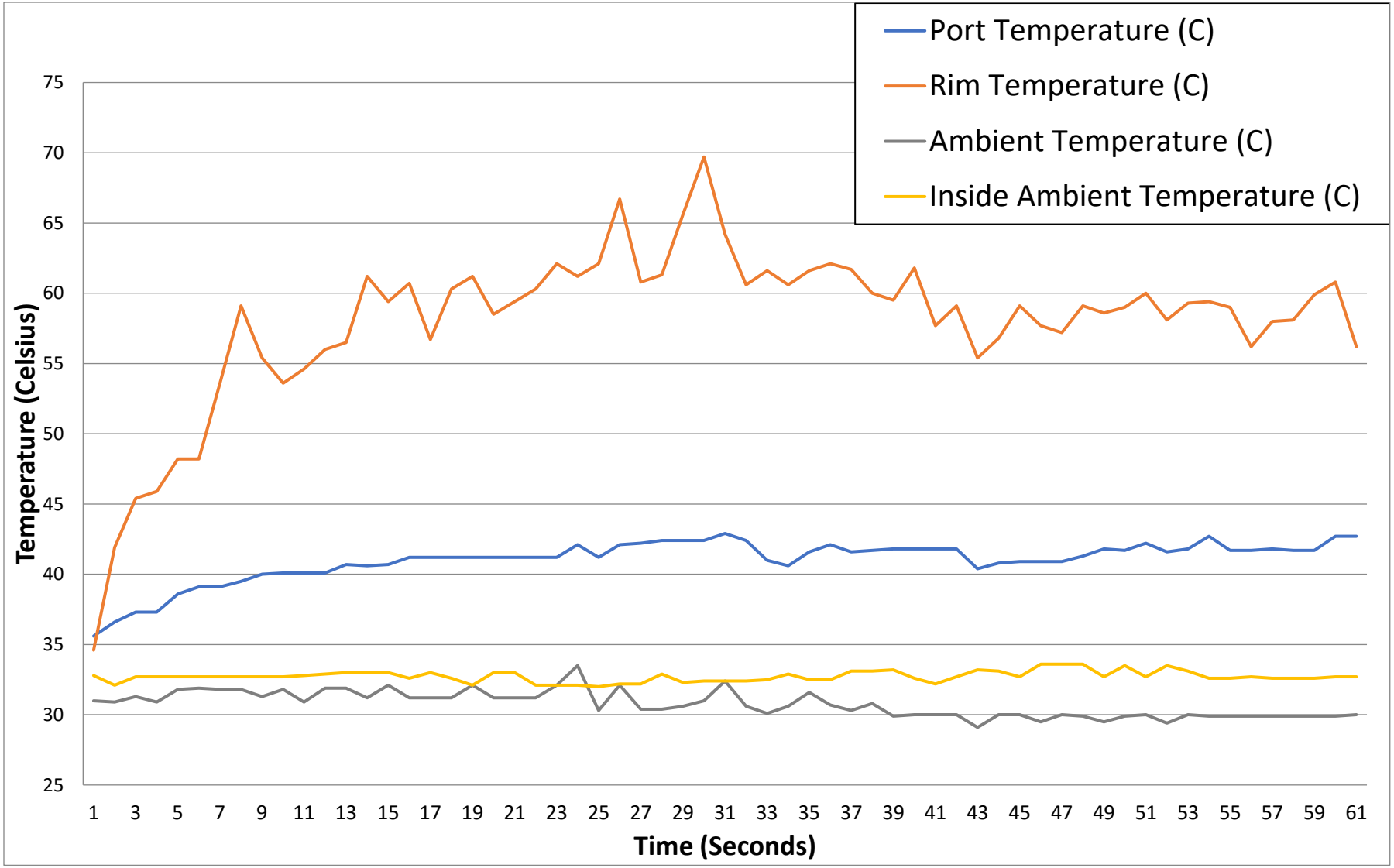

Fig S27. The graph of Polycarbonate Coated Lens B and Collector B of Trial 3 at category 4

9.20 Appendix S: Outreach Program

Team SOLIS was part of an outreach program, which is an event that is held every year during the fall at the University of Texas at Tyler in the Houston Engineering Center that is located next to Alief Early College High School at 2811 Hayes Rd, Houston, TX 77082. The 2021 ALIEF School District WIND Turbine Competition is a two-day competition event held on November 11-12^{th,} 2021, between 10 am to 4 pm each day, where students ranging from second grade to twelve grade of schools residing in the Alief Independent School District. The competition had more than two hundred and fifty entries, with the grade levels being separated into three different categories. The first category is from second to fourth grade, while fifth to eighth grades consist of the second category. Lastly, the ninth to the twelfth grades composed the final category. The competition's main objective was to encourage students to be more involved with the STEM field and showcase student ingenuity by using engineering principles to create the best-performing windmill. Before the competition, the student was given a month to prepare and register. Each student was instructed on the rules and guidelines of what components were needed for the student model to be considered a windmill; To ensure that the windmill was able to fit inside the wind tunnel, a windmill must be able to operate within its twenty-four inches by twenty-four inches internal dimension. Other rules included that the turbine blade of the windmill can be built on a vertical or horizontal axis and that the only required material that needed to be used within the windmill build was a cork.

This allows students to have more creative control in building their windmills and developing an exciting design. Due to the wide range of grade levels and wanting to expose the students to the concept of wind energy, the student was provided resources such as reading material, videos on how wind turbine systems work, and ideas on how to build their wind turbine that was appropriate for their grade level. The students were allowed to participate individually or as a team at home, or as an activity in class. Once the windmill was submitted for the competition and transported to the UT Tyler Houston Engineering Center, on the day before the competition, Team SOLIS organized and registered the windmill into the appropriate categories to ensure all the windmills were accounted for to be properly tested. The windmill that the students made in each grade category was evaluated in two different sections. The first section was about the performance of the windmill, and the second section was about the aesthetics of the windmill. On the day of the competition, due to healthy constraints and the high volume of students competing in the competition, the schools and students were allowed to observe the testing of their wind turbine virtually throughout the day, where Team SOLIS demonstrated and educated on how the windmill was being tested. Team SOLIS also played a role in evaluating the wind turbine in both the performance testing and the aesthetics section of the competition. From this experience, Team SOLIS learned to test different types of wind turbines and conduct a competition. The team feels that the outreach had impacted the community by showing the next generation that they can be involved with the STEM field and allowing the student to learn about the Engineering process, such as understanding a challenge, brainstorming ideas, and designing a prototype.

Fig S1. Outreach activity: Alief School District Wind Turbine Competition 2021.