Development of an Evaporative Cooler Pad In Order to Enhance Sustainability and Consumer Appeal of Existing Cooler Units

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Abstract

In Los Angeles, air conditioning is the dominant mode of household cooling with only a small portion of homes utilizing evaporative cooling systems. The following report will investigate a more sustainable alternative to air conditioning: swamp coolers. As the production of swamp cooler cellulose pads releases greenhouse gases, the primary focus will be on developing an alternative to the commercial cellulose pad using bamboo-based materials. The pad is made of bamboo-derived material because bamboo is more sustainable than the original pads' cellulose fibers. This bamboo pad will be developed with the goal in mind of increasing popularity and usage of evaporative coolers in LA homes.

1.0 Introduction

Residential energy usage accounts for 21% of the total U.S. energy consumption, leading to greenhouse gas emissions that affect the environment (Residential Program Solution Center, 2020). Greenhouse gases contribute to global climate change, which will increasingly impact the way we live in years to come. In current U.S. residential buildings, heating and cooling account for 53% of energy usage (Leung, 2018), or 11% of all residential energy use in America. This is an even more pressing problem in Los Angeles specifically, where homeowners turn to air conditioning in the summer time to keep cool, despite the large amount of energy it requires. About 60% of Los Angeles homes rely on air conditioning as their primary cooling system (EIA, 2009), which increases the consumption of energy and associated greenhouse gases emitted into the atmosphere. An alternative to air conditioning could appeal to suburban homeowners in Los Angeles if that cooling could also lower energy consumption, electricity bills, and greenhouse gas emissions.

1.1 Background

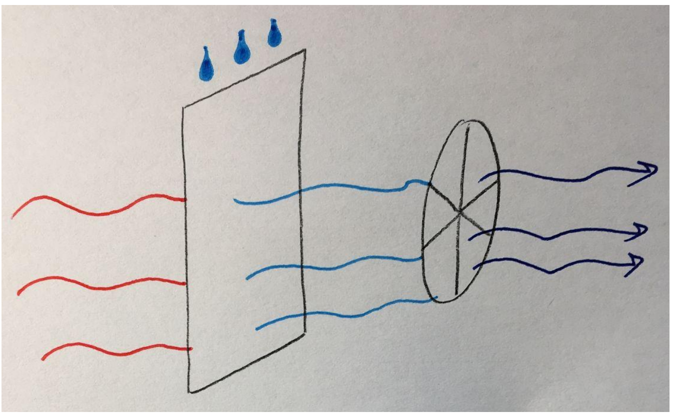
1.1.1 Choice of Evaporative Cooler as Area of Investigation

Some alternatives to air conditioning that could be implemented in current homes are earth tubes, heat pumps, swamp coolers, and ceiling fans. The pros and cons of each of these cooling alternatives are summarized in Figure 1 (see Appendix 7.1). Swamp coolers are the best option of research to pursue for the group because they decrease energy usage compared to traditional air conditioning. They are also low cost to install compared to earth tubes and heat pumps, which makes them the most realistic option after navigating a few of the cons. One significant barrier to widespread swamp cooler adoption is the perception that pads give off a moldy smell. This project will explore ways to address the issue of these manufactured pads.

1.1.2 How Evaporative Coolers Works

Swamp coolers work by removing heat from incoming air using the evaporation of water. Hot outside air flows through the damp pad in the swamp cooler, and, as the water on the pad turns from liquid to gas through evaporation, energy is lost, and this energy loss cools the air going through the pad. As shown in Figure 2, the fan at the end of the swamp cooler sucks the cool air through the pad and blows it into the house. Since evaporation is essential to cooling in swamp coolers, water is pumped from the water tank to the sprinklers above the pad to keep the pad damp.

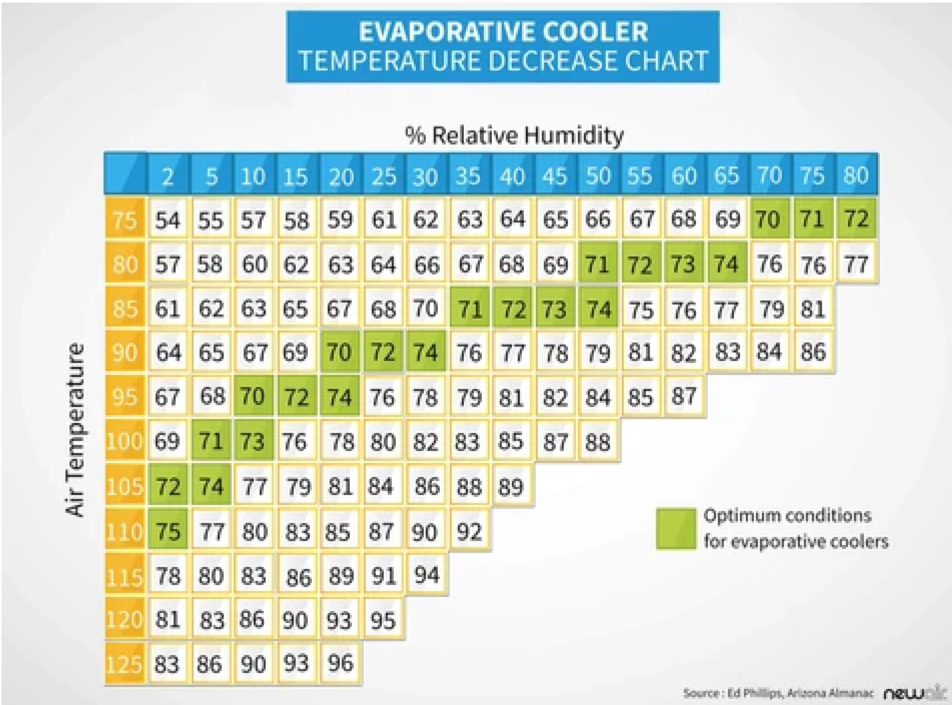
Figure 2: Swamp Cooler Diagram



1.1.3 Effectiveness of Evaporative Coolers in Los Angeles

Since swamp coolers add humidity to dry incoming air, they work best in warm and dry climates, like Los Angeles. On average, swamp coolers can cool incoming air by 10°F, which could help reduce air conditioning use during hot summer days in Los Angeles (U.S. Department of Energy, n.d.). However, swamp coolers typically do not function in a comfortable state when running in an environment that is both hot and humid, such as a temperature above 95ºF and a humidity above 70 percent, meaning that they do not cool the air at a high rate or give a 10ºF temperature difference. According to Figure 3, as the outside air temperature increases, the relative humidity in the air would need to decrease in order for the swamp cooler to still provide significantly cooler air inside the house.

Figure 3: Swamp Cooler Temperature Decrease Chart



Air Temperature	2	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
75	54	55	57	58	59	61	62	63	64	65	66	67	68	69	70	71	72
80	57	58	60	62	63	64	66	67	68	69	71	72	73	74	76	76	77
85	61	62	63	65	67	68	70	71	72	73	74	75	76	77	79	81	
90	64	65	67	69	70	72	74	76	77	78	79	81	82	83	84	86	
95	67	68	70	72	74	76	78	79	81	82	84	85	87				
100	69	71	73	76	78	80	82	83	85	87	88						
105	72	74	77	79	81	84	86	88	89								
110	75	77	80	83	85	87	90	92									
115	78	80	83	86	89	91	94										
120	81	83	86	90	93	95											
125	83	86	90	93	96												

Considering that the average humidity in Los Angeles from June to September is about 57 percent, the chart suggests that a swamp cooler would work under optimum conditions when the outside temperature is between 80°F and 85°F. The swamp cooler would provide between a 7°F to 10°F temperature difference under these weather conditions. Using swamp coolers when the temperature is under 95ºF will lower electricity bills while also helping the environment.

One of the most common manufactured evaporative cooling pads for swamp coolers is a cellulose pad. Cellulose pads are made from wood fibers that are mixed with chemicals and water to form a mixture (Ulin, 2010). This mixture is then turned into a pulp and pressed to make the paper that the cellulose pad is made of. Turning this mixture into a pulp releases greenhouse gases, specifically sulfur dioxide (*Papermaking - Processes for Preparing Pulp*, n.d.). In order to create a sustainable cooling pad, the group looked into the benefits of bamboo. Bamboo derived materials are sustainable, as bamboo grows quickly and does not require any fertilizers. In addition, the viscose industry, which makes rayon fabric from cellulose fiber, has improved their chemical management and waste treatment (Hymann, 2020). The group chose to experiment and prototype pad designs using various bamboo materials, such as bamboo rayon fabric, bamboo rayon towels, and bamboo veneer.

1.2 Literature Review

An experiment conducted by Warke and Deshmukh in India observed how the thickness and type of evaporative cooling pad affects the amount of evaporated water and the cooling efficiency of the swamp cooler (Deshmukh & Warke, 2017). The efficiency of the pad system is defined in this study as the difference between the inlet air temperature and the outgoing temperature after evaporative cooling takes place. The experiment includes three types of cooling pads: cellulose, aspen, and khus. A cellulose pad is made from cellulosic papers while an aspen pad is made from aspen wood fibers. A khus pad is made from a native Indian grass. The study found that the efficiency of evaporative cooling pad systems is impacted by the surface area, the thickness of the pad, the type of pad material used, the flow rate of water onto the pad, and the relative humidity of the incoming air that passes through the pad. The study concludes that the efficiency of the pad system increases as the thickness of the pad increases in the case of a cellulose and aspen pad. However, the efficiency of a khus pad decreases as the pad thickness increases because its high density prevents sufficient evaporation. Since bamboo is more similar to aspen wood than khus grass, the group should create a thicker bamboo pad design in order to maximize surface area. This will allow for more evaporation to occur in a smaller period of time, thus increasing the efficiency of the bamboo pad.

An experiment conducted by Welch compared an aspen pad from a blue synthetic foam pad. He found that using two aspen pads instead of one blue synthetic foam pad increased cooling efficiency by creating a greater temperature difference between the outside air and the incoming air (Welch, 2014). The aspen pad and blue foam pad are two popular pad options for swamp coolers. Welch noticed that his swamp cooler with the blue foam pad was blowing hot air into the house, so he decided to replace them with two aspen pads. When testing the outside versus inside temperature difference, Welch's results show that the aspen pads achieved a thirty-three degree temperature difference, cooling the air from 95ºF to 62ºF. The blue foam pad only achieved an eleven degree temperature difference, cooling the air to 84ºF. These results support Warke and Deshmukh's study about greater thickness leading to greater efficiency, as the increase in thickness results in a greater surface area. It will be beneficial to compare the group's prototype bamboo pads in different thicknesses to ensure that the conclusions of these two studies apply to bamboo rayon and that, as a result, the most efficient pad is made.

2.0 Methods

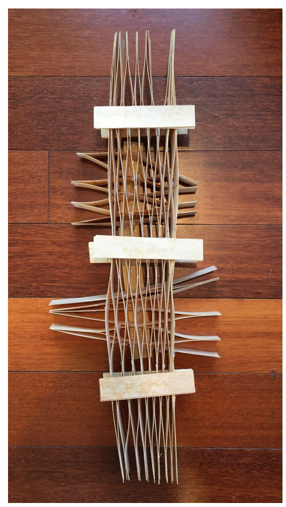
In order to make swamp coolers appealing for suburban homeowners in Los Angeles, the group is making a more sustainable, bamboo evaporative cooler pad than the manufactured cellulose pad. The bamboo prototypes will be tested and compared to cellulose pads for evaluation of effectiveness.

2.1 Pad Design

Surface area, pad thickness, and water flow are the primary parameters that affect cooling potential. Several pads were developed, with each design focusing on a single parameter.

However, throughout the design process, pad designs could not be made as thick as we initially intended due to the lengthy manufacturing and building process of the prototype designs.

Figure 5: Prototype Designs

Design #	Pattern/Material	Key Parameter	
#1	Diamond Bamboo Veneer	Water Flow	
#2	Bamboo Veneer + Bamboo Rayon Fabric	Surface Area	
#3	Honeycomb Bamboo Veneer	Thickness	

As seen in Figure 5, each prototype pad was designed based on one of the three key parameters. The holes in the diamond veneer pad allow water to flow down to the bottom of the pad quickly, evenly distributing water along the pad. The veneer+fabric pad has very few, small air slits, maximizing surface area. The honeycomb pad has two layers, as opposed to one, in order to add more thickness to the pad, which allows for more evaporation to occur.

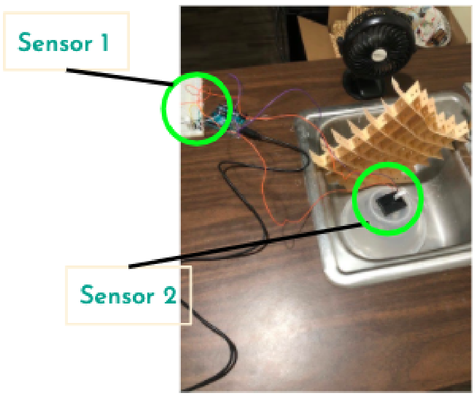
2.2 Testing Process

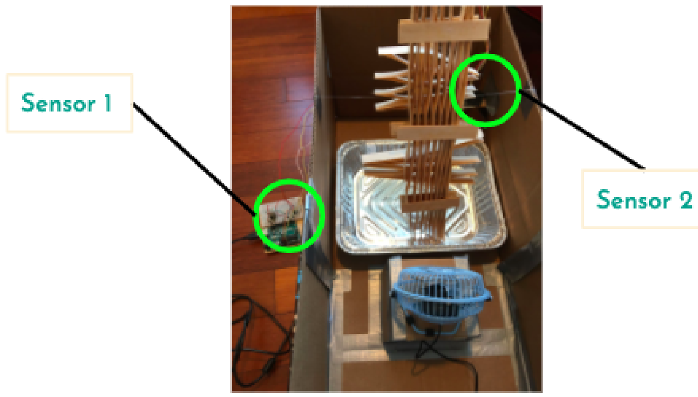
An Arduino was used to collect temperature and humidity data. Water was poured on the prototype pad being tested until the entire pad was damp. Then, the fan was turned on and the serial monitor on the arduino application started showing data. The test was complete once the prototype pad was completely dry. This is why the timing for each test varied. Once the test was over, the arduino and fan were turned off.

2.2.1 Tier 1 Testing Process

Two test beds that mimic swamp coolers were developed to quickly test prototype designs for their relative quality. Each test bed includes a small fan that is placed on the frontend of the pad being tested, two temperature and humidity sensors, a space to place the pad that is being tested, and a space to catch the water that is poured onto the pad. In both testbeds, the space where the pad is placed and the space that catches water are one in the same. To test the prototypes, water was poured over the pad, then the fan was switched on, and the sensors immediately began collecting data. Tests lasted between 10 and 80 minutes. Data was collected until the outgoing temperature stabilized; this was also when the pad dried to a dampness. Sensor 1 (indicated in Figure 4) is placed outside of the testbed area, collecting data for the temperature and humidity of the room in which the testbed is. Sensor 2 (also indicated in Figure 4) is placed within the testbed on the side of the pad opposite the fan. This sensor collects data for the temperature and humidity post-evaporation. The data collected through Sensors 1 and 2 are presented in section 3.0 Results.

Figure 4: Tier 1 Testbeds





2.2.2 Tier 2 Testing Process

Tier 2 testing is intended to simulate a typical Los Angeles summer day outdoors. three parameters had to be met to achieve this goal: 1) control humidity and temperature simultaneously 2) enough air volume to provide the swamp cooler with consistent input air 3) a collection reservoir to allow measurement of the cooled air. The final testbed design choice was a two-box system consisting of an input, being simulated LA environment, and an output, with the swamp cooler in between. The input box air was created by utilizing a heat lamp and placing aluminum foil along the floor of the box, and cutting a hole to fit an insulator tube connected to a humidifier into the box as well. A fan was placed inside the input air box to push the air through a cardboard tube connected to the output box. The swamp cooler then takes the temperature/humidity controlled air and blows it out into the same output box. Both containers have DHT22 temperature/humidity sensors.

2.3 Validation

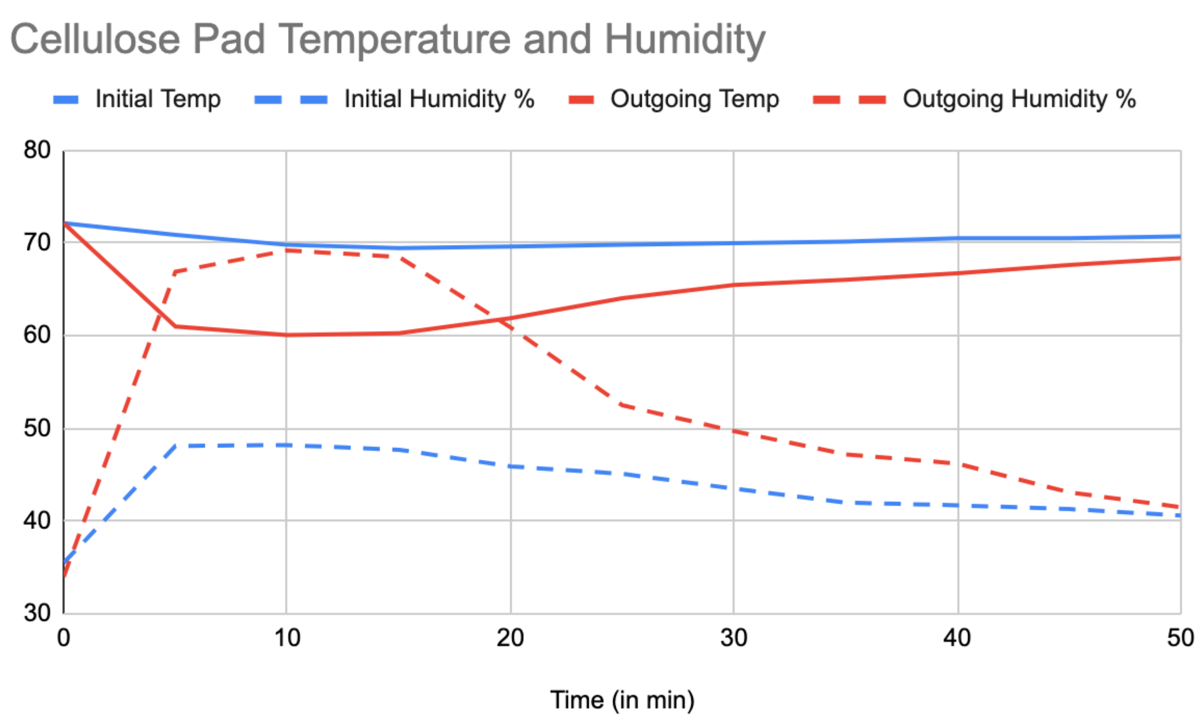
To know if the project is successful, proof that the bamboo prototypes can perform evaporative cooling is needed. This means that in the results, the outgoing humidity should be greater than the initial humidity, as this shows evaporation occurring. In addition, the outgoing temperature should be less than the initial temperature to show that cooling is occurring as a result of evaporation.

3.0 Results

3.1 Tier 1

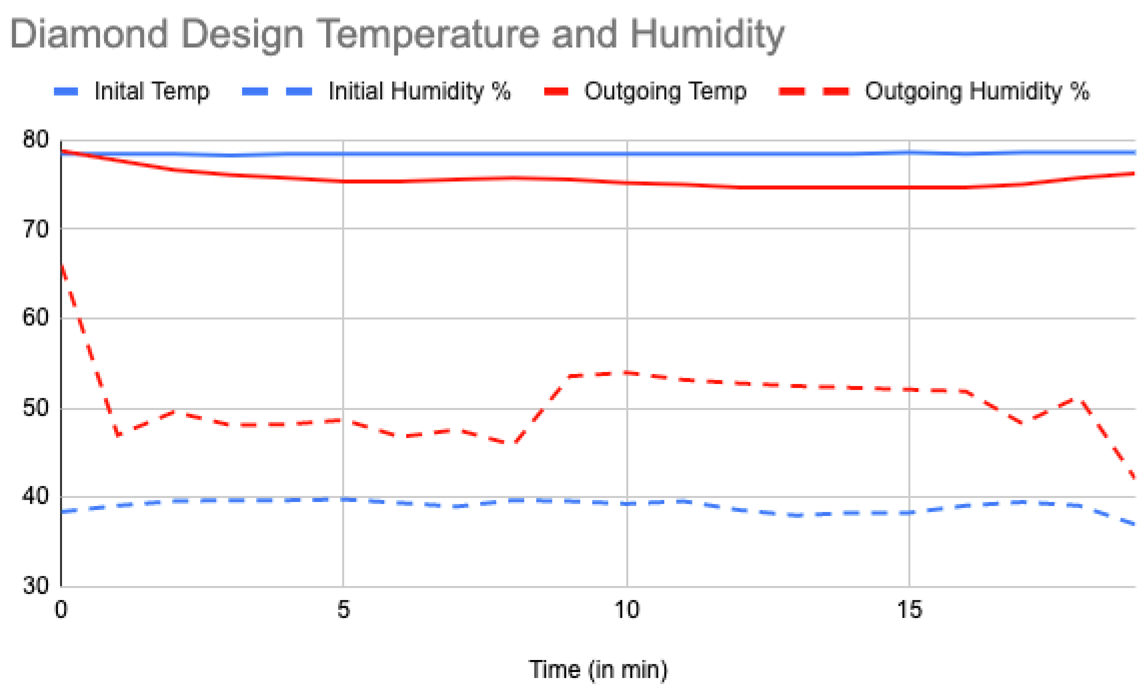
3.1.1 Cellulose Pad (12.64ºF ±0.5ºC temperature drop)

This graph presents the data collected in Tier 1 testing for the manufactured cellulose pad. The test occurred over a period of 50 minutes.



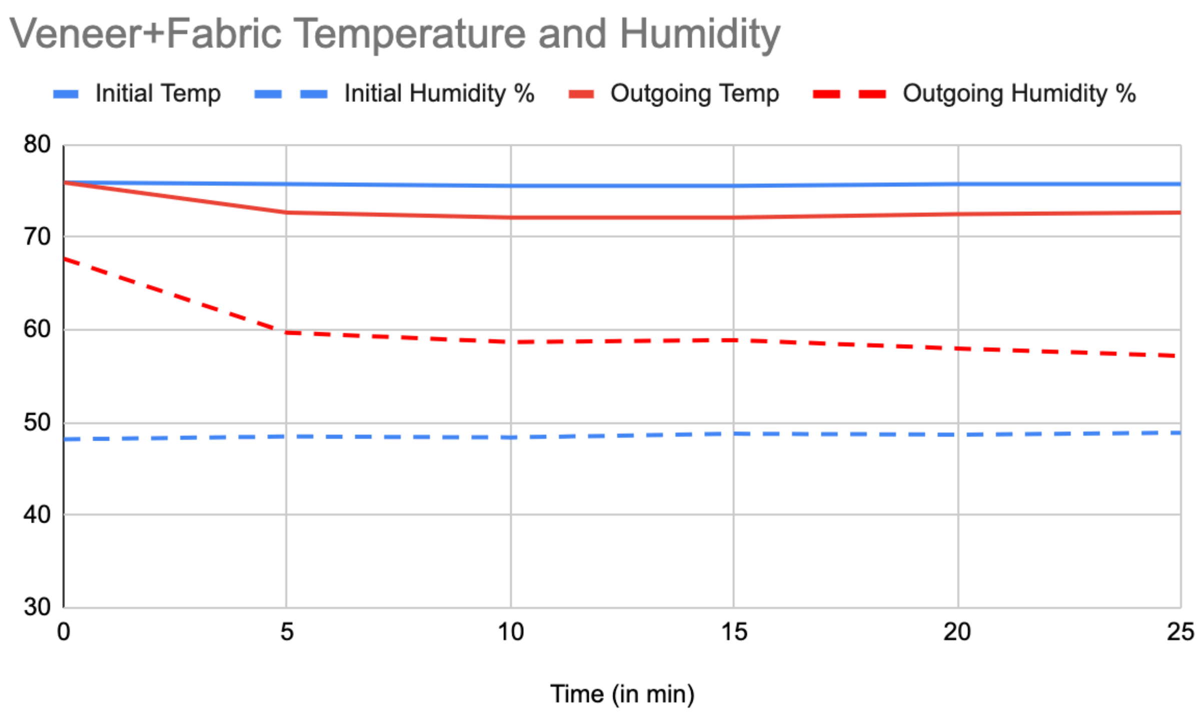
3.1.2 Diamond Veneer Pad (3.78ºF ±0.5ºC temperature drop)

This graph presents the data collected in Tier 1 testing for the diamond veneer prototype. The test occurred over a period of just under 20 minutes.



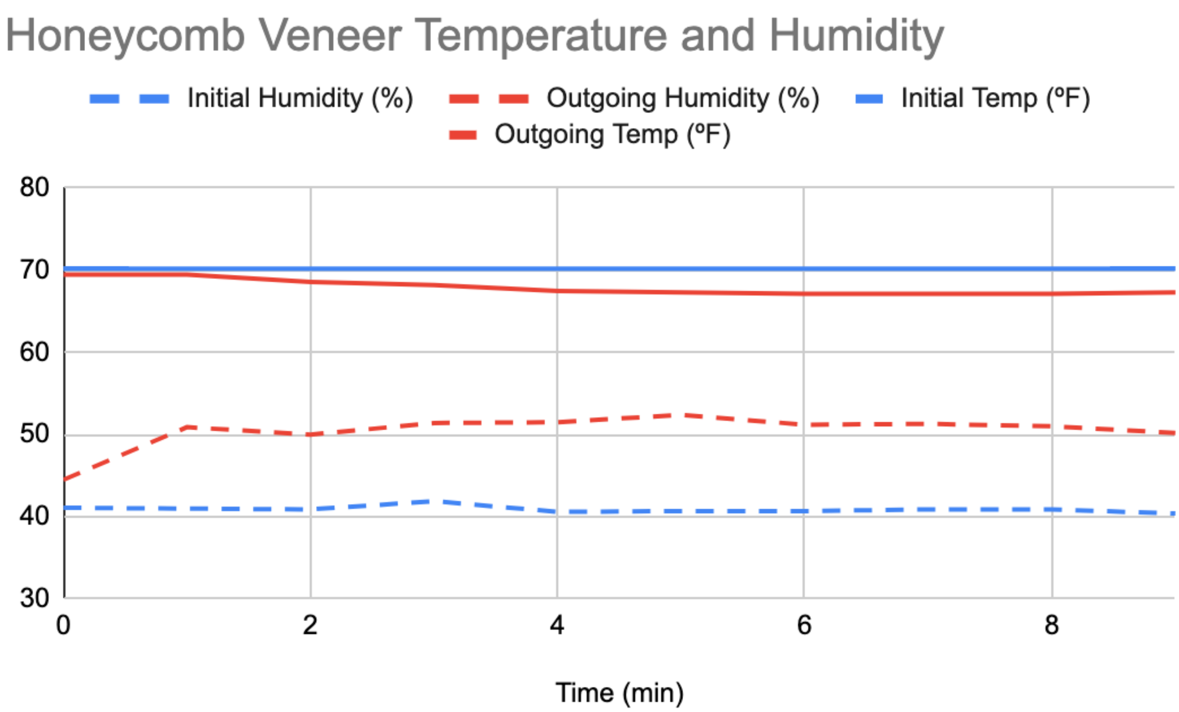
3.1.3 Veneer+Fabric Pad (3.78 ºF ±0.5ºC temperature drop)

This graph presents the data collected in Tier 1 testing for the veneer and fabric prototype. The test occurred over a period of 25 minutes.



3.1.4 Honeycomb Pad (3.06ºF ±0.5ºC temperature drop)

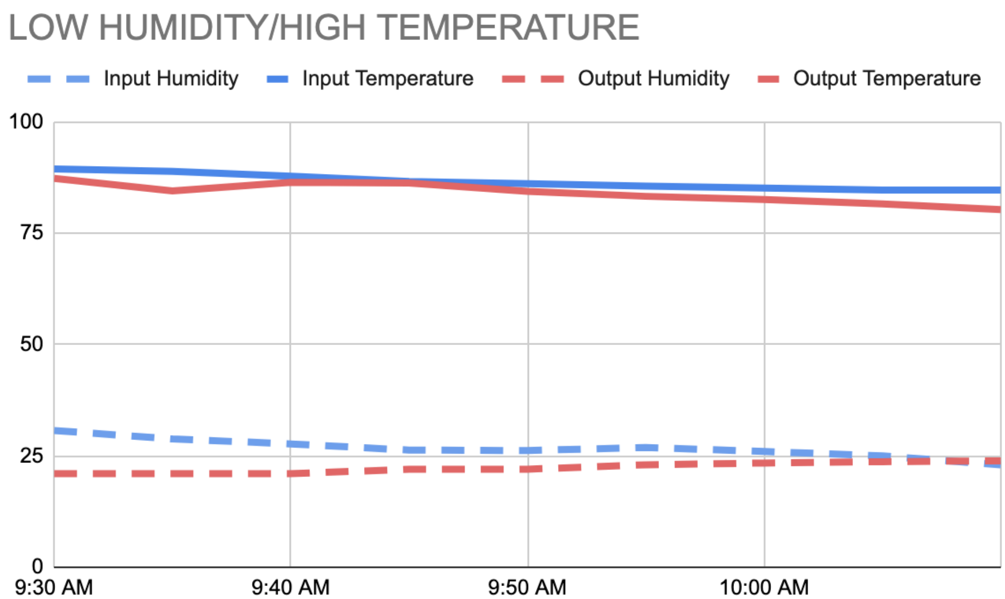
This graph presents the data collected in Tier 1 testing for the honeycomb prototype. The test occurred over a period of 9 minutes.



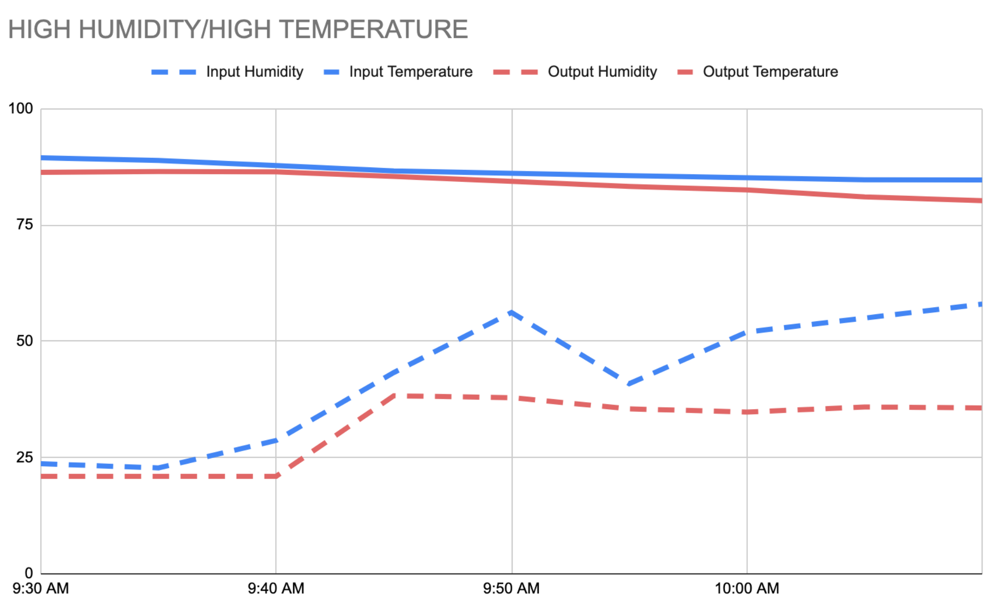
(see Appendix for other four prototype pad graph results)

3.2 Tier 2

3.2.1 Tier 2 Testbed (Low Humidity/High Temperature)



3.2.2 Tier 2 Testbed (High Humidity/High Temperature)



4.0 Discussion

4.1 Evaporative Cooler Pads

The commercial cellulose pad was tested first. Humidity increased throughout the cellulose pad (3.1) test, therefore, evaporation occurred. The temperature also dropped 12.64ºF over the course of 50 minutes. Because cooling occurred, the Tier 1 testbed successfully demonstrated evaporative cooling. Next, the three prototype pads were tested for comparison. All three prototypes showed cooling potential in Tier 1 testing. However, the Diamond Veneer design had inconsistent humidity changes. A potential reason for the initial drop in humidity could be that the pad was too saturated in water, so the fan blew away some water droplets before they had time to evaporate. Then after about 6-7 minutes, it is possible that the pad dampness stabilized to the climate so that it could finally proceed with evaporation (humidity increased).

While testing the Veneer+Fabric design, this prototype's humidity consistently tended downward. This is odd because the temperature dropped (cooling occurred), but evaporation did not (evaporation itself is meant to be what cools the air). Additionally, humidity consistently decreased over a somewhat lengthy 25 minutes. Like the Diamond Veneer design, it is possible that the initial drop in humidity occurred due to the pad being saturated. However, the remaining, less drastic humidity decrease could have occurred because the room was already high in humidity, compared to an average day. Another interesting observation is that the Diamond Veneer (3.1.1) had the same temperature drop as the Veneer+Fabric (3.1.2), even though the designs for both are quite different. The Diamond Veneer has a lot more thickness than the Veneer+Fabric. They probably had the same temperature drop because the Veneer+Fabric had a greater surface area than the Diamond Veneer.

For the Honeycomb Veneer pad, one can observe that the outgoing temperature is inversely related to the outgoing humidity, like the commercial cellulose pad is. Therefore, a potential reason for the honeycomb pad's humidity to stabilize when it did is that that is when the outgoing temperature began stabilizing as well.

One highly possible reason for the variability in the Tier 1 testing environment is that the testbed is open to the natural climate (temperature and humidity) of the room, which is not entirely controllable. Thus, Tier 2 testing is needed in order to provide data taken in controlled environments, showing whether or not this data variability is actually the case. Additionally, water amounts used on the pads differed for each test, potentially causing error such as pad saturation, or lack thereof. Water amounts should be standardized in future testings. Overall, temperature decreased for each of the three prototypes, indicating that some evaporation was occurring, and Tier 2 testing is imperative to the acquisition of controlled and accurate data.

4.2 Tier 2 Testing

The results yielded from the tier 2 testing was proof of concept that the testbed worked. In the graphs seen above, for low humidity + high temp (3.2.1), there was a 7.1 degree drop for the thirty minute block of time that the testbed was running. This means that the sensors, heat lamp, and fan were all working to provide a constant input temperature that the swamp cooler effectively converted into a lower temperature. Similar results were yielded for the high humidity + high temperature environment (3.2.2), but this time there is a clear difference from when the humidifier was off (23%) to when the humidifier was turned on (56%), thus showing that the testbed is fully functional and meets all parameters listed in the 2.2.2 Tier 2 Testing section.

4.3 Future Work

The first step toward the group's goal was made through building and testing bamboo prototypes in Tier 1 testing, but there is still more that needs to be done to fully meet the goal. Given time in the future, the bamboo prototypes would be tested in Tier 2 in order to gain data on how they perform in a controlled, Los Angeles summertime environment. In addition, the pad designs would be further developed through further incorporation of increased surface area and thickness in the manufacturing process. Finally, an app and DIY kit would be manufactured. The app would allow homeowners to easily keep track of their swamp cooler and give feedback on when and when not to use their swamp cooler. The DIY kit will include temperature and humidity sensors, which is where the app will get its data from, that homeowners will install in their swamp cooler. The DIY kit will also of course include a bamboo evaporative cooler pad for homeowners to live more sustainably.

5.0 Conclusion

The majority of Los Angeles homeowners use air conditioning as their primary cooling system. Running air conditioning for long hours in the hot Los Angeles summertime climate requires a lot of energy, which is typically produced while emitting greenhouse gases. This project investigated swamp coolers as an alternative to air conditioning based on their low energy use and suitability in Los Angeles' climate. The primary task was to find an alternative to commercial cellulose pads used in swamp coolers, since the production of these pads release greenhouse gases. Alternative pads were designed based on bamboo materials, and two testing protocols were developed.

6.0 References

Deshmukh, S., Warke, D. (2017, August 1). *Experimental Analysis of Cellulose Cooling Pads Used in Evaporative Coolers*. https://www.researchgate.net/publication/339551692_Experimental_Analysis_of_Cellulose_Cooling_Pads_Used_in_Evaporative_Coolers

EIA. "Household Energy Use in California." U.S. Energy Information Administration, 2009. https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/ca.pdf

Hymann, Y. (2020, December 7). *Material Guide: Is Bamboo Fabric Sustainable?* Good On You. https://goodonyou.eco/bamboo-fabric-sustainable/

Leung, J. (2018, July). *Decarbonizing U.S. Buildings*. Center for Climate and Energy Solutions. https://www.c2es.org/document/decarbonizing-u-s-buildings/#:~:text=In%202015%2C%20CO2%20emissions,emitting%20sector%20).

Papermaking - Processes for preparing pulp. (n.d.). Britannica. https://www.britannica.com/technology/papermaking/Processes-for-preparing-pulp

Residential Program Solution Center. (2020). *Energy Data Facts*. Energy Data Facts | Residential Program Solution Center. https://rpsc.energy.gov/energy-data-facts#:~:text=1.,of%20total%20U.S.%20energy%20consumption

Times-Standard, The. "Amid Drought, Los Angeles Looks to Upgrade 'Swamp Coolers.'" *Times-Standard*, MediaNews Group, Inc., 28 Aug. 2018, www.times-standard.com/2016/01/02/amid-drought-los-angeles-looks-to-upgrade-swamp-coolers/.

Ulin, D. (2010, December 15). *The Chemical Process of Cellulose to Paper*. A Moment of

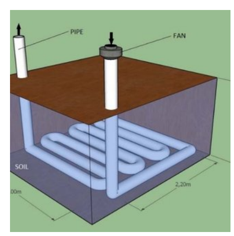
Science.
https://indianapublicmedia.org/amomentofscience/chemical-cellulose-paper.php#:~:text=To%20begin%20the%20process%2C%20the,be%20beaten%20instead%20of%20chopped.

U.S. Department of Energy. (n.d.). *Evaporative Coolers*. Energy.gov.
https://www.energy.gov/energysaver/home-cooling-systems/evaporative-coolers

Welch, G. (2014, July 7). *How to Get Maximum Cooling from your Swamp Cooler*. 15000 Inc.
https://www.15000inc.com/2014/07/07/529/

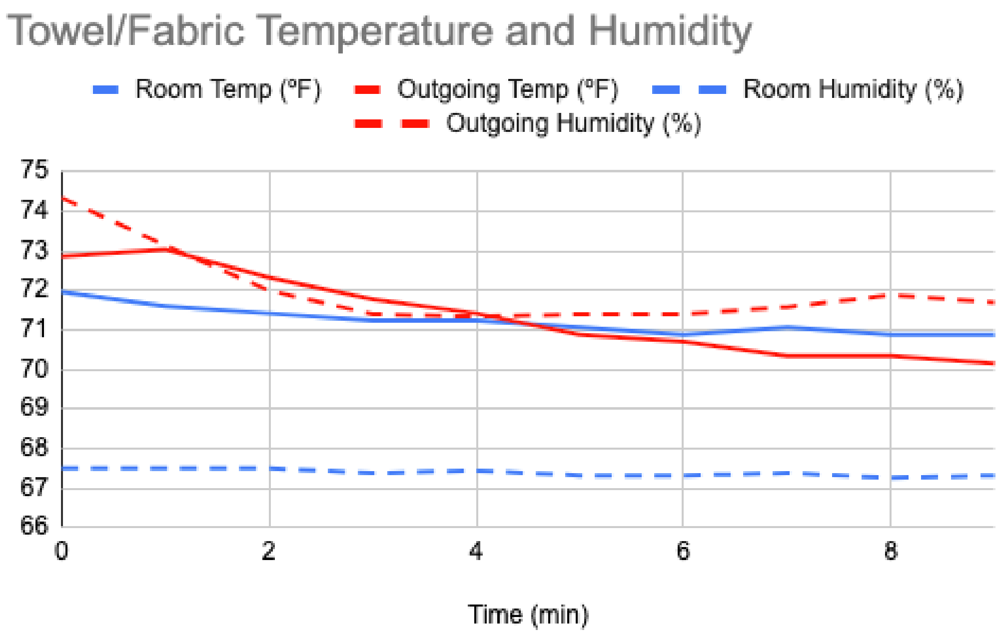
7.0 Appendices

7.1 Figure 1: Alternatives to Air Conditioning

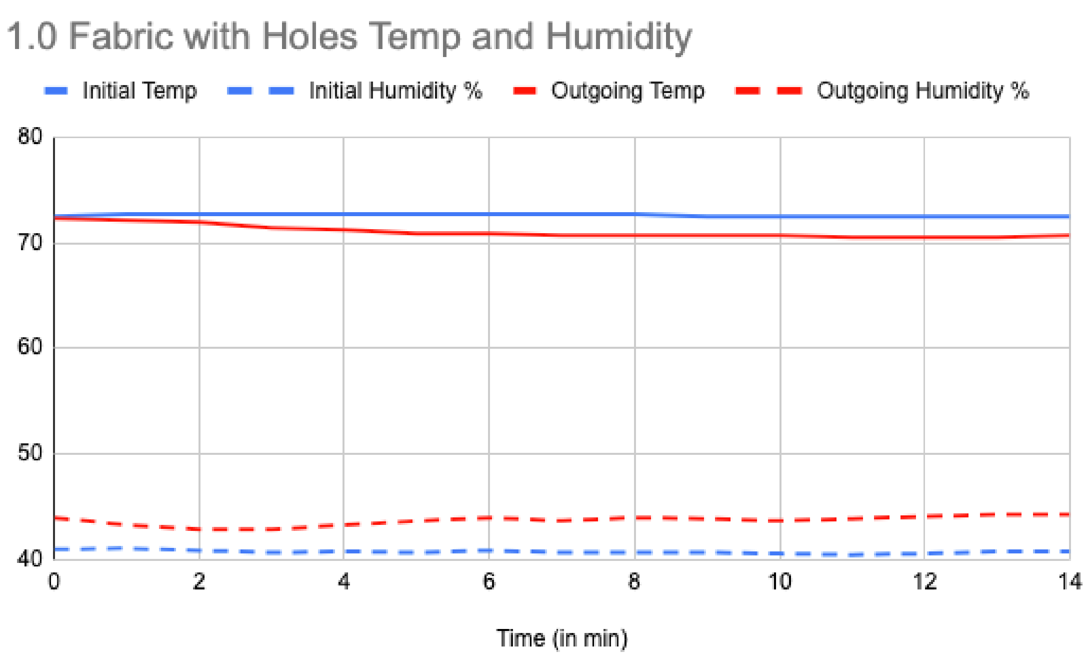
Alternatives to Air Conditioning:	**Heat pumps** 	**Ceiling Fans** 	**Earth Tubes** 	**Swamp Coolers** 
Pros	-Lower running costs -Reduces CO2 emissions (still	-Constant air circulation -Decreases energy bills	-No fossil fuel usage (passive cooling)	-Doesn't consume as much energy (lower bills) -Costs less than traditional AC

	requires electricity though)			
Cons	-High upfront cost -Cold weather damages system	-Limited to location -Noise problems	-High installation cost -Earthquakes damage underground loops	-Difficulty cooling above 95ºF and 70% humidity -Uses a lot of water (3-5 gallons per hour) -Mineral deposits form quickly -Molds quickly

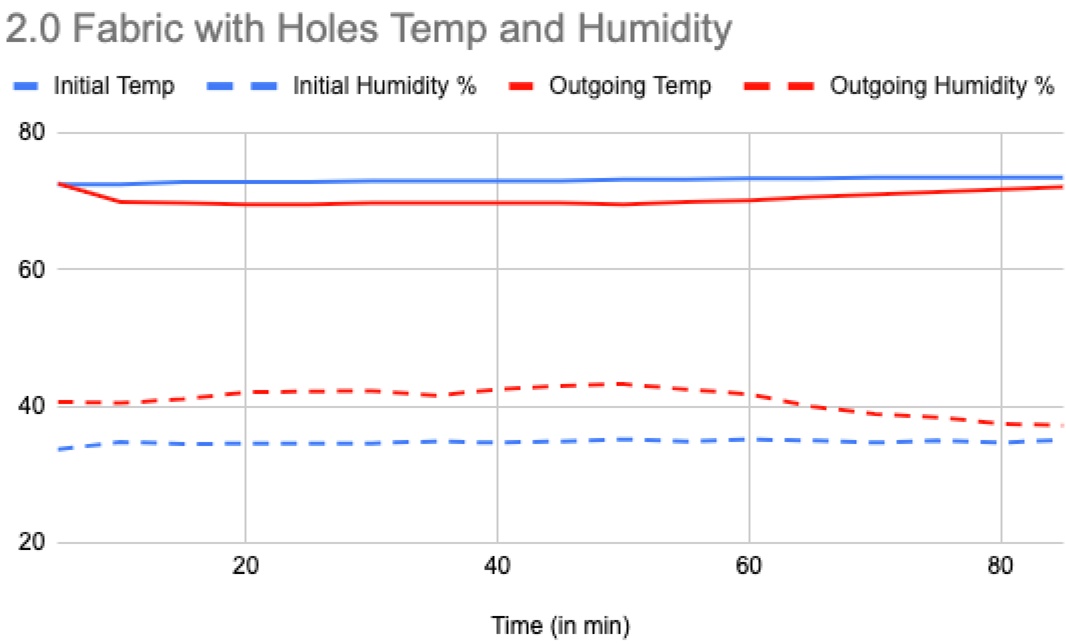
7.2 Towel/Fabric Pad (1.8ºF temperature drop)



7.3 Fabric With Holes 1.0 (1.98ºF temperature drop)



7.4 Fabric With Holes 2.0 (2.88ºF temperature drop)



7.5.1 Figure 6: Bruce's Chart on the Impacts of Air Conditioning, Evaporative Cooling via Commercial Cellulose Pad, and Evaporative Cooling via Bamboo Pad

Cooling homes is a major contributing climate change factor because of energy consumption related carbon production. Deforestation also releases carbon into the atmosphere and eliminates trees as carbon sinks.

Impacts	Air Conditioning	Evaporative Cooling via Commercial Cellulose Pad	Evaporative Cooling via Bamboo Pad
Direct Energy Use	Highly Negative	Less Negative	Less Negative
Deforestation	Neutral	Negative	Positive
Chemical Pollution	Neutral	Negative	Positive
Pad Production Energy Use	Neutral	Negative	Less Negative
Pad Mold Growth/Odor	Neutral	Negative	Less Negative
Others…			

An evaporative cooler which uses bamboo pads allows home cooling with a minimal environmental impact.

7.5.2 Figure 7: Bruce's Chart on Solving Climate Change With A Bamboo Evaporative Cooling Pad