Engineering a Desiccant-Driven ($CaCL_2$) Self-Contained Solar Distillation System to Collect Drinking Water from the Atmosphere

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ABSTRACT

Fresh water accounts for 2.5% of the planet's water, and the UN's estimated 7.7 billion people on Earth are taxing that supply. With 3,100 cubic miles of freshwater vapor trapped in the atmosphere, a desiccant-driven solar distillation system may be a viable solution to a crisis in areas with limited water sources. An octahedron-shaped solar distillation system was designed and built using impact-resistant polycarbonate and stainless steel and tested in 45–100 ºF temperatures under diverse weather conditions. Calcium Chloride absorbed ambient water vapor then the still utilized solar energy to help regenerate the $CaCl_2$ by forcing it to release the water through solar distillation. The design eliminated the traditional trough system and was managed by one person. While productivity was dependent on climatic conditions, the still could produce 6.5 ounces with external temperatures above 85 ºF. External temperatures below 60 ºF produced measurable water of 2.5+ oz with full sun exposure. The predominant factor contributing to higher water collections was the amount of solar exposure on any given day. Insulation of the stainless steel base and black cloth substrates allowed for internal temperatures above 110 ºF on mid–60 ºF cold weather days.

KEYWORDS: Desiccant Water Production, Solar Distillation System, Water Distillation using Calcium Chloride, Drinking Water Solutions, Water Sourcing with Desiccants, Engineered Water Collection

INTRODUCTION

For millions of years, the amount of freshwater on our planet has remained much the same. The earth's hydrologic cycle has continuously moved that water through a cycle of evaporation and precipitation again and again. Yet as global populations rise, humans are finding themselves in a drinking water crisis that is becoming a race for survival. With freshwater accounting for only about 2.5% of the water on our planet, the 7.7 billion people on earth, as estimated by the U.N. World Population Prospect (2019), are taxing this water source.

While for much of the current population, this crisis is not a concern, for others, it is a devastating reality. The U.N.'s 2030 Agenda goal SDG6 that sets a goal of ensuring available and sustainable management of drinking water is not close to being on track (U.N., 2015). We need drinking water to survive. According to the Geneva Sphere Project (2004), in emergency situations, the human body needs 2.5 – 3 liters of drinking water a day depending on climate and individual physiology.

It is necessary to understand how global freshwater is used and how that use has changed. Freshwater withdrawals globally are estimated by the United Nations at 69% agriculture, 19% industry, and 12% municipal (Aquastat, 2014). At the same time, global diets are changing from starchy foods to more meat and dairy, and those foods require more water. The *Water Footprint Assessment Manual* (Hoekstra et al., 2011) details that producing 1 kg of rice requires 3,500 liters of water, while 1 kg of beef uses about 15,000 liters. Even a cup of coffee requires 140 liters overall to produce.

Beyond dietary shifts that are expected to continue, the climate changes we are experiencing are adding to the crisis. NASA's Gravity Recovery and Climate Experiment, GRACE, tracked the movement of freshwater around the globe from 2002 to 2016 (NASA, 2018). The data showed the wet climates are getting wetter and dry climates are losing groundwater creating global hotspots that are expanding.

Safely managed drinking water services are still only available to about 71% of the global population, with the average for rural areas being only 53%, according to UNICEF (2019). Uganda, and other highly rural under-developed countries, ranked as low as 7% coverage. While solutions have been proposed to resolve the inequalities of poor drinking water access in rural, arid climates, one answer may rest in finding ways for individuals to be responsible for their supply.

In coastal regions, water collection is being attempted through fog harvesting, but it is regionally limited. Solar stills for brine and brackish water distillation are certainly an option. These types of stills have been used for hundreds of years, dating back to the 16th century in the Middle East. In 1872, a Swedish engineer, C. Wilson, designed and built the first solar distillation plant in Chile at a saltpeter mine. Using the mine's effluents, fresh drinking water was distilled to supply drinking water to the mining community (Kalogirou, 2009). This type of highly concentrated brine solution distillation indicates that water can be pulled from solutions under the right conditions.

Problem

Can this process be taken one step further and applied to arid climates where water sources are not available? The answer is yes. In areas of groundwater scarcity, there is still atmospheric water vapor that can be accessed. The problem is how to access it. The volume of water in our atmosphere is about 3,100 cubic miles, or enough to cover the ground with approximately 2.5 in. of water if it all rained down at once (Gleick, 1996). That water just needs to be collected.

In 2017, MIT started developing a high surface area material called metal-organic frameworks (MOFs) that can extract potable water from desert air. According to one of the developers, O. Yaghi, the cost of the process has yet to be determined (Chandler, 2017). Similar to this laboratory-created compound, there are other readily producible hygroscopic materials. Desiccants like $CaCl_2$ provide a natural way to absorb water vapor.

Previous student experimentation on this project has concluded that $CaCl_2$ is among one of the most effective non-toxic, food-grade desiccants for use in solar still freshwater production. Prior year's experimentation also showed that by increasing surface area of a specific volume of $CaCl_2$ solution increased the amount of water vapor absorbed, resulting in higher distillation yields. William and colleagues at the University of Egypt have shown successful results using $CaCl_2$; however, the tests for this study were selected, non-continuous test days, so consistent success was not recorded (William et al., 2015).

While solar distillation of brine or brackish water may help solve the drinking water solutions to people with access to those sources, this is not a viable solution for a large percentage of the global population. In June 2019, the World Health Organization estimated 785 million people lacked fundamental drinking water sources (WHO, 2019). This service is defined as a 30-minute round trip to collect water. When there is no fresh groundwater source available—even one that is contaminated source—there is still a need to find a simple method of supplying drinking water. With over 3,100 cubic miles of freshwater trapped in vapor in our atmosphere (Gleick, 1996), it may be possible to tap into that source. Redesigning a solar distillation container that will provide safe drinking water using a readily available desiccant, such as $CaCl_2$, is a solution that needs to be explored.

Criteria

The design criteria were developed over the last two years of desiccant type and surface area studies and was based off of previous problems and goals. The criteria determined for creating a successful prototype were defined in the following:

- The solution should provide a distillation system that requires minimal daily maintenance.
- Water collection should be a simple 2-step method of water collection: 1) absorption of water vapor by the calcium chloride and, 2) release of the water through solar distillation.
- Distillation system should be able to be operated by one person.
- The still should rely on solar energy, with no requirements for electricity, so that the availability to low-income communities is possible.
- Materials used to build the prototype should resist damage from different weather conditions, including rain, wind, and extreme heat.
- Materials used in construction should be affordable and readily available.
- The $CaCl_2$ desiccant must be contained inside the still but separate from collected, distilled water to avoid contamination.
- The surfaces in contact with distilled water must not be toxic to humans or cause distilled water to be contaminated.
- The design should reach consistent daily collection measurement levels with the understanding that weather is still a constraint.

Constraints

While experimenting with Calcium Chloride absorption and regeneration using solar energy, several constraints had become apparent. While taking in the design criteria stated above, constraints considered in the design and build included:

- Weather change—temperature, humidity, wind—is the most critical constraint as it will directly affect water condensation and collection.
- The collected distilled water must pass drinking water testing, including pH, alkalinity, and hardness.
- Accessibility and affordability of materials needed needs to be considered as the prototype has the potential to be needed globally.
- $CaCl_2$ is corrosive to metals, so while it will be housed inside the solar still, it requires safe container considerations.

MATERIALS AND METHODS

Desiccant Selection

Distillation is a simple process that can be used to purify water. It uses a heat source to evaporate water and separate that water from dissolved matter. In solar distillation, the energy used is heat from the sun. The engineering of a solar distillation unit that utilizes a powerful desiccant, however, requires a firm understanding of not only $CaCl_2$ but the materials that will house the chemical.

Calcium Chloride is hygroscopic and able to attract and hold water molecules from the surrounding environment. $CaCl_2$ is a deliquescent substance, meaning when it is exposed to air, it rapidly absorbs the surrounding water vapor and tends to become a liquid. It can absorb several times its weight in ideal conditions and will eventually dissolve its crystal lattice in water. For example, at 85 °F and 22% relative humidity—a mild, arid summer climate—solid $CaCl_2$ will absorb enough water vapor to liquefy. During a period of 70% humidity and 77 °F temperatures, 1 lb of $CaCl_2$ can absorb 2.5 lb of water vapor. These numbers are based on studies completed by multiple chemical companies that manufacture $CaCl_2$ (Occidental Chemical).

Surface tension was an important factor in choosing this desiccant. Surface tension acts as a barrier or wall on a liquid's surface. When Calcium Chloride has absorbed enough water vapor to liquify, its surface tension decreases as temperature increases. Water molecule movement in and out of the solution is related to viscosity. Once solid $CaCl_2$ liquifies with water, it is a solution, and that solution has a thickness and strength to hold itself together (viscosity) on a molecular level (Occidental Chemical).

However, as temperatures increase, $CaCl_2$ solution viscosity decreases and allows more molecular movement. So, as the molecules in the solution become agitated from a temperature increase, it should be easier to pull water from the solution. Regeneration of the desiccant can be done in temperatures as low as 116.6 °F (Bouzenada et al., 2013). Its non-toxic and food-safe properties make $CaCl_2$ a useful component. Caution, however, must be noted with $CaCl_2$ as it is highly corrosive to metals.

Still Design

There have been decades of study regarding solar distillation designs. The most common still design is a single basin with a sloping glass condensation panel, as illustrated in Figure 1. The single basin is coated in dark material for absorption of heat and holds brine or brackish water at the same time. The single condensation panel, however, prevents full exposure of the sun unless the still is moved repeatedly to follow the sun as it travels across the sky.

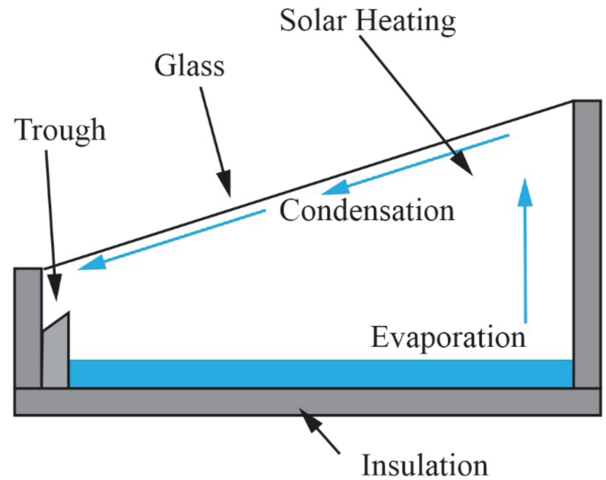

Figure 1. Diagram of a single basin solar still with sloping glass condensation panel.

Double basin, spherical, hemispherical, tubular, pyramid, and concentrator coupled single basin solar stills have been studied by engineers for productivity. In a 2012 article published in the International Scholarly Research Notices (Arunkumar et al., 2012), engineers concluded that concentrators coupled with stills offering higher condensation areas were more productive. The angle of the condensation panels is also an important consideration of the design. An Egyptian study of condensation panel angles—tested from 30° to 50°—published at the 2016 7th International Renewable Energy Congress showed promising increases of up to 40% in distillate accumulation at lower panel angles (Kabeel et al., 2016). The experimental study was completed in Tanta City, Egypt, a similar latitude as this project's testing location.

It was determined that the design of the distillation system would utilize a combination of successful still features—materials, shape, angles—that would provide the best measurable water collection. Successful still elements included large condensation surface areas, materials that withstood the elements, and shapes that increased solar heating. As a result, in order to increase the condensation surfaces, a square-based pyramid was built for the still top, with the four pyramid side panels of the top of the still angled within the successful 30° to 50° panel angles of other researched studies.

Condensation panel materials in solar stills have long been a topic of debate. While everything from plastic bags to hard plastics to glass has been used, the need for a material that is nearly impervious to weather conditions is essential. Polycarbonate, often called Lexan, has about 200x the impact resistance of glass and is 30x stronger than acrylic. Acrylic is 17x more impact resistant than glass. Both plastics are 50% lighter than glass. Polycarbonate offers greater insulation capabilities than glass and still allows 89% light transmission. Acrylic, on the other hand, offers 92% light transmission (Hydrosight GmbH). Both polycarbonate and acrylic are more chip-resistant than glass, but polycarbonate is nearly indestructible and is

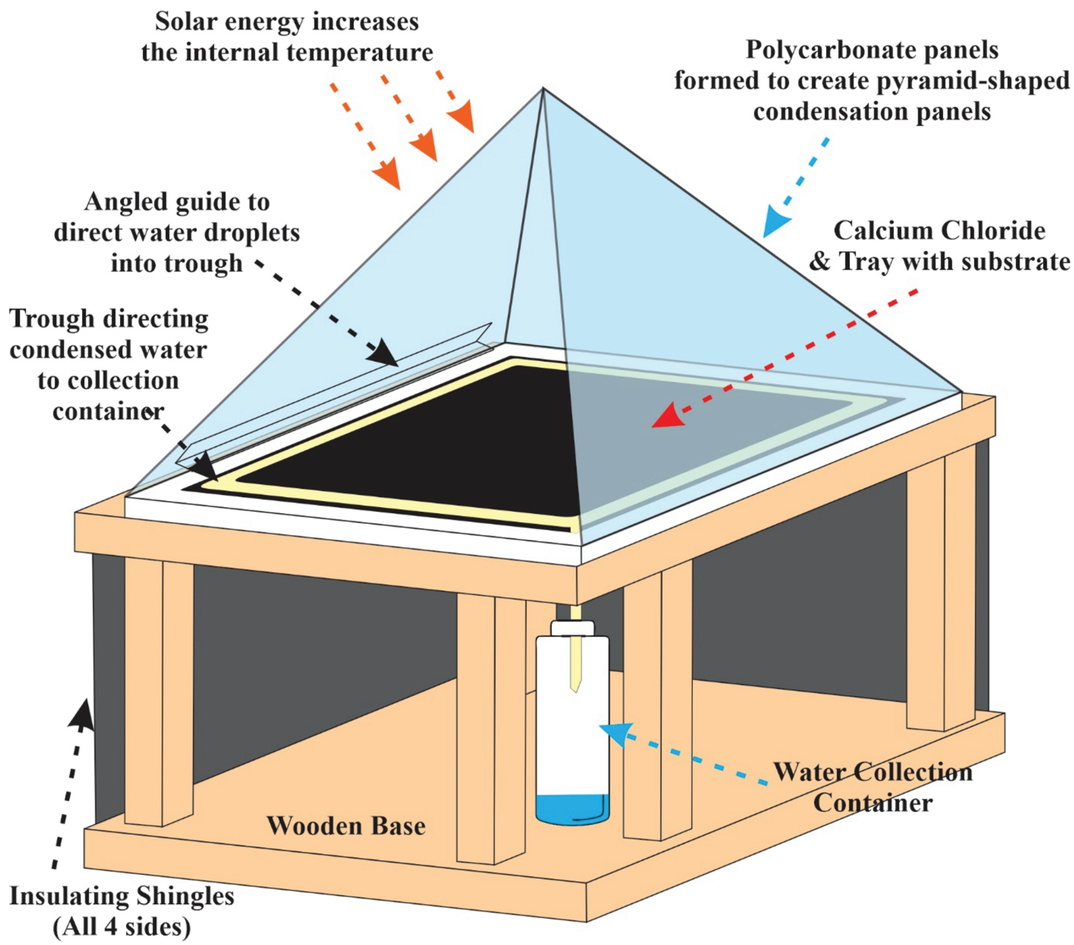

Figure 2. Diagram of Prototype 1 using a flat basin and angled troughs for water collection from the polycarbonate condensation panels.

used in thick panels as bulletproof protection. The strength of polycarbonate comes with a price or 2-3 times that of acrylic. The deciding advantage that polycarbonate has over acrylic is polycarbonate's continuous working temperature is 240 °F, which is much better that acrylic's 130 ºF (A & C Plastics Inc.).

Attempts were made to minimize the need to use metal materials in this solar distillation system for two reasons: $CaCl_2$ corrosion and galvanic corrosion. Corrosion in traditional solar stills is a common issue due to the high sodium content of brackish and saltwater. $CaCl_2$ is an inorganic salt compound, and also highly corrosive to metals. Galvanic corrosion is the result of an electrochemical reaction that can occur when one anode and one cathode metals are used in conjunction with an electrolyte such as water. As the electrolyte passes from one metal to another, the anode can lose electrons to the cathode, causing the anode metal to disintegrate or corrode (Avenston LLC). That corrosion can create acidic water, rendering a still's collection non-drinkable.

Figure 2 represents the initial prototype design. The footprint of the still measured about 35 sq. inches. The base of the solar still was designed using plastics to eliminate corrosive issues while it housed the $CaCl_2$. The trough system was a traditional water collection plan, except it was also limited to plastics. To record internal temperatures without opening the condensation top, a digital temperature probe was permanently hung midway between the peak of the pyramid top and the $CaCl_2$. Appendix A provides photos of the build.

Once the prototype was built, it was placed into daily operation. Anhydrous $CaCl_2$ was loaded into the basin and given five days of exposure to the air to bring it to a solution using only water vapor. A single testing period began at 8:00 p.m. each day with a 12-hour evening exposure phase followed by a 12-hour daily distillation phase. The flat base sides of the condensation panels were oriented to the cardinal directions so that direct exposure would begin as the sun rose. Every attempt was made to maintain continuous testing.

Daily procedures for a single test period involved the following steps:

1. 8:00 p.m. – Open the condensation top to allow for atmospheric exposure of the $CaCl_2$.
2. 8:00 a.m. – Replace the condensation top and check seal with base.
3. 12:00 p.m. – Check and record internal temperature with digital probe.
4. 3:30 p.m. – Check and record internal temperature with digital probe.
5. 7:30 p.m. – Measure distilled water in collection bottle prior to opening still for $CaCl_2$ exposure.
6. Record all measurements: water collected, daily external temperature highs, evening humidity average, and weather breakdown of cloudy, partly cloudy, or sunny as well as any observations regarding operation, design problems, ideas.

The success of the prototype was based on long-term testing periods. Once the still was operating uninterrupted for a period of five days, samples were used for water testing. While the system performed well initially, failures with the trough materials occurred once internal temperatures reached 170 °F. With the failure of the initial prototype, it was determined that material choices in the design needed to be revisited.

Prototype 2, shown in Figure 3, was built with several new changes incorporated into the distillation unit. With the failure of the trough in the original prototype, it was determined that a more streamline pyramid still should be built to eliminate the trough. To execute a trough-less still, there had to be a single, uninterrupted flow direction from the condensation panels into the collection bottle. The most apparent design was a diamond or octahedron shape using the original square pyramid shape top and an inverted pyramid-shaped top.

Food grade stainless steel was selected as the still's base material instead of galvanized steel that is used in construction. Galvanizing is the process of hot-dipping a metal in zinc to prevent corrosion. Industrial uses are varied, and while galvanized pipes are still considered safe to transport water, there is some concern with low pH waters because they are corrosive due to their acidity (APEC Water Systems). Distilled water from solar stills can test at pH levels on the lower spectrum at 5.5 to 6.0 pH. The combination of the still's internal heat and the water's acidity can potentially release higher than allowable zinc levels into the collection water, making galvanized steel an inferior choice to stainless steel.

The condensation panel configuration changed in three ways. The panel angles were created to match the latitude of the location, approximately 32°. This angle also took full advantage of the most solar exposure to the panels during the summer months. This angle matched the latitude of the testing location and meant the panels would receive equal solar exposure when the sun was at its highest daily location during that season. The lateral edges of the panels were reinforced with metal brackets prior to sealing the edges with silicone. Finally, an aluminum right angle edge was added to the inside base edges after being coated in a non-toxic silicone sealant. This edge provided a directional flow of the water away from the base edge and onto the inverted stainless-steel base as well as providing a lip to seal in the

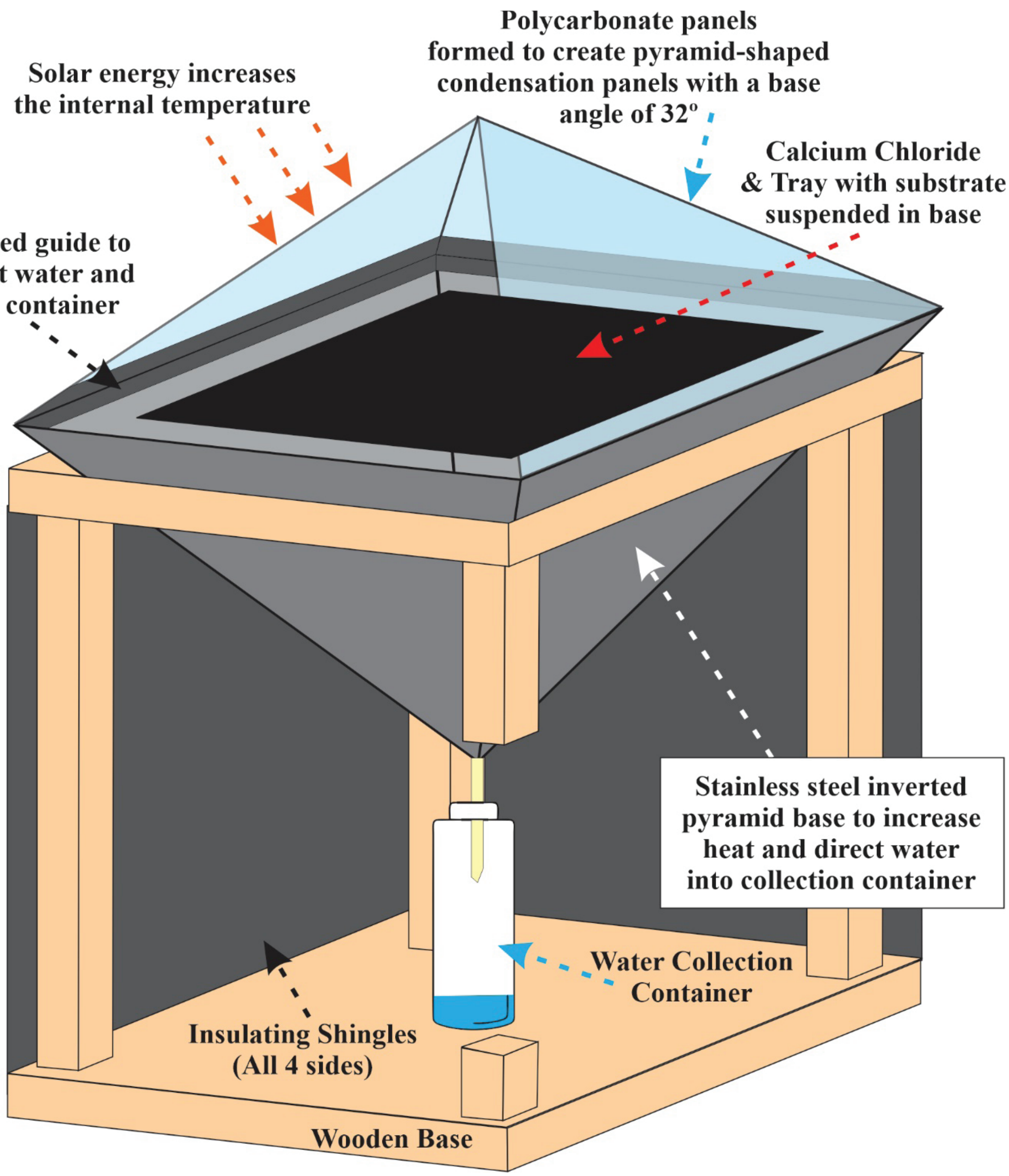

Figure 3. Diagram of Prototype 2 using polycarbonate panels for the condensation top and a stainless steel inverted base to eliminate troughs for collection and provide solar concentration for increased internal heat.

internal air during the condensation period. A thin line of waterproof/weatherproof stripping was added along the edge of the still base to prevent the two metals from contact and help maintain a closed environment in the still.

With the introduction of two metals into the design—the aluminum edge on the condensation panel and a stainless-steel base—the Calcium Chloride containment had to be redesigned. The solution was to create a suspended tray that allowed the distilled water to flow freely to the bottom of the still for collection. After several trial trays, the final 22" square tray was built from hard plastic and polycarbonate to prevent issues with $CaCl_2$ or galvanic corrosion. Additionally, the $CaCl_2$ was moved to a set of smaller food-grade containers with a similar total surface area to facilitate moving the desiccant should the still require repairs.

With the addition of asphalt panels to the base structure and R32 insulation between the still base and asphalt panels, the water collection area was protected from the elements, and the internal heat was better maintained in cooler weather. Black felt substrate in the $CaCl_2$ trays also held in heat. Appendix B provides photos of the build.

RESULTS

Prototype 2 was in operation for 79 days of testing with the closed distillation process occurring from 8:00 am to 8:00 pm. The data from the testing days was divided into three categories: SUNNY being clear skies with no clouds, PARTLY CLOUDY being clouds either half of a given day or sporadically throughout the day, and CLOUDY being total cloud cover during distillation. This division allowed for detailed understanding of the effects of internal and external temperatures, humidity, and solar radiation exposure during distillation periods. Appendix C is a full list of the raw data collected. Prototype 1 data was not included in the results or discussion.

It should be noted that when temperatures dropped below 65 ˚F at night during the water absorption period, the $CaCl_2$ began to crystalize. This required the $CaCl_2$ trays to be brought inside away from the low temperatures in order to remain in solution form and continue absorbing water molecules.

Water collection measurements consistently peaked during days with the most solar exposure except for two consecutive days—test days 10 and 11—of zero water collected. These two days immediate followed repairs. During these two days it was discovered that a series of small openings in the prototype's seals allowed temperature equalization and prevented condensation. These two days were eliminated in order not to skew averaging data, and this brought the number of test days used in the summary results down to 77 : 44 SUNNY, 21 PARTLY CLOUDY, and 12 CLOUDY test periods.

The total amount of water collected during the entire test phase was 3913 mL on SUNNY days, 534 mL on PARTLY CLOUDY days, and 378 mL on CLOUDY days. On SUNNY days this averaged to 88.9 mL—over 3 times the average of 25.4 mL collected on PARTLY CLOUDY days and 2.5 times the averaged 31.5 mL on CLOUDY days.

External daily high temperatures of 70 °F and warmer accounted for the greatest amounts

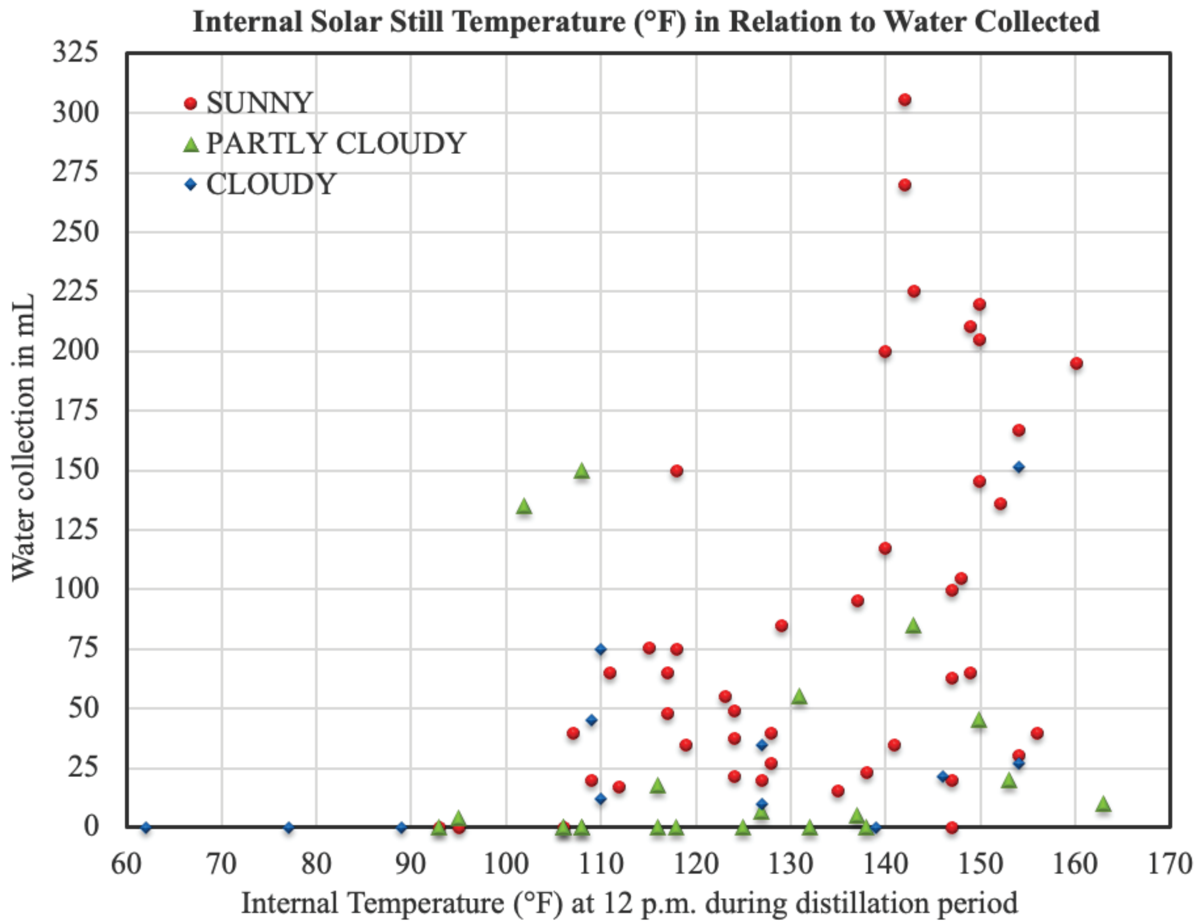

Figure 4. A comparison of daily internal still temperatures taken at noon in relation to the total water collected for that day. The graph further details the results by categorizing solar exposure.

of water collected with averages increasing to 105.5 mL during SUNNY days, 40.5 mL during PARTLY CLOUDY days, and 45.8 mL during CLOUDY days.

Internal temperatures of the solar still ranging 140 °F to 150 °F were the most productive SUNNY water collection days with an average daily amount of 142.9 mL. A comparison of PARTLY CLOUDY and CLOUDY days cannot be made as the data is not as consistent.

In addition to testing the distillation design, a 16-part drinking water test was performed on the distilled water collected in Prototype 2. The testing strips used were FDA-approved ON4HOME water test strips that included hardness, pH, Fluoride, Chlorine, Nitrate, Nitrite, and total alkalinity, as well as low range heavy metals. This test was also performed on bottled distilled water, tap water, and Aquafina bottled drinking water for comparison. The noticeable difference among the tests was the alkalinity of the tap water in comparison to the distilled, Aquafina, and Prototype 2 water which registered within normal ranges.

A second, more detailed, pH test was conducted using Med Lab Diagnostics test strips. The results showed the tap water tested at about 7.5 pH while the other samples, including the Prototype 2 distilled water, ranged from 5.5–6.0 pH. These tests were performed on multiple samples over the course of the experimental phase.

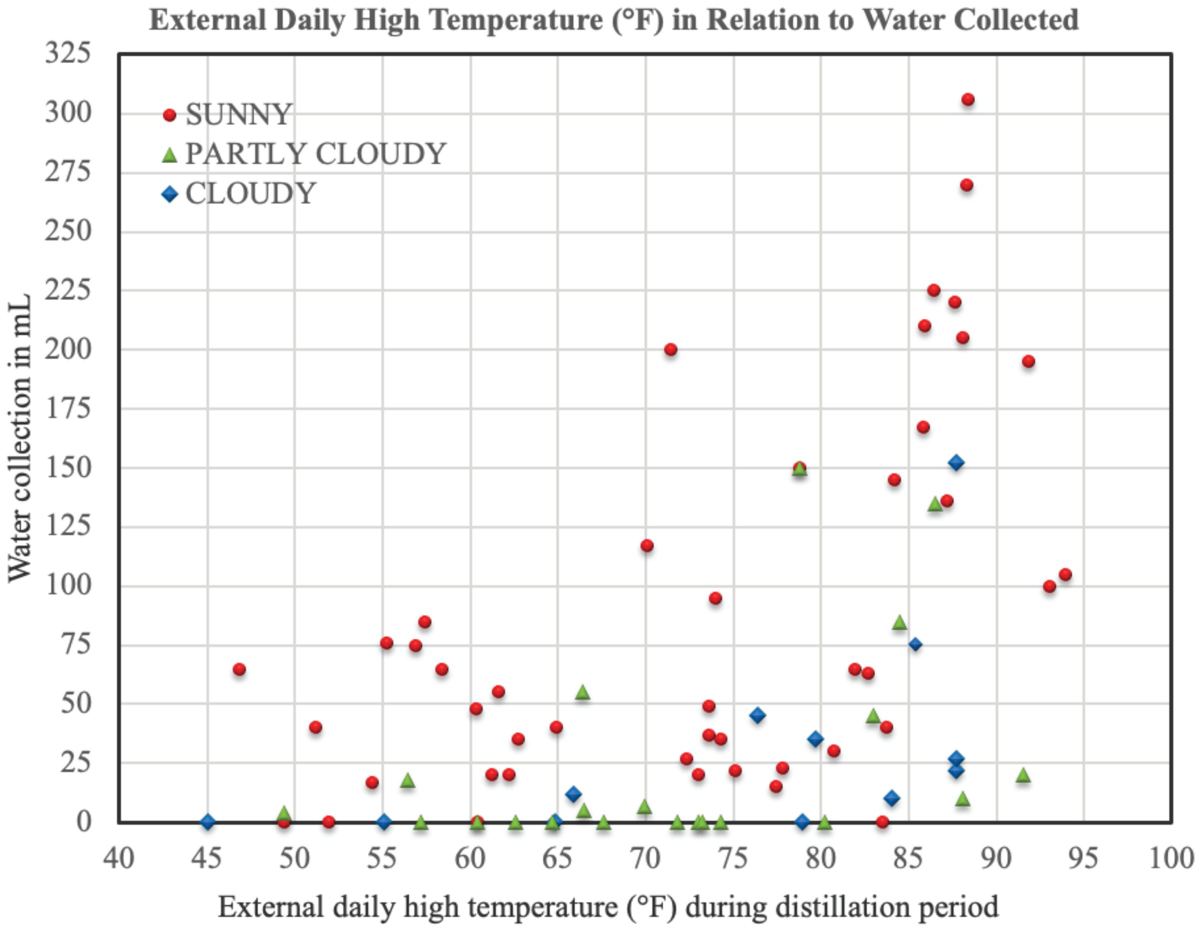

Figure 5. A comparison of daily external temperature highs in relation to the total water collected for that day. The graph further details the results by categorizing solar exposure.

Chloride is an essential electrolyte for the human body but it can also cause corrosion. Due to prototype galvanic corrosion problems that had to be solved, it was decided that a separate test would be conducted to verify that the solar distilled water collected was not picking up chloride ions. WaterWorks™ chloride test strips were used and provided a range from 0–500 ppm. Results consistently showed the samples were below the EPA secondary drinking water standard of 250 ppm.

CONCLUSIONS

The advantages of the final prototype still design were quickly apparent. The stainless steel base helped regulate the still's internal temperature because it held heat better than the plastic base and the exposed sections visible through the condensation panels doubled as a concentrator of the solar energy, directing it toward the $CaCl_2$ trays. This increase of solar energy, or heat, helped with the regeneration of the desiccant and increasing condensation. While the prototype $CaCl_2$ solar still was unable to produce the desired two liters of distilled water, there was a lot of data gathered for future designs and testing.

During testing periods with full solar exposure, sunny days, the external daily highs could range from 70°–90 °F without dropping the internal temperature below 140 °F. At 46.8 °F and full solar exposure, the still maintained an internal temperature of 111 °F and produced 65 mL. This was not expected, but it does indicate that the still can possibly operate in a variety of regions.

Cloud coverage of any kind interfered with the distillation process, although if the cloudy cover burned off in the morning hours, production was only slightly decreased. Heavy periods of high humidity also increased the amount of water vapor absorbed and provided unusually high collection measurements the next day. This does not mean to suggest the $CaCl_2$ was compromised with rainwater. During rainy periods, a waterproof tarp was secured well over 12in from the desiccant surface to allow for water vapor absorption but not rainwater.

Since the experimental phase of this prototype was long enough to see seasonal changes and a drop in the sun's position, it was noticed that the condensation on the panel directly exposed to the sun at noon decreased as the sun's position moved lower in the sky. Whether this decreased condensation on the direct sun-facing panel can be corrected by adjusting the position of the still has yet to be tested.

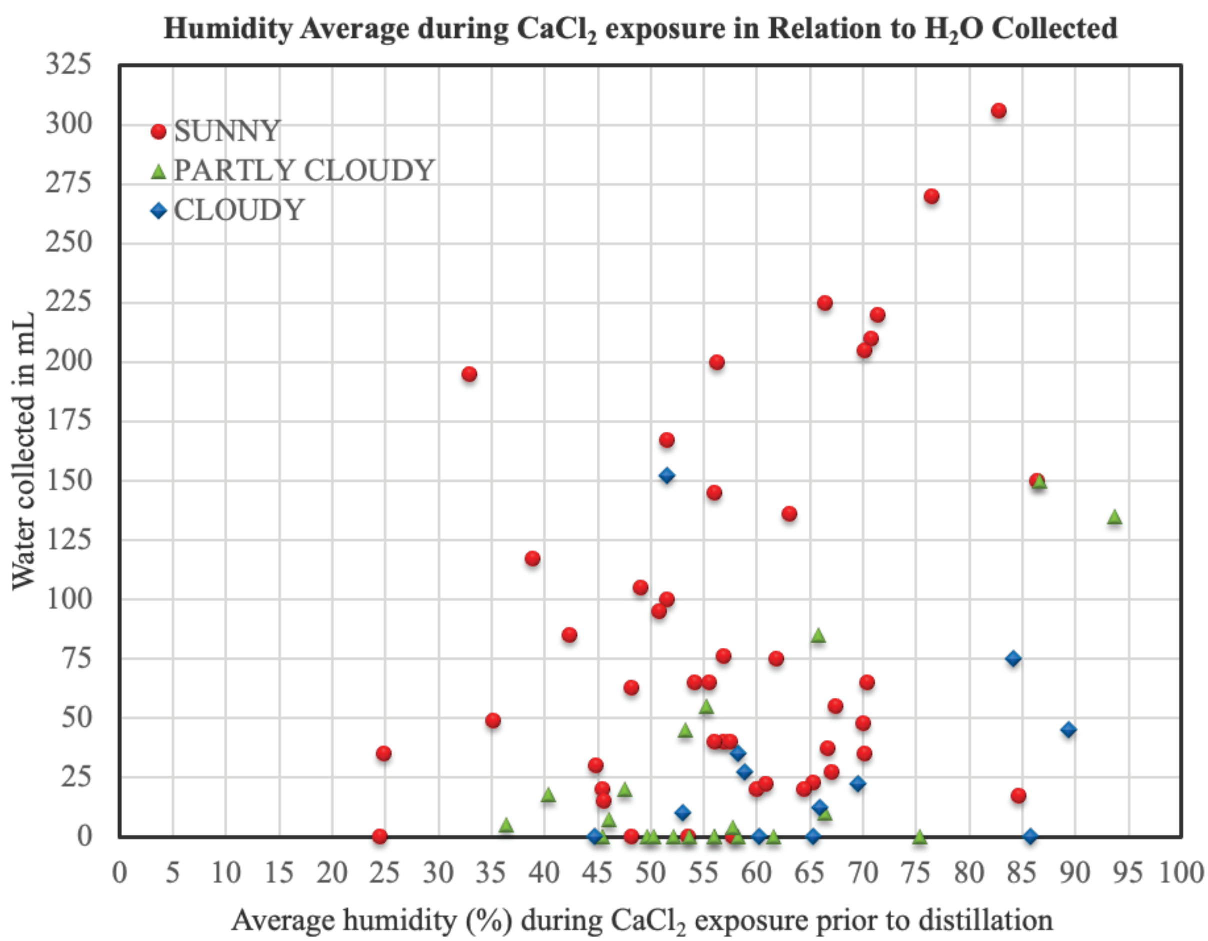

Figure 6. A comparison of average humidity readings during the night of CaCl2 air exposure prior to the condensation period (8 am to 8 pm) in relation to the total water collected for that day. The graph further details the results by categorizing solar exposure.

It also needs to be noted that as the $CaCl_2$ began to crystallize once temperatures during the absorption period dropped below about 60 °F yet was able to deliquesce to a solution within the first hour of solar exposure. The distillation process, however, was not as effective during the colder periods. Moving the desiccant to a warmer location—and allowing it to absorb water vapor—eliminated some of the problems but options need to be studied more.

Water Collection Categorized by Solar Radiation Exposure

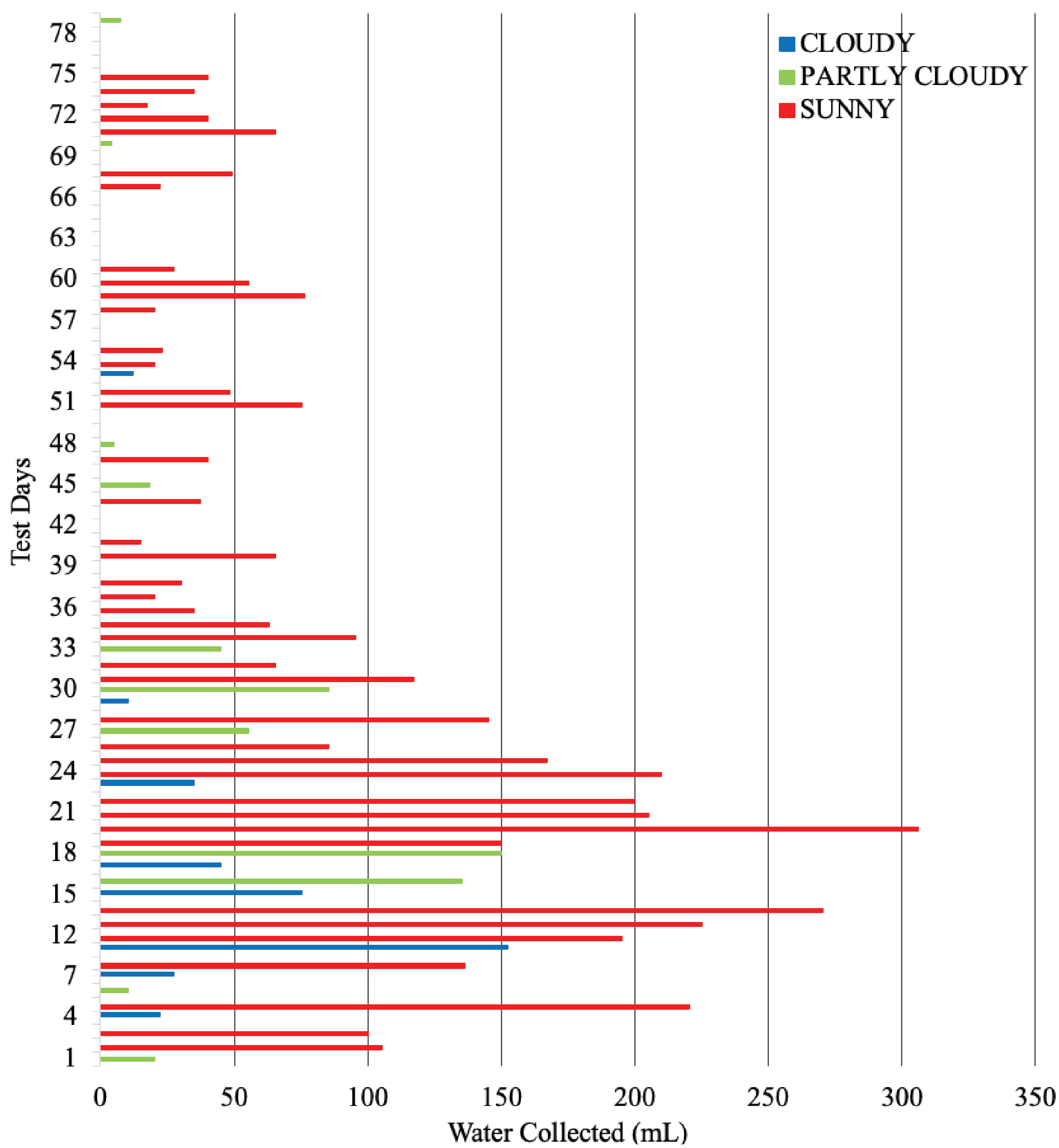

Figure 7. A chart showing daily water collection in relation to the solar exposure to show trending. This chart represents the total daily collection of distilled water as divided into the three solar exposure categories. As the daily temperatures cool, the amount of water collected decreases. It should be noted, however, that as the daily high temperatures began to drop and remain in the 50 °F to 65 °F range, the solar still remained active with full solar exposure during the distillation period. The water measurements values are also available in Appendix C.

Further Work

The ability of the condensation panels to allow solar heat energy to pass through to the inner still system is critical as without the internal heat the $CaCl_2$ will not begin the regeneration process and give up the water molecules. The polycarbonate was selected because of its durability and its insulation capabilities; however, an unexpected property of the material was discovered during the testing phase.

While cleaning the outside of the polycarbonate panels during one of the condensation test periods, it was observed that wiping a hand across the surface of the panel caused the condensed water droplets to gather together, creating larger droplets. This effect could be repeated nearly every time it was attempted. A working hypothesis may be that the polycarbonate was allowing a static charge to be conducted through the panel surface. Dry human skin, when it comes in contact with other solids, has a high tendency to give up electrons and become positive in charge (Kurtus, 2018). Water molecules are polarized molecules that arrange randomly in a liquid state, but the positive charge from the skin caused the molecules to orient the negative oxygen toward the positive charge and begin to clump. The implication of this discovery means that if a positive charge can be regularly maintained over the outer surface, the condensation inside the still will increase as the water molecules pull together. Additionally, slight vibrations on the panels increase the movement of the larger droplets downward in the still for collection, allowing more surface area for coalescing water molecules to condense on the panels. These features merit more study.

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ABBREVIATIONS

$CaCl_2$, Calcium Chloride; F, Fahrenheit; GRACE, Gravity Recovery and Climate Experiment; NASA, National Aeronautics and Space Administration; SDG, Sustainable Development Goal; UN, United Nations; H_2O, Water; WHO, World Health Organization.

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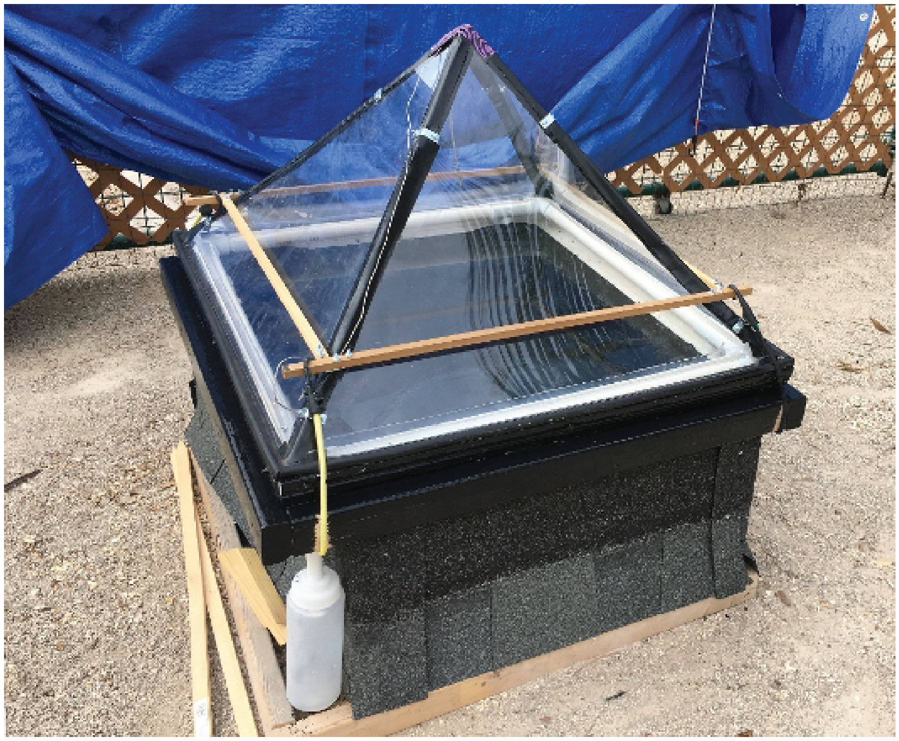
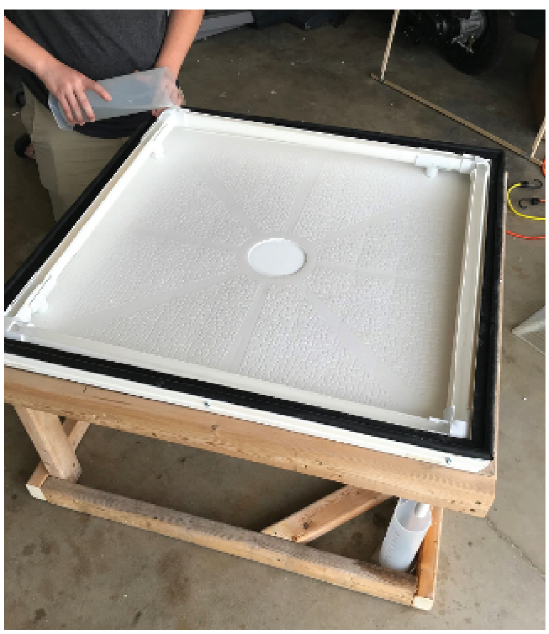
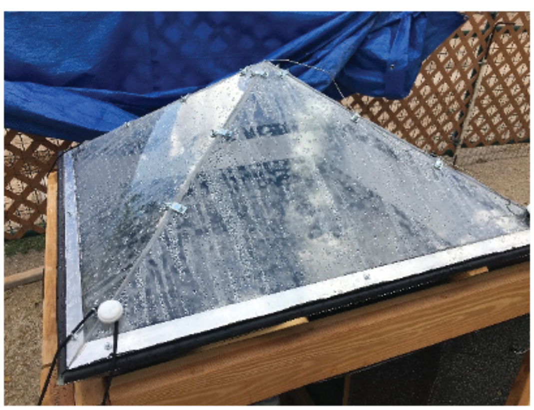
APPENDIX A
IMAGES OF PROTOTYPE #1





TOP: Final version of Prototype #1 in testing phase. BOTTOM LEFT: Testing of the plastic trough system during construction. BOTTOM RIGHT: Condensation on the polycarbonate panels during the daily solar exposure.

APPENDIX B
IMAGES OF PROTOTYPE #2



TOP LEFT: Final version of Prototype #2 in testing phase. TOP RIGHT: Image of prototype prior to addition of insulation and asphalt shingles around base. BOTTOM LEFT: Condensation on the polycarbonate panels during the daily solar exposure. BOTTOM RIGHT: Collection bottle of distilled water prior to measuring volume.

APPENDIX C

Solar Exposure VS. Water Collected (water measurements in mL)

PROTOTYPE #2

Test Day	Sunny	Partly Cloudy	Cloudy	Daily high temp °F	12pm Internal temp °F	Notes
1		20		91.5	153	
2	105			93.9	148	
3	100			93	147	
4			22	87.7	146	
5	220			87.6	150	
6		10		88.1	163	
7			27	87.7	154	
8	136			87.2	152	
9			152	87.7	154	
10	0			91.9	154	*seal leaks
11	0			96.3	159	*seal leaks
12	195			91.8	160	
13	225			86.4	143	
14	270			88.3	142	
15			75	85.4	110	
16		135		86.5	102	
17			45	76.4	109	
18		150		78.8	108	
19	150			78.8	118	
20	306			88.4	142	
21	205			88.1	150	
22	200			71.4	140	
23			35	79.7	127	
24	210			85.9	149	
25	167			85.8	154	
26	85			57.4	129	
27		55		66.4	131	
28	145			84.2	150	
29			10	84	127	
30		85		84.5	143	
31	117			70.1	140	
32	65			81.9	149	
33		45		83	150	
34	95			74	137	
35	63			82.7	147	
36	35			74.3	141	
37	20			73.2	147	
38	30			80.7	154	
39			0	45	62	*Colder during mid-condensation than start
40	65			58.4	117	
41	15			77.4	135	
42	0			83.5	147	* lack of measurement

43		0		60.4	116	
44	37			73.6	124	
45		18		56.4	116	
46		0		73	132	*$CaCl_2$ removed from outside
47	40			83.7	156	evening due to crystallization
48		5		66.5	137	
49			0	64.8	89	
50			0	78.9	139	
51	75			56.9	118	
52	48			60.3	117	
53			12	65.9	110	
54	20			62.2	127	
55	23			77.8	138	
56		0		80.2	118	
57		0		74.3	138	
58	20			61.2	109	
59	76			55.2	115	
60	55			61.6	123	
61	27			72.3	128	
62			0	55.1	77	*$CaCl_2$ started to crystallize
63		0		71.8	125	
64		0		57.2	108	
65		0		64.7	106	
66		0		73.2	108	
67	22			75.1	124	
68	49			73.6	124	
69	0			51.9	93	*NOTE temp/no water/sunny
70		4		49.4	95	*Possible dew measurement
71	65			46.8	111	
72	40			51.2	107	
73	17			54.4	112	
74	35			62.7	119	
75	40			64.9	128	
76		0		62.6	106	
77	0			60.4	106	
78		0		67.6	93	
79		7		69.9	125	