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Flat Plate Solar Collector for a Tiny Home

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FLAT PLATE SOLAR COLLECTOR
FOR A TINY HOME:
AN ENGINEERING DESIGN
CASE STUDY

By

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Abstract

Pallet Shelter is a company that builds tiny houses for the homeless. We partnered with them to build a solar water heater for their homes so that their tenants can have hot running water. The collector panel sits on the roof of the shelter and absorbs the energy of the sun and uses it to heat water flowing through an array of copper pipes. The hot water is then stored in an insulated tank inside the shelter.

Quad Chart

Solar Water Heater

Team JACCE: James Poek, Alvin Dau, Clarice Nicholas, Crosby Olson, Ed Weise

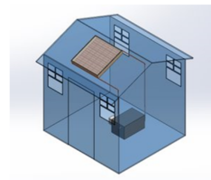
Objective:

- **To improve the quality of life of the tenants of Pallet Shelter by providing them with hot running water**
- **To help lead Pallet Shelter towards supplying fully off-the-grid housing**
- **Target audience is low-income individuals who don't have any means to access hot water**
- **Current tenants only have a bed and maybe a table and chair as their facility**

Concept:

Install a solar water heater system on a Pallet Shelter house to provide hot water, storage of hot water, and the ability to dispense this hot water for the tenants

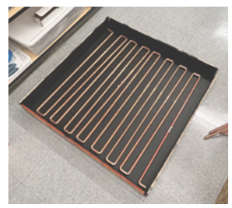
- **Temperature: At least 120 degrees Fahrenheit**
- **Storage: Holds at least 10 gallons of water (roughly enough for a 5 minute shower) and keeps it hot for at least 4 hours**



Approach:

1. **Implement a flat plate solar collector to capture the sun's thermal energy**
2. **Store hot water in an insulated tank to keep the water hot for multiple hours so that the tenants may use it when they please**
3. **Dispense hot water using a dispense valve inside the Pallet Shelter**

Physical System:



Flat Plate Solar Collector

Insulated Water Tank

Critical Features

Critical Features

- Capture solar energy (convert to heat)
- Storage of hot water
- Dispenses hot water

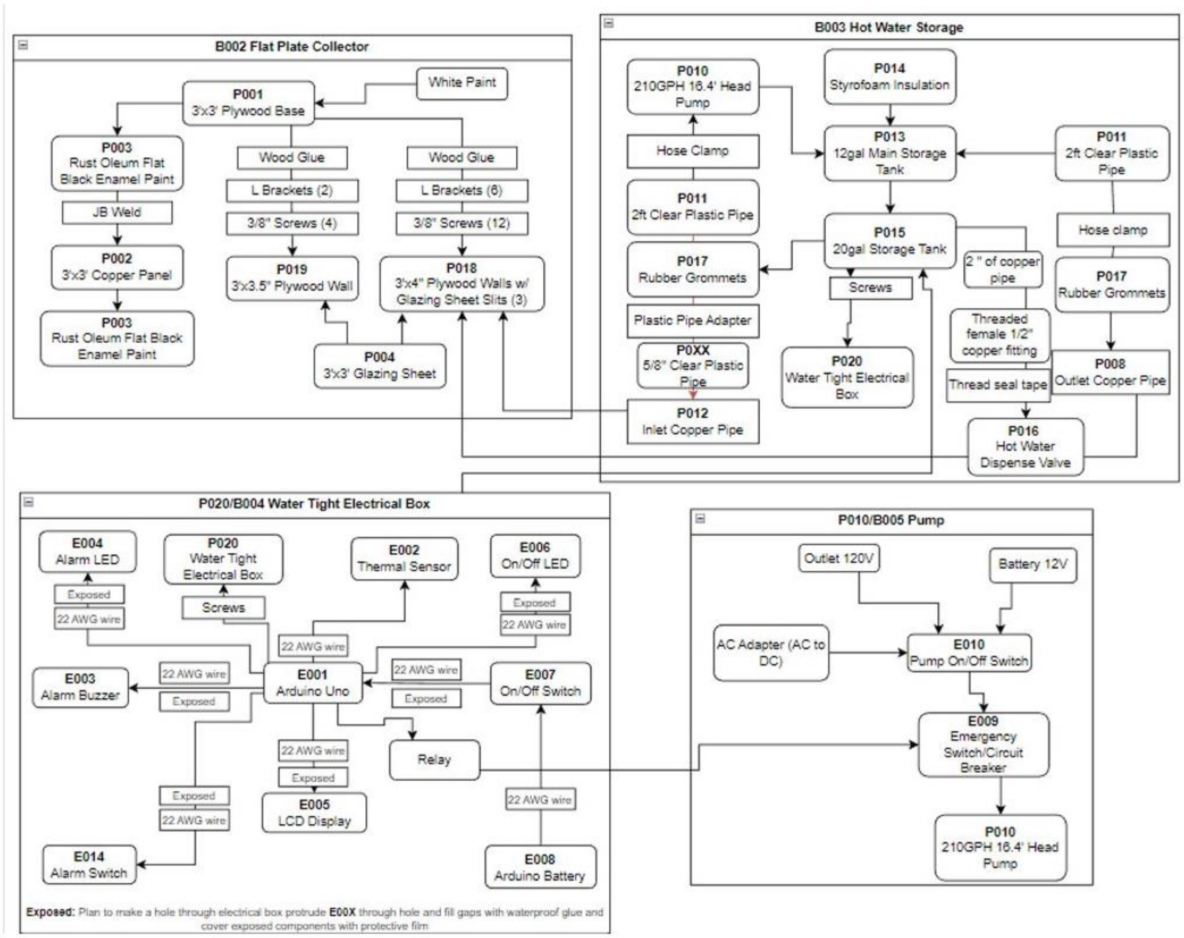
Reliability	20
Durability	20
Safety	15
Efficiency	10
User-Friendly	10
Cost (Maintenance)	10
Power Consumption	5
Security	5
Size	5
Total	100

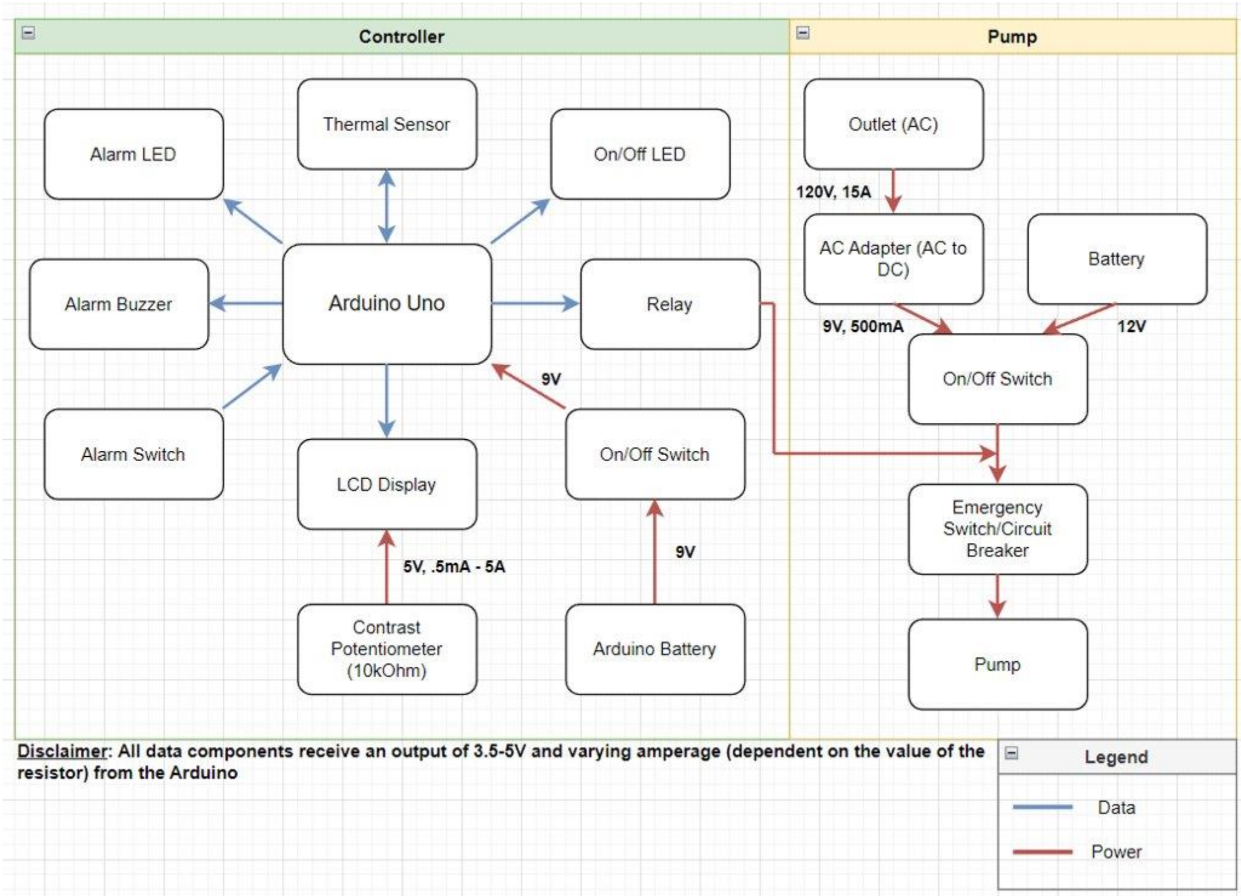
Customer Prototype

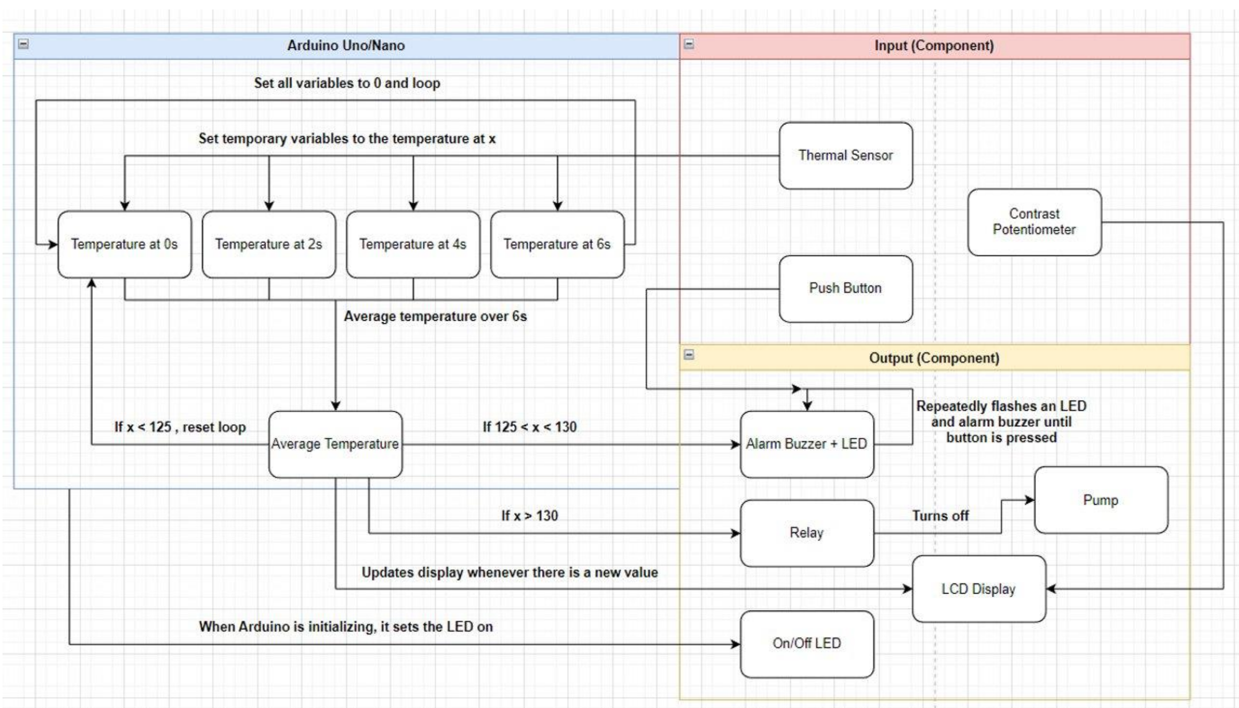
1) **Who is our target audience?**
    a) Pallet Shelter – Our targeted company where we plan to sell our product
    b) Low-income communities
    c) Homeless community
2) **Who are our competitors?**
    a) Low Income Housing Institute
    b) RV companies
3) **Why hasn't it been solved yet?**
    a) Cost of solar thermal energy products might be too expensive
    b) Not necessary for on-the-grid housing
    c) Consumers must actively seek out solar water heaters relying on non-standard sales channels (decreasing the demand)

Pallet Shelter would be receiving our addition to their product, which eventually would go towards aiding those in need of a home. Most likely Pallet Shelters will be targeting the low income and homeless communities around Washington. These communities will be able to have a roof over their heads and a sense of security that would supply a quality of life they may not have been experiencing much previously, including the luxury of hot water. The shelter must be able to survive all types of weather that various areas of Washington can muster and keep our addition, along with all other amenities, functioning and safe within the shelter. This addition will set the Pallet Shelter apart from others as these can be used off the grid and provide a more private living situation with access to hot water.

Block Diagram




Controller
Pump
Thermal Sensor
Alarm LED
On/Off LED
Outlet (AC)
120V, 15A
AC Adapter (AC to DC)
Battery
Alarm Buzzer
Arduino Uno
Relay
9V, 500mA
12V
9V
On/Off Switch
Alarm Switch
LCD Display
On/Off Switch
Emergency Switch/Circuit Breaker
5V, .5mA - 5A
9V
Contrast Potentiometer (10kOhm)
Arduino Battery
Pump
Disclaimer: All data components receive an output of 3.5-5V and varying amperage (dependent on the value of the resistor) from the Arduino
Legend
Data
Power


Arduino Uno/Nano
Input (Component)
Set all variables to 0 and loop
Set temporary variables to the temperature at x
Thermal Sensor
Contrast Potentiometer
Temperature at 0s
Temperature at 2s
Temperature at 4s
Temperature at 6s
Push Button
Average temperature over 6s
Output (Component)
Repeatedly flashes an LED and alarm buzzer until button is pressed
If x < 125 , reset loop
Average Temperature
If 125 < x < 130
Alarm Buzzer + LED
Pump
If x > 130
Relay
Turns off
Updates display whenever there is a new value
LCD Display
When Arduino is initializing, it sets the LED on
On/Off LED

Risk Reduction Prototype

Electrical/Computer: Thermal and weight/volume sensors: The use of sensors is required to be able to measure the current temperature of the water as well as being able to find the value for the current capacity. We have had some prior experience working with other sensors on an Arduino Uno but nothing like the ones required for this project. **For the RRP, we propose to build a system that can analyze the capacity and temperature of any sized storage tank.**

Mechanical: We have never designed a plumbing system before and it has been close to a year since our MEs have taken Thermodynamics, Fluid Mechanics, and Heat Transfer. Our ability to properly design and build a working plumbing system is a concern for us. In addition, we are concerned that we will need a lot of review of our courses to properly do the analysis for heat loss, head loss, etc. **For the RRP, we propose to build the piping required for the water supply and finalize all calculations before the quarter ends. Then we will move forward within future quarters.**

Engineering Analyses

This analysis is based on equations taken from the textbook *Solar Engineering of Thermal Processes* by John A. Duffie and William A. Beckman

We solved for the useful energy output of the collector using the equation $Q_u = A_c F_R[S - U_L(T_i - T_a)]$ where A_c is the area of the collector, F_R is the collector heat removal factor, S is the solar radiation absorbed by the collector, U_L is the heat transfer coefficient for the energy lost from the collector, T_i is the fluid inlet temperature, and T_a is the ambient temperature.

To find the collector heat removal factor F_R we used the equation $F_R = \frac{\dot{m}C_p(T_{f,o}-T_{f,i})}{A_c[S-U_L(T_{f,i}-T_a)]}$ where $\dot{m}$ is the fluid flow rate, C_p is the specific heat capacity, $T_{f,i}$ is the fluid inlet temperature, and $T_{f,o}$ is the fluid outlet temperature. We used 120˚F for the outlet temperature and 80˚F for the inlet temperature.

To find the total heat transfer coefficient U_L we found heat transfer coefficients for the top, bottom, and edges of the collector and then added them so that $U_L = U_t + U_b + U_e$

To find the heat transfer coefficient from the top of the collector we used the equation $U_t = \left(\frac{1}{h_{p-c} + h_{r,p-c}} + \frac{1}{h_w + h_{r,c-a}}\right)^{-1}$ where h_{p-c} is the convection coefficient between the plate and the cover, $h_{r,p-c}$ is the radiation coefficient from the plate to the cover, h_w is the wind heat transfer coefficient, and $h_{r,c-a}$ is the radiation coefficient from the cover to the air.

For the radiation between the plate and the cover we used $h_{r,p-c} = \frac{\sigma({T_p}^2+{T_c}^2)(T_p+T_c)}{\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_c}-1}$ where σ is the Stefan-Boltzmann constant, T_p is the temperature of the plate, T_c is the temperature of the cover, ε_p is the emittance of the plate, and ε_c is the emittance of the cover and then for the radiation from the cover to the air we used $h_{r,c-a} = \varepsilon_c \sigma({T_c}^2 + {T_s}^2)(T_c + T_s)$ with those same variables.

We used 120˚F for the plate temperature and 80˚F for the ambient temperature and for the cover temperature we used $T_c = T_p - \frac{U_t(T_p-T_a)}{h_{p-c} + h_{r,p-c}}$ where we would guess a cover temperature and calculate h_{p-c} and $h_{r,p-c}$ using it and then plug them back into that equation and repeat again using the result until we reached a result close to the input.

For h_{p-c} we used $h = Nu\frac{k}{L}$ where Nu is the Nusselt number, k is the thermal conductivity of air, and L is the space between the plate and the cover.

To find h_w we used $h = \frac{8.6V^{0.6}}{L^{0.4}}$ where V is the wind speed and L is the length of the roof. We used 5 m/s for the wind speed because that is close to the world average wind speed.

For the heat transfer from the bottom of the collector we just used $U_b = \frac{k}{L}$ where k and L are the thermal conductivity and thickness of the plywood.

For the heat transfer from the edges of the collector we used $U_e = \frac{(UA)_{edge}}{A_c}$ where we found $(UA)_{edge}$ by dividing the thermal conductivity of the plywood by it thickness, then multiplying by the length of the perimeter, and then multiplying that by the thickness of the collector.

To find the Nusselt number we used the equation $Nu = 1 + 1.44\left[1 - \frac{1708}{Ra\cos\beta}\right]\left(1 - \frac{(\sin 1.8\beta)^{1.6}1708}{Ra\cos\beta}\right) + \left[\left(\frac{Ra\cos\beta}{5830}\right)^{1/3} - 1\right]$ where Ra is the Raleigh number and β is the slope of the panel.

To find the Raleigh number we used $Ra = \frac{g\beta' \Delta T L^3}{v\alpha}$ where g is the gravitational constant (9.81 m/s^2), and β' is the volumetric coefficient of expansion which is just $1/T$ for an ideal gas, ΔT is the temperature difference, L is the plate spacing, v is the kinematic viscosity, and α is the thermal diffusivity.

To find the solar radiation we used $S = I_b R_b(\tau\alpha)_b + I_d(\tau\alpha)_d\frac{(1+\cos\beta)}{2} + \rho_g(I_b + I_d)(\tau\alpha)_g\frac{(1-\cos\beta)}{2}$ where I is intensity, ρ is reflectance, and $(\tau\alpha)$ is the transmittance-absorptance product and the subscripts b stands for beam, d stands for diffuse, and g stands for ground. Also R_b is a geometric factor (we used 1) and β is the slope of the panel. The transmittance-absorptance product $(\tau\alpha) = \frac{\tau\alpha}{1-(1-\alpha)\rho_d}$ where τ is the transmittance and α is the absorptance.

The transmittance $\tau = \tau_a\tau_r$ and the absorptance $\alpha = 1 - \tau_a$ where τ_a is the absorption transmittance and τ_r is the radiation transmittance and the reflectance $\rho = \tau_a(1 - \tau_r)$

The absorption transmittance $\tau_a = e^{-KL/\cos\theta_2}$ where K is the extinction coefficient (we used 4 m^{-1}), L is the thickness of the cover, and θ_2 is the angle of refraction.

The radiation transmittance $\tau_r = \frac{1}{2}\left[\frac{1-r_{\parallel}}{1+r_{\parallel}} + \frac{1-r_{\perp}}{1+r_{\perp}}\right]$ where $r_{\parallel}$ is the parallel reflectance and $r_{\perp}$ is the perpendicular reflectance.

The parallel reflectance $r_{\parallel} = \frac{tan^2(\theta_2-\theta_1)}{tan^2(\theta_2+\theta_1)}$ and the perpendicular reflectance $r_{\perp} = \frac{sin^2(\theta_2-\theta_1)}{sin^2(\theta_2+\theta_1)}$ where θ_1 is the angle of incidence and θ_2 is the angle of refraction. We find the angle of refraction using $\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$ where n_1 is the refractive index of air and n_2 is the refractive index of the cover.

To find the intensity, first we found the clear sky beam radiation using $I_{cb} = 3600 G_o \tau_b$ where we used $G_o = G_{sc}[1 + 0.033\cos\left(\frac{360n}{365}\right)]\cos\theta_z$ where G_{sc} is the solar constant (1353 W/m^2), n is the day of the year, and θ_z is the zenith angle and $\tau_b = a_o + a_1 e^{-k/\cos\theta_z}$ where $a_o = 0.4237 - 0.00821(6-A)^2$ and $a_1 = 0.5055 + 0.00595(6.5-A)^2$ and $k = 0.2711 + 0.01858(2.5-A)^2$ where A is the altitude.

Then we found the clear sky diffuse radiation using $I_{cd} = 3600 G_o \tau_d$ where $\tau_d = 0.271 - 0.2939\tau_b$

The clear sky total radiation is then $I_c = I_{cb} + I_{cd}$ and now I/I_c can be determined.

I_d/I is then found using $\frac{I_d}{I} = \begin{cases} 1.00 - 0.1\frac{I}{I_c} & \text{for } 0 \le \frac{I}{I_c} < 0.48 \\ 1.11 + 0.0396\left(\frac{I}{I_c}\right) - 0.789\left(\frac{I}{I_c}\right)^2 & \text{for } 0.48 \le \frac{I}{I_c} < 1.10 \\ 0.20 & \text{for } 1.10 \le \frac{I}{I_c} \end{cases}$ and from there we can solve for I_d and then I_b is just $I - I_d$

We plugged all these equations into excel and found that $Q_u = 929.76848$ J

Specifications

Project Definition

Team JAACE's goal is to design a flat plate solar collector that can heat up water for the tenants of Pallet Shelter. This device will greatly increase the quality of life for the tenants of Pallet Shelter as their health and hygiene can be maintained more.

1. The system works by absorbing the Sun's thermal energy and using it to heat the copper pipes that run inside the collector.
2. The copper plates attached to the base of the collector will absorb thermal energy from the sun and heat up the copper pipes and water running inside them.
3. A water pump will then be installed in the insulated water tank to pump water through the system.
4. The water will circulate through the system until it reaches a temperature of 120°F-130°F.
5. The controller in the system will notify the tenant when the desired heat is reached, as well as the capacity of the tank.
6. The tenant is then free to collect the hot water through a dispense valve located on the main storage tank.

Goals

Safety (S)

Maintaining clean and healthy water for our tenants is the most important goal but creating a secure and simple installation process and system are also top priorities. The system will be securely fastened to the shelter roof able to withstand extreme weather/winds. The plumbing will be completely concealed removing the chance of contact burning and the water will maintain a temperature that will not scald users with contact for less than 4 minutes.

S001 Bacteria growth prevention: **The water shall be heated to between 120°F and 130°F and should be heated to between 125°F and 130°F by the time it is dispensed.** Water in plumbing systems has to be kept at a certain heat for the water to remain bacteria free. The minimum temperature is 120°F but the main goal is to prevent all bacteria growth so the goal will be to reach and maintain a minimum temp of 125°F. Water will keep circulating in the system until the optimal temperature is reached. To ensure the desired temperature is met, a thermometer and the thermal sensor (part# E002) will be used to measure/validate this temperature.

S002 Withstanding high winds: **The panel shall be able to withstand wind speeds of less than or equal to 70 MPH and should be able to withstand wind speeds of less than or equal to 90 MPH.** The flat plate solar collector will be secured in place on the roof of the Pallet Shelter house. Pallet Shelter claims their tiny home can withstand up to 90 MPH winds therefore, the solar collector being a part of the Pallet Shelter system must meet the same standards. This will be validated by conducting multiple static structural analyses on the collector attached to the roof with 90 mph winds coming from different directions in each scenario.

Efficiency (E)

The solar collector system needs to collect enough sun to heat the water consistently to 120°F for the tenants. The system must be insulated properly so as not to lose heat, and the panel's function must collect an appropriate amount of sun to efficiently heat the water while it circulates through our copper plumbing.

E001 Pump power: **The pump shall be able to pump water at least 8 feet vertically to flat plate panel in 1 minute or less and should be able to pump water at least 9 feet 2 inches vertically to flat plate panel in 45 seconds or less.** This will ensure the pump can pump water from the floor to the roof of Pallet Shelter. The current pump has specifications of being able to pump water vertically 16.4 feet. This specification will be validated by pumping 5 gallons of water vertically 9 feet 2 inches (height of collector on shelter) through a copper pipe.

E002 Water tank: **The water shall lose no more than 10°F after 4 hours in the 10-gallon water tank and should lose no more than 5°F after 4 hours in the 10-gallon water tank.** The water tank should be able to store and keep 10 gallons of initially 130°F water hot (at least 120°F). Record the temperature of water after 2 hours and after 4 hours using a thermometer and the thermal sensor (part# E002) to validate that the tank can hold heat inside it. This will additionally be validated by conducting a heat loss analysis on the fully insulated tank.

E003 Flat Plate Solar Collector: **The flat plate solar collector shall succeed in raising the water temperature (of at least 80°F) by at least 40°F and should succeed in raising the water temperature (of at least 80°F) by at least 45°F.** The flat plate solar collector will be used to heat water. It needs to be able to raise the heat of the water above room temperature, starting with lukewarm water and making it hot. A sunlight simulation analysis will be done to ensure that the flat plate solar collector could absorb the heat required to heat the water running inside them. Then a test will be conducted to determine the accuracy of the simulation.

E004 Pump head: **The pump shall be able to pump 5 gallons of water through at least 48 feet of piping in 5 minutes or less and should be able to pump 5 gallons of water through at least 50 feet of piping in 5 minutes or less.** This will demonstrate that the pump is powerful enough to circulate water through our entire plumbing system. We will use a tape measure to validate the length of the pipe and use a timer to time how long it takes for the water to travel through.

E005 Water Dispensing: **The valve that dispenses water from the storage tank shall be able to dispense at least 7 gallons of water and should be able to dispense at least 9 gallons of water.** Proving that the hot water is easily accessible for the Pallet Shelter tenants. We validate this by dispensing water from the storage tank through the dispensation valve into a 5-gallon bucket and measuring the amount water dispensed.

E006 Volume Measurement: **The water level gauge shall measure the volume of water in the storage tank with an accuracy of ≤ ½ gallons and should measure the volume of water in the storage tank with an accuracy of ≤ ¼ gallons.** This demonstrates that our system can accurately communicate to the tenants how much hot water is at their disposal. This will be validated by conducting multiple tests comparing the measurement from the water level gauge to the amount measured when the water from the tank is poured into 5-gallon buckets.

Cost (C)

With a low-income community being our target audience, we want to make sure our system has been planned out and is reasonably priced, making the system available to more people. The system we will be building will be a representation of our desired final product. With additional material purchases and some alternative metals for the structure we have outlined a cost estimate.

C001 Total Cost: **The total cost of the system shall be less than or equal to $1200 and should be less than or equal to $1000.** The total cost of all our system needs to stay reasonable for Pallet Shelter to implement it into their design. We will total the cost of our system by adding together the costs of our materials and labor hours.

Durability (D)

With our flat plate solar collector being secured to the roof of Pallet Shelter, as well as other parts of our system being secured to the outside of Pallet Shelter, we understand the importance of building a system that can withstand weather conditions and last for multiple years without needing maintenance.

D001 Wear and Tear: **The system shall experience less than or equal to 2 leaks during final testing and should experience 0 leaks during final testing.** During the testing phase the copper piping system (B001) should experience no leaks to ensure the most efficient heating and circulation of the water. This will be validated through visually observing the interior of the collector for any evidence of a water leak.

Electrical (A)

For the electrical specifications, most of them pertain to the safety of the controller, this spans from the prevention of water from entering the controller to a safety switch to turn off all electrical components with high voltages to prevent any hazards. The remaining specifications pertain to quality-of-life characteristics, such as the alarm that notifies users to when the water achieves its desired temperature.

A001 Alarm System: **The system shall sound off an alarm as the temperature of the water is ≥120°F and ≤130°F, and it should sound off when reaching ≥125°F and ≤130°F**. A thermometer will be used to validate the temperature when the alarm goes off, with the alarm being an audio cue from the buzzer along with a flashing LED to notify the user to turn off the pump/system.

A002 IP Water Resistance Rating: **The controller shall have no harmful effects from an IPx4 rating of water being poured on the enclosure from any direction and should have no harmful effects from an IPx6 rating of powerful water jets projected onto the enclosure**. Voltmeter to assure the system continues to function.

A003 On/Off grid: **The pump should be able to function off the power from an AC outlet and should function off both an AC outlet and DC battery using different plugs**. Voltmeter to assure the system continues to function and visual validation that water is being circulated around the system.

A004 Safety Switch: **The system shall turn off the pump from either the AC outlet or DC battery and should be able to turn off the pump from both AC and DC.** Voltmeter to assure the system continues to function and visual validation that water is being circulated around the system.

A005 Relay: **The system shall turn off the pump when the temperature of the water within the tank reaches past ≥135°F and turn back on when ≤135°F and should turn off the pump when it is ≥130°F and turn it on when ≤130°F.** Voltmeter to assure the pump is off and visual validation that the water is not being circulated around the system.

ID	Requirement	Threshold (Shall)	Objective (Should)	Validation
		SAFETY		
S001	Bacteria growth prevention	≥120°F and ≤130°F	≥125°F and ≤130°F	Thermometer, thermal sensor
S002	Withstanding high winds	≤70 MPH	≤90 MPH	Static wind/structural analysis
		EFFICIENCY		
E001	Pump Power	≥ 8ft in 1 minute	≥ 9ft 2" in 45 seconds	Visual validation of pumping 5 gallons of water vertically
E002	Water Tank	Loses ≤ 10°F in 4 hours	Loses ≤ 5°F in 4 hours	Thermometer and thermal sensor. Heat loss analysis
E003	Flat plate solar collector	Initial temp ≥80°F, Raise ≥ 40°F	Initial temp ≥80°F, Raise ≥ 45°F	Sunlight simulation analysis
E004	Pump Head	In 5 minutes, water travels ≥ 48ft	In 5 minutes, water travels ≥ 50ft	Tape Measure Timer
E005	Water Dispensing	≥ 7 gallons dispensed	≥ 9 gallons dispensed	5-gallon bucket
E006	Volume Measurement	≤ ½ gallons	≤ ¼ gallons	Water Level Gauge, 5-gallon buckets

COST				
C001	Total Cost	≤ $1200	≤ $1000	Excel Budget and Receipt Tracker
DURABILITY				
D001	Wear and Tear	Within one week of testing, we shall experience ≤ 2 leaks	Within one week of testing, we shall experience 0 leaks	Post 1-week observations
ELECTRICAL				
A001	Alarm System	≥120°F and ≤130°F	≥125°F and ≤1230°F	Thermometer, Visual and Audio cue from alarm
A002	IP Water Resistance Rating	IPx4: Protected against splashing water	IPx6: Protected against water jets	Voltmeter to assure the system continues to function
A003	On/Off Grid	Pump functioning off an AC outlet	Pump functioning off both AC outlet and DC battery	Voltmeter and visual validation that water is being circulated around the system
A004	Safety Switch	Turns off the pump from either AC or DC	Turns off the pump from both AC and DC	Voltmeter and Visual validation that water is being circulated around the system
A005	Relay	≥135°F and ≤135°F	≥130°F and ≤130°F	Voltmeter and visual validation that the water is not being circulated around the system

Test Log

Introduction and Overview

This document outlines the procedures in which Team JACCE will complete their testing for all their functional specifications. Each specification test plan outlined provides clear directions on how each test should be conducted as well as which specification the test covers. The most important section of each specification test plan is located in the "Description and/or images of test setup" section where there is a clear step by step instruction guide on how the test should be conducted. One important note to make is that no specification test plan covers specifications S002 or C001. This is because S002 is a specification that has already been proven through an analysis and C001 is a specification team JACCE will confirm once the entire system is finished, and the costs have been compiled.

Specification	**Test**
S001	ST001
S002	N/A
E001	ST003
E002	ST002
E003	ST001
E004	ST004
E005	ST002
E006	ST005
C001	N/A
D001	ST001
A001	ST006
A002	N/A
A003	N/A
A004	ST007
A005	ST006

Specification Test Plan 1

Team/Project:	**JACCE/Solar Collector for Tiny Homes**
Test Name:	**Water Circulation**
Test ID Number:	**ST001**
Relevant functional specification(s) being tested:	S001 D001 E003
Type of test (circle)	Black Box
Purpose of test and test summary including number of replicates of test	To ensure that the water circulating around the system will experience an increase in temperature of 40°F while maintaining its temperature between 120°F and 130°F and experiencing no leaks. The electrical system will be able to turn the system on and off at appropriate times to keep the water temperature within our desired range. This test will be conducted at least three times this quarter to ensure that the test result is valid.
Equipment List:	• Halogen lamps • Solar collector • Insulated tank • Water pump • 80^{o}F water • Thermal sensor with electrical box display
Necessary dummy inputs, their source, and mechanism for validation of dummy inputs:	Halogen lamps are necessary to simulate the sun and similar temperatures experienced in Riverside, California. The lamps will both be set up pointing directly at the solar collector to do so. The water inside the tank will initially be 80°F so when the temperature increase for E003 is surpassed the S001 spec can be properly tested in succession. Different tests from a range of initial water temperatures will take place separately.
Description and / or images of test setup	1. Connect the solar collector to the insulated water tank 2. Connect the electronics to the electric socket 3. Fill the insulated tank with 80°F water 4. Turn the system on and wait for water to circulate until the desired temperature is reached by checking the electrical display every 30 minutes 5. During this time ensure the system continues to circulate and does not turn off 6. Record the time it takes to increase the water temperature by 40°F 7. Have the system continue circulating until it reaches a temperature greater than 130°F to ensure our system stops circulating to prevent scalding

	8. Once the system has turned off at 130°F artificially alter the temperature of the water down to 120°F and leave the water to decrease below 120°F 9. When the water falls below 120°F the system should then turn on again by itself to maintain the desired temperature range.
Inputs or input ranges to be used (include number or test points and increments)	We will be using an input of 80°F water with the hope of our system achieving an increase in the temperature of the water by at least 40°F and maintaining that temperature between 120°F and 130°F.
Anticipated results/outcomes	• The water maintains a temperature of between 120°F and 130°F • The system will turn off when >130°F and will turn back on once the temperature <120°F • The temperature of the water was raised by at least 40°F • When the system is turned on and circulating, the system experiences no leaks

Specification Test Log

Date/Time of testing:	3/17-28/23 & 5/15-16/23 (D001), 5/16/23 (E003 & S001)
Test participants:	James, Crosby, Ed, Alvin, Clarice
Test ID Number:	ST001
Relevant functional specification(s) being tested:	S001 D001 E003

Test Results

Time	Water Temp	ATM Temp
12:07	81.1F	93.8F
1:07	84.4F	95.6F
2:07	87.1F	96.0F
3:07	89.5F	95.3F
4:07	91.5F	95.0F

Test Deviations

Instead of checking just the electrical display every thirty minutes we also used a Fluke device to compare the temperatures of the water inside the insulated tank to the data on the display.

Since the water did not experience the temperature increase desired, the temperature increasing portion of the test was stopped after 4 hours and the water inside the tank was artificially altered to conduct the electrical system testing portion.

Test Results (circle)

Pass	Fail

Test Commentary

The test was considered a partial pass. Initially the temperature increase was not reached and so the test would fail right there. However, the plan was to artificially alter the temperature of the water and so once the initial portion failed the water temperature was changed manually to continue through the rest of the electrical testing portion which passed. The analyses performed show data that make this goal achievable but the halogen lamps we used were not performing as well as intended.

Signoff

Name	Signature	Role
James Poek		
Ed Weise		
Alvin Dau		
Crosby Olson		
Clarice Nicholas		

Specification Test Plan 2

Team/Project:	JACCE/Solar Collector for Tiny Homes
Test Name:	**Water Tank**
Test ID Number:	**ST002**
Relevant functional specification(s) being tested:	E002 E005
Type of test (circle)	Black Box
Purpose of test and test summary including number of replicates of test	This test ensures that the water inside the tank will not lose more than 5°F for at least 4 hours and that it can dispense at least 9 gallons of water. This test will be done at least twice to ensure that the tank can keep the water inside warm and is able to dispense the water.
Equipment List:	• Water tank • Two 5-gallon buckets • 130°F water • Thermal sensor with electrical box display • Timer
Necessary dummy inputs, their source, and mechanism for validation of dummy inputs:	The two 5-gallon buckets are necessary to show a minimum of 9 gallons has been dispensed from the tank. Using a starting water temperature of 130°F, the highest in the desired range, to keep the maximum 10°F change on our spec within the 120-130°F safe range
Description and / or images of test setup	1. Set up the insulated water tank 2. Fill it up with 10 gallons of 130°F water 3. Record the time and the initial temperature of the water 4. Come back after each hour to record the change in temperature of the water by checking the electrical display 5. Repeat step 4 three times to make sure that the water does not lose more than 5°F for at least 4 hours 6. Turn the dispense valve on and dispense all the water out of the insulated tank into the two 5-gallon buckets 7. Measure the amount of water in the two 5-gallon buckets to ensure it is at least 9 gallons full
Inputs or input ranges to be used (include number or test points and increments)	Initial water temperature of 130°F which is the hottest our system will heat the water up to
Anticipated results/outcomes	• The water did not lose more than 5°F during the 4 hours of testing • The dispense valve was able to dispense at least 9 gallons of water

Specification Test Log

Date/Time of testing:	5/16/2023 (E005), 5/14/2023 (E002)
Test participants:	James, Crosby, Ed, Alvin, Clarice
Test ID Number:	ST002
Relevant functional specification(s) being tested:	E002 E005

Test Results

The water started at a temperature of 130.8˚F and after 4 hours had dropped down to 122.3˚F.

Test Deviations

Instead of taking a measurement of the temperature of water every hour, during the second iteration of this test the team measured the temperature of the water twice, once every 2 hours. A fluke temperature measurement device was also used to find the temperature of the water.

Test Results (circle)

Pass	Fail

Test Commentary

This test was completed without the final layer of insulation installed when the tank will be fully sealed. Once this layer has been installed and the box is sealed then the expected temperature drop would be lower. Team JACCE is working to install all electrical components and ensure water tightness before the top of the tank is sealed.

Signoff

Name	Signature	Role
James Poek		
Alvin Dau		
Crosby Olson		
Clarice Nicholas		
Ed Weise		

Specification Test Plan 3

Team/Project:	JACCE/Solar Collector for Tiny Homes
Test Name:	**Water Pump Head Height Test**
Test ID Number:	**ST003**
Relevant functional specification(s) being tested:	E001
Type of test (circle)	White Box
Purpose of test and test summary including number of replicates of test	This test ensures that the pump is powerful enough to pump the water from the insulated tank into the roof of the Pallet Shelter house where the solar collector is placed. We plan to conduct this test at least three times to provide confidence that our pump is powerful and consistent.
Equipment List:	• 5 gallons of water • Two 5-gallon buckets • Water pump • 9’ 2” of rubber hose • Timer
Necessary dummy inputs, their source, and mechanism for validation of dummy inputs:	Test will not take place on the shelter but somewhere else where the pipe can be extended at least 9’ 2”. Two 5-gallon buckets will be used. One at the base of the pipe and one at the top of the pipe to show that 5 gallons can be pumped up the required height.
Description and / or images of test setup	1. Get 5 gallons of water and fill a 5-gallon bucket with it 2. Place the water pump inside the 5-gallon bucket 3. Connect the water pump to the 9’ 2” hose 4. Hold the hose and turn the pump on to let water flow up 9’ 2” into the empty 5-gallon bucket 5. Measure the amount of time it takes for all 5 gallons to be pumped up 9’ 2” into the empty 5-gallon bucket
Inputs or input ranges to be used (include number or test points and increments)	We have an input of 9’ 2” of vertical piping because that is the maximum height of Pallet Shelter. While we do not intend for our tank to sit on the floor of the shelter resulting in needing to pump the water up vertically 9’ 2”, we want to account for all potential optimal design changes.
Anticipated results/outcomes	• Water was pumped vertically to a height of 9’ 2”

Specification Test Log

Date/Time of testing:	4/13/2023
Test participants:	James, Crosby, Ed, Clarice
Test ID Number:	ST003
Relevant functional specification(s) being tested:	E001

Test Results

The pump managed to pump all 5 gallons of the water in the bucket up the entire 9 feet and 2 inches. However, it was not able to do it in the time frame that we had hoped, leading us to a partial pass. This is not detrimental because a slower flow rate would assist our heat transfer.

Test Deviations

As stated in the log we did not perform this test on the shelter itself. There was not a specific location listed but we ended up doing this in the staircase near the back doors of Otto Miller to accommodate the required height.

Test Results (circle)

Partial Pass	Fail

Test Commentary

The test received a partial pass because the time limit was surpassed for pumping the water up the height we wanted to achieve.

Signoff

Name	**Signature**	**Role**
James Poek		
Alvin Dau		
Crosby Olson		
Clarice Nicholas		
Ed Weise		

Specification Test Plan 4

Team/Project:	JACCE/Solar Collector for Tiny Homes
Test Name:	**Pump Power Test**
Test ID Number:	**ST004**
Relevant functional specification(s) being tested:	E004
Type of test (circle)	White Box
Purpose of test and test summary including number of replicates of test	This test is done to demonstrate that the water pump is powerful enough to circulate water through the solar collector and around the system. We plan to conduct this test at least three times to provide confidence that our pump is powerful and consistent.
Equipment List:	• Tape Measure • Timer • Solar Collector • Water pump • Water and two 5-gallon bucket • Rubber hoses • Clamps
Necessary dummy inputs, their source, and mechanism for validation of dummy inputs:	Spec E004 mentions a 5-minute time limit for the water to circulate. A circulation time of over 5 minutes is not detrimental as a slower flow rate may prove more efficient for a temperature rise in the water. One 5-gallon bucket will be placed at the inlet side of the solar collector to feed water and one on the outlet of the solar collector to catch and prove the 5 gallons make it through the solar collector instead of using the insulated tank.
Description and / or images of test setup	1. Measure and record the length of the pipes that run inside the solar collector to ensure it is at least 50' of piping 2. If not, add additional rubber tubing until it reaches 50' 3. Connect the inlet and outlet pipes to a rubber hose using a clamp to let water flow to a bucket that is placed under the outlet pipe 4. Connect the water pump to the rubber hose that connects it to the inlet pipe 5. Place the 5-gallon water bucket on both ends of the solar collector 6. Place the water pump inside the 5-gallon bucket and fill it with water 7. Turn the pump on and start the timer 8. Record the time it takes to pump 5 gallons of water from one end to the other
Inputs or input ranges to be used (include number or test points and increments)	We have an input of at least 50 feet of piping because that is roughly the amount of piping throughout our whole system.

Anticipated results/outcomes	• The pump was able to pump water through 50 feet of piping in at least 5 minutes

Specification Test Log

Date/Time of testing:	5/15/2023
Test participants:	James, Crosby, Ed
Test ID Number:	ST004
Relevant functional specification(s) being tested:	E004

Test Results

The 5 gallons of water were successfully circulated through the 50ft of piping. The duration of the circulation lasted about three and half minutes which is below the 5 minute threshold goal set.

Test Deviations

There were no deviations from the test.

Test Results (circle)

Pass	Fail

Test Commentary

During the second iteration we only measured the temperature twice. A longer piece of plastic tubing was used on the outlet increasing the length of the plumbing well past 50ft.

Signoff

Name	Signature	Role
James Poek		
Alvin Dau		
Crosby Olson		
Clarice Nicholas		
Ed Weise		

Specification Test Plan 5

Team/Project:	JACCE/Solar Collector for Tiny Homes
Test Name:	**Water Level Gauge**
Test ID Number:	**ST005**
Relevant functional specification(s) being tested:	E006
Type of test (circle)	White Box
Purpose of test and test summary including number of replicates of test	This test demonstrates that our system can accurately communicate with its tenants about how much hot water is at their disposal. To ensure that it gives an accurate reading, the result will be compared to the measurement from the water level gauge to the amount measured when the water from the tank is poured into 5-quart buckets. This test will be repeated at least three times to ensure that it gives an accurate reading
Equipment List:	• 5-quart water bucket • Water • Water level gauge • Insulated water tank
Necessary dummy inputs, their source, and mechanism for validation of dummy inputs:	The 5-quart water bucket will be used to remove water from a prerecorded volume in the tank. This will prove the gauge is reading an accurate water volume.
Description and / or images of test setup	1. Fill the insulated tank with random amount of water ranging from 5 gallons to 10 gallons 2. Connect the water level gauge 3. Record the volume of water using the water level gauge 4. Dispense water into the 5-quart bucket until it is full, record the volume, and then dispose of the water 5. Repeat step 4 until all the water is out of the tank 6. Add together how much water was measured using the 5-quart bucket 7. Compare to the measurement recorded using the water level gauge
Inputs or input ranges to be used (include number or test points and increments)	The initial water volume will be recorded below when test is performed. A 5-10 gallon range is used to fill the tank the majority of the way and to increase amount of water level gauge statistics per test.
Anticipated results/outcomes	• The water level gauge should measure the volume of water in the water tank with an accuracy of ≥ ¼ Gallons

Specification Test Log

Date/Time of testing:	5/16/2023
Test participants:	James, Alvin, Crosby, Ed
Test ID Number:	ST005
Relevant functional specification(s) being tested:	E006

Test Results

We passed the test. The one-gallon bucket's measurement always matches the readings on the water level gauge after each one-gallon fill.

Test Deviations

Instead of filling the insulated tank with random amount of water ranging from 5 to 10 gallons, we filled the tank with a one-gallon bucket, starting at one-gallon inside the insulated tank. With the volume level marked on the water level gauge, we can then see how much difference there is between the gauge and one gallon bucket. The test was repeated 9 times until the tank volume reached 10 gallons.

Test Results (circle)

Pass	Fail

Test Commentary

We added more markings to the water level gauge, so it now has ½ gallon markings and ¼ gallon markings.

Signoff

Name	**Signature**	**Role**
James Poek		
Alvin Dau		
Crosby Olson		
Clarice Nicholas		
Ed Weise		

Specification Test Plan 6

Team/Project:	JACCE/Solar Collector for Tiny Homes
Test Name:	**System Software Test**
Test ID Number:	**ST006**
Relevant functional specification(s) being tested:	A001, A005
Type of test (circle)	Black Box
Purpose of test and test summary including number of replicates of test	This test is done to assure and alert the user that the water within the tank is at a safe temperature to use. It will passively record the average temperature of the water every 6 seconds and once it reaches a range of 120˚F -130˚F, it will turn off the pump and notify the user that the water is ready to use. To assess this, we will use water of varying temperatures to ensure that the correct temperature is noted in comparison to the thermometer and if the function for the temperature range is activated.
Equipment List:	• Thermometer • Water tank • Water • Controller
Necessary dummy inputs, their source, and mechanism for validation of dummy inputs:	Instead of waiting for the water to circulate to the minimum temperature, there will be a control water of varying temperatures that will be placed in the tank to test the software. A thermometer will be used to ensure to note the temperature of the control water before being used for testing.
Description and / or images of test setup	1. Record the temperature of the water using a thermometer 2. Turn on the controller 3. Dispense the water into the tank 4. Proceed to wait 6 seconds for the controller to calibrate the average temperature 5. Record and compare the control temperature with the temperature noted by the controller 6. Record if the controller functions as behaved for the current temperature 7. Dispense the remaining water within the tank 8. Repeat steps 1-7 for water of different temperatures
Inputs or input ranges to be used (include number or test points and increments)	Control water with varying temperatures from 70˚F-140˚F (70˚F-90˚F, 100˚F-110˚F, 120˚F-130˚F, and 130˚F-140˚F)

Anticipated results/outcomes	• The controller will continue to have the water circulating if the water is under 120˚F • The controller will alert the user that the water is ready to use at the range of 120˚F-130˚F, as well as shutting off the pump • The controller will shut off the pump if the water is over 130˚F

Specification Test Log

Date/Time of testing:	5/16/2023
Test participants:	Alvin, Ed, James
Test ID Number:	ST006
Relevant functional specification(s) being tested:	A001, A003, A005

Test Results

Thermometer Temp (° F)	Arduino Temp. (° F)	Water Status	Pump Status
60	60	Not Ready	Pumping
63	63	Not Ready	Pumping
66	66	Not Ready	Pumping
69	69	Not Ready	Pumping
72	72	Not Ready	Pumping
75	75	Not Ready	Pumping
78	78	Not Ready	Pumping
81	81	Not Ready	Pumping
84	84.6	Not Ready	Pumping
87	87.1	Not Ready	Pumping
89	90.1	Not Ready	Pumping
93	93.4	Not Ready	Pumping
96	96.1	Not Ready	Pumping
99	98.8	Not Ready	Pumping
102	102.4	Not Ready	Pumping
105	105.8	Not Ready	Pumping
108	107.5	Not Ready	Pumping
111	111.1	Not Ready	Pumping
114	114.4	Not Ready	Pumping

117	116.5	Not Ready	Pumping
120	120.8	Ready	Pumping (going to 125) Pumping Stopped (reached 125)
123	123.1	Ready	Pumping (going to 125) Stopped Pumping (hit 125)
126	125.9	Ready	Stopped Pumping
129	129.3	Ready	Stopped Pumping
132	131.6	Not Ready	Stopped Pumping
135	135.2	Not Ready	Stopped Pumping

Test Deviations

There were no deviations for this test.

Test Results (circle)

Pass	Fail

Test Commentary

This was our statistical test. We are going to redo it before Tuesday.

Signoff

Name	Signature	Role
James Poek		
Alvin Dau		
Crosby Olson		
Clarice Nicholas		
Ed Weise		

Specification Test Plan 7

Team/Project:	JACCE/Solar Collector for Tiny Homes
Test Name:	**Electrical Safety Test**
Test ID Number:	**ST007**
Relevant functional specification(s) being tested:	A004
Type of test (circle)	White Box
Purpose of test and test summary including number of replicates of test	This test is done to ensure the safety of the electrical system from the power source (AC or DC) to the pump. The test will revolve around a circuit breaker and whether or not it will open the circuit upon reaching 3A.
Equipment List:	• Multimeter • Circuit Breaker • Power Supply
Necessary dummy inputs, their source, and mechanism for validation of dummy inputs:	Instead of using power directly from a battery or outlet, the test will be done through the laboratory power supply where the amperage of the circuit could be adjusted. The amperage of the circuit will be tested and validated with a multimeter.
Description and / or images of test setup	1. Turn on the power supply and set the amperage 2. Record the amperage of the circuit using the multimeter 3. Attach the circuit breaker to the power supply using 24 AWG wiring 4. Record if the circuit breaker is activated or not 5. Using the multimeter, see if there is any voltage on the other side of the circuit breaker (check if the circuit is open) 6. Compare the recording of the amperage to the result of the circuit breaker 7. Repeat steps 1-6 for varying amperages
Inputs or input ranges to be used (include number or test points and increments)	Amperage from the power supply ranging from .5A-3.5A (.5A-2.5A, 3-3.5A)
Anticipated results/outcomes	• The circuit will remain closed under 3A • The circuit will open when reaching 3A

Specification Test Log

Date/Time of testing:	5/16/2023
Test participants:	James, Alvin
Test ID Number:	ST007
Relevant functional specification(s) being tested:	A004

Test Results

Voltage	Amperage	Fuse (Wire)
10V	0A - 0.5A	Attached
10V	0.5A - .1A	Attached
10V	1.5A - 2A	Attached
10V	2.5A - 3A	Attached
10V	3A – 3.5A	Attached
10V	3.5A - 4A	Attached
10V	>4A	Snapped

Test Deviations

There were no deviations for this test.

Test Results (circle)

Pass	Fail

Test Commentary

The fuse snapped exactly when we wanted it to.

Signoff

Name	Signature	Role
James Poek		
Alvin Dau		
Crosby Olson		
Clarice Nicholas		
Ed Weise		

Safety Specifications

Specification	Threshold	Objective	Test Result
S001: Bacteria Growth Prevention	≥120ºF and ≤130ºF	≥125ºF and ≤130ºF	Partial Pass
S002: Wind Protection	≤70 MPH	≤90 MPH	Partial Pass

S001:

This one is a partial pass due to the analytical evidence that we provided.

Temp(F)	Temp(K)	Flow rate(gph)	Mass flow rate(kg/s)	specific heat of water(kj/kg*K)	Heat required(W)	Time to get from 80-120(hours)	Time it takes for 1 cycle(hour)
80	299.816667	210	0.220153284	4.187	**1 degree raise per cycle:**		0.047619048
81	300.372222				512.101	1.904761905	
80.5	300.094444				**.5 degree raise per cycle:**		
80.3333333	300.001852				256.0505	3.80952381	
80.1190476	299.882804				**1/3 degree raise per cycle:**		
					170.7003333	5.714285714	

Average annual solar radiation in Riverside, CA		A(m^2)
6.35	kWh/m^2/day	0.7715
264.5833333	W/m^2	
204.1260417	W	

Halogen Lamps:	
10 degree raise in 4 hours	
840	gallons
84	cycles
0.119047619	degree increase per cycle
60.96440476	Watts

S002:

Partial Pass due to the analytical evidence we provided.

Wind Speed = 90mph

Panel:

- a 90-mile-per-hour (mph) wind speed creates a pressure of $(0.00256 \times (90^2)) = 20.736$ psf
  psf = pounds per square foot
- Force = Area x Pressure x C_d = $9ft^2$ x 20.736psf x 2.3 = 429.23psf
- Area = 3ft x 3ft = 9 ft^2
- C_d of a solar collector = 2.3

Brackets:

- Coefficient of exposure (K) = 0.003052 (Because it is in a flat, unobstructed areas.)
- Estimate wind pressure on a structure: $q = KV^2$
  q = 0.003052 x 902 = 24.72psf
  I am assuming that the Pallet Shelter home is an important structure. Which means, wind pressure should be multiplied by 1.15
  Calculated wind pressure = 24.72psf x 1.15 = 28.428psf

Therefore, since the pressure created by a 90mph wind is smaller than the calculated wind pressure, it is ensured that the panel will stay in place under a 90mph wind.

Efficiency Specifications

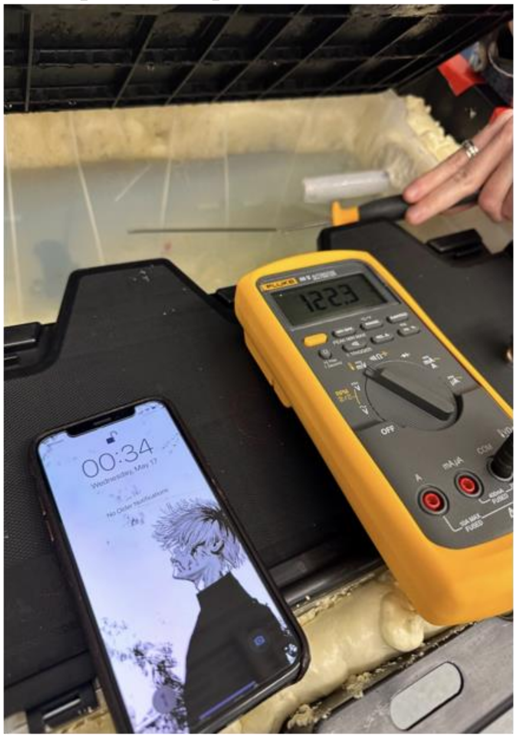
Specification	Threshold	Objective	Test Result
E001: Pump Power	Pump water >8ft in 1 min	Pump water >9ft 2in, in 45 sec	Fail
E002: Water Tank	Loses ≤ 10°F in 4 hours	Loses ≤ 5°F in 4 hours	Pass
E003: Flat Plate	Initial temp ≥80°F, Raise ≥ 40°F	Initial temp ≥80°F, Raise ≥ 45°F	Fail
E004: Pump Head	In 5 minutes, water travels ≥ 48ft	In 5 minutes, water travels ≥ 50ft	Pass
E005: Water Dispensing	≥ 7 gallons dispensed	≥ 9 gallons dispensed	Pass
E006: Volume	≤ ½ gallons	≤ ¼ gallons	Pass

E001:

Remains a fail for now, retesting before Tuesday 5/30 meeting.

E002:

This spec was a pass.



E003:

This one is a fail due to inadequate temperature rise from the halogen lamp testing performed.

Temp(F)	Temp(K)	Flow rate(gph)	Mass flow rate(kg/s)	specific heat of water(kj/kg*K)	Heat required(W)	Time to get from 80-120(hours)	Time it takes for 1 cycle(hour)
80	299.816667	210	0.220153284	4.187	**1 degree raise per cycle:**		0.047619048
81	300.372222				512.101	1.904761905	
80.5	300.094444				**.5 degree raise per cycle:**		
80.3333333	300.001852				256.0505	3.80952381	
80.1190476	299.882804				**1/3 degree raise per cycle:**		
					170.7003333	5.714285714	

Average annual solar radiation in Riverside, CA		A(m^2)
6.35	kWh/m^2/day	0.7715
264.5833333	W/m^2	
204.1260417	W	

Halogen Lamps:	
10 degree raise in 4 hours	
840	gallons
84	cycles
0.119047619	degree increase per cycle
60.96440476	Watts

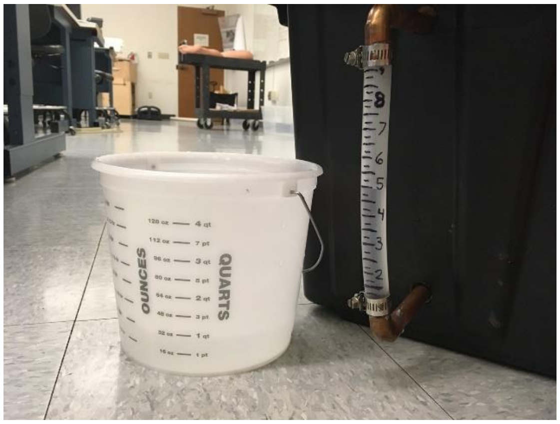
E004:
This a pass, but we are retesting before our Tuesday 5/30 meeting.

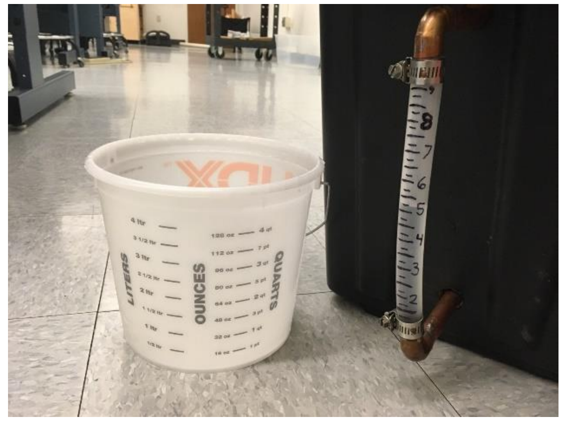
E005:

This spec is a pass.

E006:

This spec is a pass and additional water level marking have been implemented to satisfy the threshold. We will discuss this in the Tuesday 5/30 meeting.





Cost Specification

Specification	Threshold	Objective	Test Result
C001	≤ $1200	≤ $1000	Pass

C001:

This spec is a pass. We could make our estimate for the cost of labor more accurate by considering the cost of the factory.

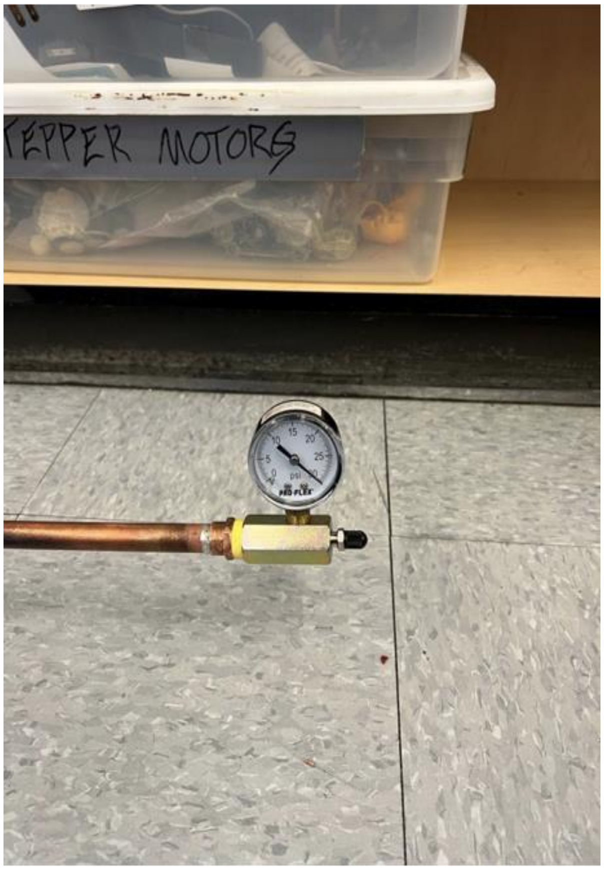
Part ID	Part Name	Supplier	Stock or Material Price (Per 1)	Quantity to Order	Total for Annual Budget
P001	3'x3' Plywood Base	Home Depot	$10.90	1	$10.90
P002	3'x3' Copper Panel	Amazon	$30.99	6	$185.94
P003	Rustoleum Flat Black Enamel Paint	Lowe's	$45.98	1	$45.98
P004	3'x3' Glazing Sheet	Home Depot	$43.88	1	$43.88
P005	45ft Interior Copper Plumbing	Lowe's	$16.97	5	$84.85
P006	32 90 Degree Copper Bends	Home Depot	$27.41	1	$27.41
P008	8ft Outlet Copper Pipes	Home Depot	$16.97	1	$16.97
P009	2ft Clear Rubber Pipe	Lowe's	$6.88	1	$6.88
P010	430 GPH 8.2' Head Pump	Home Depot	$52.53	1	$52.53
P011	2ft Clear Plastic Pipe	Lowe's	$4.47	1	$4.47
P012	7.5ft Inlet Copper Pipes	Home Depot	$16.97	1	$16.97
P013	12gal Main Storage Tank	Home Depot	$11.98	1	$11.98
P014	Styrofoam Insulation	Home Depot	$9.97	6	$59.82
P015	20gal Storage Tank	Lowe's	$24.98	1	$24.98
P016	Hot Water Dispense Valve	Home Depot	$4.87	1	$4.87
P017	Rubber Grommets	Home Depot	$17.95	1	$17.95
P020	Water Tight Electrical Box	Amazon	$22.99	1	$22.99
P021	90 Degree Bend Connecter Pipes	Lowe's	$16.97	1	$16.97
E001	Arduino Uno	Arduino	$27.60	1	$27.60
E002	Thermal Sensor	Amazon	$2.40	1	$2.40
E003	Alarm Buzzer	Amazon	$0.70	1	$0.70
E004	Alarm LED	Amazon	$0.05	1	$0.05
E005	LCD Display	Amazon	$4.50	1	$4.50
E006	On/Off LED	Amazon	$0.05	1	$0.05
E007	On/Off Switch	Amazon	$0.90	1	$0.90
E008	Arduino Battery and Case	Amazon	$3.50	1	$3.50
E009	Emergency Switch	Amazon	$11.99	1	$11.99
E010	Pump On/Off Switch	Amazon	$11.99	1	$11.99
E011	Contrast Potentiometer	Amazon	$1.00	1	$1.00
E014	Alarm Switch	Amazon	$0.90	1	$0.90
				Subtotal	$721.92
				Tax (10.1%)	$72.91
				Total	$794.83
				Labor Hours($18/hr)	20 hours
				Payment for Labor	$360
				Total Price	$1,154.83

Durability Specification

Specification	Threshold	Objective	Test Result
D001: Wear and Tear	Within one week of testing, we shall experience ≤ 2 leaks	Within one week of testing, we shall experience 0 leaks	Pass

D001:

This spec is a pass. Done correctly following construction procedure the system will experience no leaks.



We left the pressure test for the panel plumbing for about a week and experienced no leaks.

Electrical Specifications

Specification	Threshold	Objective	Test Result
A001: Alarm System	≥120ºF and ≤130ºF	≥125ºF and ≤130ºF	Pass
A002: IP Rating	IPx4: Protected against splashing water	IPx6: Protected against water jets	Fail
A003: On/Off Grid	Pump functioning off an AC outlet	Pump functioning off both AC outlet and DC battery	Partial Pass
A004: Safety Switch	Turns off the pump from either AC or DC	Turns off the pump from both AC and DC	Pass
A005: Relay	≥125ºF	≥125ºF and ≤128ºF	Pass

A001:

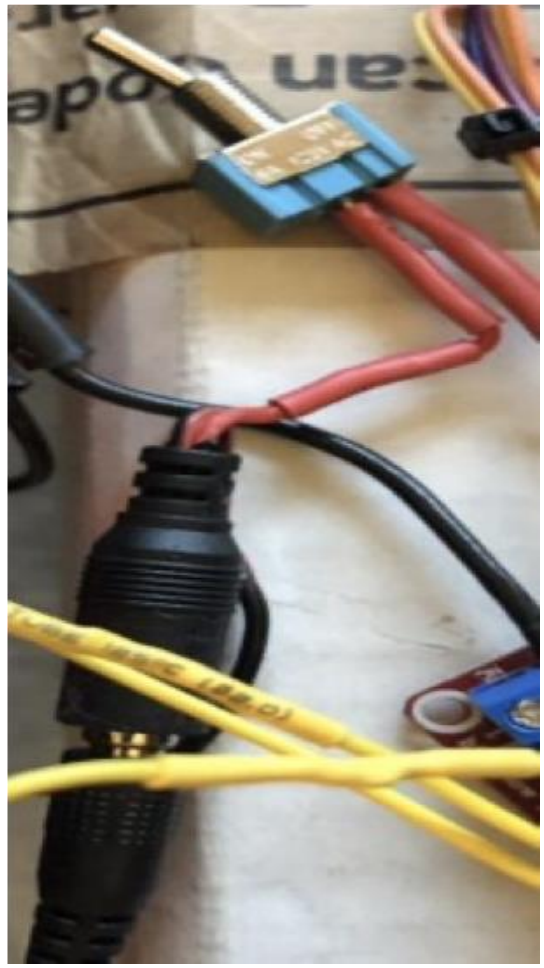
This spec is a pass.

A002:

This spec is a fail and will be tested before our Tuesday 5/30 meeting.

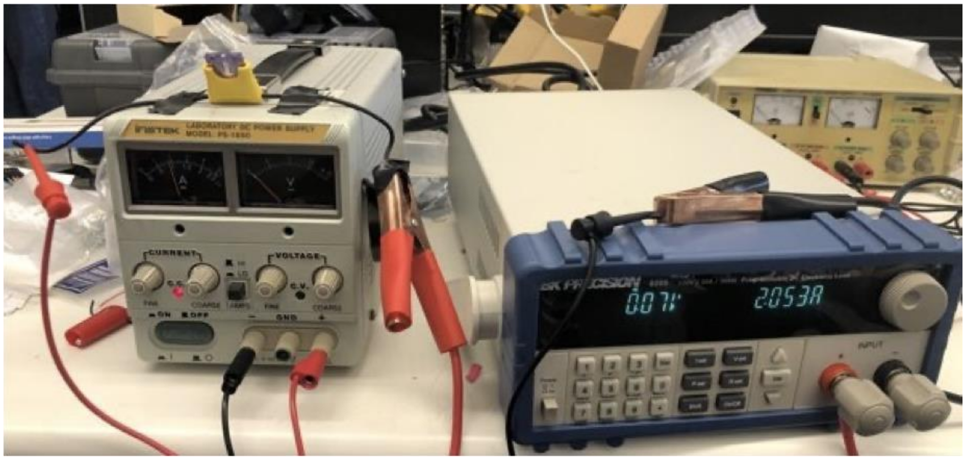
A003:

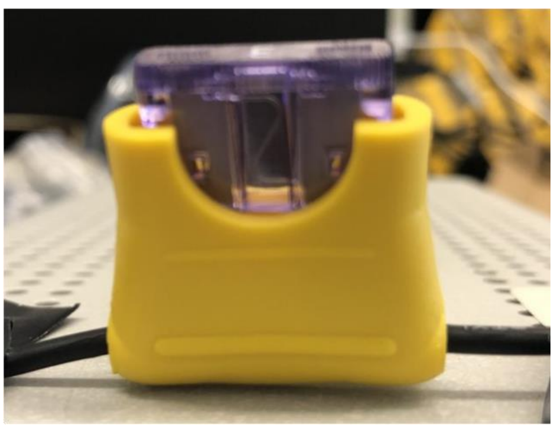
This spec is a partial pass and will be tested properly before our Tuesday 5/30 meeting.

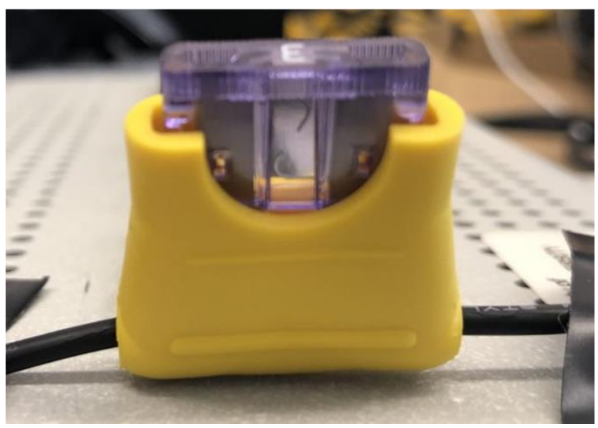


A004:

This spec is a pass.







A005:

This spec is a pass.

Thermometer Temp (° F)	Arduino Temp. (° F)	Water Status	Pump Status
60	60	Not Ready	Pumping
63	63	Not Ready	Pumping
66	66	Not Ready	Pumping
69	69	Not Ready	Pumping
72	72	Not Ready	Pumping
75	75	Not Ready	Pumping
78	78	Not Ready	Pumping
81	81	Not Ready	Pumping
84	84.6	Not Ready	Pumping
87	87.1	Not Ready	Pumping
89	90.1	Not Ready	Pumping
93	93.4	Not Ready	Pumping
96	96.1	Not Ready	Pumping
99	98.8	Not Ready	Pumping
102	102.4	Not Ready	Pumping
105	105.8	Not Ready	Pumping
108	107.5	Not Ready	Pumping
111	111.1	Not Ready	Pumping
114	114.4	Not Ready	Pumping
117	116.5	Not Ready	Pumping
120	120.8	Ready	Pumping (going to 125) Pumping Stopped (reached 125)
123	123.1	Ready	Pumping (going to 125) Stopped Pumping (hit 125)
126	125.9	Ready	Stopped Pumping
129	129.3	Ready	Stopped Pumping
132	131.6	Not Ready	Stopped Pumping
135	135.2	Not Ready	Stopped Pumping

Project Impact

The global impact of our project is limited because our product is designed for use by Pallet Shelter which is an American company. In the future it is possible that our design could be modified for use in other parts of the world, but currently we are focusing on optimizing our project for conditions in California where many of the current Pallet Shelter villages are located. Rather than creating a product with a global impact, we are focusing for now on meeting the needs of a specific local market. Our project is designed for use by the tenants of Pallet Shelter, but the concept could be extended fairly easily to fit other contexts in the future. We designed our product to serve people experiencing homelessness, but a solar water heater could also possibly be useful for people trying to take their homes off-grid.

Our project has an impact on the economy because we designed our product to be cheap so that it can be used by homeless and low-income individuals without being excessively limited by cost. Creating a cheap solar water heater causes it to become accessible to lower-income populations as well as just generally reducing the price of solar water heaters overall. Our target customer is the homeless tenants of Pallet Shelter, but if we put a cheap solar collector on the market then that would also lower the price of solar water heaters for people like hobbyists because the price would drop in order to stay competitive. Designing our product to not be very expensive causes it to be a viable option for our target homeless customer, but it also makes solar water heating a more cost-effective option for people who may not be low-income but might just be interested in heating their water with a solar collector.

Our project has a positive environmental impact because it provides a way to heat water without using as much electricity. The solar collector panel uses sunlight to heat the water instead of using electricity to make the heat, and so the only electricity that the water heater needs to use is just enough to run the pump. Our system is also designed to be able to operate off-grid, which makes it even more environmentally friendly because then it doesn’t need to be drawing electricity from the grid at all and it just runs off of a battery instead. The minimal electricity used and the ability to go fully off-grid have a positive effect on the environment, but we need to pay attention to the materials that we use in the water heater so that none of them negatively impact the environment. The plastics used for the tank could potentially be bad for the environment depending on what we use.

The social impact of our project is very positive because our product is designed to help those in need to have a better quality of life. Our water heater is designed to be implemented on the houses used by Pallet Shelter to serve people experiencing homelessness and our goal for our project is that it will raise the living standards of the people staying in the shelters by providing them with hot running water which is currently an amenity that they do not have. Providing hot running water for the tenants of these shelters is a way to humanize a group of people who are often marginalized by society by providing them with a basic human need (water) so that they can be a little more comfortable in their temporary homes. Having the solar water heater to provide them with hot water when they need to will help the tenants of the shelters feel more welcomed in the community.

The effect of our product on local communities is very positive because it improves the quality of life of the homeless tenants in the Pallet Shelter houses and helps them feel a greater sense of belonging in their temporary homes. Having hot running water in their houses will make the lives of the tenants a little bit easier and help them feel more comfortable while they are staying in the shelters. The homeless villages that our product will serve are local communities that will be positively impacted by our project and the broader community around the villages of people who are not homeless will also be positively impacted because our product will help close the disparity between them and their homeless neighbors. By improving the quality of life of the homeless tenants we are helping bring them closer to transitioning out of homelessness which is positive for their whole community.

Appendix

Honors Panel Speech

My project looks a bit different from most of the other ones here because, as an engineering student, my senior capstone was a design project, and not a research paper like most other majors. What sets me apart from some other honors projects is that my project was a group project, designed and built with a team of my engineering peers. Our teams were assigned based on shared interests and my team was formed around our desire to build a product with a humanitarian purpose. We knew from the beginning that we wanted to build something that addressed a serious need in our community through our talents in engineering, rather than just creating a consumer product. We chose to focus our attention on the homeless community, and we partnered with a local company called Pallet Shelter which builds tiny homes for unhoused people. Pallet Shelter builds villages of transitional housing to provide a stable environment for people experiencing homelessness as they work towards more permanent housing. Their shelters provide the tenants with a roof over their heads and a bed to sleep on, but they have few amenities beyond these basic needs. Our project seeks to improve the quality of life of the tenants by providing them with hot running water through the installation of a solar water heater on the roof of the shelter.

Homelessness can be a very dehumanizing experience because it isolates individuals from the rest of society. Much of what it means to be human centers around our communal nature and our interactions with the people around us. This makes the experience of homelessness devastating because it marginalizes unhoused people and distances them from those societal interactions. Homeless people are often looked down upon by society and treated as somehow less human than people with more stable housing situations. It can be difficult for them to form meaningful relationships when they are struggling to meet their most basic human needs. A major factor in the dehumanization of people experiencing homelessness is their lack of agency. Homeless people have less resources than those with permanent housing which can cause them to rely heavily on other people and systems around them. This creates a lack of control over their own lives which strips them of their dignity and individuality. Our project seeks to combat this dehumanization of homeless people by providing the tenants living in Pallet Shelter's villages with a little more agency over their lives. Access to water is one of our most basic human needs. Pallet Shelter provides a communal water supply for each of their villages, but the individual shelters do not have direct access to running water within each unit. By providing hot running water to the individual shelters within the village, our project provides the tenants with an increase in their agency over their lives. Having access to hot water within their own shelters allows the tenants a little more individuality and gives them control over their own experiences by reducing their reliance on the central water supply. An individual water supply may seem like a small thing when compared to the huge scope of the problems facing the homeless community, however it gives tenants an increase in agency, which provides them with a sense of privacy and normalcy which combats the effects of the dehumanization that homeless people often experience. Participating in community makes us human, but we cannot engage in this shared community until our individual humanity is affirmed.

Our project addresses this issue by providing hot running water for the tenants of Pallet Shelter through the installation of a solar water heater onto their tiny homes. The three main functions of the system are heating the water, storing the water for later use, and dispensing the water so that the tenants can access it. The water heater is composed of two main components: the flat plate solar collector panel, which sits on the roof of the shelter and heats the water, and the insulated water tank which stores the heated water inside the shelter so that it can be accessed whenever the tenant needs it. The flat plate collector panel is a 3' x 3' panel built of plywood with a transparent acrylic glazing sheet on the top for the sunlight to enter through. The bottom of the panel is lined with copper sheets and the entire inside of the panel is painted black to absorb the heat of the sun. The water flows through an array of copper pipes which snake back and forth across the entire length of the panel for a total length of almost 50 feet of piping. The heat from the sun enters the panel through the acrylic glazing sheet and becomes trapped inside, heating up the copper pipes which in turn heat the water flowing through them. The pipes exiting the panel continue through the roof of the shelter and deposit the water inside the insulated tank which is mounted on the wall inside the shelter where the tenants can access it. The water tank can contain 10 gallons of water and is surrounded by a layer of Styrofoam insulation which keeps the water hot even while the system is not in use so that the tenants have access to warm water at whatever time of day they need it. The water is circulated through the system using a pump which is installed inside the tank. The water in the tank is pumped up through the panel and then returns to the tank at a higher temperature. The pump can be run off both an AC outlet and a DC battery, allowing the system to be run off-grid if necessary. This provides more flexibility for Pallet Shelter by allowing the system to be operated in situations where access to an on-grid power supply may not be available. This is an important consideration in homeless communities where reliable access to power is not guaranteed. It also provides Pallet with the opportunity to make their villages more sustainable by transitioning away from on-grid power and potentially integrating renewable energy sources such as photovoltaic solar panels onto their shelters. The target temperature of the water produced by our panel is 120˚F because we want it to be hot enough to kill any bacteria in the water so that it is safe for the tenants to drink, but we don't want it to be so hot that it scalds the users. This temperature is maintained by our electrical system. The tank is equipped with a temperature sensor which measures the temperature of the water inside the tank and relays that information to our controller. When the temperature measured is below 120˚F the pump turns on and circulates the water through the system. The water continues to circulate until the temperature reaches our desired range of between 120˚F and 130˚F. Once the temperature is within the range, the pump shuts off and the system notifies the user that the water is ready for use through a LED light indicator and a quiet alarm that goes off. If the temperature drops below 120˚F the pump turns back on, and the water circulates until it gets back up to the desired temperature range. Both the temperature of the water and the status of the system (ready or not ready) are displayed on a screen on the outside of the tank for the tenant to see. There is also a water level gauge on the front of the tank so that the tenant can see how much water is left inside the tank. When the water in the tank runs out the tenant can refill the tank through a refill funnel on the top of the tank. This provides clear feedback for the user on the state of the water. For easy access, there is a dispense valve installed on the front of the tank so that the tenant can dispense the hot water whenever they are ready. Our main goals for the system were for it to be safe, efficient, durable, and inexpensive. The safety of the tenants was extremely important to us, which is why we were careful to ensure that the temperature of the heated water would be sufficiently high to kill any bacteria that might be in the initial water so that it would be safe to drink while not becoming so hot that it might scald the tenants when they use it. The system also needed to be durable enough to survive being outside in the elements on the roof of the shelter for a long time without maintenance because the communities that our product is serving will not have access to maintenance services and will need to be able to rely on the system to run consistently and without issues after it is installed. Cost was a huge consideration for our product because the communities that we are serving are low-income and cannot afford expensive products. In order to effectively serve our target customers, our system needed to be simple and inexpensive. The business model that Pallet Shelter follows is to sell their shelters to local nonprofits and social work organizations in areas that express interest in establishing a Pallet Shelter village and then the organization that purchased the shelters is responsible for operating the village and providing social services for the tenants. Pallet does not sell individual shelters directly to tenants. The organizations operating the villages are required to provide resources for the tenants to help them find employment and transition towards permanent housing. Our goal is to make our product affordable to the social service organizations running the villages so that they are able to install our product on the shelters in their villages. In order to achieve this goal, we focused on designing our product in a simple and efficient way with inexpensive materials that could easily be mass-produced.

Overall, my team and I have created a simple solar water heater system, composed of a collector panel and a water storage tank, which is ready to be sold to Pallet Shelter and their partner organizations as well as potentially to any other companies providing transitional housing for homeless people who might be interested in our product. Our hope is that providing access to hot running water within their shelters will increase the quality of life of people living in these shelters and will help them feel less dehumanized and better equipped to participate in society and move towards more permanent living situations. Homelessness is very stigmatized in our culture and this stigmatization cuts unhoused people off from the rest of society and prevents them from connecting fully with the people around them. Their marginalization causes them to be viewed as “other” and can hinder us from empathizing with them as our fellow human beings. Our hope for this project is to begin to bridge that gap by treating the tenants of these transitional villages as human beings with human needs who deserve living situations that provide them with dignity, agency, and privacy, beyond just having their basic needs for survival met. We created this product not just as a demonstration of our engineering skills, but because we wanted to serve a group of people who are routinely underserved and not given the dignity that they deserve as human beings made in the image of God. Our hope is that our product, as small as it is in comparison to all the struggles that these people face, will have a positive impact on their lives and help them feel a sense of agency over their lives.