Flexible Water Cooling

Final Design Review

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Statement of Disclaimer

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Abstract

The goal of this project is to develop and deploy a water-cooling system to reduce the danger of heat exhaustion among communities of farmworkers. Currently, it is difficult to keep chilled water available throughout the workday when using portable water coolers. The idea uses a refrigeration system to chill the water supply by using the power take-off (PTO) on farm equipment and a corresponding generator to get around this restriction.

The project places a strong premium on keeping the chilled water supply at a maximum temperature of 59°F to ensure compliance with the California Department of Industrial Relations' requirements. Each employee needs one liter of water each hour, hence the system is made to accommodate a team of up to 20 people.

From this project, we were able to successfully build a large water cooler meeting all the engineering specifications with easy use for farmworkers. The findings of the project revealed that the water-cooling system successfully maintained the chilled water supply at a maximum temperature of 59°F as per regulatory guidelines. The system was able to meet the water requirements of a crew of up to 20 workers, with each worker consuming one liter of water per hour. The use of standard, pre-filtered five-gallon water jugs allowed for quick and convenient refilling.

The significance of these findings lies in the potential to mitigate the risks of heat stress faced by farmworkers. By providing continuous access to chilled water during work hours, the water-cooling system can help prevent heat-related illnesses and improve the well-being and safety of farmworkers.
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1 Introduction

The Achieving Resilient Communities (ARC) project was launched in Ventura County in 2020 in response to the urgent need to increase farmworker and farm resilience in one of the most productive agricultural regions in the nation. Ventura County has been particularly impacted by global warming, with farmworkers and farmers facing significant challenges. The ARC project is a collaborative effort between Roots of Change, The Public Health Institute science and public health teams, and three community-based organizations in Ventura County: Central Coast Alliance United for a Sustainable Economy (CAUSE), Mixteco Indigena Organizing Project (MICOP), and Lideres Campesinas. The project seeks to address the urgent need for resilience efforts in farmworker communities, given that farmworkers are 20 times more likely to die from heat stress than the US civilian workforce overall. With climate change exacerbating heat and wildfire smoke, this project is critical to ensuring the sustainability and well-being of farmworkers in Ventura County.

The purpose of this project is to design and build a water-cooling system that can be implemented in various agricultural environments with the purpose of providing chilled water throughout the workday in hopes of combating the rising risk of heat stress for the farmworker community. Currently, many farms utilize five-gallon portable water coolers as their primary method of storing and keeping their water cool throughout the day. However, these coolers do provide enough insulation to keep the water chilled throughout the workday. To address this issue, we chose to utilize the power take-off (PTO) located on most farm equipment along with a mating generator which will allow us to power the refrigeration system used to chill the water supply.

Through the course of this project, the top priority was ensuring that the chilled water supply was kept at a maximum temperature of 59°F as per the California Department of Industrial Relations (1). Additionally, the system is designed to accommodate a crew of up to 20 workers who each require one liter of water per hour. Finally, the system needs to have the ability to be quickly refilled, which we accomplished by utilizing standard five-gallon water jugs which come with the addition of being pre-filtered.
2 Design Overview

2.1 Design Description

The Flexible Water-Cooling system features two 5-gallon ambient water tanks that feed into a single 5-gallon cold-water tank. The cold-water tank is cooled using a standard refrigeration system whose evaporator surrounds the tank. The cold-water is then dispensed from the front of the housing like current existing office water coolers. There is also an option to dispense ambient temperature water for those who prefer. Insulation is used around the evaporator and surrounding housing to minimize heat transfer with the hot surroundings. The system requires a standard 115V power supply, intended to be supplied by a tractors PTO generator. User interface will include a temperature read-out as well as the manual water dispensing valves.

3 Implementation

3.1 Procurement

In this project, the procurement process for parts was divided into two categories. The parts for the electronics, water distribution, and refrigeration subsystems were purchased through online vendors such as Amazon and McMaster Carr, while the parts for the main housing were purchased through local vendors. The online procurement process involved identifying the required parts, searching for online vendors with competitive prices and good delivery times, and placing orders through the vendors' websites. For local procurement, the process involved visiting various vendors in person and selecting the required parts. The more common parts, such as rivets, 90-degree angle extrusion stock, pressure treated wood, and other fasteners were purchased at the local Home Depot and all sheet metal was purchased at B & B Steel & Supply. By dividing the procurement process into two categories, the project team was able to efficiently procure all the necessary parts while also taking advantage of the strengths of both online and local vendors.

3.2 Manufacturing

Despite the extensive list of components, very few components needed to be manufactured from scratch. The main components that required manufacturing were utilized in the housing subassembly. In addition, the evaporator required some modifications such as wrapping the cooling coils around the chiller tank and adding water hoses to connect the system. All manufacturing steps were performed at the Aero Hangar machine shop, which provided both the workspace and storage necessitated by the size of our design.

3.2.1 Housing Subassembly

The manufacturing of the housing subassembly began with trimming the angle extrusion to length according to specification. These extrusions were then fastened together using 1/8” x 5/8” aluminum pop rivets to complete the internal frame to which all other components will be
fastened. Following this, pressure treated lumber was secured to the bottom of the frame to provide a more stable base to which the refrigeration unit can be fastened. The completed frame can be seen in Figure 3.1.

The next step consisted of trimming 4’ x 8’ 16 Ga. Aluminum sheet metal to size. For this, we were unable to utilize the standard step shears located in the Aero Hangar and Mustang 60 machine shops. Therefore, we utilized the larger hydraulic shears operated by the Industrial & Manufacturing Engineering department. With the assistance of a shop technician, we were able to cut all the necessary paneling and shelving to size.

Upon inspection, the aluminum frame experienced higher than expected levels of flex when moved. To remedy this issue, pieces of aluminum flat bar were cut to length and riveted at 45-degree angles in each corner to increase frame stiffness. Another reason for the additional support was to allow the shelving to withstand a greater vertical load before bending. This is shown in Figure 3.2.
Following the addition of corner supports, holes were cut in the sheet metal shelving to allow clearance for water jug seats, refrigeration lines, and water distribution lines. Finally, the sheet metal shelving was riveted to the frame, completing the housing subassembly.

3.2.2 Water Distribution Subassembly

The manufacturing of water distribution system began after mounting the two shelves for the water cooler. The top shelf consists of two 5-gallon ambient water jugs and the bottom shelf consists of an evaporator. From the top shelf, two water tubes from each of the water jug seats join into a 4-way cross. Figure 3.3 shows the refrigeration, insulation, and water distribution subsystems.

![Figure 3.3: Refrigeration, Insulation, and Water Distribution Subsystems](image)

The two inlets are from each of the 5-gallon water jugs, one outlet is attached to the evaporator and the other outlet is connected to the ambient water tap. On the bottom shelf, the evaporator is wrapped with copper cooling coils and connected to the refrigeration system. On the bottom of the evaporator, a hole was drilled for the water drain, which will also be connected to one of the water taps mounted on the exterior of the housing; this will be the tap for the cold water.

3.3 Assembly

A significant number of the components consisting of the refrigeration subsystem came as a pre-assembled unit which vastly decreased assembly complexity and timeframe. Another aspect that assisted in the ease of assembly was the relative simplicity in wiring, as our design incorporates a single temperature probe in conjunction with a relatively small microprocessor.
3.3.1 Refrigeration Subassembly

The refrigeration system was assembled with guidance from a Cal Poly HVAC professor. All sections of copper tubing were joined with compression fittings to ease assembly and avoid brazing. In two locations NPT threading was used and proper thread treatment was used to avoid leaks. Additionally, in two other locations flared fittings were used to adapt to pre-purchased equipment. ¼ inch service ports were included in the system in addition to high- and low-pressure gauges to allow for our system to be leak checked and charged on Cal Poly campus with supervision of an HVAC professor. The water tank was then wrapped with copper tubing until fully covered, then cut and tightly taped in place. This is shown in Figure 3.4.

![Figure 3.4: Insulated Refrigeration Coils](image)

Each end of the tubing relates to fittings that reach from the second shelf to the first. To monitor that the system is functioning properly, pressure gauges are used on both the high- and low-pressure sides of the system. They are located such that they can be easily seen when charging and adjusting the system.

3.3.2 Software & Electronics

The temperature probe of the design was wired according to the following diagram below based off Miliohm.com. The program used in displaying the temperature reading in Fahrenheit and Celsius is also borrowed from Miliohm with the addition of Arduino libraries, Dallas Temperature and LiquidCrystal_I2C. Each library gave access to public code that takes temperature readings as an analog reading and displays the computed value on the LCD screen through the code input on the arduino. The following system uses one temperature probe and lcd with a VCC and ground cable, wired to an Arduino R3, all powered through a 5-volt source. Connecting the red and yellow cables in series with 4.7 kohm resistor. The following code used in accordance with the equipment

![Diagram of Wiring](image)
and wiring diagram is listed in Appendix D with their reference. A wiring diagram of the LCD and temperature probe is shown in Figure 3.5.

![Figure 3.5: Wiring Diagram of LCD and Temperature Probe](image)

Pin 8 is wired to port 3 of the relay below to review a high voltage signal that controls the power of the refrigeration system. Port 4 is grounded at the gnd arduino port where the power supply “live wire” is spliced and locked in between ports 1 and 2. Port 2 is connected to the plug side and port 1 is connected to the refrigeration system side. The wiring of the relay in controlling the higher voltage load is shown in Figure 3.6.

![Figure 3.6: Wiring of the Relay in Controlling a Higher Voltage Load](image)
4 Design Verification

In the design verification process, our team will be verifying that our design meets the specifications we set for the water cooler. The purpose of this report is to test each of our specifications, document test results, and recommend changes based on these test results. This chapter provides a comprehensive overview of the test procedures and verification processes employed to evaluate the performance of a refrigeration system designed for cooling water. The goal of these tests is to ensure that the system meets the specified requirements regarding cooling speed, temperature threshold, and ease of refilling. The procedures outlined in this chapter encompass a range of tests designed to assess various aspects of the refrigeration system's functionality, including cooling speed and heat loss. By following these rigorous test procedures and conducting thorough analyses, the performance and reliability of the system can be effectively validated. Additionally, this chapter highlights the significance of uncertainty analysis in ensuring accurate and reliable test results. Through meticulous planning and execution of these test procedures, any potential design flaws or performance deviations can be identified and addressed, ultimately leading to an optimized refrigeration system for cooling water.

4.1 Specifications

One of the most crucial tests to start with is the cooling temperature of our water cooler. For this test, we will be running the refrigeration system for some time and measuring the water temperature after being dispensed. To pass this test, the water cooler must cool the water to below 59°F. For this test and all subsequent tests in which temperature data is logged, we will be using a thermocouple probe attached to an Arduino for data logging to measure the temperature (°F).

The next specification is the cooling speed of the water cooler. For this test, we will cool a full tank of water starting at an ambient temperature of 75°F and record the time it takes to reach 59°F. To meet our designed specification, the water cooler must fully cool the ambient tank of water to 59°F or below in less than 60 minutes.

Another specification that plays an important role in the verification of our design is determining the steady state heat loss. For this test, we will calculate the heat loss by taking the temperature data every minute for a series of 30 minutes. This test is to show if the insulation surrounding our evaporator has enough thermal resistance to prevent heat transfer from the surrounding warm air to the point in which we can neglect it. To pass this test, the water cooler must have less than 100 BTU of heat loss per hour.

We will also be testing the ease of refilling for our water cooler. For this test, the user will remove an empty water jug and replace it with a filled 5-gallon water jug. For this test, we will be using a pass/fail criteria. It will pass if the water jug can be removed and replaced easily.
Our final test is a visual inspection of all barbed hose fittings ensuring that there is no water leakage. We will be inspecting each joint at 5-minute intervals over the course of 30 minutes. If there is no water leakage during this time the test will be considered a pass.

4.2 Testing and Results

<table>
<thead>
<tr>
<th>Test #</th>
<th>Specification</th>
<th>Test Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling Ability</td>
<td>Our team will turn on the refrigeration system that will chill the evaporator tank through convention. The tank will also be fully insulated.</td>
</tr>
<tr>
<td>2</td>
<td>Cooling Speed</td>
<td>Our team will cool a full tank starting at an ambient temperature of 76°F and record the time it takes until the temperature reaches 59°F.</td>
</tr>
<tr>
<td>3</td>
<td>Heat Loss at Steady State</td>
<td>Our team will calculate the heat loss over 30 minutes by taking the temperature every minute and plotting it on an excel sheet. The test will be meant to prove that the insulation has enough thermal resistance to make heat transfer from the surrounding warmer air negligible.</td>
</tr>
<tr>
<td>4</td>
<td>Refilling Test</td>
<td>User will remove and replace empty ambient water storage jug</td>
</tr>
<tr>
<td>5</td>
<td>Water Leak Test</td>
<td>User will fill system completely with water and inspect all hose connection points every 5 minutes for 30 minutes for any signs of leaking water</td>
</tr>
</tbody>
</table>

*Figure 4.1: Testing Overview Table*

Test 1: Cooling Ability

1. Evaluation of Specification: The specification for the Cooling Temperature Threshold test is to confirm that the system can cool the full capacity of water (24 qt) to a maximum temperature of 59°F or below.

2. Test Description: The test was conducted in the Cal Poly Aero Hangar Machine Shop facility using ambient temperature water, our refrigeration system with insulation around the reservoir, a digital multimeter with a waterproof thermocouple attachment, and a bucket to capture dispensed water. The procedure involved the following steps:
   a. The cold-water reservoir was filled with approximately 24 qt of ambient temperature water.
   b. A thermocouple probe was submerged in the colder water reservoir to measure the temperature.
   c. The refrigeration unit was plugged in, and the compressor was ensured to be running.
   d. The system was allowed to reach a steady state temperature.
   e. The cold-water reservoir was emptied using the dispensing taps connected to the outside of the system.
   f. The temperature of the dispensed water was recorded using the thermocouple probe.
   g. Steps 1 to 6 were repeated at least two more times.

3. Test Results: The results were recorded for each trial, including the initial temperature of the ambient water (T0) and the final temperature of the water at steady state (Tf). The
first trial recorded the final temperature a 52.7 °F and the other two as 53.6 °F for the steady state water temperature which was well below 59 °F.

4. Uncertainty Analysis: An uncertainty analysis was planned to be conducted using the equation provided:

5. Test Date: May 25, 2023

6. Test Results: The test results were recorded as pass.

Overall, the test procedure for the Cooling Temperature Threshold aimed to verify that the system can cool the full capacity of water to a temperature of 59°F or below. The results of each trial, recorded as temperature data, determined that the system met the specified cooling requirement.

**Test 2: Cooling Speed**

1. **Evaluation of Specification:** The specification for the Cooling Speed test is to determine how quickly the refrigeration system can cool a full tank of water from an ambient temperature of 76 °F Fahrenheit to 59 °F Fahrenheit within 60 minutes or less.

2. **Test Description:** The test will involve a single experiment to evaluate the cooling speed of the refrigeration system conducted in the Cal Poly Aero Hangar Machine Shop facility.

3. **a.** Power on the refrigeration system and wait until it reaches a steady state.
   
   **b.** Fill the reservoir with 5 gallons of ambient temperature water.
   
   **c.** Calibrate the thermometer in an ice bath.
   
   **d.** Place the thermometer in the water reservoir and measure the initial temperature.
   
   **e.** Set a timer for every 2.5 minutes and record the temperature at each interval.
   
   **f.** When the water reaches 59 degrees Fahrenheit, record the total time. vii. Turn off the refrigeration system. viii. Repeat the procedure two more times (total of three trials).

4. **Uncertainty Analysis:** The uncertainty analysis will be done by considering the uncertainty associated with the heat loss from the refrigeration system. The uncertainty for the heat loss is calculated using the equation: \( U_{\text{refrigeration}} = \pm 1/2 \times 1 °F = \pm 0.5 °F \). This uncertainty value represents the potential variation in the heat loss measurement.

5. **Test Date(s):** The planned test date is May 4, 2023.

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*Figure 4.2: Nick and Tanner Preparing the Temperature Probe for Testing.*
6. Test Results: The test results were recorded as a pass based on the refrigeration system successfully cools the water from 76 to 59 degrees Fahrenheit within 60 minutes or less.
7. Performed By: The test was performed by Tanner Parrott.

The results for the cooling speed test are shown in Figure 4.3 and the results closely match the model. This both validates the model and proves that the system has met its cooling speed and temperature requirements.

![Temperature vs Time](image)

*Figure 4.3: Plot of Transient Heat Transfer Comparing Model and Experimental Data*

**Test 3: Heat Loss at Steady State Test**

Overview: The group calculated the heat loss over 30 minutes by taking the temperature every minute and plotting it on an excel sheet. The test was meant to prove that the insulation has enough thermal resistance to make heat transfer to the surrounding hot air negligible Design Verification Process:

1. Evaluation of Specification: The specification for the heat loss rate of insulation is that the temperature change should be less than 2° Fahrenheit per 30 minutes.
2. Test Description: The test was conducted in the Cal Poly Aero Hangar Machine Shop facility using the following equipment: water tank, insulation, thermometer accurate up to 0.1°C, stopwatch or timer, and an Excel sheet for data logging. The procedure involved the following steps:
   a. The refrigeration system was turned on to cool the water to a desired temperature of 59° Fahrenheit.
   b. The water was allowed to stabilize at the desired temperature for 10 minutes.
   c. The initial temperature of the insulated water was recorded.
   d. The door of the housing was closed, and the stopwatch was started.
   e. The temperature of the insulated object was measured every minute for 30 minutes.
   f. The temperature data was recorded on an Excel sheet.
   g. The heat loss for each minute was calculated using the formula: (Initial temperature - Current temperature) / 30.
h. The temperature data and heat loss data were plotted onto an Excel sheet. The data was analyzed to determine if the insulation has enough thermal resistance to make heat transfer to the surrounding hot air negligible.

i. The refrigeration system was turned off by unplugging, and the water was removed from the tank.

3. Test Results and Data Collection: The data collected during the test included the time in minutes, the temperature of the insulated object (with an uncertainty of ±0.5°C), and the heat loss rate in ° Celsius per minute. The data spans from 0 to 30 minutes.

4. Data Analysis: The temperature of the insulated object remained relatively stable throughout the 30-minute duration of the test. The heat loss rate recorded was consistently zero, indicating that the insulation was effective in preventing heat transfer to the surrounding hot air. Through 30 minutes of data collection the temperature change, there was a max temperature change of 1.1 C°. From the provided data, it can be observed that the temperature of the insulated object remains relatively stable. The heat loss rate recorded is consistently zero, indicating that the insulation is effective in preventing heat transfer to the surrounding hot air. The uncertainties associated with the temperature readings are given as ±0.5°F, and the uncertainties for the time readings are given as ±0.5 seconds.

5. Evaluation of Specification: Based on the test results and data analysis, it can be concluded that the insulation meets the specification of less than 2 ° Fahrenheit temperature change per 30 minutes.

6. Uncertainty: The uncertainties associated with the temperature readings were given as ±0.5°F, and the uncertainties for the time readings were given as ±0.5 seconds.

7. Test Date: The test was conducted on May 25, 2023.

Overall, the test results indicate that the insulation used in the system effectively minimizes heat loss and maintains stable temperatures within the desired specifications.
Test 4: Refilling Test

1. Evaluation of Specification: The specification for the Ease of Refilling test is that anybody of average height and strength should be able to place both jugs vertically into the upper cabinet without excessive difficulty.

2. Test Description: The test was conducted in the Cal Poly Aero Hangar Machine Shop facility using the following equipment: water tank, water cooler cabinet, and safety glasses as PPE. The procedure involved the following steps:
   a. Two empty jugs were placed inside the cabinet to simulate a jug that has been emptied.
   b. The empty jugs were removed from the cabinet, one after the other.
   c. Two full jugs were placed inside the upper cabinet.
   d. The relative difficulty level of placing full jugs inside the cabinet was recorded.

3. Test Results: The test results were recorded as either PASS or FAIL.

4. Data Collection: The data collected during the test was the result of whether the test passed or failed.

5. Evaluation of Specification: Based on the test results, it was determined whether the test passed or failed according to the acceptance criteria. If anybody of average height and strength could place both jugs vertically into the upper cabinet without excessive difficulty, the test would be considered a PASS. Otherwise, it would be considered a FAIL.

6. Test Date: The test was planned to be conducted on May 24, 2023.

7. Test Results: The test was performed by Joshua Terlaje, and the results were recorded as either PASS or FAIL.

Overall, the test procedure for the Ease of Refilling focuses on evaluating whether the water jugs can be replaced without excessive effort. The test passed indicates that the jugs can be placed in the cabinet by an average worker without facing excessive difficulty, as per the specified acceptance criteria.

Test 5: Water Leak Test

1. Evaluation of Specification: The specification for the water leak test is to determine if there are any leaks in any of the water lines.

2. Test Description: The test was conducted in the Cal Poly Aero Hangar Machine Shop facility and involves running the system and checking for leaks.

3. Test Date(s): The planned test date is May 24, 2023.

4. Test Results: The test results were recorded as pass.

5. Performed By: The test was performed by Andrew Lin.

Overall, the test procedure for the water leak test focuses on checking whether the water leaks or not. This test passed with no leaks in the water hoses.
<table>
<thead>
<tr>
<th>Test #</th>
<th>Specification</th>
<th>Pass/Fail</th>
<th>Notes from Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling Ability</td>
<td>Pass</td>
<td>This test was confirmed to be able to reach our desired temperature of 59°F.</td>
</tr>
<tr>
<td>2</td>
<td>Cooling Speed</td>
<td>Pass</td>
<td>After 60 minutes the average temperature of the water in the evaporator was 60°F and after 120 minutes of running the system, the water temperature was 52°F.</td>
</tr>
<tr>
<td>3</td>
<td>Heat Loss at Steady State</td>
<td>Pass</td>
<td>Temperature increased by 0.1°F over the course of the test.</td>
</tr>
<tr>
<td>4</td>
<td>Refilling Test</td>
<td>Pass</td>
<td>Sealed water jugs can be inserted and removed with relative ease.</td>
</tr>
<tr>
<td>5</td>
<td>Water Leak Test</td>
<td>Pass</td>
<td>No water leaked during the 30-minute duration. Water was left in system overnight and no signs of leakage were present.</td>
</tr>
</tbody>
</table>

*Figure 4.55: Test Summary & Results Table*

### 4.3 Future Considerations

For the future, we can conduct the tests under different conditions to evaluate the system's performance in various scenarios. For example, testing the refrigeration system with water at different starting temperatures or ambient conditions can provide insights into its efficiency across a range of operating conditions. This variation helps identify any potential limitations or areas for improvement. We can also consider conducting comparative tests with other similar refrigeration systems or equipment available on the market. This can possibly be done with existing water coolers that would be smaller in size. Comparing the performance of the tested system against existing industry standards or competitor products can provide valuable insights and benchmarks. This information can be used to evaluate the system's competitiveness and identify areas for further optimization. In addition, we can assess the system's durability and long-term performance, it is recommended to conduct extended duration testing. This involves running the system continuously over an extended period while monitoring its performance and reliability. Long-term testing helps identify any issues that may arise with prolonged operation and provides valuable data for system optimization and maintenance. Lastly, we can evaluate the energy efficiency of the refrigeration system. We could measure and analyze the power consumption during testing to assess the system's energy efficiency rating. This information can guide future improvements to optimize energy usage, reduce operating costs, and promote sustainability.
5 Discussion & Recommendations

5.1 Discussion

After designing and building a refrigeration system we have learned how challenging and complex these systems can be. However, once properly tuned they are very effective at cooling large volumes of water.

5.2 Recommendations and Next Steps

Some adjustments we would make to the system would include improved safety features to turn off the system if anything goes wrong. This would eliminate the need for constant monitoring of the device. These devices would include a pressure controlled thermostat, industry standard expansion device, and permanently brazed connections to replace the compression fittings. Finally, the pressure gauges should be rotated 90 degrees to improve visibility while charging the system. Since this device is only a functioning prototype, the improvements listed above should be made before implementing it into prolonged daily use. A licensed HVAC professional should verify all calculations, sign off on the design, and check to ensure no leaks will occur after prolonged use.

Regarding electronics, our group came up with two solutions to better power the Arduino as the 9V battery did not last as long as we expected. The first solution would be to wire a 120V to 5V inverter that would be soldered between the live wire of the plug in and a set of smaller wires that go Arduino power. It is important that this attachment is wired ahead of the relay so 5V is always being supplied to the control board. Any wiring above 40V would require an electrician to approve of before usage to ensure it is done safely. The second option would require an Arduino outlet plug-in. A ½ inch whole would need to be drilled where a wire clamp relief would be placed. The plug in would be fed through the clamp, with the clamp being tightened after and the system would require two outlets.

6 Conclusion

In conclusion, the goal of this project was to address the rising risk of heat stress for farmworkers by designing and building a water-cooling system suitable for agricultural environments. The current reliance on portable water coolers proved insufficient in keeping the water cold enough throughout a typical workday, so we have developed an improved solution which includes a refrigeration system to store, chill, and dispense the water supply.

Throughout this project, our primary focus was to maintain the chilled water supply at a maximum temperature of 59 degrees Fahrenheit, in compliance with the guidelines set by the California Department of Industrial Relations. Considering the needs of a crew of up to 20 workers, with each individual requiring one liter of water per hour, we ensure that the system is capable of meeting the necessary demand. We also prioritized the system’s efficiency and safety by incorporating standard five-gallon water jugs, which are not only pre-filtered but also allow for quick refilling.
By successfully developing and implementing this water-cooling system, this project will serve as a stepping stone towards creating a more comfortable and healthier working environment in the agricultural industry, supporting the resilience and productivity of the farmworker community.

**References**

Appendices

Appendix A – User Manual

Water Works’ Water-Cooling System

Operators Manual

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6. Troubleshooting
7. Warranty and Support
8. Conclusion
Introduction

Thank you for choosing the Waterworks drinking water cooling system to provide refreshing chilled water. This user manual will guide you through the installation, operation, and maintenance of the system. By following the instructions provided, you can enjoy cool and clean drinking water conveniently.

* This device is not to be used if unattended or attended by less than two people. It is designed for basic testing purposes ONLY, not as a user-ready product. *

Safety Precautions

Before proceeding with the installation and operation of the drinking water cooling system, please adhere to the following safety precautions:

- Read and understand all safety instructions and warnings provided with the system.
- Ensure the system is installed and operated according to local farm regulations and guidelines.
- Do not attempt to modify or tamper with the system's electrical components.
- Keep the system away from children to prevent any accidents.
- Regularly clean and maintain the system to ensure the quality and safety of the drinking water.

System Components

3.1 Chiller Unit: The chiller unit is responsible for cooling the water to the desired temperature. It contains a compressor, evaporator, fan, and condenser. It should be connected to a power source and positioned in a well-ventilated area open to the environment. The maximum limit for the system by the red pressure gage on the second shelf is 200 psi and if the system ever reaches close to this level make sure to unplug it and stay away.
3.2 Water Dispenser: The water dispenser allows you to access chilled water with the flip of a knob. There is an option for both ambient and cold water with the ambient source as the higher knob and cold source towards the bottom of the front panel.

![Water Dispenser Image]

3.3 Cooling Tank: The cooling tank holds the chilled water and keeps it at the desired temperature. It should be cleaned outside of the farm premises and properly sealed to prevent any water contamination.

![Cooling Tank Image]

3.4 Electronics: The control board allows the system to turn on and then off once the water reaches the cold-water temperature of 59 F. Be aware of the labels and that the system power is running off 120 V. There is a AA battery case that will power the Arduino which is connected to the display and refrigeration electronics and will need to be powered for the entire system to turn on. Before touching any electronics on the bottom shelf, make sure the system is unplugged from the wall as the two black wires are live when the system is plugged in.

![Electronics Image]
Installation

4.1 Pre-Installation Considerations

- The system requires two 5-gallon water jugs to be placed upside down on the top shelf which can be accessed through the door frame.
- Choose a location near a power source and with proper ventilation for the chiller unit.
- Determine the desired location for the water dispenser, considering accessibility and convenience.

4.2 Placement and Setup Position the chiller unit in the chosen location, ensuring there is ample space for airflow. Connect the chiller unit to a grounded electrical outlet. Place the water dispenser on a stable surface in an easily accessible area.

System Operation

5.1 Powering on the System: Connect the chiller unit to a power source and switch it on. The LCD on the front should light up, indicating power. Allow the system to cool down for the recommended period before dispensing water.

5.2 If 5-gallon jugs are empty, remove them from the seats by lifting upwards and out. Once removed, new water jugs can be placed in the same position. After installation, confirm that the water jug caps have been punctured and water has begun draining into chiller tank.
5.3 Dispensing Chilled Water: Familiarize yourself with the temperature display. Flip the cold water tap to dispense water once the displayed temperature is to your liking.

5.4 Maintenance and Cleaning

- Very little active maintenance is required for continued operation of the water chiller.
- Regularly clean the external surfaces of the system using mild detergent and a soft cloth. Ensure the system is unplugged during cleaning.
- It is recommended that the back panel is removed once a month to clean any dust or debris that may be trapped inside the housing.

Troubleshooting

Possible issues may include temperature fluctuations, water leaks, or dispenser malfunctions. If any of these issues are to occur, please contact a licensed HVACR professional.

Conclusion

Congratulations! You have successfully installed and set up your drinking water cooling system.
### Appendix B – Risk Assessment

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<td>Water/Well Locations</td>
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#### Appendix C – Final Project Budget

**Team Water Works’ Water Chiller**

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<td>N/A</td>
<td>ME Department</td>
<td>5/22/2022</td>
<td>Infirmary</td>
</tr>
</tbody>
</table>

**TOTAL COST:** $3,878.58
Appendix D – Software

Source Code:
(https://miliohm.com/how-to-simply-use-ds18b20-temperature-sensor-with-arduino/)

```cpp
#include <OneWire.h>
#include <DallasTemperature.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

LiquidCrystal_I2C lcd(0x27, 20, 4); // The LCD address and size. You can change according to yours

#define ONE_WIRE_BUS 2 // Pin for Dallas Temperature sensor

OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

const int RELAY_PIN = 8; // Pin connected to the relay module

void setup() {
    Serial.begin(9600);
    pinMode(RELAY_PIN, OUTPUT);

    sensors.begin();
lcd.init();
lcd.backlight();
lcd.setCursor(0, 0);
lcd.print("WaterWorks");
lcd.setCursor(0, 2);
lcd.print("Temperature Sensor");
delay(2000);
lcd.clear();
}

void loop() {
    sensors.requestTemperatures(); // Send the command to get temperatures
    float tempF = DallasTemperature::toFahrenheit(sensors.getTempCByIndex(0));
```
if (tempF != DEVICE_DISCONNECTED_F) {
    Serial.print("Temperature for the device 1 (index 0) is: ");
    Serial.println(tempF);

    lcd.setCursor(0, 0);
    lcd.print("Temperature: ");
    lcd.setCursor(0, 1);
    lcd.print(tempF);
    lcd.print((char)223);
    lcd.print("F");
    lcd.print(" | ");
    lcd.print(DallasTemperature::toCelsius(tempF));
    lcd.print("C");

    if (tempF > 62) {
        digitalWrite(RELAY_PIN, HIGH); // Set relay pin to HIGH
        lcd.setCursor(0, 3);
        lcd.print("System On "); // Display "System On" message
    } else if (tempF < 57) {
        digitalWrite(RELAY_PIN, LOW); // Set relay pin to LOW
        lcd.setCursor(0, 3);
        lcd.print("System Off "); // Display "System Off" message
    } else {
        Serial.println("Error: Could not read temperature data");
    }
}

delay(500);
## Appendix E – Design Verification Plan & Report (DVPR)

<table>
<thead>
<tr>
<th>Test #</th>
<th>Specification</th>
<th>Test Description</th>
<th>Measurements</th>
<th>Acceptance Criteria</th>
<th>Required Facilities/Equipment</th>
<th>Parts Needed</th>
<th>Responsibility</th>
<th>Test Date</th>
<th>Final Date</th>
<th>Numerical Results</th>
<th>Notes on Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling Time</td>
<td>Our group will turn on the refrigeration system that will cool the tank through evaporation. The tank will be entirely insulated.</td>
<td>Temperature in F &amp; (Pass/Fail)</td>
<td>Design needs to cool water below 59°F and be within 1°F of the initial temperature</td>
<td>AeroHanger using a thermocouple probe</td>
<td>Team will need the cool water tank, insulation, and functioning refrigeration kit</td>
<td>Nick</td>
<td>9/25/2023</td>
<td>5/25/2023</td>
<td>Pass</td>
<td>This test was confirmed to be able to reach our desired temperature from the subsequent test (Cooling Speed) reaching a temperature of 52°F.</td>
</tr>
<tr>
<td>2</td>
<td>Cooling Speed</td>
<td>Our group will cool a full tank starting at an ambient temperature of 79°F and record the time the process until it reaches 59°F.</td>
<td>Temperature in F</td>
<td>Time in seconds</td>
<td>Design should be able to fully cool an ambient tank of water in 90 minutes</td>
<td>AeroHanger using a thermocouple probe</td>
<td>Team will need the cool water tank, insulation, and functioning refrigeration kit</td>
<td>Tanner</td>
<td>9/25/2023</td>
<td>5/25/2023</td>
<td>After 60 minutes the average temperature of the water in the evaporator was 60°F and after 120 minutes the water temperature was 52°F.</td>
</tr>
<tr>
<td>3</td>
<td>Heat Loss at steady state</td>
<td>The group will calculate the heat loss over 30 minutes by taking the temperature every minute and plotting it on an excel sheet. The test will be meant to prove that the insulation has enough thermal resistance to make heat transfer to the surrounding hot air negligible.</td>
<td>Temperature in F</td>
<td>Time in seconds</td>
<td>Design should be able to prevent loss of 100 BTU of heat loss per hour</td>
<td>AeroHanger using a thermocouple probe</td>
<td>Team will need the cool water tank, insulation, and functioning refrigeration kit</td>
<td>Nick</td>
<td>9/25/2023</td>
<td>5/25/2023</td>
<td>Temperature increased by 3°F over the course of the test. Over the course of 30 minutes the temperature increase while the system was off was much less than expected showing that our insulation worked better than anticipated.</td>
</tr>
<tr>
<td>4</td>
<td>Ease of filling</td>
<td>User will remove and replace empty ambient water storage jug.</td>
<td>Pass/Fail</td>
<td>Water jug should be able to be removed with relative ease</td>
<td>No outside parts needed</td>
<td>Josh</td>
<td>9/20/2023</td>
<td>5/25/2023</td>
<td>Pass</td>
<td>Sealed water jugs are able to be inserted and removed with relative ease depending on weight of the system off the ground.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Water Leak Test</td>
<td>User will fill system completely with water and inspect all hose connection points every 5 minutes for 30 minutes for any signs of leaking water.</td>
<td>Pass/Fail</td>
<td>All hose connection points are dry with no water leakage</td>
<td>No outside parts needed</td>
<td>Josh</td>
<td>9/25/2023</td>
<td>5/25/2023</td>
<td>Pass</td>
<td>No water leaked during the 30 minute duration. Water was left in system overnight and no signs of leakage was present.</td>
<td></td>
</tr>
</tbody>
</table>
Appendix F – Test Procedures

Test 1: Cooling Full Capacity of Water to Desired Temperature

**Purpose:** The purpose of this test is to confirm that the system can cool our full capacity (24 qt) to a maximum temperature of 59°F. Scope: This test is designed to verify that our system can meet the design specifications of cooling water to a temperature of 59° or below.

**Equipment:**
- Ambient temperature water (T > 85°F)
- Constructed refrigeration system with insulation around reservoir
- Digital multimeter with waterproof thermocouple attachment
- Bucket to capture dispensed water

**Hazards:**
- Damage to equipment if water is spilled
- Frostbite if skin is directly exposed to reservoir walls for prolonged time

**PPE Requirements:**
- Gloves – Safety Glasses

**Facility:** Testing will be done in either Mustang60/AeroHangar

**Procedure:**
1. Completely fill cold water reservoir with ~24 qt ambient temperature water.
2. Submerge thermocouple probe in colder water reservoir.
3. Plug in the refrigeration unit and ensure the compressor is running.
4. Record data from multimeter every minute until the temperature reaches a steady state.
5. Empty the cold-water reservoir using the dispensing taps connected to the outside of the system.
6. Repeat steps 1 through 5 at least four more times
Test 2: Cooling Speed

Objective: This test determines the cooling speed for our refrigeration system. The goal is to cool a full tank of water from an ambient temperature of 76 degrees Fahrenheit to 59 degrees Fahrenheit and record the total time it takes to do so. In addition, a second test will be carried out where chilled water will be dispensed at the same rate as the ambient source feeding into the water cooler. This will test how long the water cooler can maintain the temperature running consistently.

Equipment:
- Cold-water reservoir
- Refrigeration system
- Thermometer
- Stopwatch
- Small container (ice bath to calibrate thermometer)

Hazards:
- Water damage to electronics
- Refrigerant leaks

PPE Requirements:
- Goggles
- Gloves

Facility:
- Cal Poly Aero Hangar Machine Shop

Procedure: (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):
The first experiment procedure will be as follows:
1. Power on refrigeration system and wait until steady state.
2. Fill the reservoir with 5 gallons of ambient temperature water.
3. Calibrate thermometer in ice bath (32 degrees Fahrenheit).
4. Place the thermometer in the water reservoir and measure initial temperature.
5. Set a timer for every 2.5 minutes and record the temperature every 2.5 minutes.
6. When the water reaches 59 degrees Fahrenheit, record the total time.
7. Turn off the refrigeration system.
8. Repeat this procedure 2 more times. (3 Total)
The second experiment procedure will be as follows:

1. Power on refrigeration system.
2. Fill the reservoir with 5 gallons of ambient temperature water.
3. Calibrate thermometer in ice bath (32 degrees Fahrenheit).
4. Place the thermometer in the water reservoir and wait until the temperature reaches steady state (around 50 degrees Fahrenheit).
5. Dispense 1L (approx. 0.25 gallon) of cold water every 2.5 minutes and add 1L of ambient water back into the water reservoir.
6. Measure and record the cold-water reservoir temperature every 2.5 minutes.
7. When the water reaches above 59 degrees Fahrenheit, record the total time.
8. Turn off the refrigeration system.
9. Repeat this procedure 2 more times. (3 Total)
Test 3: Transient Water Temperature Response

Purpose: This test determines the cooling speed and power of our refrigeration system.

Scope: The goal is to cool a volume of water from 80 to 59 degrees Fahrenheit in a 60-minute time.

Equipment:
- Cold-water reservoir
- Refrigeration system
- Scale
- Thermometer
- Stopwatch
- Small container (for ice bath)

Hazards:
- Water damage to electronics
- Refrigerant leaks

PPE Requirements:
- Goggles
- Gloves

Facility:
- Cal Poly Aero Hangar Machine Shop

Procedure: (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):
   The experiment procedure will be as follows:
   1. Weigh and record empty cold-water reservoir.
   2. Fill reservoir with approximately 30 Liters.
   3. Weigh full reservoir to obtain precise volume of water.
   4. Calibrate thermometer in ice bath (32 degrees Fahrenheit).
   5. Place the thermometer in the water reservoir.
   6. Let stand until temperature reaches equilibrium with surroundings.
   7. Power on refrigeration system and start stopwatch.
   8. Record temperature and time every 10 minutes for 60 minutes.
   9. When the water reaches 59 degrees, turn off the refrigeration system and empty the water tank.
   10. Repeat the above steps for 6 trials, changing the water between each.
For baseline:

1. Weigh the empty cold-water reservoir.
2. Fill the reservoir with approximately 30 Liters.
3. Calibrate the thermometer in the ice bath for a starting point.
4. Place the thermometer in the water reservoir.
5. Record the temperature and time every 10 minutes for 60 minutes to determine the change in temperature.
Test 4: Ease of Refilling

**Purpose:** This test determines if a person of average height and strength is able to lift both jugs into the cabinet and place them onto the seats.

**Scope:** The goal is to cool a volume of water from 80 to 59 degrees Fahrenheit in a 60-minute time.

**Equipment:**
- Two 5-Gallon Water Jugs
- Water Cooler

**Hazards:**
- Water damage to electronics
- Lifting Heavy Objects

**PPE Requirements:**
- Safety Glasses

**Facility:**
- Cal Poly Aero Hangar Machine Shop

**Procedure:** (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):

The experiment procedure will be as follows:
1. Place two empty jugs into the cabinet and onto seats to simulate water being emptied.
2. Remove two empty jugs from cabinet, one at a time.
3. Lift a single, full, water jug into the cabinet and flip upside down, with the spout facing down and place the water jug onto the seat.
4. Repeat step 3 with another full water jug, placing onto the reaming seat.
5. Objectively record the difficulty as to whether a person of average height and strength could accomplish.