Final Design Report: Parabolic Heater System

Prepared for:
Mr. Timothy Baxendale
Portales, NM

Date: June 8th, 2022

Submitted by:
Wesley Ho, Cem Okutan, Christian Joseph Englert, and Paul Kim
Section 28, Team 2

Sponsored by:
Design Thinking and Communication Program
Professors Linsey Seitz and Barbara Egel
McCormick School of Engineering and Applied Science
Northwestern University
Evanston, Illinois 60208

Table of Contents

Appendices

List of Figures

List of Tables

Executive Summary

Introduction and Problem Statement

Extreme temperature conditions, particularly ones that vary greatly within a short time span, can cause great discomfort to people living in such conditions. Having an uncomfortable glut of heat in the afternoon while there is an uncomfortable dearth of heat in the morning is a frustrating circumstance. Standard solutions such as blinds must be configured frequently, but removing blinds results in a loss of in-home privacy. Consequently, our team was tasked by Mr. Timothy Baxendale with creating a cost-efficient solution that provides temperature and privacy control.

Primary Research and Insights

The most promising model products were solar pool heaters and parabolic troughs–both of which covert solar power into heating. The pool heater absorbs solar heat through black tubing in which water is stored. As a result, the heat warms the water. This can to heat a large volume of water several degrees. Parabolic troughs on the other hand, reflect solar energy from variety of angles onto a tube and are often used in solar power stations. Our design uses a parabolic trough to heat water to much higher temperatures than a traditional pool heater so that we can use solar energy to heat homes with a traditional radiator.

Design Concept and Rationale

The design is a circuit consisting of a parabolic mirror (referred to as a "parabolic heater"), a hot water tank, a radiator, and a room-temperature water tank. The parabolic heater imparts heat to water by reflecting solar heat to the water. The heated water is cycled through the circuit to a radiator, allowed to release its heat to the house, and is then cycled back to the heater as cool water for the cycle to begin again.

The design leverages the ability of a parabola shape to reflect solar heat to a focal point. This maximizes the amount of solar heat that can be harnessed for residential heating. In addition, the use of solar heat at no cost for residential temperature control that can be toggled on and off on demand makes the design advantageous. Despite the upfront financial investment the system requires, installation of the system will likely result in monetary savings in the long term.

Conclusion and Future Recommendations

This design uses solar heat to regulate the heat conditions of Mr. Baxendale's residence while also being cost efficient. The current design is customized to Mr. Baxendale's house and requires a degree of house modification, so improvements regarding accessibility and simplification can be explored in the future. In addition, improvements to the design that improve user privacy would be particularly useful, as the prototype prioritizes autonomous temperature control over privacy.

Introduction

Certain locations in the world have large diurnal temperature variations, which is to say that the difference between the highest and lowest temperatures in a day are quite large. Afternoons in locations with large diurnal temperature variation can warm residences by 30 degrees Fahrenheit each day, while temperatures can be roughly around freezing at night and in the morning. The overabundance of heat in the afternoon forces residents to turn to solutions involving high cooling costs, which is usually non-renewable and costly. This overabaundance is particularly frustrating as the large diurnal temperature variation leads to a residence being too cold in the morning and at night, when the excess heat present in the afternoon is sorely needed but not present. In addition to its financial impact, large diurnal temperature variations also result in decreased productivity [1].

Storing ambient heat when a home is too hot and releasing this ambient heat into the home when the home is too cold would achieve temperature control, allowing a home to stay within a comfortable temperature range at all times. For privacy concerns, blocking people outside seeing in would also be one of the advantages of the solution. While conducting research, we learned that changing or attaching a device to the windows will most likely involve replacing the entire frame. (See Appendix B) Although using an acrylic window frame proved to reduce the temperature inside, for example, it required redesigning for each window in the house. (See Appendix D)

One of the existing solutions is the use of tinted glass. Top-quality tinted windows are great for privacy by minimizing the amount of sunlight that enters inside and safety by making the window harder to be penetrated. [2] However, it is not a reliable solution due to its tendency to block heating sunlight during winter. The same problem applies for regular, horizontal slatted blinds, which block people outside from seeing inside the house. The manual work required to adjust these blinds according to the time of the day and the position of the sun is an additional cost. As day-to-day outside temperatures can affect whether you want sunlight or heat or not, swapping out tinted and non-tinted windows from time to time is also not feasible. Other possibilities include thermochemical systems that store thermal energy (heat) as chemical energy that can be converted back to thermal energy and released on demand [2], and splayed windows, which maximizes the daylight allowed to enter a living space while also minimizing the solar radiation allowed to enter [3].

Our solution is a circuit consisting of a parabolic mirror (referred to as a "parabolic heater"), a hot water tank, a radiator, and a room-temperature water tank. The parabolic heater reflects solar heat to water so that the water can absorb the heat and eventually travel to a radiator where the heat can be dissipated to warm the house. The circuit autonomously changes its behavior based on whether the indoor house temperature is below, at, or above a minimum comfortable temperature specified by the user. When the indoor temperature is below the minimum comfortable temperature, hot water is allowed to flow to the radiator so that its heat can be dissipated to warm the house. When the indoor temperature is at or above the minimum comfortable temperature, hot water accumulates in the hot water tank rather than flowing to the radiator. This accumulated water can be allowed to flow to the radiator if the indoor temperature drops below the minimum comfortable temperature. Thus, the circuit, referred to as the parabolic heater system, harnesses the cost-free natural resource of solar heat for autonomous temperature control. Solar heating has also proven to be a cost-effective and energy-efficient means of residential temperature control [4].

This solution attempts to satisfy the following requirements (see Appendix A for more detailed information):

1. Easily installable implement
2. Easily understandable value proposition
3. Provides low-maintenance temperature control

This report documents our design development process including Users and Major Requirements, Design Concept and Rationale, and Future Development, and the Conclusion.

Users & Major Requirements

The primary user for our project is Mr. Timothy Baxendale who is bothered by the heat control issue in his house. The user base is determined to be the people who live in areas with large single-day temperature variation in New Mexico and live in houses that have a roof and enough space inside to store a water storage depending on the size of the house. The house sizes vary, so the design of the project had to be adjustable and compatible for all sizes or cost-efficient and lasting to be useful in the long-term. If it is an apartment, for instance, the scale of the design will be much bigger compared to the design built for a separate house. It is important to note that this design is to be retrofitted to the building. A new build is not necessary unless more space for the water storage is hoped to be created. The user will need to know the basics of how the design works for him to be able to fix it if it breaks or malfunctions.

As for major requirements of the project, the predominant one is temperature control. The temperature should be controlled to allow for heating inside when the ambient temperature is low so that other cooling costs, like air conditioning, are reduced. Because the design will continue to work for the entire the year, it must be lasting and cost-efficient. Choice of material/liquid to store heat is also important for this matter.

Although privacy is a key concern for the design of residential homes, this concern is secondary to temperature control. Privacy could be achieved along with temperature control through the use of regular blinds or other existing precautionary measures in conjunction with the parabolic heater system.

The safety of the solution is also key. Storing liquids at high temperatures could be a difficult and dangerous task. For this reason, the storage tank for hot water should be located in a place that the user does not typically interact with in common daily activities. Thus, having a water storage that will hold the heated water a distance away from the parabolic heating system, for instance in the attic, is a good idea.

Design Concept and Rationale

Figure 1: Acrylic Parabola Covered with Reflective Film

The system is a circuit consisting of a parabolic mirror (referred to as a "parabolic heater"), a hot water tank, a radiator, and a room-temperature water tank. Each element of the system is connected to the next element with a water pipe.

The basic subunit of the parabolic heater is a long sheet of acrylic curved into a parabola . This acrylic sheet is covered with reflective film (Figure 1). A copper tube with water pumped through it is suspended lengthwise inside the parabola formed by the metal sheet such that the copper tube rests at the focal point of the parabola (as illustrated via the cross section in Figure 2).

Figure 2: Copper Pipe at Focal Point of Reflective Parabola

Water pipes are adhered to each side of the copper tube. The film-covered parabola and tube assembly is then laid into a wooden bed for stability (Figure 3).

Figure 3: Wooden Bed containing Acrylic Parabola and Pipe Assembly

In order to form the parabolic heater, several parabolic subunits are laid side-by-side within a frame, as shown in Figure 3.

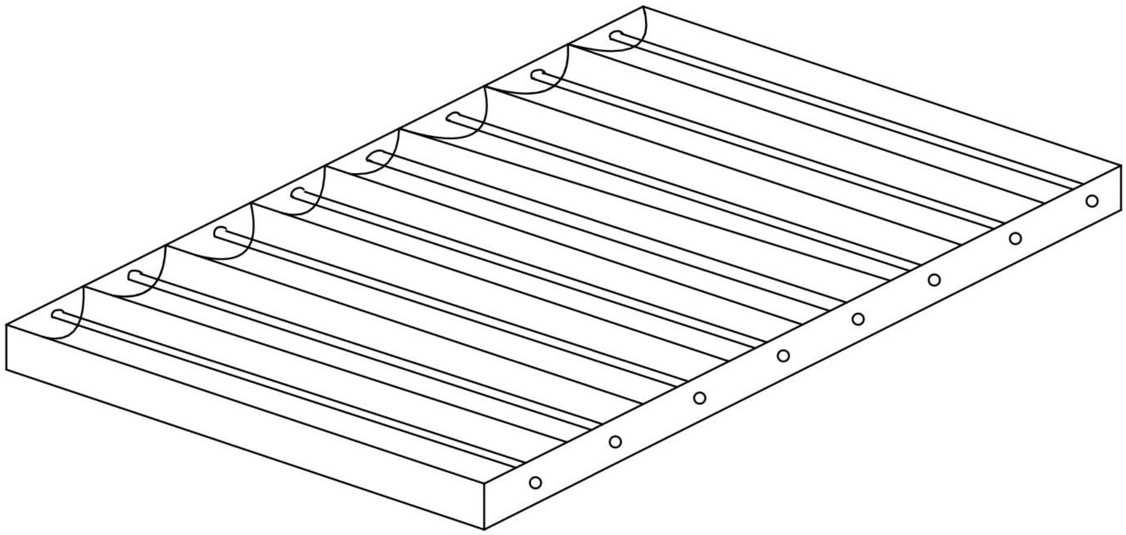

Figure 4: Array of Parabolic Subunits

For additional information regarding construction and composition of the parabolic heater, please see appendices E and F,

The key operation in the system is the heating of water in the parabolic heater. The reflective film on the parabolic subunits reflects and concentrates light and heat onto the copper tubes containing the water. Because copper is a strong conductor of heat, the water warms up.The mirror will work in both sunny and overcast conditions, but less heat will be stored in overcast conditions. When the water reaches 65°C (at which point an appreciable amount of heat will have been stored in it), a signal from a temperature sensor will open a valve between the parabolic heater and a hot water storage tank. As a result, the hot water flows to the hot water storage tank. More water is then moved from a room temperature water storage tank into the water hose to replace the warm water that had moved to the hot water storage tank.

Once the hot water has reached the hot water storage tank, it will either flow to a standard household radiator without stopping to heat the home, or it will accumulate in the hot water storage tank. If the indoor room temperature is above the minimum comfortable temperature, the flow of water between the hot water storage tank and the radiator will be cut off with a valve, and hot water will accumulate in the hot water storage tank. If indoor room temperature drops below the minimum comfortable temperature (set by the user), the valve for the flow of water between the hot water storage tank and the radiator will open. Then, water will no longer accumulate in the hot water storage tank. Instead, accumulated water will flow to the radiator, and water flowing into the hot water storage tank from the parabolic heater will continue through the storage tank without stopping to the radiator.

Once the water in the radiator has given up all of its heat to the surroundings, it is pumped to the water storage tank, and thus continues to cycle through the system.

The use of a parabola to concentrate reflected light and heat onto a focal point means that the design stores more heat than could otherwise be stored by leaving water in an exposed container in the sun. In addition, the design harnesses the natural resources of sunlight and solar heat to provide in-home temperature control on demand. Despite the necessary upfront capital costs, the system will likely result in financial savings in the long run.

Water was chosen as the means of heat storage mainly due to its high heat capacity (its ability to store a large amount of heat per unit mass). In addition, its lack of corrosive properties, wide availability, and low cost make it a strong candidate for the means of heat storage [5].

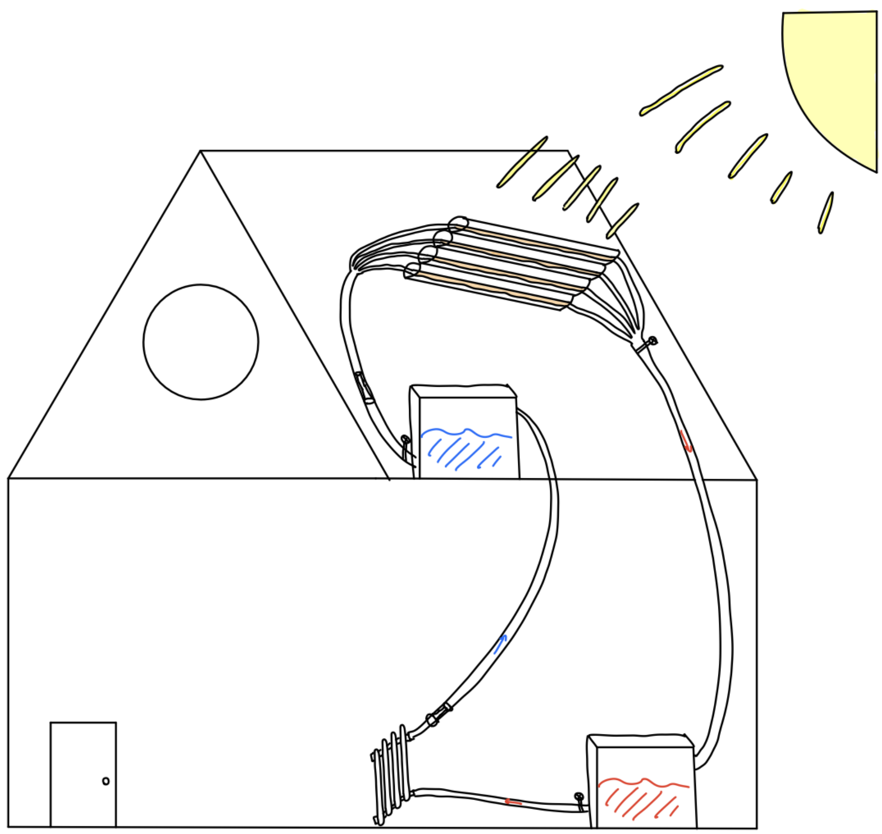

Figure 5: House Installation of Parabolic Heater System

How the Design will be used:

Before use, the parabolic heater system must be installed in the user's home. This involves installing the parabolic heater on the roof so that it is exposed to the maximum level of solar heat. Installation of water tanks in unobtrusive locations such as the attic, as well as the installation of a radiator in the room that requires heating, is also necessary. Lengths and locations of tubes connecting the components of the system to each other must also be determined; these logistics will be specific to the home in which the system is installed (please see appendix G for additional information). The user will specify a minimum comfortable temperature on a thermostat-like interface inside their home. This temperature will be transmitted to the system's temperature sensor, which will open and close the flow of hot water between the hot water tank and the radiator as described above.

If the indoor room temperature is above the minimum comfortable temperature, the temperature sensor will trigger a piece of rubber to block the path of the flow, cutting off the flow of hot water between the hot water storage tank and radiator. Because the design will operate autonomously, there will be minimal involvement from the user.

In the rare case that the indoor room temperature is below the user's desired minimum comfortable temperature, but there is no hot water accumulation in the hot water storage tank, and it is overcast so there is little sunlight to heat water, the user would need to employ their HVAC system to heat their house.

Description of the benefits of the Design:

The design allows the user to harness the natural resource of solar heat at no cost to heat their home on demand. It maximizes user comfort by autonomously turning off and on heat flow when necessary.

Table 1: Benefits and Uses of the Design

Feature of Design	**Benefit/Use**
Uses natural solar heat	No cost to operate system
Autonomous operation with temperature sensor	Minimal maintenance or involvement from user

Future Development

Further Testing

Further user testing would be beneficial to universalize the design to residents in other areas with large diurnal temperature variations. The final product was created for Mr. Baxendale specifically to work comfortably in his home in Portales, NM. Ideally, the design should be capable of working effectively in any geographical location subject to large temperature variations. Installing the system in a house in Portales, NM and measuring indoor house temperature over the course of one week with the system operating would be a worthwhile test of the system's efficacy (further testing details are included in Appendix C) .

Accessibility

One area of future development would be to make the design more accessible to people of different socioeconomic backgrounds. At present, the design requires capital investment and home remodeling to be used. If the design could be distilled into a single product that could be mass-produced, bought, and installed without home remodeling, the upfront capital investment would be decreased. Future iterations of the design that are able to achieve this goal would be more accessible across socioeconomic levels.

Maintenance of System Integrity

Over time, the usage of water as it pertains to the materials involved in the system may cause corrosion or degradation, which may affect the functioning of the entire system. Continuous exposure to sunlight may also damage the parabolic heater and the film, so longer term testing may be needed to figure out the lifespan of the system as well as methods to reduce equipment damage.

Conclusion

By harnessing the natural resource of solar heat and storing the heat via water to be released on demand, the design provides a low-cost and environmentally friendly method of maintaining a comfortable temperature in a residential space. Using this design will allow the user, Mr. Baxendale, to work comfortably in his home without feeling the effects of the severe diurnal temperature variation that is characteristic of Portales, NM. This design successfully meets the requirements outlined earlier in the report. Ways to further improve on this solution include improving accessibility and widening range of application to various conditions.

References

[1] M. Ala-Juusela and M. Shukuya, “Human body exergy consumption and thermal comfort of an office worker in typical and extreme weather conditions in Finland,” Energy and Buildings, 11-Mar-2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378778814002035. [Accessed: 05-Apr-2022].

[2] S. F. Wu, G. L. An, L. W. Wang, and C. Zhang, “A thermochemical heat and cold control strategy for reducing diurnal temperature variation in the desert,” Solar Energy Materials and Solar Cells, 02-Nov-2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0927024821005006. [Accessed: 05-Apr-2022].

[3] L. Huang and J. Wu, “Effects of the splayed window type on daylighting and solar shading,” Building and Environment, 06-Aug-2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0360132314002509. [Accessed: 05-Apr-2022].

[4] M. Kakaza, KA Folly, “Effect of solar water heating system in reducing household energy consumption,” ScienceDirect, vol. 48, no. 30, pp. 468–472, Dec. 2015, doi: https://doi.org/10.1016/j.ifacol.2015.12.423.

[5] Lavinia Socaciu. (2012). Seasonal Thermal Energy Storage Concepts. Universitatea Tehnica Cluj-Napoca.
https://www.researchgate.net/publication/272179312_SEASONAL_THERMAL_ENERGY_STORAGE_CONCEPTS

Appendices

Appendix A: Project definition

Project Definition Version 3

Date: 17 May 2022

Project Name: Block Sight not Heat

Client:

Our project partner is Mr. Timothy Baxendale, a resident of Portales, NM, and a McCormick alumnus.

Project Team Members: Wesley Ho, Cem Okutan, Christian Joseph Englert, Paul Kim

Mission Statement:

Design a cost-saving implement for people who live in areas with large diurnal temperature variation that provides low-maintenance temperature control.

Project Deliverables:

- A proof of concept and scale model to demonstrate how any implement or accessory would provide temperature control
- Final prototype which will effectively demonstrate how to idea will be applied in the real world
- Final report

Constraints:

- Budget: Our budget for this project is USD $100. We must stay under budget in buying resources to construct prototypes and our final product.
- Time/Due Date: Our team has until the end of this quarter to work on this project. This limits us because we must come up with a feasible solution or proof of concept within that timeframe.

Users and Stakeholders:

- Mr. Timothy Baxendale, our project partner, will use this accessory/implement to maintain temperature control in his house so that he remains comfortable throughout the day, can control his privacy, and is not disrupted by unwanted sunlight.

User's profile

We will be designing for Mr. Timothy Baxendale, a man who graduated from NU (McCormick) and now lives in Portales, New Mexico. Mr. Baxendale has experience living in areas with extreme climates, as he has previously experienced Michigan winters.

User scenario:

As a resident of Portales, New Mexico, Mr. Baxendale is regularly subject to large diurnal temperature variations as he goes about his daily tasks when he's at home and works from home. In the mornings, Portales can be 30-40 degrees Fahrenheit but can reach the 70s in the afternoon. Sunlight also varies proportionally with temperature. This means that Mr. Baxendale is often cold in the morning while working in his home, affecting his comfort and thus productivity. Afternoons can become too hot and the sun's glare can reflect onto Mr. Baxendale's computer monitors, further affecting his comfort and productivity. The inconvenience of having abundant heat and light in the afternoon when it is unneeded, combined with the lack of heat and light in the morning when it is needed, merits a solution.

Table 2: Needs and target specifications

Needs	Metrics	Units	Ideal Value	Allowable Value	Notes
Easily installable	Installability, on a scale of 1 to 5 (5 being the easiest to install, 1 being the hardest)	N/A	5	4	Method of installation must not provide additional monetary or temporal costs fo user
worthwhile value proposition	Worth, on a scale of 1 to 5 (5 being the most worthwhile, 1 being the least)	N/A	5	4	
Environmentally friendly	Environmental impact on a scale of 1-10, 10 being the	N/A	1	4	"Environmental friendliness" is subjective depending.

	most impact and 1 being the least				Need to solicit input from project partner and perform additional research.

Appendix B: Interview summary

<u>Introduction</u>
Our team, along with several other teams, interviewed our project partner, Mr. Timothy Baxendale, to learn more about the scope and circumstances of the problem which he has tasked us to solve. The problem is the high amount of heat that is accumulated inside house. We hoped to learn what factors we need to consider in our temperature control solution, what form our solution might take, and who our target audience might be.

Our team will be working to create an easily installable accessory for people who live in areas with significant diurnal temperature variation that provides low-maintenance temperature control and household privacy. With such an accessory, Mr. Baxendale and people like him would remain comfortable throughout the day while living in areas with major diurnal temperature variation.

<u>Methodology 1: Project Partner Interview</u>
4 teams from 2 different DTC sections coordinated a joint meeting with Mr. Baxendale to ask questions and hear his perspective on the problem and possible solution considerations. Mr. Baxendale based his explanations on a comprehensive write-up of the problem that he sent to us later.

<u>Results 1: Project Partner Interview</u>
Key learnings mainly took the form of solution considerations given by Mr. Baxendale. For instance, the means of installment into a house for a solution, including retrofitting, remodeling, and reconstruction. Another important consideration was the balance between financial viability and effectiveness of a solution. Crucially, Mr. Baxendale declared light and heat control to be the priority over privacy. Our team learned that finding a way to harness unneeded heat to be utilized at a convenient time was a possible key to the solution.

Other important aspects discussed were the scope of the design challenge and the nature of the solution. While we had previously believed that we were designing with Mr. Baxendale himself in mind, our team learned that we could be designing for any resident of a geographical area with high diurnal temperature variation. In addition, the challenge was intentionally presented with a variable scope so that either a systemic solution involving a change to an entire house, or an accessory, could address the challenge. Equally importantly, we now know that a proof of concept or a scalable prototype are possible forms that our final work may take, given the impracticability of making large-scale changes to a person's home.

Methodology 2: All Glass Interview

One of our team members, Christian, arranged and facilitated a phone interview with All Glass, a window-making company in Portales, NM, where Mr. Baxendale lives. During the interview, Christian asked questions while Wesley transcribed notes.

Results 2: All Glass Interview

The interview yielded several key insights regarding the use of windows to combat severe diurnal temperature variation. Our main finding was that there are no window insulation mechanics or techniques specifically optimized for use in areas with large diurnal temperature variation such as Portales, NM. We learned that the best window in the circumstances would be composed of insulated glass units fitted into a window frame. In addition, we were informed that specially trained personnel and custom window builds are required to install a window correctly. When we asked about less-involved solutions that did not involve replacing an entire window, our interviewer did not offer any.

Discussion

It seems that we face a complex optimization problem. Rather than optimizing one property, our solution must optimize multiple. It must be easily installable, financially viable, and effective. We will need to consider harnessing ambient heat as a possible angle of our solution. Another difficulty is that our target user and scope of the problem are up to us to define, and in order to make headway on a solution we must make a decision on this matter. In sum, the path forward is not fully illuminated due to a need for optimization of multiple properties and ambiguity surrounding the scope of the project, but rapid ideation and organization of ideas will allow our team to break ground on our design work.

Appendix C: User Testing

Testable Properties

- How "low/high maintenance" the solution is
  - Whether the amount of manual adjustment the solution involves would be excessive
  - Can't be performance tested by our team because of inherent bias to say that the solution works
- Temperature
- Economic viability
  - User has more firsthand knowledge of NM energy costs - solicit input from him about whether a solution would be economically feasible
- What we will need

○ To arrange a time to talk to the user
● Finding proxy users
○ Friends, roommates, etc.
● Collecting feedback
○ Verbal feedback
○ Google form

User Testing

● Meet with user to discuss economic viability and degree of maintenance of solution
○ Not a “test” in the usual sense but the closest possible alternative given the circumstance of our user not being near us geographically
● Give a friend/roommate/acquaintance the solution and allow them to operate it for half a day or a day
○ Solution still TBD

Performance Testing
● If a mechanical design is required for design of the blinds or curtains,
○ testing for different materials, which are differentiated in terms of their ability to refract light and absorb heat, in various thicknesses.
○ The shape is also an important factor to consider. The design could be more effective if it is hexagonal, rectangular, or bended in a way that could allocate light in a specific direction.
● If a large mechanical system with liquid is decided to be used,
○ there should be no leaking, which requires a dense and strong material in most situations.
○ The liquid should be chosen in terms of the amount of light refraction, possibility of changing the color of the light (which is in correlation with the amount of light absorbed and heat given out), and the freezing and boiling temperatures.
● If the solution involves a liquid physically connected to the window,
○ it should be checked if there is any difference in how the outside/inside is seen when the liquid is in stable conditions and when it is moving.
○ The pressure that could be held upon the window should be taken into account and tested if the solution makes sense in this perspective or if the thickness of the window or the frames could be changed to overcome the possible effects of this variable.
● Computer modeling can be used to test the design under different temperatures and orientations.
● Any system: test temperature variation over a set period of time to determine the magnitude of the temperature range allowable by the system

Appendix D: Mockup Feedback and Testing Summaries

Purpose

The purpose of this test was to determine the effectiveness of using acrylic as insulation to achieve temperature control. The test also compared the effectiveness of pigmented acrylic to unaltered acrylic for insulation.

Methodology

Two acrylic “covers” were fashioned by using a bench shear to cut two 5” by 5” pieces of acrylic. One of the acrylic pieces was fully colored with a Sharpie marker on one side, and the other was left unmodified.

Three paper cups were filled with water that had been microwaved, and the temperature of the water in each cup was measured with an oral thermometer. Then, all three cups were left to rest in an ambient environment at room temperature. One cup was left completely uncovered, another was covered with the clear acrylic piece, and the last cup was covered with the acrylic piece with Sharpie on it. The temperatures of the water in each cup were measured every 5 minutes for approximately 25-30 minutes.

Results

Table 3: Acrylic Insulation Trial 1 Data

Time (min)	Control (no covering) temperature (F)	Clear acrylic covering temperature (F)	Black acrylic covering temperature (F)
0	102.8	102.6	*102.7-Missed this number, so made an estimate.**
7	95.9	97.4	96.1
10	93.6	95.5	94.2
15	91.6	94.3	93.3
20	Too low to measure	93.4	92.6
25	Too low to measure	92.1	91.0
Percent change in temperature after 15 minutes	10.89	8.09	9.15

*Data inaccuracies: may have attributed wrong data to each cup in this trial. Also, the estimated starting temperature for 3 makes the accuracy of the data suspect.

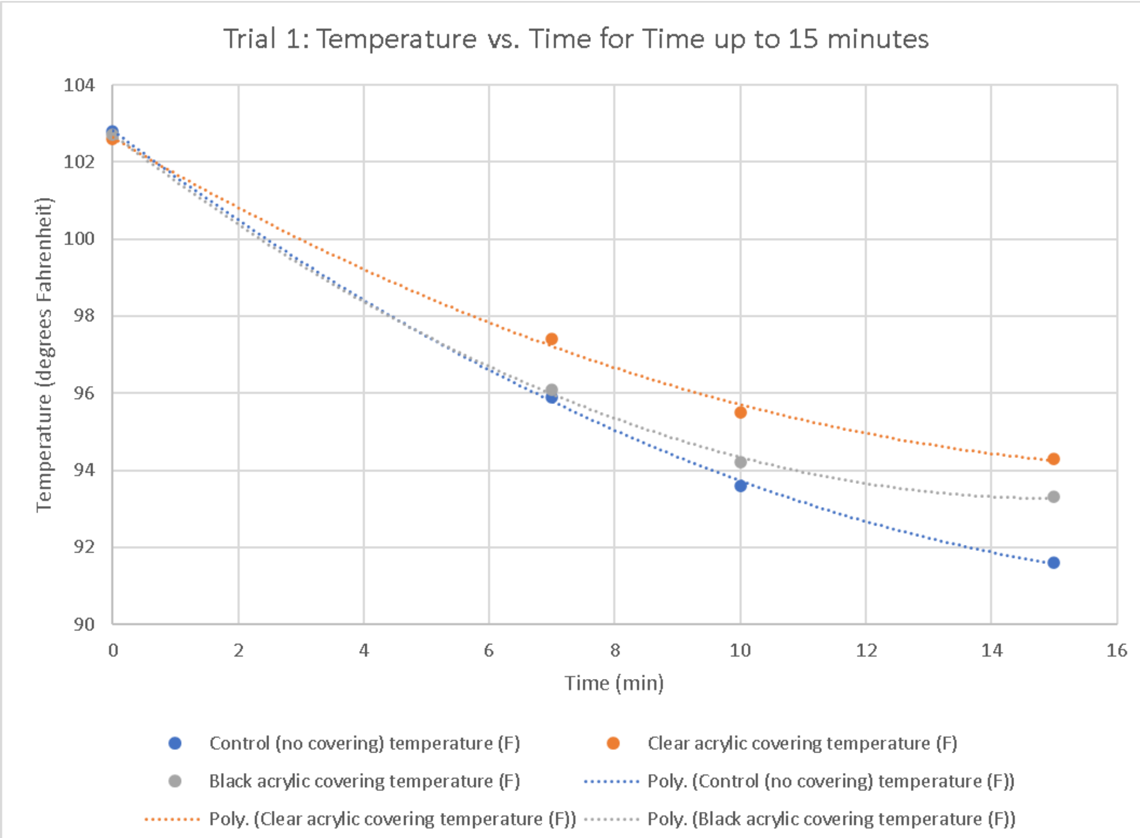

Figure 6: Graphical Representation of Acrylic Insulation Trial 1 Data

Table 4: Acrylic Insulation Trial 2 Data

Time (min)	Control (no covering) temperature (F)	Clear acrylic covering temperature (F)	Black acrylic covering temperature (F)
0	105.1	105.4	105.2
5	99.6	100.4	100.2
10	96.3	97.9	97.7
15	93.6	95.4	95.6
20	90.9	93.9	95.3 *Outlier?*
25	Too low to measure	91.9	92.3

30	Too low to measure	91.3	92.0
Percent change in temperature after 20 minutes	13.51	10.91	9.41

Discussion

The results clearly show that acrylic does provide a fair amount of insulation. With higher-quality acrylic, it can be theorized that the insulation provided by acrylic would improve. In addition, the minor disparity of results between the open cup and the covered cups could be attributed more to the failure of the paper cup to insulate the water well than the ability of the insulation to insulate. However, the results from the cup covered with the clear acrylic and the cup with the darkened acrylic are not markedly different. This can be attributed to the inaccuracy of the thermometer.

These results indicate that our prototype could involve one or multiple layers of acrylic installed as an add-in to a window frame to provide additional insulation. Such products already exist and must be custom-built for individual windows, but perhaps our team can make a version that is more accessible and low-tech than the existing products. Future testing could involve testing how well multiple layers of acrylic insulate compared to just one layer. This testing could be done in a similar fashion with cups of water to determine if additional layers have an appreciable effect.

Appendix E: Bill of Materials

Table 5: Bill of Materials

Item Description	Qty	Source	Part #	Unit Cost	Total Cost
Semi-Flexible Plastic Pipe for Water 1.049” inner diameter, 1 ¼ “ outer diameter	1 (5 ft long piece)	McMaster-Carr https://www.mcmaster.com/flexible-pipe/flexibility~semi-flexible/semi-flexible-plastic-pipe-for-water/	4884K52	21.91	21.91

General Purpose Copper Tubing 3/4” outer diameter, 0.686” inner diameter	1 (3 feet long piece)	McMaster-Carr https://www.mcmaster.com/pipe/general-purpose-copper-tubing/	8967K74	34.13	34.13
Hot glue	5 sticks	Shop	N/A	$0	$0
Acrylic	1x 14.1” by 15.25” by 0.125” sheet	Shop	N/A	$0	$0
Plywood	1x 10.25” by 15.75” by 0.75” sheet (Section A) 2x 3.75” by 16.375” by 0.375” sheet (Sections B.1 and B.2) 2x 10.25” by 3” by 0.5”sheet (Sections C.1 and C.2)	Shop	N/A	$0	$0
Duct tape	4 pieces; each piece is 5” x 2”	Shop	N/A	$0	$0
Metalized Moisture-Resistant Polyester Film (Reflective film)	1	McMaster-Carr https://www.mcmaster.com/7538T11/	7538T11	10.52	10.52
				Total Cost for the Prototype	66.56

				:	

Appendix F: Instructions for Construction

The parabolic heater system reduces variation in indoor room temperature in climates with large diurnal temperature variation. The main component of the system is the parabolic heater, which reflects solar heat (primarily IR radiation) to a focal point where the radiation is converted into heat and absorbed by a water-filled tube. This heat can be released as needed by allowing hot water to flow through a radiator.

The following instructions serve as a guide to the fabrication of the parabolic heater.

Major steps include:

- Building wooden bed
- Building parabolic trough
- Overall Assembly

Time: 2.5 hours

WARNING: The parabolic heater focuses solar radiation. Do not expose the device to direct sunlight during construction or place flammable materials near the trough. Take care in building the reflective surface to ensure the radiation is focused onto the water pipe and not nearby surfaces. Wear eye protection when the mirror is brightly lit.

Theory of Operation

The system is a circuit consisting of a parabolic mirror (termed a “parabolic heater”), a hot water tank, a radiator, and a cold-water tank. Each element of the system is connected to the next element with a tube and water flow is controlled with pumps and valves.

The parabolic heater consists of several parabolic subunits. Each parabolic subunit consists of a long sheet of acrylic curved into a parabola. This acrylic sheet is covered with reflective film. A copper tube with water pumped through runs lengthwise inside the parabola formed by the acrylic sheet such that a cross section of the subunit shows the copper tube at the focal point of the parabola. In order to form the parabolic heater, several parabolic units are laid side-by-side within a frame, as shown in Figure 1.

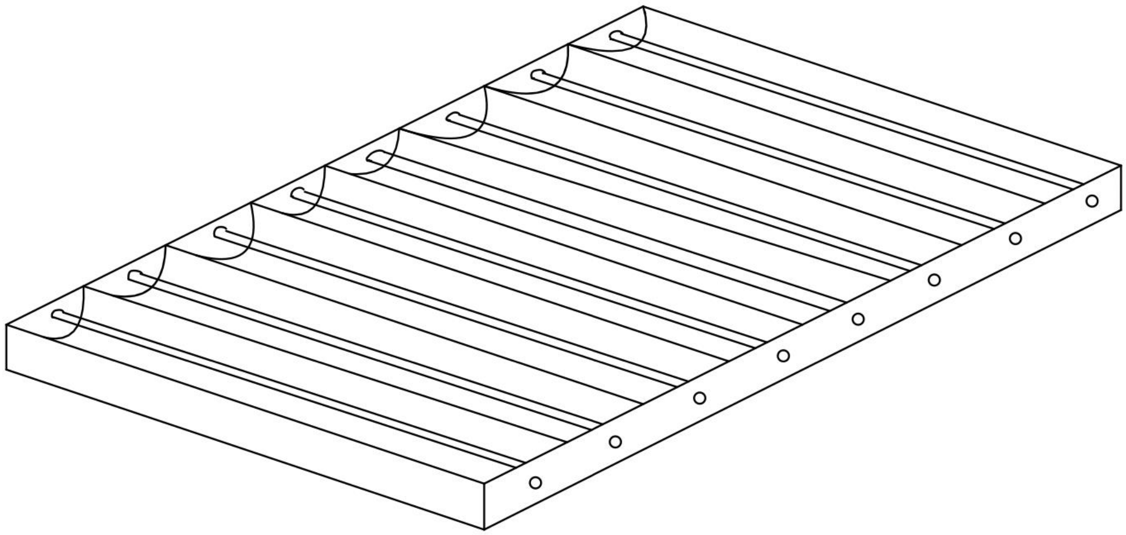

Figure 7: Array of Parabolic Subunits

The use of a parabola to concentrate reflected light and heat onto a focal point means that the design generated water at a higher temperature than could otherwise be generated by a conventional solar pool heater.

The key operation in the system is the heating of water in the parabolic heater. The reflective film on the parabolic subunits reflects visible, infrared, and other radiation onto the copper tubes containing the water. Because copper is a strong conductor of heat, the water warms up.The mirror will work in both sunny and overcast conditions, but less heat will be stored in overcast conditions. When the water reaches a certain temperature detected by a temperature sensor, it is moved with a pump to a hot water storage tank. More water is then moved from a room temperature water storage tank into the water hose to replace the warm water moved to the radiator.

If indoor room temperature is below the minimum comfortable temperature (which is set by the user), then the water will proceed directly through the storage tank to a radiator. If the indoor room temperature is above the minimum comfortable temperature, the flow of water between the hot water storage tank and the radiator will be cut off, and hot water will accumulate in the hot water storage tank. This water can then be released to the radiator when the indoor room temperature does drop below a comfortable level. The radiator used in the system will be a conventional radiator that dissipates heat from the hot water pumped into it.

Once the water in the radiator has given up all of its heat to the surroundings, it is moved (either by gravity or with a pump) to the water storage tank, and thus continues to cycle through the system.

Required Tools

1. Bandsaw
2. Hot glue gun
3. Heat gun
4. Heat-resistant gloves

5. Drill press
6. Pipe cutter
7. Scissors

Fabrication Instructions

Building Wooden Bed

1. Use bandsaw to cut one 10.25” by 15.75” by 0.75” section of plywood from a larger piece of plywood.
a. This section will be known as Section A.
2. Use bandsaw to cut two 3.75” by 16.375” by 0.375” sections of plywood from larger pieces of plywood.
a. These two sections will be known as Sections B.1 and B.2.
3. Glue the 16.375” edge of Section B.1 perpendicular to the 15.75” edge of Section A so that equal lengths of the 16.375” edge of Section B.1 protrude from each side of the 15.75” edge of Section A.
a. This is shown below in Figure 1.

Figure 8: Protrusion of Section B.1 from Section A

b. The intersection of Section B and the 15.75” edge of Section A should resemble an L shape.
4. Repeat step 3 with Section B.2 with the other 15.75” edge of Section A.
5. Use bandsaw to cut two 10.25” by 3” by 0.5” sections of plywood from larger pieces of plywood.
a. These two sections will be known as Sections C.1 and C.2.
6. Use the drill press to cut semicircles of diameter 0.75” in the middle of the 10.25” edge of Sections C.1 and C.2.
7. Glue the 10.25” edge of Section C.1 to Sections B.1 and B.2 so that it is perpendicular to the 10.25” edge of Section A.
a. The intersection of the 10.25” edge of Section C.1 and the 10.25” edge of Section A should resemble an L shape, as in Figure 2.

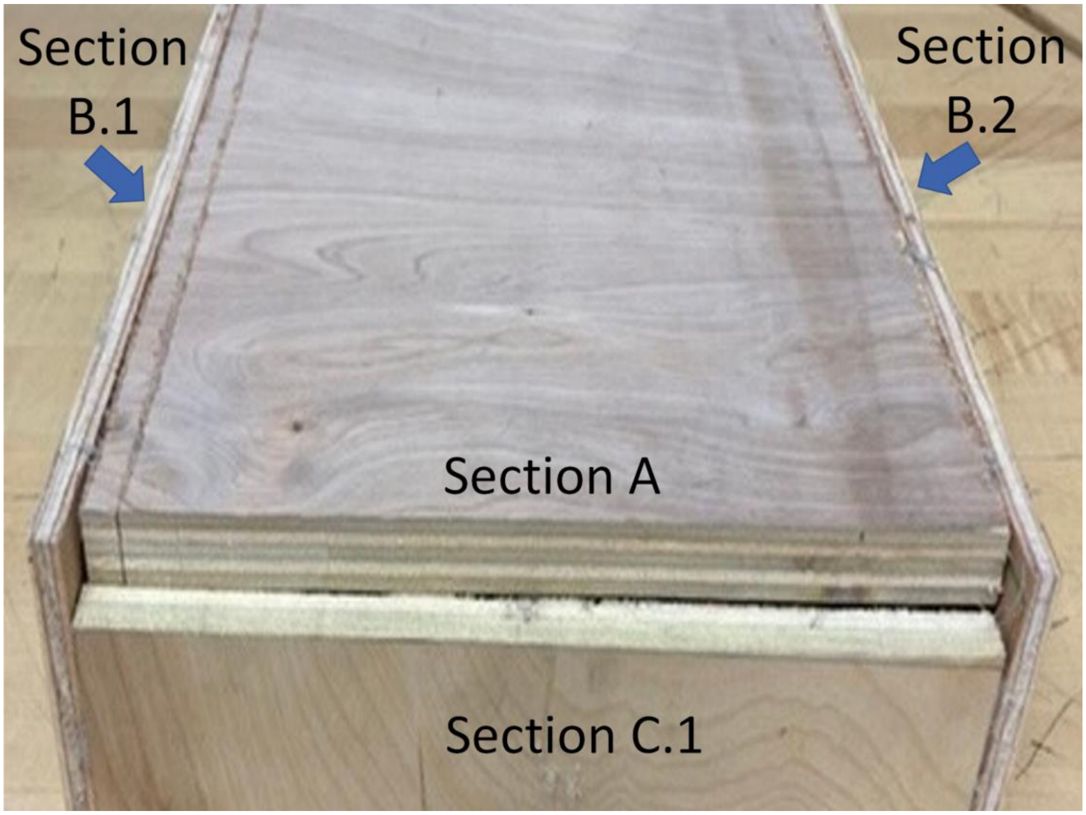

Figure 9: Intersection of Sections A, B.1, B.2, and C1

8. Repeat step 3 with Section C.2 and the other 10.25” edge of Section A.

<u>Building parabolic trough</u>

1. Use bandsaw to cut an 14.1” by 15.25” by 0.125” section of acrylic from a larger piece of acrylic.
2. While wearing heat-resistant gloves, use heat gun to bend acrylic section into parabola with height 3.625” and a length between the highest points of 9.5” (Figure 3).
a. WARNING: Wear heat resistant gloves while performing this step. If heat resistant gloves are not worn, there exists a risk for burns.

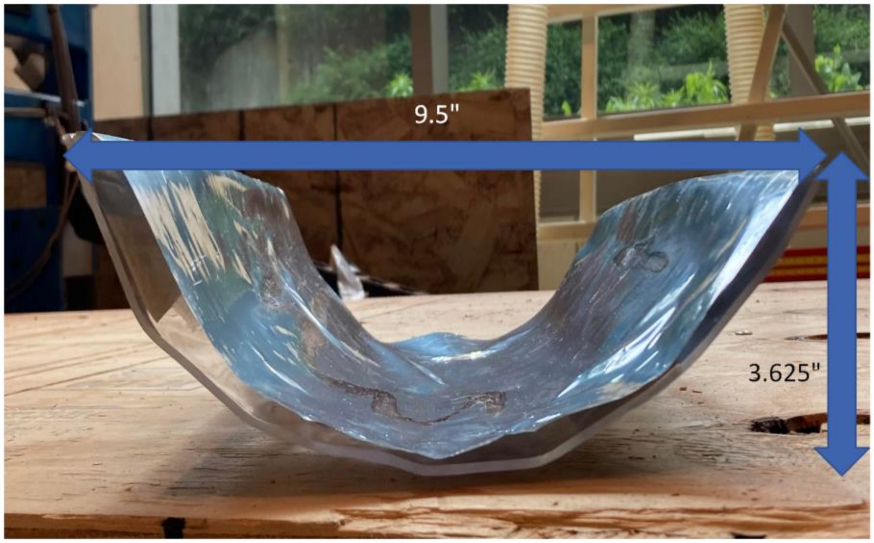

Figure 10: Parabola dimensions

3. Use scissors to cut a 20.6” by 15.25” section of reflective film.
4. Use duct tape to tape the reflective film section to the acrylic parabola so that the film takes the shape of the parabola.
a. The tape should adhere to the outside of the parabola, as in Figure 4.

Figure 11: Reflective Film

Overall Assembly

1. Cut a 18.5” long section of copper pipe using the pipe cutter.
2. Place the 18.5” copper pipe into the slot formed by the 2 parallel semicircles in the wooden bed.
3. Cut the water hose into 6 10.7” sections.
4. Glue 1 10.7” section of water hose to the side of the wooden bed so that the hose envelops the copper pipe extending off the water bed
5. Repeat step 4 with another 10.7” section of water hose and the other protruding end of the copper pipe.
6. Place the film covered parabola inside the wooden bed such that the parabola faces the ceiling.
7. The final prototype should resemble Figure 5.

Figure 12: Completed Prototype

Table 6: Bill of Materials

Item Description	Qty	Source	Part #	Unit Cost	Total Cost
Semi-Flexible Plastic Pipe for Water 1.049” inner diameter, 1 ¼ “ outer diameter	1 (5 ft long piece)	McMaster-Carr https://www.mcmaster.com/flexible-pipe/flexibility~semi-flexible/semi-flexible-plastic-pipe-for-water/	4884K52	21.91	21.91
General Purpose Copper Tubing 3/4” in outer diameter, 0.686 in inner diameter	1 (3 feet long piece)	McMaster-Carr https://www.mcmaster.com/pipe/general-purpose-copper-tubing/	8967K74	34.13	34.13
Hot glue	5 sticks	Shop	N/A	$0	$0
Acrylic	1 14.1” by 15.25” by 0.125” sheet	Shop	N/A	$0	$0
Plywood	1x 10.25” by 15.75” by 0.75” sheet (Section A) 2x 3.75” by 16.375” by 0.375” sheet (Sections B.1 and B.2) 2x 10.25” by 3” by	Shop	N/A	$0	$0

	0.5”sheet (Sections C.1 and C.2)				
Duct tape	4 pieces; each piece is 5” x 2”	Shop	N/A	$0	$0
Metalized Moisture-Resistant Polyester Film (Reflective film)	1	McMaster-Carr https://www.mcmaster.com/7538T11/	7538T11	10.52	10.52
				Total Cost for the Prototype:	66.56

Appendix G: Instructions for Use

Instructions for Using the Parabolic Mirror Heater

The following are the steps to follow when using the Parabolic Mirror Heater.

System Installation: Set up is done by the owner of the house or a heating, plumbing, or similar professional.

1. Ensure that it is safe to attach/mount the parabolic heater to the roof. This step depends on the specific build of the roof.
2. Ensure that the roof can be safely reached and traversed without without the need for a professional. If there is no easy or safe access to the roof, contact an experienced professional to attach/mount the device on the roof.
3. Determine the length of the pipes that will carry cold/warm water according to where the water storage will be located and how far it will be from the parabolic heater on the roof.
4. Climb up to the roof and mount the parabolic heater on a stable part of the roof that maximizes sunlight exposure.
5. Install two water tanks in unobtrusive areas of the house, such as the attic. One water tank will be for hot water, and the other will be for room-temperature water.
6. Install a radiator in the room that needs to be heated.
7. Install water pumps on the hot water storage tank and the right side of the parabolic heater to allow the water to flow in the correct direction.
8. Install 4 flexible water tubes, between:

a. The parabolic heater and the hot water tank.
b. The hot water tank and the radiator.
c. The radiator and the room-temperature water tank.
d. The room-temperature water tank and the parabolic heater.
9. Fill up the water storage with water. The device will work efficiently on its own throughout the year provided the necessary sanitation and safety actions are taken.

General Use

1. The system is designed to work autonomously with minimal human involvement, except periodic sanitation, which is detailed below.
2. WARNING: Do not touch the copper pipe while the parabolic heater is in operation. This will lead to burns, as the copper pipe conducts large amounts of heat to the water inside the pipe.
3. WARNING: The radiator element contains scalding water. Do not leave flammable materials near the radiator.

Sanitation: This sanitation process is recommended to be done once every month.

1. **WARNING:** To avoid burns or exposure to bright light, service on during an overcast day, early morning, or late night when the heater is cool. Be safe on the rooftop. Contact professional gutter cleaners as needed.
2. Cut off the flow of hot water between the hot water tank and the radiator by closing the valve in between.
3. Allow all of the water cycling through the system to accumulate in the hot water tank before proceeding with sanitation to prevent hot water being left in the parabolic heater, which may pose a burn hazard.
4. Dampen a towel with tepid water.
5. Clean the inside of the parabolic mirror with the towel.
6. Let it dry by waiting for approximately 5 minutes for the parabolic mirror heater to work properly again.