Final Report on Focus
A Solar Hot Water Heating Device

Abstract

Focus, our solar water heater, was very successful, heating 100mL of water to boiling in less than 22 minutes on a moderately sunny midday. Our objective for Focus was to heat a volume of 100mL of water as quickly as possible, while staying within a half-meter cube and a $120 budget. The design was conceived and developed via a collaborative, fractal, recursive process of brainstorming and idea selection which was documented in our notebooks. The resulting design was a tilting parabolic reflective device with a black copper tube at the parabolic focus where all light beams striking the reflective parabolic surface converge. After three rounds of testing, we determined a few small improvements to the design that will make Focus even more effective at heating water quickly. With these improvements, Focus will make the world a better place by pasteurizing the water of the rural poor across the globe. If wildly successful, the Focus could contribute to the health and happiness of billions of water drinkers.

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Introduction

A solar water-heating device that heats 100 ml of water in a very short period of time is of significant importance to the environment as well as the large customer base in need of hot water. It is commonly observed that due to its high specific heat, water takes longer to become heated than most liquids. Hot water is normally needed for cooking, showers, coffee-making, etc., but the time it takes to actually heat the water is unbearable; not to mention, using a source such as a stove to heat the water only creates pollution and raises health concerns because of the carbon monoxide vented out into the atmosphere.[1] To avoid this time-consuming and detrimental catastrophe, this 21W.732 project was to conceive, design, prototype, and evaluate a solar water heating system that heats water quickly and in an ecologically friendly manner. In addition to the requirement that the water become hot, the product needed to satisfy three subsidiary requirements:

- be safe to build, operate, and store
- Stay within the budget of $125 for all three units
- Fit in a 0.5 meter cube

The two main design targets were:

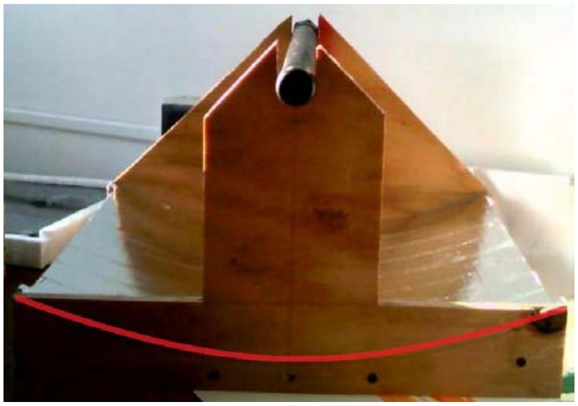
- accuracy—the degree to which the device heats water should match the design prediction
- precision—the performance results from three different units should match closely

For environmental and economic reasons, the solar water heating device called “Focus” was constructed in the MIT hobby shop.

Background

Parabolic Shape

Parabolas have one focus point.[2] When parallel rays come vertically downward, they reflect to hit this specific focus point.[3] Extending the parabola to make a parabolic cylinder allows the reflected rays to hit along a line, which is where Focus has a copper tube filled with water. It this way, the heat radiation is concentrated along the tube where it will heat the tube, heating the water. Figure 1 is a graphic of the shape of our actual model and the actual curvature of the final design.



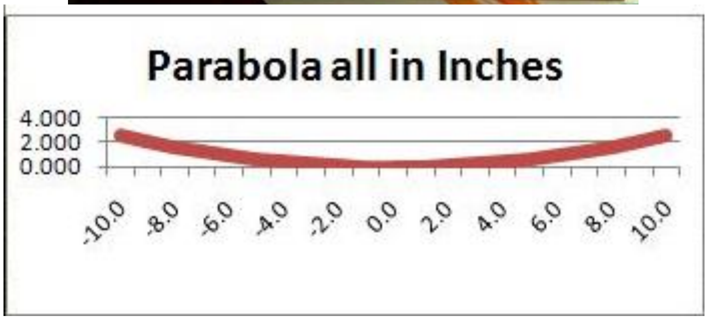


Figure 1: This graphic shows flattened parabolic shape of Focus. The actually focus is 10 inches above the vertex. In the actual model, the focus is at the center of the copper pipe.

The height of the focus above the vertex is inversely related to the degree to which the parabola is bent upward.[4] The design has this flattened parabolic shaped (which means that the focus is higher) so that the wood can be more easily bent into the parabolic shape. If the curvature of the parabola were greater, it would be more difficult for the wood to be bent and retain in the correct shape. In Figure 1, the wood is directly beneath the foil tape.

Angle of Sun in Cambridge, MA

The latitude and longitude for Cambridge Massachusetts is 42.3631, 71.103.[5]
On October 21 (the day of testing) the sun will be 32.72 degrees above the horizon.[6]
This means that since the angel of the sun will be at such a drastic angle, it is imperative that Focus have the ability to rotate so that the vertical axis of the parabola is parallel to the incoming rays.

Radiation

There exist several types of radiation that are made up of different energy contents of heat and light. Among these *electromagnetic radiations* are gamma rays, x-rays, infrared rays, visible light, radio waves, and ultraviolet rays. Ultraviolet radiation, in particular, is more energetic than visible radiation by a significant difference in wavelengths, where UV waves range from 100 nanometers to 400 nanometers in contrast to visible waves of 400 nanometers to 780 nanometers. The energy of ultraviolet radiation is considerably powerful that it can change chemical structure by heat. With that said, the sun is the major source of ultraviolet radiation. About 99% of the sun's rays are made up of the combination of visible light, UV rays, and infrared rays; whereas merely 1% consists of the other types of electromagnetic radiation.[7] There are factors that affect the intensity of UV radiation like the sun's position, the amount of ozone in the stratosphere, clouds, altitude, land, and location. Research shows that solar electromagnetic waves travel shorter paths through the earth's atmosphere at a time during the day in comparison to a time like 5 pm. The ozone relates to UV indirectly. Low ozone correlates with much ultraviolet radiation.[8] Moreover, clear skies increase UV levels as opposed to cloudy skies, because clouds deflect the UV rays up into space. There are exceptions, however. Clouds, at times, can increase UV levels as do clear skies because they are capable of functioning as reflection. A fact from Biospherical Instruments Incorporation states that ultraviolet levels increase about 4% for every 1,000 foot gain in altitude. This occurs not because of the increase in closeness to the sun but because of the decrease in the UV irradiance which is due to the atmosphere's width. Furthermore, land features like snow and sand reflect off UV radiance. A factor like location—being near the equator—increases the amount of UV rays absorbed.
To calculate the amount of energy radiated by the waves:
E=(hc)/wavelength, where c=speed of light and h=plank's constant

Thermal Model

The product of light intensity and area is energy, which is the amount of energy being transferred into phononic vibrations (heat). We can thus estimate the rate energy is added to the system. This rate multiplied by a time (t) indicates the total energy added to the system. This energy (Q) can be considered to conduct perfectly through the copper, given that the R-value of air is 0.025 W/(m*k) and the R-value of water is .6 W/(m*k) which is 24 times larger than air's (copper has an R-value of 1/401, which is .00249 W/(m*k), which is far larger than either, thus indicating it will transfer heat directly to the water) [9,10]. Thus, conduction and convection to the air can be neglected in final calculations. Based on this assumption, the total energy, Q, is equal to the product of the water's mass (m), heat capacity (c), and change in temperature (ΔT). Solving for a final T, knowing the initial temperature and difference in light intensities, we get

$$T_{final} = [(I_1-I_2)(SA)(t)/mc]+T_{initial}$$

I_1-I_2= the difference between the intensity going into the copper pipe - the intensity leaving the copper pipe

SA= the surface area of the copper pipe= $2\pi r^2+2\pi r*height$
t= time radiation shines upon collector
m= mass of water
c= specific heat of water
$T_{initial}$= initial temperature of water

The mass of the water m = 100mL = 100mL*(1g/mL) = 100 g. This is based on the density of water[11] which is 1g/ml.

The specific heat of water[12] c = 4.1921 J/(g·K) at 100 kPa and at 10˚C = 10*9/5+32 = 50˚F.

The intensity of the light reaching the ground[13] is about 198 W/m^2.
The area of the parabola in m^2 is 18 in *18 in * 1m^2 / 1550 in^2 = .209 m^2
That means there is a light intensity of 198 W/m^2 * .209 m^2 = 41.36W.

However, the foil tape, which we assume to be equal or better than aluminum foil in terms of reflection, will reflect 95% of incoming infrared rays.[14]

The black painted copper pipe will absorb 98% of solar rays. [15]

The final intensity * Surface area = 41.36 W * .95*.98 =38.5W
Putting all of that into the equation is T_{final} = [(38.5 W)(t)/(100 g * 4.1921 J/(g·K))]+$T_{initial.}$

That yields is **T_{final} = (.0918K/s)* t+$T_{initial}$** where t = time in seconds.

The water should hit boiling in a little less than 14 minutes given that the water starts at 25 ˚C.

Initial Temp (C):		25
Time (s)	Time (m)	Final Temp
0	0	25
300	5	52.54
600	10	80.08
900	15	107.62
1200	20	135.16
1500	25	162.7
1800	30	190.24
2100	35	217.78
2400	40	245.32
2700	45	272.86
3000	50	300.4
3300	55	327.94
3600	60	355.48

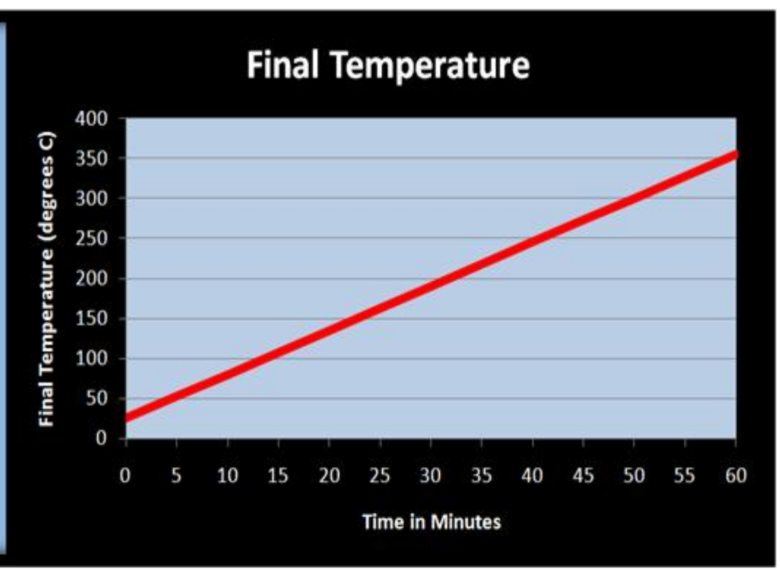


Table 1 and Figure 2: This table and graph display the linear relationship of the model as a function of time.

Limitations of Thermal Model

Our model's prediction diverges from the actual value of T at large values of time; that is our line is an accurate model as a linear approximation of the actual temperature function up until a large amount of time has passed.

The model also does not factor in the heat of vaporization, which by definition is the amount of energy per unit mole to change a matter's state from a liquid to a gas.[16]

This divergence at large values of time is due to the inability of our model to factor in heat loss by the water once it has reached a large temperature (which occurs at large values of time). There is a highly favorable equilibrium in place when the temperature of the water is low, but once the temperature gets high the hot copper will stop transmitting a large percentage of its photonic heat to the water. This will slow down the rate at which the water's temperature increases, resulting in an asymptotic equilibrium temperature to be discovered experimentally.

Our model is thus best when the energy in (the intensity of light) is high, factors such as wind are low, and the time of testing is brief.

Aluminum Foil vs. Foil Tape/Reflecting Tape:

Given that both Aluminum foil and foil tape have approximately the same cost, and the fact that with a crinkled surface (more likely in Aluminum foil because of its malleability) our reflective material will not be able to focus the light as well as a smooth surface, we choose foil tape over Aluminum foil, as the tape can be applied smoothly. This smooth surface allowed us to reflect the light in the proper direction, maximizing our design's efficiency.

Aluminum reflects about 95% of incoming infrared rays[17]. We assume for our thermal model that foil tape has the same reflectivity as Aluminum foil.

Copper vs. PVC

Copper has an R-value of 1/401, which is .00249 W/(m*k).[18]
PVC has an R-value of 5.2 W/(m*k).[19]

Copper is much more conductive (as it is less resistive), and so copper was our preferred choice over PVC, despite the higher cost. It should be noted that since both copper and PVC pipes are very thin, there would not necessary be a sizable difference between the effects of copper and PVC.

Why Paint it Black

Flat black paint absorbs between 97% and 99% of solar rays; however, it emits about 97% to 99% of infrared rays too.[20] A thin coat of black paint on copper, which is highly conductive, proved to be highly effective.

The fact that black paint emits rays is not too much of a concern as the heat will be quickly conducted to the water inside. This will keep the black paint absorbing much more than is lost, especially in the beginning.

Methods

Diameter of the Copper Pipe

The diameter needs to be large enough to hold 100 mL water easily, to be wide enough to make sure the sun-rays will still hit the copper pipe even if the parabola is not exact, and to be purchasable.

The length of the copper pipe will be .5 meters in order to stay within the constraints of the project.

$V= \pi r^2 L = .1\ L = 1*10\text{-}4\ m^3 = \pi r^2(.5m)$. Solving for r yields .007979m = .7989 cm

1 inch = 2.54 cm. So .7989cm/2.54 cm = the radius in inches = .314 inches.

Thus the diameter, which is twice the radius, is .62 inches.

In other words, the ideal copper pipe should have a diameter of about ¾ to 1 inch. The models all used a 1 inch design because the original intent was to have just a hole at the top of one copper end cap to remove the hot water. (See Appendix 1 for original design.) Thus space would have been needed in the pipe. This was not necessary as the final models used screw-on plugs.

Construction

The majority of the building of all three models took place in the MIT Hobby Shop. Available there were additional wood supplies and a variety of tools. Some of the tools used were:

- Band Saw – used for many smaller cuts
- Table Saw – used for cutting larger quadrilateral shapes
- Pipe Cutter – used for cutting the copper pipe to the correct length
- Drill Press – used for cutting out circular shapes
- Metal Sander/ Metal Band Saw – used to shorten and shape boths
- Nail Gun – used to attach bendable plywood to parabolic base
- Electric Drill – used to quickly drill screws
- Squares – used for straight edges, center lines, and measuring
- Clamps – used generously to help glue set
- Awl – used to punch centers of cuts for drill press.
- Sliding Compound Miter Saw – used to cut dowel pieces equal lengths

All of these tools required proper instruction, mainly given by Ken Stone.[21]

Safety was a priority; eye glasses and even dusk masks were worn.

Three models were constructed. The first one was fully completed and the following two, built at a later time, were nearly finished. They did not have the angling device.

Result/Discussion

Changes to the Model

The project design was fairly successful. A few changes were made to make this a functional creation. For instance, initially, the idea was to use dowels for accuracy in the alignment with the sun. However, it was found that it is not only simpler, but also a tad more effective, to merely cut the sides vertically parallel. This would allow more precise alignment. In Figure 3, the first two pictures, show the original down alignment. This was hindered as the sun cast a shadow over the dowel when in use. The third picture in Figure 3 shows the final improvement. Notice how the design is simplified and made more effective.

Figure 3: First two pictures are initial dowel aligning device. The third picture shows the improved design. Parallel rays do not cast a shadow from the side piece when the device is parallel to incoming rays.

The original plan also was to use dowels wrapped in sandpaper to support the device at the correct angle while preventing slipping. (See Appendix 1, labels A and D). Initial building and advice from Hobby Shop master Ken Stone[22] led to a new design which used bolts, nuts, and washers. The added length of this angling technique is the reason for decreasing the width of the future models. This made it possible to satisfy the half-meter cube constraint. The angling technique is shown in Figure 4.

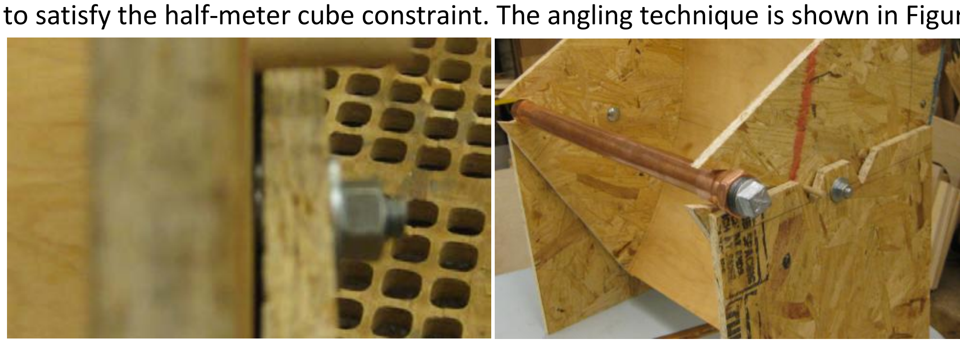


Figure 4: The new angling technique is shown from first the front view and then obliquely angled from the side. The central washer that constitutes the gap in between the wood pieces in the first picture is used to make up for the protruding heads of the screws used to attach the braces to the side piece (not shown). The bolts are pressed into the wood. We used clamps to do this. This keeps the bolt from turning. Then the nut can be tightened sufficiently using just one hand.

Another change made to the design was the adhesiveness of the pipe and closing. Instead of the original epoxy idea, which was used for the first model constructed, welding was found to be just as effective. Welding may help maintain a better water quality than epoxy. Both methods appear the same from the outside. Both methods retained water equally well. Leakages only came from the plugs, which were neither “epoxied” or welded in place.

In addition, a significant alteration was in the material used to form the parabola. The original plan was to use quarter-inch plywood. A cheaper alternative found at the store was quarter-inch masonite. However, research, experimentation, and professional assistance from Ken Stone[23] triggered a wiser idea of using bendable plywood instead. This alteration made forming a perfect parabola easier. As shown in the Figure 5, the bendable plywood is very thin.

Figure 5: Bendable plywood can be easily shaped into a parabolic cylindrical surface. The pictures shows the gluing process of attaching the supporting beams that prevent the bendable plywood from bending in any way other than in the parabolic cylindrical shape

Furthermore, pipe tape was used to prevent the water from spilling out of the pipe. The temperature extremes of the water inside the pipe caused expansion, and water leaked to varying degrees anyway. Figure 6 shows the plug with and without pipe tape.

Figure 6: White pipe tape was used to help seal the plug. The first pictures shows the threads without pipe tape and the second picture shows the threads with the pipe tape. The pipe tape is intended to fill in the spaces between the threads.

Testing

There were a total of three tests. One was done on 10/23 at 10:45 AM. There was an informal test on 10/23 at 4PM. The last test was on 10/28 at 1:15 PM.

The first test on 10/23 at 10:45 AM was with the first prototype (labeled Model '3'), which had the dimensions of 18" * 18." The test showed lots of leakage, as pipe tape had not been utilized. What was important was that the water inside did reach boiling very quickly (less than 22 minutes). When the plug was screwed off, lots of steam was emitted. This test had the best conditions compared to any of the other tests. See table 2 and figure 7 for the test results.

Initial Temp (C):		25.0	Testing 10/23/10 10:45 AM
Prediction			
Time (s)	Time (m)	Temp 18"*18"	Model '3' 18"*18"
0	0	25.0	25
900	15	107.6	100
1320	22	146.2	100

Notes: Slightly windy, but bright sunny day with a few clouds. One cloud got in the way for 30 seconds. After about 12 to 15 minutes the rod was too hot to pick up to test inside water temperature. After much time (22 minutes) the end cap registered 210 F, essentially boiling. It is likely that the water inside reaching boiling closer to 15 minutes.

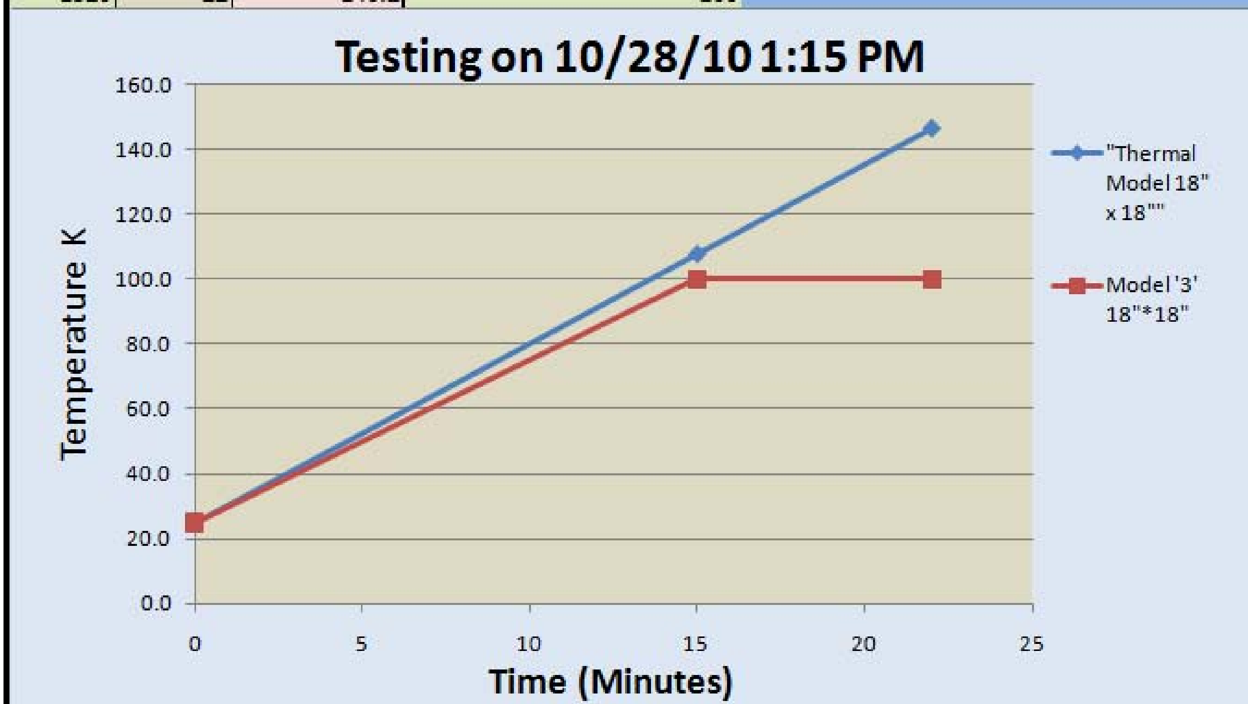


Table 2 and Figure 7: This initial tested showed that on prime conditions (bright sun), focus can reach boiling. This design was the 18" by 18" model. It has two data points for boiling because the water had likely reached boiling by about 12 to 15 minutes, but it was not formally measured until 22 minutes

The second test on 10/23 at 4PM was to put pipe tape to the test. There was no leakage and the copper pipe, via a finger test, had heated up a lot within eight minutes. Notably, this was at 4PM on a partially cloudy day. Since the solar rays are generally much less under these conditions, Focus' design empirically showed that it was very effective.

The third and final test (shown in Table 3 and Figure 8) was on 10/28 at 1:15 PM. For this, the testing conditions were not ideal. It was very windy, but there was initially full sun and few clouds. Due to a rather unfortunate placement of the models, the sun's rays were inhibited about halfway through the testing due to a tall building. It is likely that even when the shadow of the building's shadow was not cast on the devices, the drop in ambient temperature and inhibited indirect rays may have resulted in the peak in temperatures. Moreover, the wind blew Model 1 and Model 2 over on multiple occasions. These two models, lacking the proper stability of the base tended to tip over since they were propped up against a wall. There was also a cloud that after twenty minutes directly blocked the sun.

Other problems arose during the testing. Model 1 lost about 50% of its water despite the pipe tape. Model 3 lost about 25%. Model 2 did not lose any water. The leakage, as suggested by evaluator Dave Custer[24], may have been due to the copper pipe expanded faster than the plug. This hypothesis is substantiated by the fact that the plug was screwed in tighter during the experiment (when the copper pipe was hot and expanded) and later the plug would not easily unscrew. It can be assumed that the copper pipe shrunk when cooled more than the plug did, causing this dilemma.

Moreover, much sunlight exposure was not utilized as efforts were made to screw the copper plugs on tighter and tighter.

There are many important messages to take away from this testing. Primarily, the copper cap does not reflect the inside temperature of the water as high as measurements underneath. Shown in Table 3 and Figure 8, the temperature seems to spike at the second to last measurement taken at 23 minutes. (The max temperature was by the 18" by 18" Model 3 which registered at 77.8˚ C, highlighted in red in the table). The discrepancy of measurements between the end caps and the copper pipe's surface where the light is absorbed is due to the large amount of surface area on the copper cap, and the requirement that heat had to travel through the water, air inside the pipe, and the copper to be able to heat this. This makes all the other measurements using the copper cap slightly beneath what was likely to be the actual temperature of the water.

The second most important message to take away from this testing is the effect of water loss. Model 2, which lost no water, took the longer to heat than Model 1 (also a 18" by 17.5" model), but Model 2 retained heat longer than Model 1. Water's high heat capacity thus both help to restrict changes in temperature, both increasing and decreasing.

Another significant note is that Model 3, (a 18" by 18" model) took longest to start heating up. This is likely due to the heat needed to heat up the extra copper pipe length. The slightly larger dimensions of Model 3 is clearly shown favorable as Model 3 reaches the highest temperature and does not cool back down as much as the other models. Larger dimensions certainly prove more effective as more energy can be absorbed, but may initially heat water slower than corresponding smaller models.

Initial Temp (C): 31.7				Results:					Full, sun, few clouds, 1:15PM, 10/28/2010, All temp. coverted to C, Model 3 is larger model, all measured by side cap, unless otherwise noted
Prediction									
Time (s)	Time (m)	Temp 18"*18"	Temp 18"*17.5"	Time (s)	Time(m)	Model 1	Model 2	Model 3	Notes:
0	0	31.7	31.7	0	0	30.0	31.7	33.3	Assume outer temp = inner temp
150	2.5	45.4	45.1	150	2.5	42.8	41.1	32.2	Model 1 is leaking
300	5	59.2	58.4	300	5	48.3	40.0	40.0	
450	7.5	73.0	71.8	450	7.5	53.1	46.7	48.3	1 leaks a lot, 2 none, 3 some
600	10	86.7	85.2	600	10	56.1	51.7	54.4	
720	12	97.8	95.9	720	12	62.8	54.4	65.6	
870	14.5	111.5	109.3	870	14.5	63.9	62.8	66.7	Wind knocks down 1 and eventually 2
990	16.5	122.5	120.0	990	16.5	63.9	62.8	71.1	
1110	18.5	133.6	130.7	1110	18.5	60.0	66.7	71.7	Model 1 is in shade
1230	20.5	144.6	141.4	1230	20.5	55.6	61.7	72.8	Sun goes behind cloud at 20 minutes
1350	22.5	155.6	152.2	1350	22.5	51.1	57.2	71.1	
1380	23	158.4	154.8	1380	23	52.8	56.1	77.8	*measured underneath
1440	24	163.9	160.2	1440	24	47.8	52.8	66.7	*measured on the cap, like usual

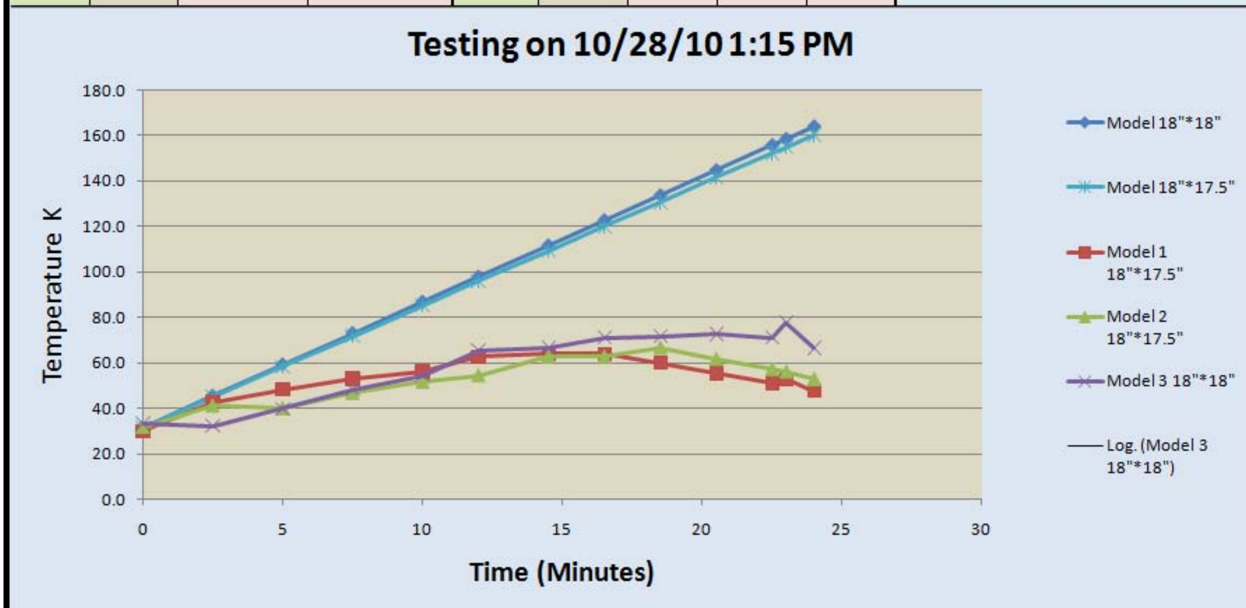


Table 3 and Figure 8: The data from one afternoon test using three models. Models 1, 2, and 3 are actual models constructed. The first two "models" are the linear thermal models. The highlighted value is the maximum temperature registered among the three models.

Effectiveness of Thermal Model

The thermal model seems very much supported by the first round of testing (Table 2 and figure 7) and very much challenged by the third round of testing. Although many caveats to this model have already been described (see Limitations of Thermal Model), the third round of testing brings in another factor for the model: light intensity. The light intensity used in the model is. On a sunny day around noon, the incoming light intensity could be higher than 198 W/m^2 and on a cloudy day in the evening, the light intensity could be much less. The light intensity is surely less when the incoming light is blocked by a building, as in the case with the third round of testing. Thus, the thermal model would prove more effective if the intensity of incoming light is considered.

Also, sky cover (clouds) may redirect incoming rays so they are not parallel. This would hinder the effectiveness of the design to fully direct the rays at the copper pipe, providing for even more deviation from the model.

Nonetheless, the model is substantiated by one small result shown from the third round of testing. The initial slope of both Model 1 and Model 2 nearly match that of the model. This gives reason to believe that the model, correctly estimated the original incoming rays, despite its inability to factor in heat loss.

Recommended Improvements

To improve safety, a depressurizing value should be added. This would prevent against explosion. A teapot-like whistle could be added. Until this improvement is made, Focus should not be used to fully boil water. See *Safety* (next section) for more information.

The inner diameter of the copper should be decreased closer .62 inches. This is because the extra space at the top of the pipe was not necessary in the final model; no hole was put in the end cap to allow drainage. With a screw-on end cap or plug, the ideal size of the copper pipe would be closer to the volume of the liquid needed to be heated. (Please read safety message below before doing this though). The reason is that the water in the pipe rests on the bottom of the copper pipe. When the device is tilted at an angle, which is always the case at this time of year (see *Angle of Sun in Cambridge, MA)*, the incoming light does not fully heat the part of the copper pipe in direct contact with the water. See Figure 4 below:

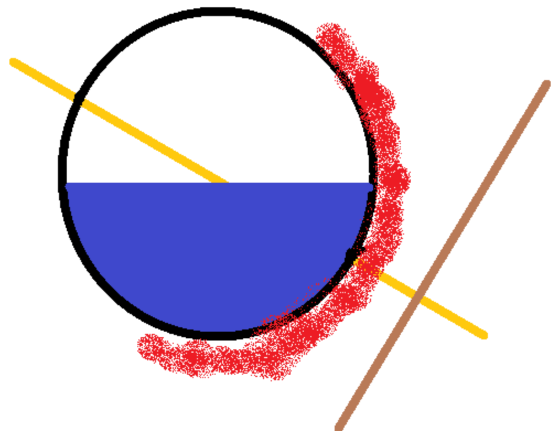


Figure 4: Blue is the water. The yellow line is parallel to the incoming rays. The brown line is parallel to the base of the parabola. The red indicated the part of the copper pipe (the black circle) that is heated. Notice that at such a steep angle (which happens in Cambridge, MA where the testing took place), much of the heat that hits the copper pipe does not hit the copper pipe where the copper pipe is in direct contact with the water. Much of this heat is then lost to the outside air as it is not as easily conducted into the water.

Safety

Focus has the potential, as shown in all three rounds of testing, to considerably heat up. It is thus imperative that all users of Focus have oven mittens or another tool to help remove the end plug when the pipe is very hot. It may also be helpful to wear sunglasses as the reflected rays, even when not viewed from the focal point, can be strong. Looking at the rays from the focal point may be blinding.

One of the safety hazards of Focus is the potential for the heated water inside to become under great pressure, causing the potential for explosion. Water should be removed from Focus before vaporizing. Moreover, the addition of a pressure value or a “teapot-like” whistle that opens or sounds under high pressure would prevent any risk of explosion.

Environmental Impact

Our model uses minimal resources and does not appreciably contribute to global warming. The copper, wood and bolts in our model may be recycled or reused, reducing the ecological impact with respect to material usage. The parabolic design of Focus concentrates the light, so that black spray-paint is only required paint on pipe rather than on a larger surface. This causes fewer anthropogenic gases to escape into our outer atmosphere.

Reproducibility

Focus is highly reproducible. This is evident in that three models were constructed. (The last two were nearly finished, only missing the angling devices). The third round of testing shows that the results were fairly consist, especially between the two 18” by 17.5” models. This would be expected, and the fact that the 18” by 18” model outperformed them slightly makes reasonable sense. It is reasonable to expect another 18” by 18” model would perform equally well as the first 18” by 18” model. The models were very sufficiently precise.

Figure 10: Picture of all the models during testing. This duplication proves reproducibility.

Cost to Build

Our models took us 27 hours to build, in whole; approximately 10 hours for each model (three models, only the first fully completed). The total cost exceed the budget in that other materials were purchased but were unused (such as PVC pipe and extra wood). The budget (see Appendix 3) reflects the more reasonable cost of the materials used in the project. Using scrap wood and free screws helped to reduce the cost of the model.

Conclusion

We conclude that Focus is an effective device that can effectively heat 100 mL of water quickly. Testing showed that Focus has the potential to boil water under ideal weather conditions. Under these ideal weather conditions, the thermal model nearly matches Focus' performance too. With small improvements to the design, Focus can be more effective at heating water and safer. Additionally, Focus' design is environmentally friendly, within budget, and reproducible. In the long run, Focus has the potential to improve the quality of lives for the water drinking population of the world.

Appendices:
Appendix 1: Detailed Original Design Description

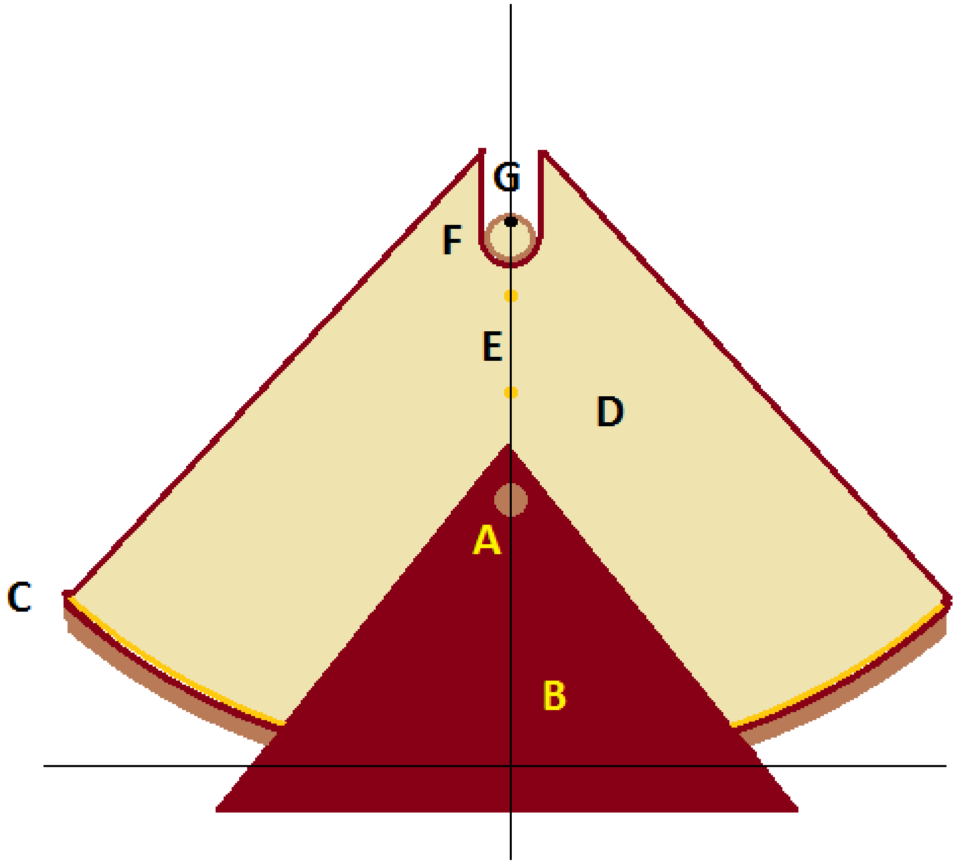


Figure 11: Original Design

*Changes to Focus are label with asterisk.

A is the point of the center of mass of the structure not including the base. The parabolic structure will rotate at this point so that the parabola's vertical axis (here drawn perfectly vertical) will be parallel with incoming rays.

B is the base on which the structure rests and rotates.

C is the parabolic layered structure. The layers from bottom to top consist of 1) a 1/2" thick slab of wood that is shaped as a parabola, 2) a 1/4" thick sheet of plywood bent (*1/8" bendable plywood was actually used in the models) and nailed to layer 1, and 3) a coating of reflecting tape.

D is a board that is attached to the thick slab of wood shaped as a parabola. D extends beyond the end of the parabola. D will be attached to part A using a small cylindrical block of wood (i.e. a short portion of a thick dowel). The dowel is wrapped in sandpaper (*instead of a dowel and sandpaper, bolts, nuts, and screws were used to hold Focus in place) as to insure that while it will not rotate when Focus is tilted if, perchance point A is not the exact center of mass. D will also include a cut at its top where the copper pipe (F) will rest.

E (*was replaced by part D cut parallel to vertical axis for the second two models. The first model did include this) is also attached to D. E consists of two smaller rods or dowels only 1” protruding from D. E is along the vertical axis of the parabola. E exists to help tilt the parabola so it directly faces the incoming rays.

F is the copper pipe. Note that the copper pipe is capped with two metal caps on each end. The copper pipe is also painted black.

G(*replaced by plug; to be replaced by another fixture in future) is a hole in one cap located at an edge. G serves as a way to pour water in and out of the pipe.

Appendix 2: Original Recipe

*Steps marked with an asterisk are modified or deleted in final model

1. Cut the 1/2” thick piece of plywood in shape of parabola matching Figure 1. Allow about two inches beneath the parabolic shape to allow for stability. Cut the ends (where the parabola stops) vertical so that the brace does not protrude beyond the parabola. (The goal is to maximize the sunlight redirected). This is shown in Figure 1 C layer 1.The horizontal length of this piece should not exceed 19”, so 9” to each side left and right will be sufficient. Note: there are two braces.
2. *(Use thin bendable plywood, length for second and third model was less than 17”) Cut the 1/4” thick piece of plywood 17” x the length of the curvature. Although a calculation could be done, this simplification of just cutting to size will help prevent error if the initial parabola brace is not perfect.
3. Nail and glue the 1/4” plywood to the braces. Note: clamps are very helpful.
4. Trace the bottom of the braces onto a 1/2” board (part D) and the parabola’s top. Using a drill press cut a diameter hole at that spot the size of the copper pipe. Cut a vertical path down to that point. Cut into a triangular shape.*(This was modified to be parallel to vertical axis) Note: This there are two side braces.
5. Cut the 1” ID copper pipe 19.” *(Or less depending on length of copper plug, if applicable)
6. *(Do not do. Use plug or something else.) Cut a 3/8” hole in one end of one copper cap.
7. Epoxy the caps onto the ends of the copper pipe, ensuring they fit over the edge of the parabola. If they fit very tightly, leave the cap with the hole unglued. This can be glued in the future if necessary. *(Or weld/solder)
8. Paint the copper rod and caps (now attached) black.
9. Estimate the center of mass for the parabolic structure. Mark with a pencil. Drill hole and insert/glue wood dowel. (The size of the dowel will be based upon the availability of free materials at the hobby shop). Glue sand paper on the part of the dowel that protrudes. (Reminder: do this for each side). *(Use a bolt. Using a clamp, push bolt into wood so that its head prevents it from rotating. Then add washers and nut as necessary to help hold device in place.
10. Make two triangular pieces that serve as the base out of 1/2” plywood (Part B). Be sure it is tall enough to be able to suspend the parabolic structure. *(Doesn’t have to be triangular).
11. *(No dowels; no sandpaper, but do cut a hole for the bolt.) Cut holes in the base near the top (the same height on each base piece). Note: make the diameter large enough to accommodate the sandpaper on the dowel.

12. Fit pieces together. Note: device can be made to come apart for easier storage, but if this is not desirable, extra pieces made into strips from the 1/4” plywood can be used to hold the two base pieces together.

Appendix 3: Budget

Item	Cost
1” ID * 20” Copper pipe	$20 (cheaper in bulk)
20” * 30” 1/8” Bendable Plywood	$10
1/2” Thick Wood braces	$10 (or Free pending availability)
1/2” Thick Bases	$10 (or Free pending availability)
Reflecting Tape/ Foil Tap	$15
Copper Caps	$5
Nails 1” long, Thin	$5
Welding/soldering material	Free
Black Paint	$10
Screws, bolts, nuts and washers	$15
Total	$100

Appendix 4: Overview of Consulted Oracles

Qualifications of primary investigators

As 1st year students at MIT, we have dedicated much time and effort to brainstorming and researching to help finalize on the Focus design.

Sources

Our sources are a number of people and web sites that show us where our need for this invention arises and how to address these needs. We also cite the necessary information pertaining to the design of the project, e.g. materials with high reflective indices and mathematical values for our parabolic design.

[1]Connecticut School Indoor Environment Resource Team, C/o Connecticut Council on Occupational Safety and Health, http://www.hartford.gov/HealthyHartford/IndoorAir_Quality/IAQSourInCont.htm

[2]Parabola - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Parabola

[3]Parabolic reflector - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Parabolic_reflector

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[5]Free ZIP Code Lookup with area code, county, geocode, MSA/PMSA., http://www.zipinfo.com/cgi-local/zipsrch.exe?ll=ll&zip=02139&Go=Go

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[19] Thermal conductivity - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Thermal_conductivity (describes R-value is inverse of k), Heat Transfer Basics – Part Zero « The Science of Doom, http://scienceofdoom.com/2010/09/12/heat-transfer-basics-part-zero/ (gives k value for PVC).

[20] G1971 Active Solar Collectors for Farm Buildings | University of Missouri Extension, http://extension.missouri.edu/publications/DisplayPub.aspx?P=G1971

[21] Ken Stone, director of the MIT Hobby Shop, dedicated much time to increasing our safety when using power tools. He also introduced better methods like using a rip fence and better clamping techniques.

[22] Ken Stone, director of the MIT Hobby Shop, offered substantial advice on easier construction techniques and provided tools, resources, and know-how for much of the project.

[23] Ken Stone, director of the MIT Hobby Shop, shared his knowledge of the usefulness of bendable plywood.

[24] Dave Custer, instructor for 21W.732 in MIT's Experimental Study Group.