# Solar Powered Doghouse

ECE 445 Final Paper, Spring 2013

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# Abstract

Our group designed and built a solar powered, temperature controlled doghouse. We chose this project because there are no commercially available doghouses which provide the owners with a convenient way to house their dogs during severe weather conditions, while being powered by solar energy.

A Nichrome wire loop in the floor serves as the heating element, and two fans fixed on the back wall serve to cool the interior. The doghouse has insulated walls and floor to ensure that heat is not lost and the temperature inside is well-maintained. Thermistors provide feedback of the temperature to a heat controller circuit and a cooling controller circuit. Depending on this feedback the heat controller and cooling controller regulate the functioning of the Nichrome wire and fans respectively. A solar panel, mounted on the roof, is used to charge a 12 V battery which in turn powers our circuitry. A battery protection circuit is also included to prevent the battery from over-discharging. The charging of the battery is also monitored by a charge controller, which among other things steps down the voltage from the solar panel to rated battery voltage.

The different circuits and the Nichrome wire are all enclosed by waterproof materials, and care is taken to insulate any exposed electrical parts to make sure the project safe to use. We were able to accomplish our goals for this project and ended up with a fully functional, deployable product.

# Contents

# 1 Introduction

## 1.1 Statement of Purpose

Our aim is to provide dog-owners with a convenient means to house their dog while they are away for the weekend. In winter months the temperature can be set to make sure the doghouse is warm. In the summer months there is an automatic fan system to ensure air circulation.  There are no commercially available doghouses that provide this service while being powered by solar energy. Our group is excited about delivering a product that is safe, economically viable, and environmentally sustainable.

## 1.2 Objectives

The goal of this project is to build a doghouse which controls its own temperature and is powered by solar energy. We will begin by developing a heated floor which will function in extreme weather conditions and will successfully heat a doghouse with inner dimensions of 44’’x 23.5’’x 26’’.  We will be using a Morningstar SunGuard Solar Controller to efficiently harness the power from the solar panels and also help protect the battery. We have a component that protects the battery from being over drained. There is a temperature control component which will receive feedback from temperature sensors that will serve to regulate the temperature of the doghouse. Two small fans will also be installed to provide relief from the heat during the summer. The fan speeds will be automatically varied depending on the current temperature in the house. Finally, the solar panels are installed on the roof of the doghouse to provide power to the various electrical components. The result is fully functional doghouse which is sturdy, safe, easy to use, assemble, and maintain.

### Functions

- Heating element underneath the floor to provide heat, and fans to cool the interior during summer.
- The temperature range specified by the owner is maintained.
- Sensors send feedback to the circuit that determines whether to turn the heating on or off.
- Generates its own power via solar panels.
- Battery for storage of energy.

### Benefits

- No extra electricity cost.
- During winter, once temperature range is set, no need to monitor regularly.
- During summer, fan speeds are automatically changed depending on internal temperature.
- Tiled floor is easy to clean.
- Owner can leave dogs in a convenient temperature-controlled shelter while away.
- Well insulated to minimize heat loss.
- Safe for the dog as there are no exposed electrical components.

# 2 Design

## 2.1 Block Diagram

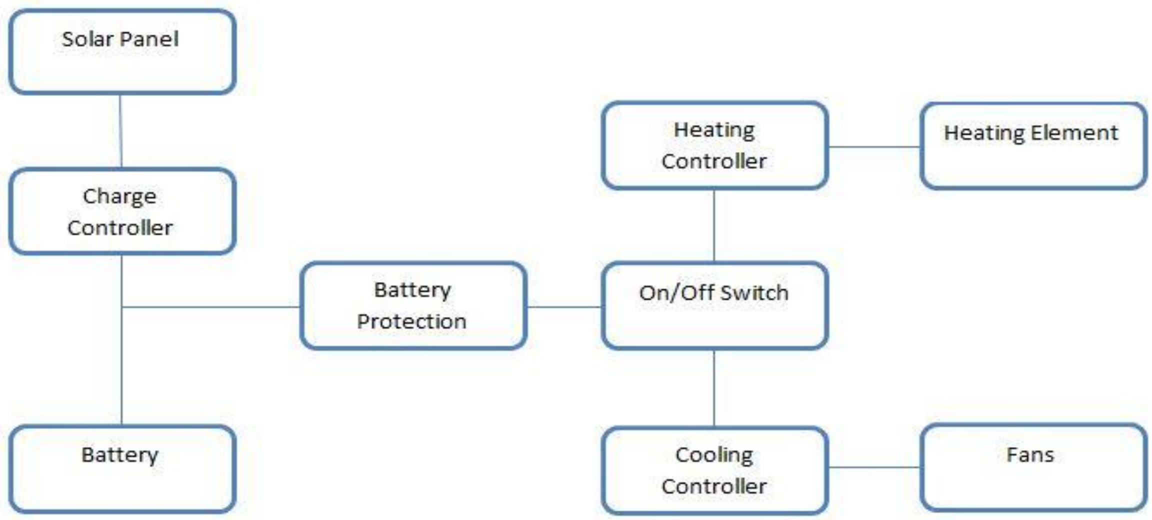



*Figure 1: Block Diagram for the Entire Doghouse System*

## 2.2 Block Descriptions

Solar Panel: The solar panel will be used to collect the energy from the sun throughout the day. The power from the panel will be controlled by the power controller and used to either charge the battery or to power the heating or cooling system. The panel is one 80W panel.

Battery: The battery will be used to power the heating or cooling system when the solar panel is not able to, due to of a lack of sunlight. The battery will be charged by the solar panel through the charge controller when daylight is available and the battery is not fully charged. The battery will be protected from overdischarge or overcurrent by the battery protection circuit. The battery will be a 12V battery with a 75Ah rating. The large Ah rating is required in order to ensure the system can be powered over a specified amount of time without charge from the panel.

Charge Controller: The charge controller will be used to charge the battery using the power from the solar panel. The charge controller will step down the higher voltage from the panel (~18V) to the voltage used to charge the battery (~12V). It also will ensure the battery is not overcharged. This module will be bought from SunGuard in order to maximize the efficiency of charging the battery.

Battery Protection: The battery protection circuitry will protect the battery from overcurrent and overdischarge by the load. The overcurrent protection will prevent the battery from outputting a high current above 5A, which would most likely occur in the event of a fault. In the event of the overcurrent protection being needed, the load will be disconnected by a 5A fuse being blown and the fuse will need to be replaced. The overdischarge current protection will prevent the battery from being over discharged to the point that the battery voltage is below 80% rated voltage, or 10.5V. A lead acid battery can be permanently damaged if discharged below 10.5V. In the event of the overdischarge protection being needed, the load will be disconnected and will not be powered until the battery voltage is recharged above 12.5V (since a fully charged battery is above 12V) and then the load will automatically be reconnected. (See schematic below in Figure 5)

On/Off Switch-: This switch will be a simple SPST switch that will be controlled by the user. When On, the switch provide the panel or battery power to either the heating system or the cooling system depending on the house temperature. There is also an off position if the user does not want the system to run, but still wants to allow the battery to be charged by the panel.

Heating Controller: The heating controller will take the temperature set by the user and begin regulating the house temperature to that setting. The controller will use a thermistor to monitor the temperature of the house. If the temperature is too low with respect to the set temperature, the power controller will start powering the heating element from either the solar panel or the battery. If the temperature is too high with respect to the set temperature, the temperature controller will stop powering the heating element until the temperature drops. The heating controller will also have two other subcomponents incorporated into it. For the protection and comfort of the dog, the heating controller will also have a thermistor used to sense the temperature of the floor and prevent it from overheating. If the floor heats up above a maximum temperature (~102F), the controller will stop powering the heating element and let the heat dissipate before continuing to regulate the overall house temperature to the set value. (See schematic below in Figure 3)

Heating Element: The heating element will consist of a 12.5 feet of nichrome wire laid into the floor. The wire will be arranged into a spread out pattern used to heat approximately half of the floor of the doghouse. Only the back half of the house is being powered due to the high power requirements of the wire and the fact that most heat provided to the floor near the front would be wasted through the door anyway. This is also convenient for the dog since it now can get off the heated portion of the floor, but still be in the warm house. The tile paste will be laid directly onto the wire and the tile floor placed on top to be heated. The heating element will have a voltage applied across it by the temperature controller whenever the temperature in the house is low with respect to the temperature set by the user when the system is set to heating mode. (See element pattern below in Figure 6)

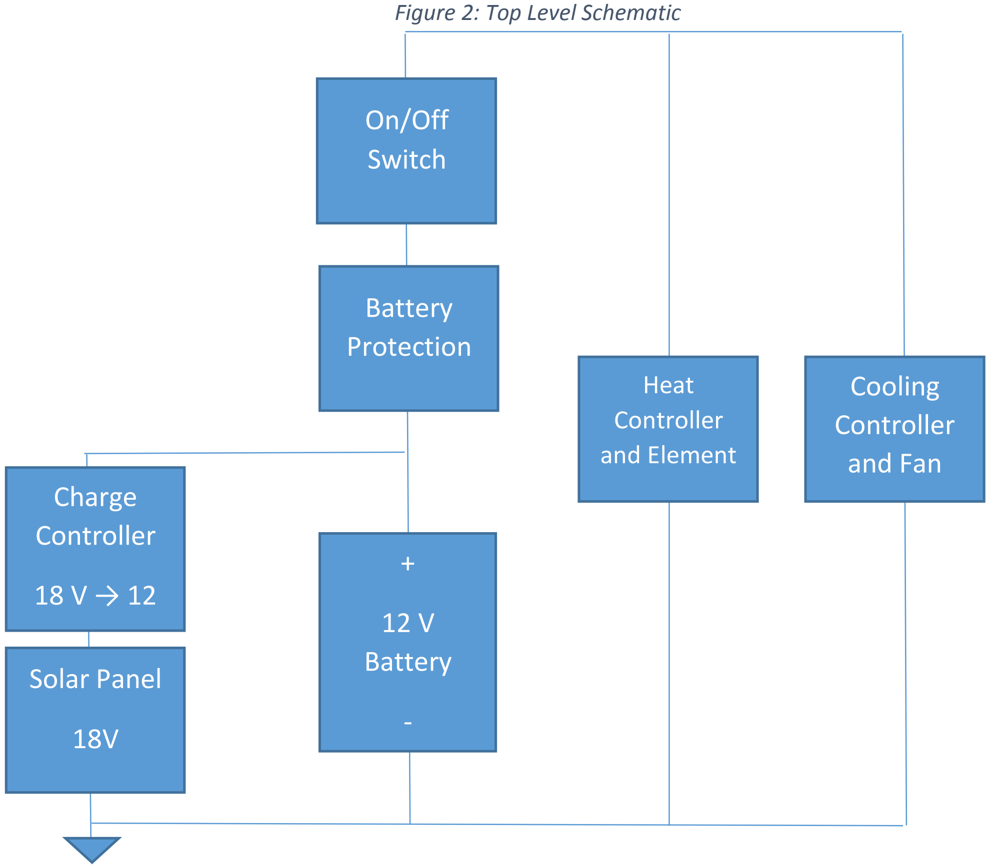
Cooling Controller: The cooling controller will be used to power the fan depending on the inside temperature of the doghouse. The controller will also use a thermistor the same way as the heating controller to sense the house temperature. The cooling controller will have a set range of temperatures in which the fan will not run, run at low speed, or run at high speed. These ranges will be preset rather than decided by the user. If the house is at a temperature below about 65F, the fan will not run. If the temperature is within about 65-80 degrees the fan will run at a low speed and above 80 degrees it will fun at a high speed. The controller will provide different voltages to the fan in order to run it at the two different speeds. (See schematic below in Figure 4)

Fans: There are two fans will be installed into the back wall of the house. The fans will be simple exhaust fans run on a dc voltage. If the system is set to cooling mode, the temperature controller will apply a certain voltage to the fan depending on the speed desired due to the house temperature.

## 2.3 Schematics

Top Level Schematic

*Figure 2: Top Level Schematic*



## Heat Controller Schematic

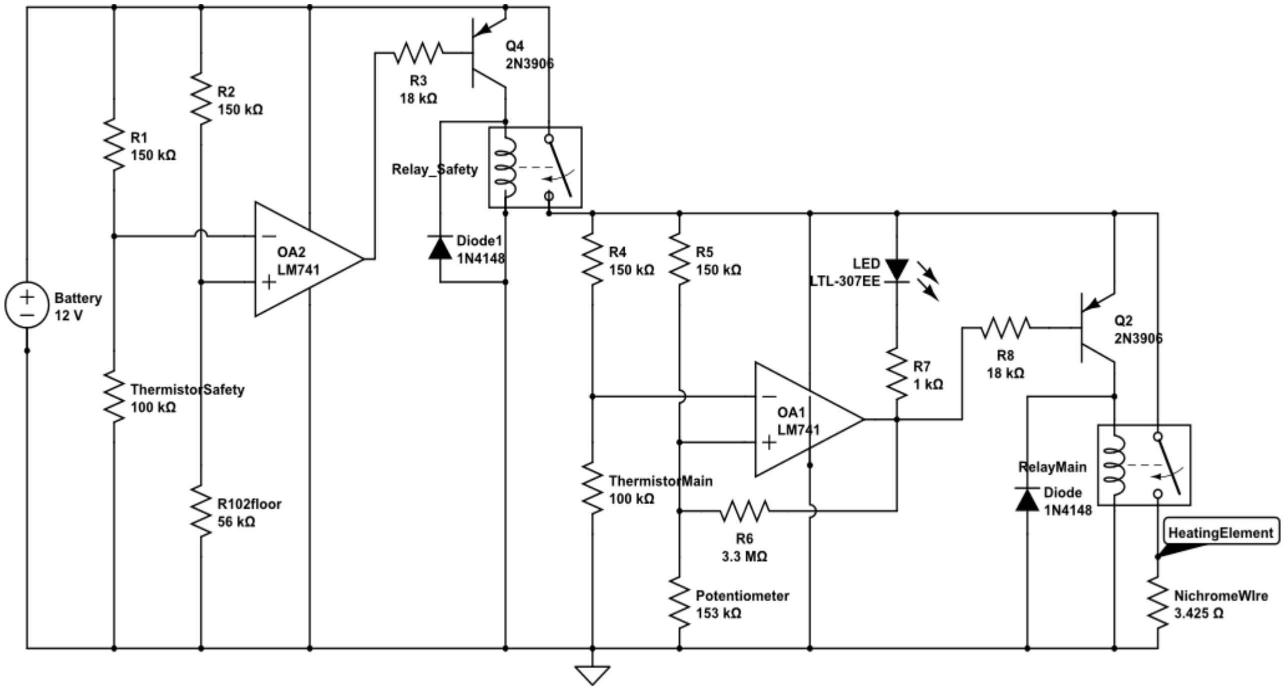



*Figure 3: Electrical Schematic for Heat Controller*

## Cooling Controller Schematic

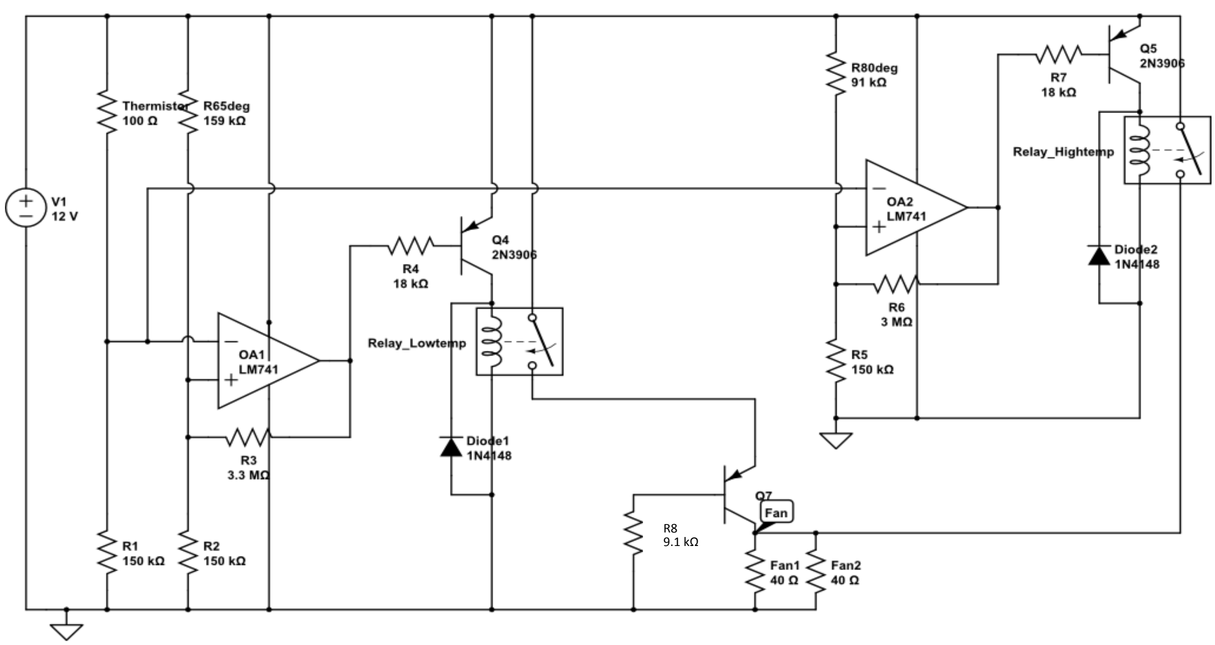



*Figure 4: Electrical Schematic for Cooling Controller*

## Battery Protection Schematic (Redesigned)

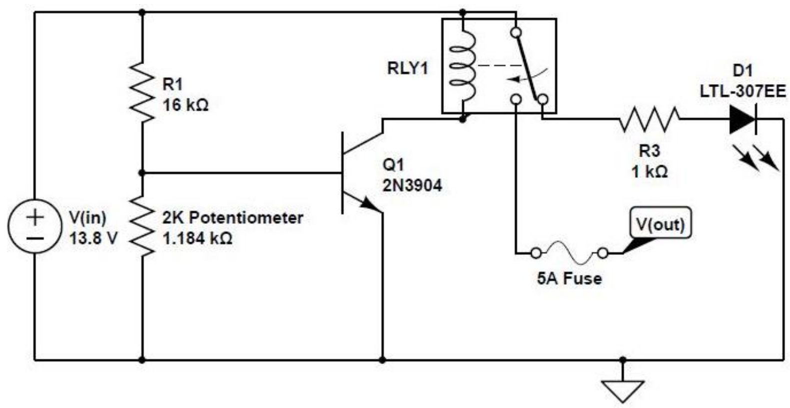



*Figure 5: Electrical schematic for the battery protection circuit*

## Nichrome Wire Pattern

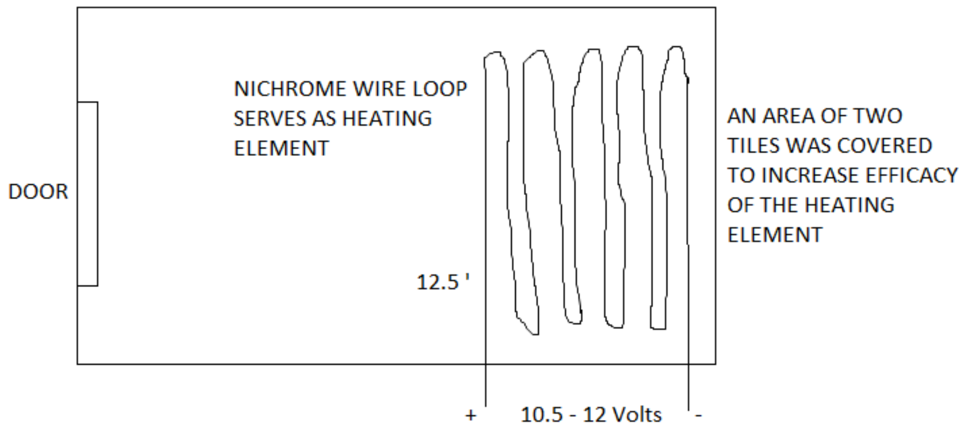



*Figure 6: Displays the location of the heating element on floor of the doghouse.*

## Doghouse Dimensions

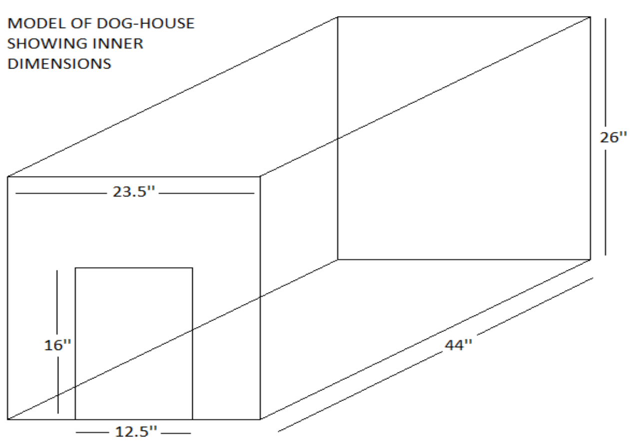



*Figure 7: Shows the interior dimensions of the doghouse.*

## User Control Panel

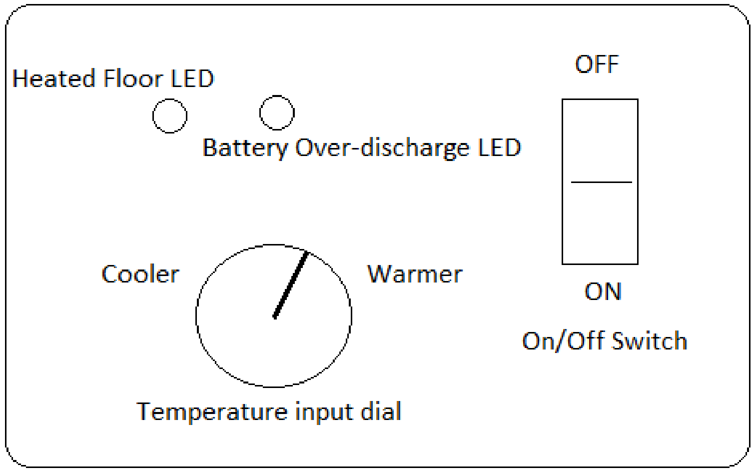



*Figure 8: Shows the user input panel.*

# 3 Calculations

## 3.1 Heating Requirements

Final doghouse inner dimensions: 44”x23.5”x26”

$$2(44in)(23.5\text{in}) = 2068\ in^2$$
$$2(44in)(26in) = \ 2288in^2$$
$$2(23.5in)(26in) = 1223in^2$$
$$\text{Total surface area} = 5578in^2 = 38.74ft^2$$

Power requirement to raise the inner house temperature 35°F with R-10 insulation (R-5 per in):

$$power\ required = \frac{surface\ area * change\ in\ temperature}{insulation\ rating}$$

$$\frac{38.74(35)}{10} = \ .24307BTU = \mathbf{39.73W}$$

## 3.2 Power Dissipated in Heating Element

$$P = VI$$
$$P = (12V)(3.69A) = \mathbf{44.3W}$$

This indicates that the heating element should provide enough power to heat the inside of the doghouse.

## 3.3 Solar Panel Power:

Power rating: 80W
Average hours of sunlight a day: 5 hours
Efficiency with optimum panel angle: 75.2%

Power produced by panel per day: $80W * 5hours * .752 = \mathbf{300.8W\ per\ day}$

This power produced indicates that the panel should provide enough power to heat the doghouse over the course of a day, as well as charge the battery.

## 3.4 Battery Calculations

Battery Voltage: 12V
Reserve Capacity Rating: 182 minutes at 25A
Expected Load Current for Heating System: 3.69A

(Heating system current used since cooling system current will be much smaller)

Discharge Time:

$$\frac{182min * 25A}{3.69A} = 1233.06\,\text{min} = 20.5hours$$

If the battery was constantly being discharged (the floor is constantly heated) the battery should last about 20.5 hours without charge, but the system will not actually run constantly. It is expected that it will only need to run for about 20minutes of every hour in order to keep the house temperature at the set temperature. With this expectation factored in, the battery should last 3 times as long, **about 61.6 hours**, without any charging from the panel.

## 3.5 Heating Element Calculations:

Nichrome Wire Rating: .26Ω/ft
Length of Heating Element: 12.5 ft
Battery Voltage: 12V

$$total\ resistance\ of\ the\ coil = .26\Omega/ft * 12.5ft \quad = 3.25\Omega$$

$$current\ used\ by\ coil = \frac{12V}{3.25\Omega} = \mathbf{3.69A}$$

This current is the load current that will be provided to the heating element by either the battery or the panel when the heating system is on and running.

## 3.6 Solar Panel Angle

In order to maximize the efficiency of the system, it is required to adjust the angle of the solar panel twice a year. If the owner lives in the northern hemisphere, the panels need to be moved on March 30th and September 12th. For the Southern hemisphere, the panels should be moved on September 29th and March 14th.

A formula was found from MacsLab [1] in order to get the optimum angle. The formulas below are valid for latitudes between 25 and 50 degrees. The angle shown is the angle that the panels need to be tilted towards the equator.

$$Summer: \quad angle = (latitude \cdot 0.930) - 21.0°$$

$$Winter: \quad angle = (latitude \cdot 0.875) + 19.2°$$

There will be two sets of solar panel supports for both the correct winter and summer lengths that come with the doghouse, in order to optimize efficiency.

# 4 Verification

## 4.1 Heating Controller

The operation of the heating controller and heating element was verified by setting a temperature on the front panel to a value warmer than the current room temperature and recording the increase in floor temperature over time.  As seen in Figure 9, the floor temperature increases steadily until the temperature setting is reached. Then, the heating controller turns off power to the nichrome wire and the temperature starts to slightly decrease over time. It does not remain flat at the desired temperature due to the built in hysteresis setting.  The emergency shutoff that turns off power to the heating element when the floor temperature reaches 102°F is also verified in Figure 9.  The front panel dial was set to a very high temperature and it can be seen that the floor temperature increases until the shutoff turns off the heat when the limit is reached.

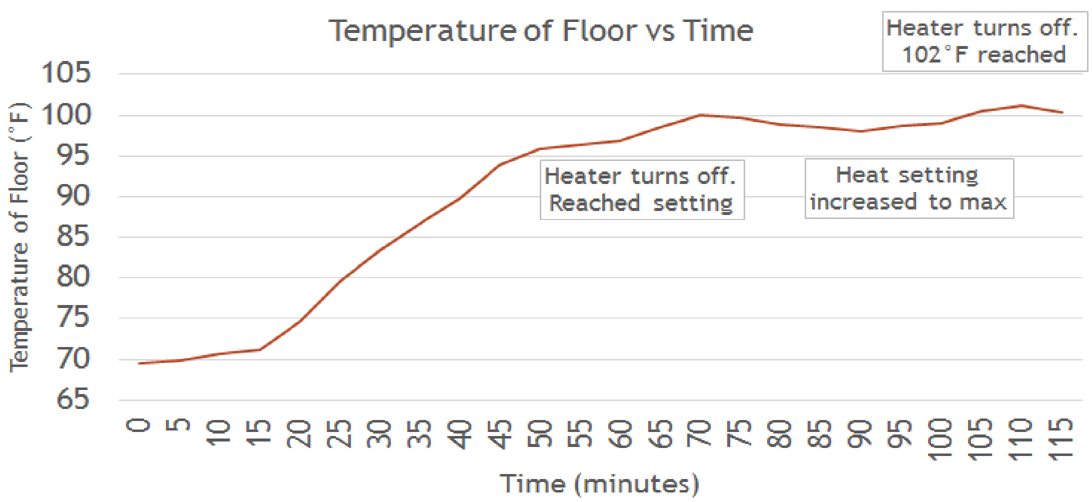



*Figure 9: Results of Heating System – Shows the floor temperature increase until user setting is reached.  Also shows the emergency temperature shutoff works.*

## 4.2 Cooling Controller

The cooling controller and fan operation was verified by simulating the different temperature ranges and watching the output voltage from the controller to the fans that corresponded to the different fan speeds.  The room this was tested in was warm enough that the fans always ran at the low speed with a controller output voltage around 5.4V.  The thermistor connected to the cooling controller was then touched by a group members hand in order to warm it up to above the 85 degree threshold between low and high speeds.  The output voltage jumped to the expected 12V and the fans increased in speed. An ice cube was used to cool the thermistor to below 65 degrees and the fans stopped due to a 0V controller output as expected.  These results are illustrated in Figure10.

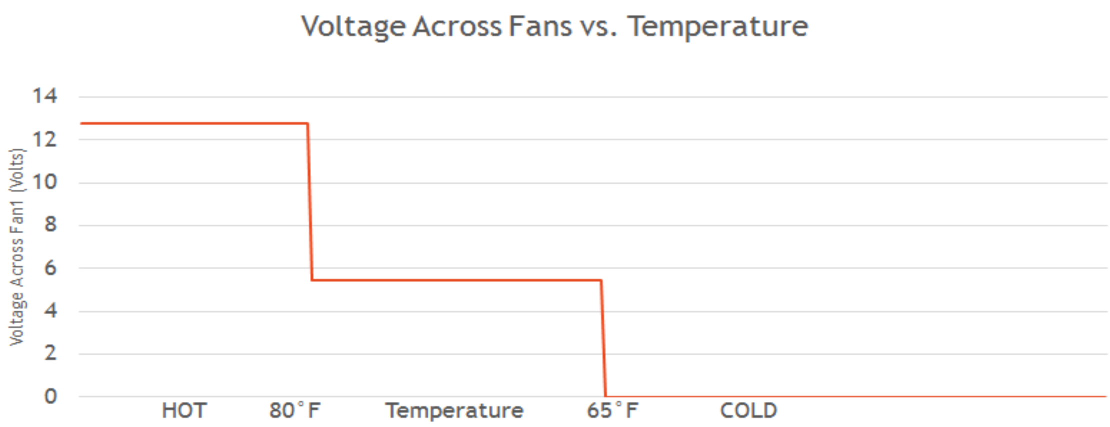



*Figure 10: Results of Cooling System- Shows the output voltage of the controller to the fans that correspond to the two speeds, high and low, depending on the house temperature.*

## 4.3 Battery Protection Circuit

The battery protection circuit operation was verified by altering the source voltage that simulated the battery being drained or recharged while the heating system was on and the fans were on low speed. The source voltage started at 12.8V so the load current was the expected ~3.8A. The voltage was then lowered until it reached 10.5V and the circuit turned off the load current completely and lit the LED to let the user know the battery was overdischarged. The voltage then was raised to above 12.5V which caused the LED to turn off and the load current to once again power the heating element.

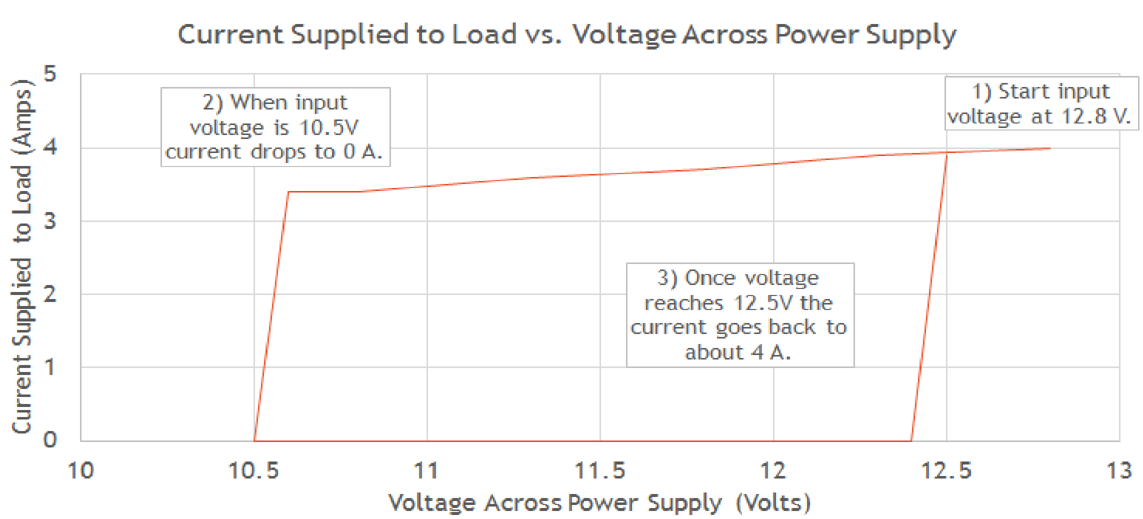



*Figure 11: Results of Battery Protection Circuit – Shows the load current being shut off when battery voltage is below10.5V and then turned back on when the voltage recharges to above 12.5V*

# 5. Cost Analysis and Schedule

## 5.1 Cost Analysis

### Labor Costs

We conducted a simplified cost analysis for our project to estimate the total cost of building a solar powered doghouse. We assumed an Hourly salary of $35.00 per person, and 150 total working hours per person.

| Name | Hourly Rate | Total Hours Invested | Total Labor Cost |
|---|---|---|---|
| Krista Giacobazzi | $35.00 | 150 | $13, 125.00 |
| Lynn Deasey | $35.00 | 150 | $13, 125.00 |
| Gurbaaz Singh Sidhu | $35.00 | 150 | $13, 125.00 |
| Total | | 450 | $39, 375.00 |

The total labor costs were calculated as shown,

$$Labor\ Costs = 35.00\ \cdot 2.5\ \cdot 150 = \$13{,}125.00$$

### Component Status and Costs

| Component | Part Number | Quantity | Cost ($) |
|---|---|---|---|
| Wooden Doghouse | N/A | 1 | 120.00 |
| 80 W LaVie Solar panel | SABO 36/72 | 1 | 100.00 |
| 12 V Basement Watchdog Battery | Model # 30HDC140S | 1 | 140.00 |
| Morningstar SunGuard Power Controller | MS-SG-4-12 | 1 | 31.74 |
| Nichrome wire | 16 Gauge 30 Feet | 162 inches | 16.50 |
| Thermistor | ATH100K1R25 | 3 | 8.22 |
| Small Fan | UTCB12 | 2 | 8.00 |
| Tiles | N/A | 8 (1 sq. foot each) | 30.00 |
| Tile Paste and Grout | N/A | - | 14.43 |
| SPST Switch | Model # 275-701 | 1 | 3.19 |
| OpAmp | LM741 | 4 | 3.88 |
| PNP Power BJT | NTE391 | 1 | 2.89 |
| PNP BJT | 2N3906 | 4 | 1.00 |
| NPN BJT | 2N3903 | 1 | .20 |
| Relay | SRU-S-112L | 5 | 16.00 |
| Resistors, Capacitors, etc. | N/A | - | 5.00 |
| Flyback Diode | 1N5817 | 5 | 2.50 |

### Total Costs

| Section | Total |
|---|---|
| Labor | $39, 375.00 |
| Components | $ 503.55 |
| **Total** | **$39,876.00** |

# 6 Tolerance Analysis

One of the most integral part of the doghouse is the system that regulates the temperature. If the house becomes too hot, the heating elements need to turn off. If the house becomes too cold, there must be a voltage applied to the heating elements. Also, the fan goes on automatically, depending on the temperature in the doghouse. If the doghouse cannot interpret the temperature at a decently accurate level, this comfortable doghouse turns into just a very expensive arrangement of wood. Another reason that temperature accuracy is important is that the floor temperature must not go over 105°F for safety of the dog. If the doghouse floor is hotter than this and the thermistors detect a temperature lower than this, the safety feature will not enable and the dog could be seriously injured.

The thermistors must have the proper resistance that corresponds to the temperature indicated on the data sheet. The thermistor data sheet says that the resistance is measured within 1% accuracy. However, for this application, a range of 2.5% will be enough to protect the dog and ensure a habitable doghouse.  This was be checked by measuring the resistance of the thermistor at various temperatures. A wide range of temperature will be tested. The thermistor will be placed in a box. A hair blower will be directed in the box and the temperature will be measured right next to the thermistor with the infrared thermometer. The resistance will then be measured and recorded. It will then be compared to the corresponding temperature on the data sheet to see if it falls in range. By placing cups of ice in the box and also by placing this in front of an air conditioner, the cold temperatures were simulated and the same measurements taken.. Twenty different data points will be measured that fall within the range of 32°F - 100°F. All of the resistances and temperature measurements were taken, and is determined that all of these points fall within 2.5% of the data sheet specification.

| Temperature Measured by Thermometer (°F) | Measured Resistance Across Thermistor (KΩ) | Corresponding Temperature Determined by Data Sheet (°F) | Percent Difference |
|---|---|---|---|
| 34.50 | 310 | 34.128 | 1.079 |
| 35.24 | 300 | 35.310 | 0.199 |
| 39.56 | 263 | 39.990 | 1.087 |
| 42.72 | 253 | 42.881 | 0.377 |
| 45.68 | 226 | 45.484 | 0.430 |
| 48.74 | 210 | 48.182 | 1.145 |
| 51.08 | 192 | 51.516 | 0.853 |
| 55.04 | 172 | 56.300 | 2.289 |
| 58.28 | 158 | 58.905 | 1.072 |
| 63.89 | 142 | 63.043 | 1.326 |
| 66.20 | 130 | 66.479 | 0.421 |
| 69.80 | 118 | 70.318 | 0.743 |
| 71.68 | 116 | 71.011 | 0.933 |
| 77.10 | 103 | 75.799 | 1.687 |
| 80.67 | 92 | 80.429 | 0.299 |
| 82.30 | 86 | 83.232 | 1.132 |
| 85.72 | 79 | 86.794 | 1.253 |

| | | | |
|---|---|---|---|
| 87.69 | 74 | 89.555 | 2.127 |
| 92.20 | 68 | 93.175 | 1.057 |
| 96.80 | 62 | 97.191 | 0.404 |
| 101.41 | 58 | 100.108 | 1.284 |

*Figure 12: This table shows the difference between the measured temperature and the temperature the thermistor indicates.*

# 7 Ethics

As engineers developing a product for use by the larger community we have an obligation to uphold the IEEE Code of Ethics [2] and Academic Honesty. Though all the points mentioned in the Code are of utmost importance, certain statutes of the Code are of pertinence to our project. Specifically,

- "to accept responsibility in making decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;"

  We will take all necessary precautions in ensuring that our project is safe to use, both for the dog and the owner, and that it does not in any way cause harm to its immediate surroundings or the environment.

- "to be honest and realistic in stating claims or estimates based on available data;"

  We will present all our data, simulations and schematics honestly and will not distort our findings.

- "to improve the understanding of technology, it's appropriate application, and potential consequences;"

  We will endeavor to build a good understanding of the various components of our project in the user's mind, and we will also elaborate upon the consequences of improper usage. This will help encourage the appropriate application of our project.

A thorough understanding of this Code as well as exercising good sense will ensure that our project is safe to use and environmentally sustainable.

# 8 Safety

Safety is one of the highest priorities for our group as our project has high current and voltage values associated with it. Consequently, we need to keep in mind the user's safety, the dog's safety as well as our own safety.

## 8.1 Safety of Dog

As we have developed a product which operates without manual supervision, it is vital that our dog-house is safe for the dog. To this end ensured that there are no exposed electrical components inside the dog-house. Our PCBs are housed in waterproof plastic boxes fixed onto the inner front wall. The Nichrome wire heating element is located under the porcelain tile floor which is made waterproof by using tile grout. No portion of the Nichrome wire is exposed through the floor. The battery protection circuit helps maintain the health of our battery by ensuring that no overdischarge takes place. Our charge controller also ensures safe charging of the battery.

## 8.2 Safety of Owner

We also need the dog-house to be safe for the owner. As described above, our project has no exposed electrical components. Our battery is also adequately protected from overdischarge and it charges up safely too. Our project is also easy to assemble and maintain so as to minimize injury from any repair or transportation.

## 8.3 Safety of Designer

Throughout the design and engineering process, we took precautions to maintain our own safety as well as the safety of others present in the Senior Design lab. Correct interpretation of data sheets and a good comprehension of the rated parameter values of each of our components held us in good stead while dealing with high voltages and currents. Fundamental aspects like correct safety gear, common sense and an uncluttered workspace also ensured smooth progress throughout the course of the semester.

# 9 Conclusion

In the end we were able to create a complete and working project.  We were able to meet and verify all of the requirements, except for the battery.  The battery in our possession was a very old and spare sump pump battery that ended up not being able to hold a charge.  We were able to verify the output of the solar panel and charge controller would in fact charge the battery, but we had to use a different dc source for the actual house system because the battery was never able to be 12V for a long period of time.  The dc source used was adjusted to simulate the battery being drained and recharged, so every other requirement could be verified for the circuitry.  We feel that if a new battery of the same capacity was purchased, our system would work the same way and therefore consider our project to be a success.  Unexpected challenges arose during the fabrication stage of the project.  Due to the large load current, and accidental damage to components, the original battery protection circuit was not able to be used and this resulted in a complete redesign to the circuit involving a relay seen in the schematics portion of the report.  This new circuit functioned the same way, except it involved a relay and required a fuse to prevent overcurrent rather than logic chips that were difficult to work with.

This project will not be taken any further, but if it were to be slightly redone or be worked on in the future there are a few changes that could possibly improve the design.  One way to make a definite improvement to the amount of time the floor takes to heat up, as well as how much of the floor could effectively be covered with the nichrome wire, would be to redesign all of the circuitry to use a higher voltage battery.  If, for example, a 24 V battery were used instead, the floor would heat up a lot faster and more than two tiles could be heated since the nichrome could be longer and still heat up the tile in a reasonable amount of time.  Another minor design change would be to put the thermistor that reads the temperature of the house closer to the floor so that the tile temperature doesn't have to be as high in order to have enough heat radiating up to the thermistor for it to detect a warm temperature.

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# Appendix A

## A.1 Requirements and Verification Table

| Requirements | Verification |
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| 1. Solar Panel<br><br>a. Solar panel should output a maximum current of 4.4 A when exposed full sunlight at noon in Champaign on an April day.<br><br>b. Solar panel should charge the voltage across the battery when exposed to sunlight.* | <br><br>a. The panel will be brought outside on a sunny April day in Champaign tilted 50 degrees toward the equator. The output current will be measured and must be a max of 4.4A.<br><br>b. The panel will be brought outside on a sunny April day in Champaign tilted 50 degrees toward the equator. The voltage across the battery should be read before it is hooked up to anything. Once the battery is hooked up to the solar panel, the voltage across the battery should be greater than the original battery voltage. |
| 2. Charge Controller<br><br>a. Controller should convert the panel voltage to within 1V of 13V*<br><br>b. Controller should stop charging the battery when it is charged to a full 13.8 +/- .2V | <br><br>a. The panel will be connected to the controller and exposed to daylight. The output voltage of the controller will be read and should be within 12 to 14V.<br><br>b. The battery should be fully charged to 13.8 volts. When hooked up to a solar panel outside on a sunny April day in Champaign tilted 50 degrees toward the equator, the voltage should never exceed 14V, even when still hooked up to the panel. |
| 3. Battery<br><br>a. Battery discharge time to depletion should be about 22 hours | <br><br>a. The battery will be attached directly to the 12.5 feet of nichrome wire. The battery voltage will be monitored every hour until the battery voltage drops to 10.5V. The result will be extrapolated to predict whether the battery will last the expected amount of time. |
| 4. Battery Protection Circuit<br><br>a. Protection circuit should turn off the load current if the battery voltage is depleted to 10.5V +/-2.5%. The load current should turn back on when the battery is charged back above 12.5 V +/- 2.5%.* | <br><br>a. The protection circuit will be connected to a DC source and the input voltage decreased from 12V. The load current will be monitored and when the input voltage reaches within 10.24V to 10.76V, the current should go to zero. When the voltage is increased above 12.19V to 12.81V, the current should go back above zero amps. |

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| b. Protection circuit should turn off the load current if the battery output current exceeds 5A +/- 5%. The load current should stay at zero.* | b. The protection will be connected to a 12V source and the load will be changed to a load requiring at least a 5A current. The load current will be measured and should go to zero when the current falls within the range of 4.75A to 5.25A. The fuse is now blown, so the doghouse will not work without replacing the fuse. |
| 5. On/Off Switch<br><br>a. The switch must route the input power to the heating and cooling systems if the switch is in the "on" position.*<br><br>b. The switch must have both systems off if it is in the "off" position | <br><br>a. The switch with be set to "on." The input voltage into the heating and cooling systems will be measured and must be within 11.5-12V when 12 V is applied to the battery terminals.<br><br>b. The switch should be set to "off." The input current for both the heating and cooling systems will be measured and must be zero. |
| 6. Heating Controller<br><br>a. When the floor temperature is exceeding 102 degrees, the voltage of the OpAmp (OA2) will increase to the source voltage (10.5-12V) and the heating element current should drop to zero.<br><br>b. When the house temperature is below the set temperature on the dial, the heating element current should be 3-4.5A and the voltage should be equal to the source voltage (10.5-13.8V).*<br><br>c. When the house temperature reaches the potentiometer setting, the heating element current should drop to zero.* | <br><br>a. A hair dryer will be directed at the floor thermistor, the temperature will be measured with a thermometer. The output voltage of OA2 will be monitored and when the temperature exceeds 102F, the voltage should jump to the source voltage (10.5-12V). The output current to the heating element will also be monitored and should drop to zero.<br><br>b. The dial will be set cooler than the room temperature. The heating element current will be monitored and should be within 3.00-4.50A as the element heats up and the voltage across the element should be equal to the source voltage.<br><br>c. The dial will be set exactly so the heating element is nearly off, but still on. We will wait and see that after a period of time, the heating element will automatically go off, as indicated by the LED. Also the current going through the element will be zero. |
| 7. Heating Element<br><br>a. The nichrome wire must be able to heat the floor tiles when being powered. | <br><br>a. A voltage of 10.5- 12V will be applied across the nichrome wire heating element. An infra-red thermometer will be used to continuously check the temperature of the porcelain tiles. The temperature should increase steadily from room temperature till the time the voltage is turned off. The test will be run until the temperature reaches 102 degrees Fahrenheit. |

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| 8. Cooling Controller | |
| a. When the temperature in the room is less than 65 degrees, the fans should both be off. | a. An ice cube will be place directly next to the doghouse thermistor. The output of OpAmp OA1 will be measured and will be 0V. The voltage across the fans will also be measured and should also be 0V. |
| b. When the temperature is between 65-80 degrees, the fans should be on low speed. | b. The room will be made to fall within this range. If needed, a hairdryer or ice cubes can be used on the thermistor. The temperature of the doghouse will be confirmed with the infra-red thermometer. The voltage will be measured and OpAmp OA1 will have a voltage of 10.5-12V. The voltage of OpAmp OA2 will be 0V. This will result in the voltage across the fan terminals to be within the range of 7-9V. |
| c. When the temperature is greater than 80 degrees, the fan should be on high speed. | c. A hair dryer will be directed at the thermistor until the infra-red thermometer confirms the temperature. The voltage will be measured and OpAmp OA1 will have a voltage of 10.5-12V. The voltage of OpAmp OA2 will be 10.5-12. This will result in the voltage across the fan terminals to be within the range of 10.5-12V. |
| 9. Fan | |
| a. The fan must have three different speeds. When 0V is applied, the fan must be off. | a. 0V is applied to the fan terminals. The fan should not rotate. This should be checked with both fans. |
| b. When 8.48 V is applied, the fan must be at medium speed. | b. 8.48 V is applied, the fan must be rotating. This should be checked with both fans. |
| c. When 12 V is applied the fan must be at full speed. | c. 12 V is now applied to the fan. It should be rotating faster than the step above. This should be checked with both fans. |

*Some of the requirements and verifications were changed due improved engineering decisions. A charged 12V battery has a voltage of 13.8V as opposed to our initial plan of 12V. This changes the correct range for many values measured. Also the length of the nichrome wire changed due to the large amount of time it takes to heat the tiles. By shortening the wire the current is greater, so more heat is dissipated. And finally the battery protection circuit was completely redesigned. We added the advantage of a hysteresis point so the power won’t be flipping on or off around the threshold at 10.5V. This changed some required voltage settings.