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Electrical Solar Panel Moisture Detector & Heater

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Electrical Solar Panel Moisture Detector & Heater

A Major Qualifying Project Report

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of The

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Bachelor of Science

By

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Approved:

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Professor Alexander E. Emanuel, Advisor

Abstract

This Major Qualifying Project approaches the need to protect solar panel devices from inclement weather conditions that involve snow and ice by creating a temperature- and moisture-sensing unit and accompanying heating unit. The use of a thermistor, moisture sensor, operational amplifier, relay and heating unit working in unison help to accomplish the goal of reducing the amount of precipitation present during cold weather periods.

Acknowledgments

I would like to first and foremost thank my mother for all of the endless, unconditional love and headstrong support she has provided during the completion of this project. Nunca me has dejado. I am also grateful to my Faculty and Project Advisor, Professor Alexander E. Emanuel, whose wisdom and patience were critical throughout this project and the rest of my WPI career. Finally, I would like to express my thanks to all of the professionals, family members, and friends who helped guide me with both advice and support. I couldn't have done it without you.

Table of Contents

Table of Figures

1. Introduction

The recent innovations in the field of renewable energy have been critical for the advancement of electrical systems in the last couple of centuries. One of the most commonly known renewable technologies are photovoltaic or solar cells, which collect energy from the sun and utilize this energy to heat or electrically power residential and commercial buildings. The cells are made of two conductive plates made of silicon, a common semiconductor. The cells absorb energy when light strikes the plates, and retain more energy when using antireflective materials – or when the light is less likely to bounce back off the surface. The light causes the electrons to flow, which produces current, and this current can be utilized in heating and electric applications. Solar panels, which are most commonly seen in large-scale applications, are made of a family or unit of solar cells.

One common issue for solar panels is the possibility of extensive damage when exposed to harsh weather conditions, particularly cold weather. Ice, snow, and hail, just to name a few forms of precipitation, can have a small or potentially hazardous impact on the solar cells. Although the presence of water itself is not necessarily a huge risk to the cells, unless there are exposed electric materials, it's the weight of the snow, the speed of the falling ice, or the impact of hail that can cause harm.

In order to address this concern, this project describes the research, design and implementation of an ice/snow detection and removal circuit. This design encompasses sensors of temperature, humidity and water to determine if there is some form of the above listed precipitation and its level(s), and then activates the appropriate technologies to activate a heating unit to melt or prevent the accumulation of whatever precipitation may be present.

2. Background

2.1 Solar Panel Construction

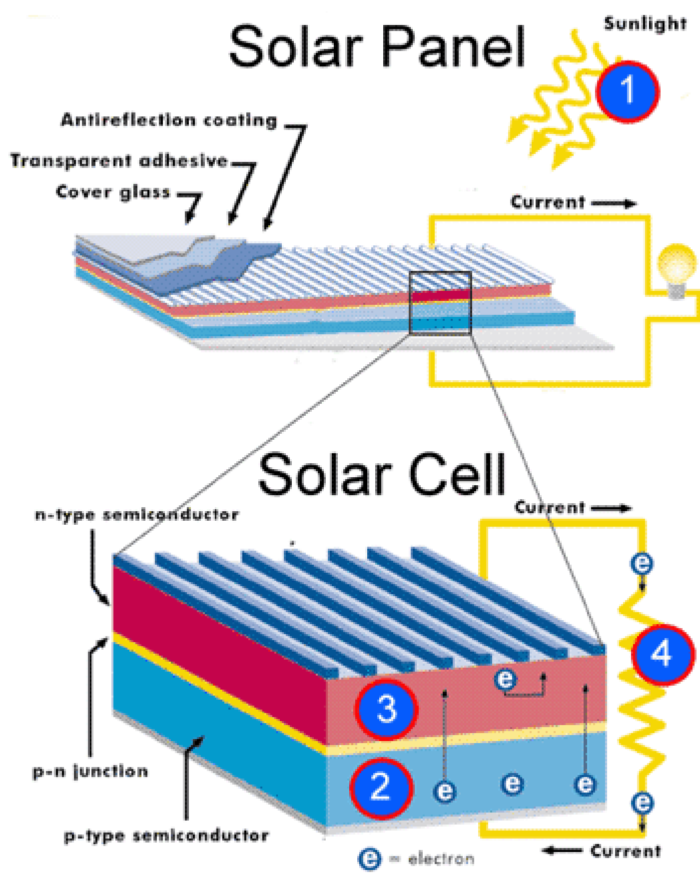

Figure 1: Structure of Solar Panels and Cells

Solar energy collection, as mentioned earlier, involves the reflection of solar light onto a semiconductor material, commonly silicon. The silicon is melted into flat stacks, similar to wafers, as either single (monocrystalline) or multiple (polycrystalline) crystal ingots, where the former has a higher silicon purity rating. These layers of silicon are stacked in parallel, like conductors, and are then doped by phosphorous and baron to create n-type and p-type layers, respectively. This difference helps to separate, diffuse, carry and transport electrons located across the material.

Electric wiring for the solar cells is placed on the plates by means of metal contacts. The cell is then sealed or encapsulated with glass and other products, such as resin and film. These materials help for antireflective glare, which can cause the light hitting the cell to bounce back off, as well as for outside weather protection. The cell is locked in with a frame, and then connected into an array to create the solar panel. When the solar energy hits the cell, the wiring helps to activate the electrons in the silicon, creating electric current. The circuitry helps take this current and utilize it as needed by the project or installation of the panel, as this energy cannot be stored within the panel.

2.1.2 Solar Panel Glass Properties

The protection of the hazardous or electric-producing components of the solar cell is essential to the durability, efficiency, functionality and overall life of the cells. The most basic protection of solar cell electric components involves placing tempered glass over both flat surfaces of the solar cell. Smaller companies or projects utilize flat, annealed plate glass as a cost-effective measure, which greatly increases the risk of damage to the material due to the increase of fracturing and breaking under stresses and tension. This is a direct contrast to tempered glass, a stronger version of heat-treated glass, whose treating process involves placing the material in an initially stressed state by first heating and then quickly cooling the glass surfaces. The hot surface will compress the surrounding glass as it cools, which will then increase the amount of pressure needed from external sources to exert a large enough force to damage the glass. Should the glass be damaged, the pieces of tempered glass break into small oval pieces, instead of regular plate glass, which breaks into large shards.

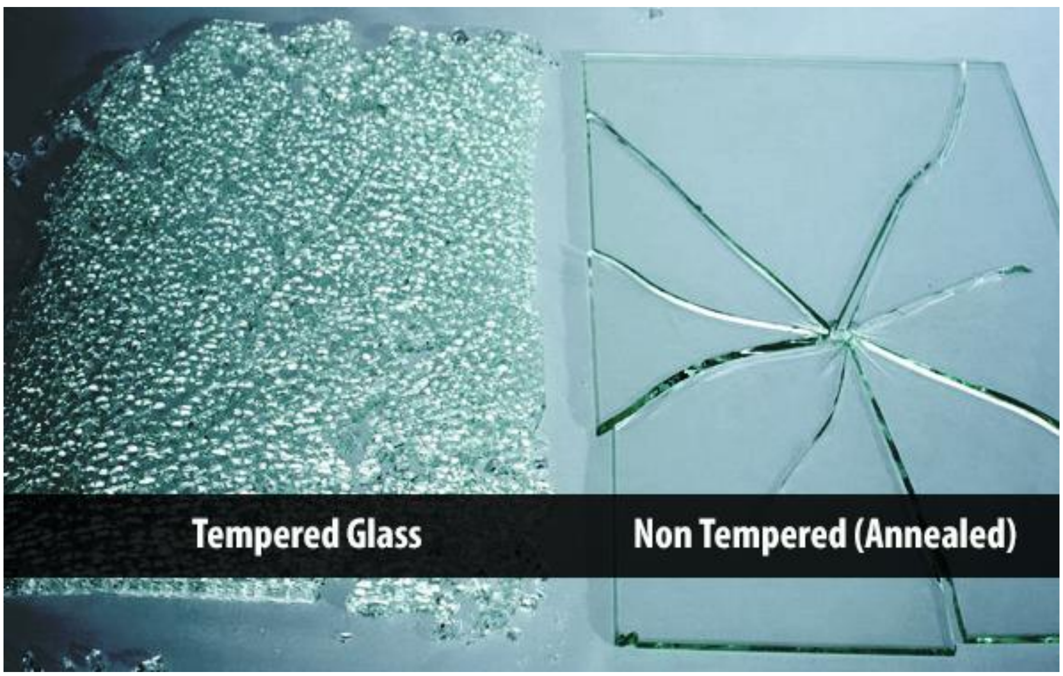

Figure 2: Fragments of Tempered vs. Non-Tempered (Annealed) Glass Plates

The installation of tempered glass greatly reduces the risk of moisture, temperature and external weather conditions to damage the protective layers of the solar cells and the cells' electrical components. However, the risk is not yet fully eliminated, and the cells are still susceptible to damage if the extenuating conditions negatively perform on the glass (e.g. at an angle that is unbearable by the glass or the panel as a whole). This project seeks to greatly minimize these risks by forecasting impending and present weather, and having the panel perform an accordingly damage-preventative behavior.

2.2 Weather Detection

When there is precipitation present, there are a few sensors installed that will actively monitor temperature, humidity/dew point, and the conductivity of any precipitation collected. Should the amount of precipitation exceed a certain threshold combination for these sensors, the panel will activate a heating unit. This heating unit, which consists of a set of insulated wire, which is used to prevent the flow of electricity, thus producing heat. This wire will be installed in order to melt the snow off, and placed within an additional insulating layer in order to not allow an excessive amount of heat to dissipate from the unit.

2.3 Weather Risks based on Environment and Geography

Certain geographical locations are more at risk to the damage present by cold weather conditions, thus possibly resulting in panels to externally installed solar panels. Climates such as those in the Northern United States are especially humid, with various forms of cold weather precipitation accumulating in extreme volumes. Other areas of the country, particularly those where solar panel collection is more feasible due to solar exposure, may also occasionally be exposed to precipitation such as snow as ice. This is especially a region that might find the use of this project as an investment, considering that these locations are historically poorly prepared and/or equipped to respond accordingly when such precipitation presents itself.

3. Problem Statement

Solar or photovoltaic cells are a resourceful and environmentally friendly method of renewable energy collection. However, there are weather-related impacts that can decrease the feasibility of having a solar panel installation in cold weather climates. This project focuses on the design and implementation of an ice/snow detection and removal system that will address this issue for the presence and impact of ice, snow and hail by the solar panel system.

4. Design Approach and Simulations

This section will discuss the design process for the snow/ice detection and removal circuit. It will describe the function and purpose of each individual component, and describe the circuitry required to install the component into the main circuit.

4.1 System Design

Below is a block diagram of the overall system. If the system is in standby, it will periodically recheck the temperature sensor to detect any possible changes.

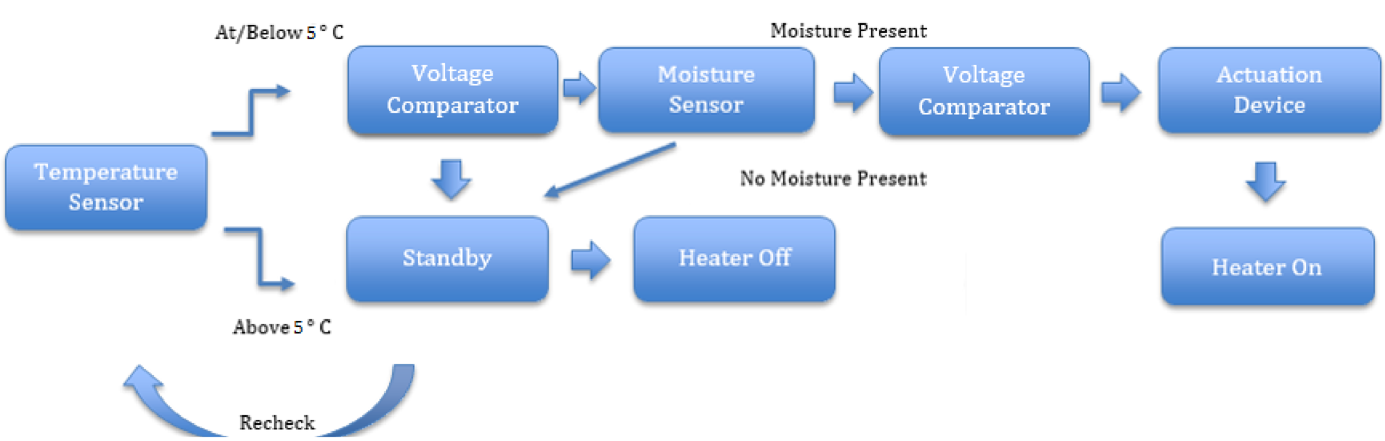

Figure 3: Block Diagram of System

4.1.1 Temperature Sensor

One of the most important attributes of weather is temperature. After a freezing point temperature of 0° C, water is susceptible to freezing. To address and include this in our design, a thermistor was selected to read the ambient temperature by the solar panel. If the temperature reads as at or above +5° C, then the system goes into standby. If the temperature is below +5° C, then the comparator will output a high signal. A higher temperature was selected than the earlier mentioned freezing point temperature, as the creation, presence and accumulation of cold weather precipitation is certainly possible at temperatures a bit higher than the listed 0° C. Additionally, providing the comparator with a bit of a higher temperature trigger will allow the circuit with room for any error presented by inaccurate thermistor readings.

4.1.2 Moisture Sensor

In addition to temperature, moisture plays a significant role for this project as it is trying to determine the presence of precipitation in the environment. To do this, a moisture sensor will check for the presence of water if the prior temperature requirement is satisfied. If there is moisture present, the operational amplifier circuit will be powered. If there is no moisture present, then the system will go into standby.

4.1.3 Voltage Comparator

Voltage comparators are useful applications of operational amplifiers where the input will affect the output based on a determined threshold voltage. These circuits utilize an operational amplifier as a comparator to change the output when the input crosses the threshold, or maintains the output when the input is within a certain range. A comparator will be incredibly value to this project as the temperature sensor emits changing analog values that will either activate a relay or maintain a standby system status. There will be two comparators in this circuit: one after the thermistor reading to determine if the temperature criteria has been met, and a second after the moisture sensor to detect for the presence of any liquids.

4.1.4 Actuation Device

When the comparator output is active (high), an NPN transistor will be activated that will power on the moisture sensing circuit. This transistor is powered at the base pin when the system is actively performing, and will send power across the relay.

4.1.5 Heater

If all of the above conditions are satisfied and successful, the heating unit will turn on and commence melting whatever precipitation is present. If the system is in standby due to not meeting the sensor detection requirements, then the heater will remain off.

4.2 In-Depth Circuit Design and Simulations

4.2.1 Temperature Sensor

Choosing an appropriate temperature sensor for the project involves understanding what purpose it will serve and how the data it collects will relate to the rest of the circuit. As this project is dependent and focused mostly on temperatures at or below

0° C, an NTC Thermistor was selected. NTC stands for negative temperature coefficient, which in this application is important to have since the lower the temperature, the higher the resistance the thermistor will produce. A thermistor was also selected over an RTD, or resistance temperature detector, due to its lower pricing and higher sensitivity. A 1k NTC Thermistor was selected due to the low temperature values that we will be detecting in our environment.

Figure 4: Vishay NTC 1kOhm Thermistor (NTCLE100E3)

The thermistor produces values in terms of resistance (Ohms, Ω), while the temperature readings need to be compared in terms of voltage (Volts, V). In order to convert this measurement to work appropriately with the voltage comparator, the following circuit was created.

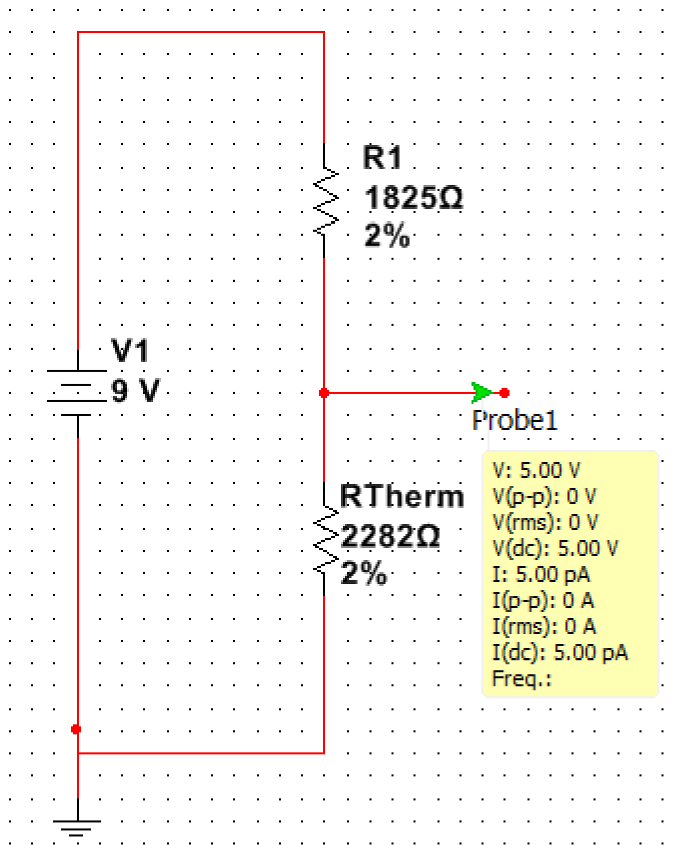

Figure 5: Voltage Divider for Thermistor @ +5 C

In the above figure, the thermistor is installed in the circuit as a resistor, forming half of a voltage divider. The thermistor was placed after the output voltage measuring point, as this is an NTC thermistor, which produces lower resistance amounts as the temperature increases. Using the datasheet provided by Vishay for their 1kΩ NTC thermistor, the value for the thermistor R_T at the desired temperature T_{OPER} = +5° C is 2282Ω. To find the respective resistor to be paired in series, we can choose a resistor value close to this value, as it will be our threshold resistance in order to change the comparator's state. Additionally, we can choose an arbitrary voltage value – say 5V – and use the equation for a voltage divider to find the value for R_1. The equation for a voltage divider is as follows:

$$V_{Out} = V_{In} * \left(\frac{R_2}{R_1 + R_2}\right)$$

Since we know or have selected values for V_{Out} (5V), V_{In} (9V) and R_2 (2282 Ω), we can rewrite this equation to solve for R_1, resulting in a value of 1825 Ω.

We would also like the voltage of the next portion of this circuit to be considered as the threshold that this voltage divider will be compared against. By calculating this, we can establish a voltage relationship so as to activate the end heating unit only at lower temperatures, i.e. those that are met by R_{Therm} being at or above 2282 Ω. By creating this fixed voltage division in the next section, we can establish the maximum allowable voltage created by this first voltage divider before the comparator outputs a low signal. Therefore, the voltage should be measured to set this threshold appropriately, which will be covered in the next section.

4.2.2 Voltage Comparator

A comparator is an operational amplifier application that measures two separate voltages and determines if the established threshold has been surpassed. The purpose of a comparator in this application is that it will compare whether the voltage produced by the divider created by the temperature sensor and a respective resistor is sufficient. If the temperature is cold enough – and therefore the voltage is sufficient enough to surpass the threshold established by the trigger – the output of the operational amplifier will be high. If not, the system will not activate, and will wait for a sufficient signal.

To create this comparator, we need to first select an appropriate operational amplifier. In order to do this, the appropriate voltage levels have to be calculated.

As stated in the earlier section, the temperature trigger value will be +5° C. The respective voltage for this temperature, using a 9V battery voltage supply, was calculated as follows:

$$V_{Out} = V_{In} * \left(\frac{R_2}{R_1 + R_2}\right)$$

Where R_2 is the resistor value of the thermistor, and R_1 is the respective voltage in series to create the voltage divider.

Since this voltage value falls within or around the middle of the rail-to-rail supply voltage, there is no need for a rail-to-rail operational amplifier.

One of the most common and affordable amplifiers used for comparator voltage purposes, the LM741, can be found within the LM324 IC chip, containing 4 similar operational amplifiers. According to its datasheet, provided by Fairchild Semiconductors, the voltage input can range between 0V and V_{IN} – 1.5V, or in this case, 8.5V. This is perfect for our circuit, so this will be the operational amplifier used for this project. Pins 4 and 11 of the IC are connected to V^+ and GND, respectively. We will use the first operation amplifier in the IC for this portion of the circuit.

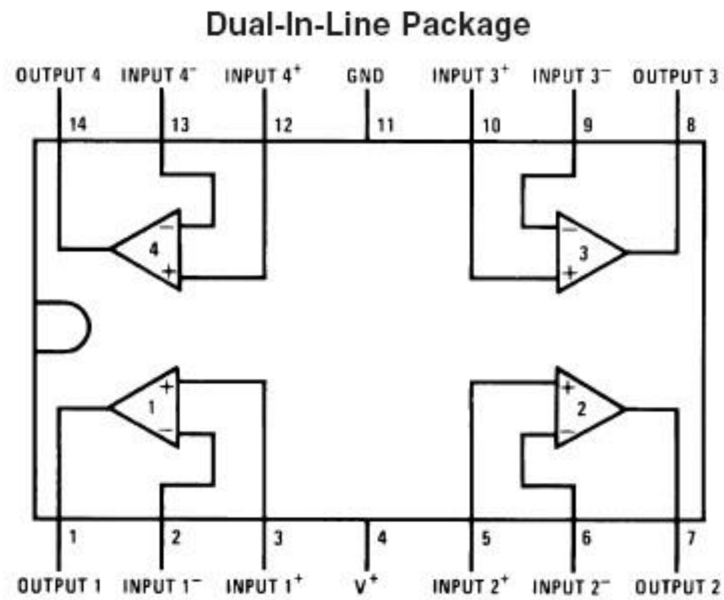

Figure 6: LM324 Pin Layout

Before wiring the operational amplifier, we need to also decide if this amplifier will be inverting or non-inverting. This means that the input voltage corresponds to the output voltage proportionately, or if it is inversely proportionate to the output, respectively. Since the output needs to go high when the temperature increases, or when the voltage increases, we will be using a non-inverting amplifier circuit. This means that the voltage divider output for the bridge containing the thermistor will be connected to the positive input of the operational amplifier, located at Pin 3 for the first op-amp. The inverting input will then be connected to the second voltage input, the output voltage of the set point voltage divider.

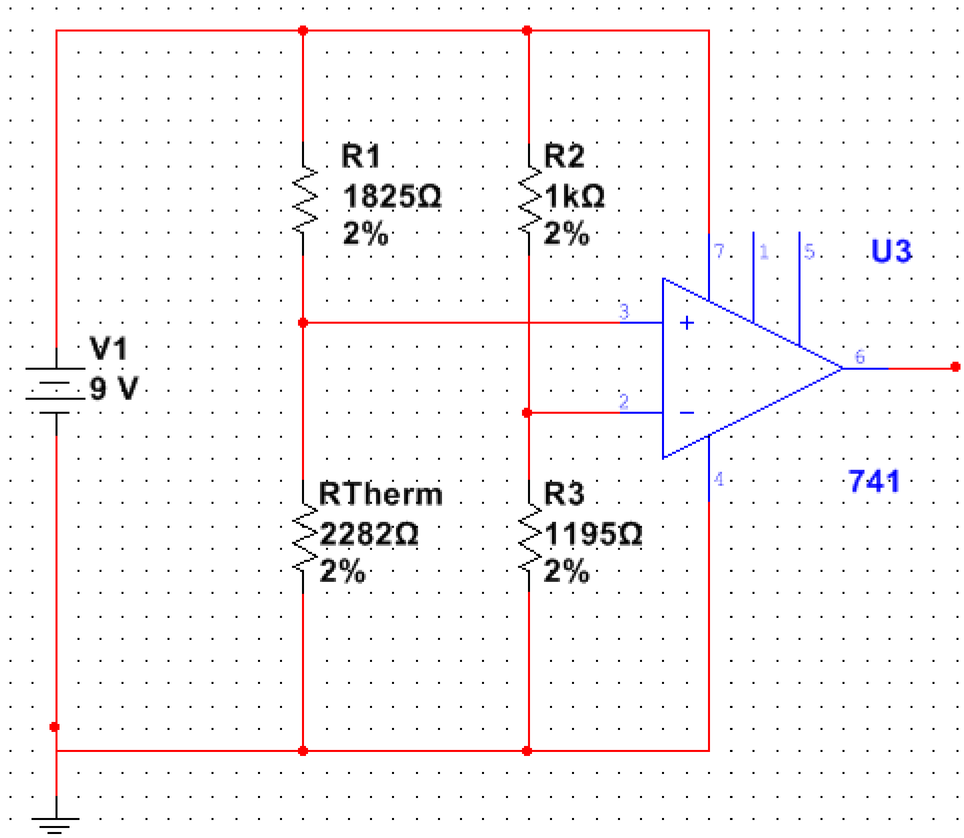

Figure 7: Comparator Setup for Thermistor Evaluation

As stated before, a set point is necessary to establish at what voltage value the operational amplifier will trigger a high or low output. To do this, we can just establish another voltage divider that will emit a voltage connected to the inverting output of the op-amp, at Pin 2. Because we want our output voltage to go low when the voltage at the negative terminal exceeds the voltage at the positive terminal, or when the thermistor R_{Therm} decreases in value, we need this voltage to output a voltage just less than the 5V located at the positive terminal. Since we do not have an external voltage source, we will again use a voltage divider created by two resistors in series. The most current will also flow when the resistor values selected are sufficiently low. To choose an arbitrary resistor value for R_2 we can select a resistor that is small enough yet large enough to allow for sufficient current flow, namely a standard value of 1000 Ω. Again, using the voltage divider equation, we find that the resistor R_3 value needed to obtain 4.9V – a voltage value that is just 2% smaller than the positive terminal voltage, due to the highly sensitive nature of this application – will be satisfied using a 1195 Ω resistor in series with R_1.

4.2.2.1 Transistor/Power Supply Switch

The last part of configuring this portion of the project circuit is ensuring that the transition is made to the next circuit, where the moisture sensor will activate and detect any presence of humidity in the air. To do this, an NPN transistor will be used to send a signal to a switch which will close and activate this second unit. An NPN transistor was used over a standard relay due to its high speed, silent features (albeit irrelevant for the project's application environment), and larger power capabilities within smaller scale applications. An NPN transistor was also chosen over a PNP transistor, albeit they perform equally the same functions, as the current will flow downstream by way of the transistor down to ground (versus current upstream through the load).

The NPN transistor that will be used in this project is the 2N2222A, rated for a temperature range well within our project design: -65 to 175° C. The current at the collector may not exceed, which is not a concern for this portion of the circuit. The switch that the NPN will be transferring current to is a simple single-pole, single-throw analog switch, often rated at about 2-10 V for supply voltage, and with a low turn-on resistance typically at 4.5-9V for 45-25Ω. These values all fall well within the range for this first circuit. The circuit design can be found as follows:

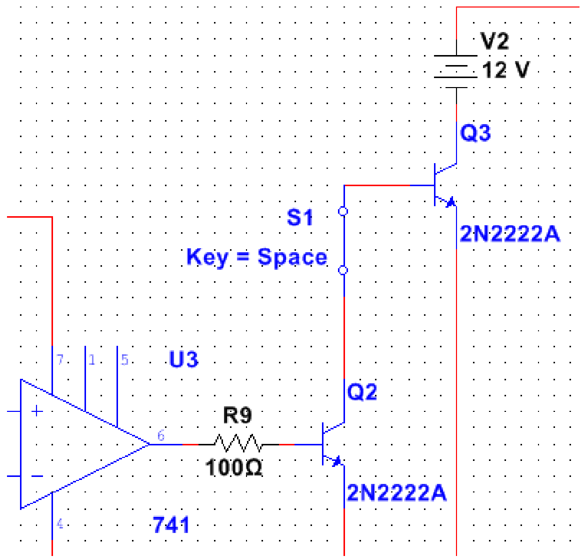

Figure 8: Transistor-Switch Connection from first LM741 to Second Supply

When the previously designed voltage comparator emits a high-level output (about 8.1 V, as it will always be about 1 V less than the positive rail), the voltage passes to the base pin of the NPN transistor Q2. R9 is used to filter the amount of voltage at this pin, ensuring that it is less than what is coming through at the current pin, in order to allow sufficient current flow through the terminals when it is activated. When Q2 has received current, it will open the connection towards S1, which is normally open, and close the switch. Then, as the current continues to flow in this direction, the NPN transistor at Q3 will activate, thus powering the 12V battery supply V2.

4.2.3 Moisture Sensor

If the supply voltage configured in the earlier section is switched on, then the next portion of the circuit will activate and measure the moisture sensor. The moisture sensor portion of this circuit needs to detect the presence of water and appropriately notify the rest of the circuit of this signal. To do this, two conductivity sensors will be installed to read the resistance that is produced from the electric conductivity of water. The sensors can be created by simply taking two pieces of conducting material that will be sensitive enough to detect the resistance. Although copper is a greatly conductive material, it is prone to corrosion at a rapid rate; therefore, stainless steel in the form of two inexpensive screws were used. Stainless steel was selected for its corrosion resistant and heat durability properties. The ends of the stainless steel material that will not be exposed to the water are covered in an insulating material to further delay corrosion, such as heat shrink wire wrap.

As before with the temperature sensor, the voltage at which the moisture sensor will accurately determine if there is moisture present or not has to be calculated or determined from the data sheet. As these are two conductivity sensor probes, this requires a bit of chemistry to determine the resistivity of water and what value(s) are sufficient to accurately determine the presence of a significant amount of water (or any precipitation).

Type 304 stainless steel, as will be selected for this project, is an alloy that has a relatively small amount of copper – about 0.030-0.08 weight percent of its chemical composition. Pure rainwater has an acidity level of 6 on the pH scale and increases through industrial byproduct (such as acid) and rainfall speed/intensity. When contaminated by external influences, and changed into other forms of precipitation due to gases and weather changes, water can become a harbor for acids and increase in corrosive properties. Therefore, it is an optimal selection of stainless steel for our application, as the metal will be exposed to various corrosive environments within the atmosphere.

Heat shrink tubing is essential for the portion of wire that will not be constantly exposed to outdoor weather conditions. This process works by fitting a tubing, usually made of a polymeric or thermoplastic material, around a set of wire or metal. The material is then heat shrunk, either through soldering or other means. Having this protective layer on the outside of the material helps to serve as an insulating, flexible material that holds and protects the material.

To connect this probe construction to the circuit and use it as a moisture sensing device, this project will use resistors and an external voltage supply to create a 4-wire Kelvin connection. This connection was chosen over a simple two-/three-wire connection, as found in the connectivity of the thermistor in earlier sections, in order to increase the accuracy of the probe sensors. Temperature has a direct effect on the conductive properties on water; when the weather gets colder, the conductivity of water decreases. This is because at lower temperatures, the viscosity of water increases due to its dynamic properties. When water reaches and decreases from the freezing point of 0 C mentioned earlier, the properties in the fluid flow less freely due to the bonding of hydrogen molecules in water. When this happens, the liquid attempts to expand to increase the strength of these molecular bonds. This is why ice increases and yet is lighter than water. The viscosity of liquid increases as the friction and stresses of the object increase as there is more resistance to the free flowing of the liquid at lower temperatures. Therefore, the resistance of water at lower temperatures is sensitive and fluctuating depending on the temperature and other compacting properties of water molecules, which requires a more accurate sensor reading.

To calculate the best resistor values, we need to first determine which voltage output value is needed from the circuit. As the circuit will be driving an actuation device in the next section - should the probe sensors read a suitable measurement - the voltage produced should be as close to the input voltage from the supply. The resistance across the probes should also correlate with the temperature conditions set forth in earlier sections, where the unit activates when the thermistor reads at or below 5 C. Therefore, the circuit should output a high voltage when the resistivity measured across the probes is at or below 60.48; the resistance of this can be found using the equation for the electrical resistance of a wire:

$$R = \frac{\rho L}{A}$$

Where R is the resistance, ρ is the resistivity, L is the length of the wire, and A is the cross-sectional area of the wire. Using stainless steel rods of about 30.48cm (1 foot) in length, and a diameter of 1.27cm (0.5 inches), the cross-sectional area would be

$$A = Pi * \left(\frac{d}{2}\right)^2 = Pi * (1.27\ cm)^2 = 3.989\ cm^2.$$

Now, the resistance can be found by plugging in all of the variables:

$$R_{probe} = \frac{(60.48\ M\Omega\text{-}cm)(30.48\ cm)}{3.989\ cm^2} = 462.13\ M\Omega \text{ @ } 5°\text{C}.$$

As can be seen, this is an extremely high resistance at such a low temperature.

The resistivity of the 304 Stainless Steel probes, as given by the datasheet, is 72 MΩ-cm at 20°C, and 116 MΩ-cm at 659°C. This gives us a rough (since this is actually a non-linear property, this will be assumed on a linear basis) resistivity of approximately 18 MΩ-cm at 5°C. Therefore, the cell constant is 25.673/cm. This cell constant, κ, refers to the ratio of the distance between the electrodes of the water measured and the area of the electrodes.

Resistance of the 304 Stainless Steel Probes is:

18 MΩ-cm * 30.48 cm / 3.989 cm^2 = 137.54 MΩ @ 5°C

72 MΩ-cm * 30.48 cm / 3.989 cm^2 = 550.15 MΩ @ 20°C

Temperature Coefficient of 304 Stainless Steel Probe is:

α = dR / dT * Rs = (137.54 – 550.15 [MΩ]) / (-15[°C])(2.00[%/°C (historical)]) = 13.754

4.2.4 Actuation Device

After the second comparator in the circuit satisfies the set threshold voltage, a high output will emit from the Schmitt trigger. This voltage will be used to activate a solid state relay, which will be needed to activate the heating unit. If there is no (or a low) voltage emitted from the trigger, the relay will not activate.

4.2.5 Heating Unit

The heating unit for this project will consist of a set of NiChrome wire insulated in an antireflective material. NiChrome is a family of high resistivity alloys commonly used in electric heating applications. NiChrome was selected due to its reliability, low cost, and durable heating capabilities. The specific NiChrome wiring selected is NiChrome C, rated with a higher resistance per foot, as it is the type commonly used in heating and de-icing applications. In order to actually heat, the NiChrome wire will be layered between two silicon plates, similar to the ones installed in a solar cell. This material was selected due to its being able to withstand moisture while still being able to produce enough heat, which is critical for this project.

When sizing the NiChrome wire, there are a variety of parameters that have to be considered depending on your application. One is the wire gauge desired, which involves selecting the diameter sizing and length of the NiChrome. Another is the amount of current you are looking to consume. A third is the amount of voltage required (or set as the maximum) for your application. Lastly, selecting the operating temperature you would like the NiChrome wire to heat up to.

For this project, we know that we would like to set a maximum of 12V DC for the battery that will be in series and connected to the heating unit once the actuation device is approved. We also will not require more than about 200°F (93°C) for the amount of heating required; in fact, it can be less than this amount if we wanted to save the amount of current required, but this is a normal temperature of operation, and will allow for flexibility. We can also select a length of about 24 feet, or 60 inches, for approximately 6 ft^2 of area. Now we can select a wire gauge and use the ratings given, along with these defined parameters, to calculate the power, current, and voltage requirements of the heating unit. Figure 9 below depicts all of these values for a few select wire gauge sizes.

Wire Size (AWG)	Resistance per Foot (Ohms) @ Room Temp*	Resistance (Ohms)	Current Required (A)	Power Required (W)
10	0.0649	2.648	4.532	54.38
12	0.1029	4.198	2.858	34.30
14	0.1648	6.724	1.785	21.42
16	0.2595	10.59	1.133	13.60
18	0.4219	17.21	0.697	8.366
20	0.6592	26.90	0.446	5.354

Figure 9: NiChrome C Wire Sizing and Relevant Calculations

*** Resistance per Foot is given for NiChrome C at room temperature. For the selected temperature of 200°F, this increases by 1.7%. This is included in the calculations.**

Another thing to consider is how much heat is required for the application being created. To melt snow at a reasonably efficient rate (where rain/moisture may still remain present), the heating application must deliver about 108 BTU/hour or 31 watts to heat approximately 6 square feet. Therefore, we can choose either the 10 or 12 gauge NiChrome C wires for this application.

In order to activate this unit, the moisture sensor circuit will be connected to an NPN transistor. When the sensors reach the designated threshold, the transistor will pull up and activate a general purpose relay. This is simulated by creating a relay coil and contact combination utilizing a general purpose diode, such as a 1N4001, with an inductor in parallel. When the relay is activated, it will switch the relay contact closed, thus supplying power to the heating unit.

5. Design Simulation

Figure 10 demonstrates a simulated circuit containing all of the previously mentioned components that compromise this circuit.

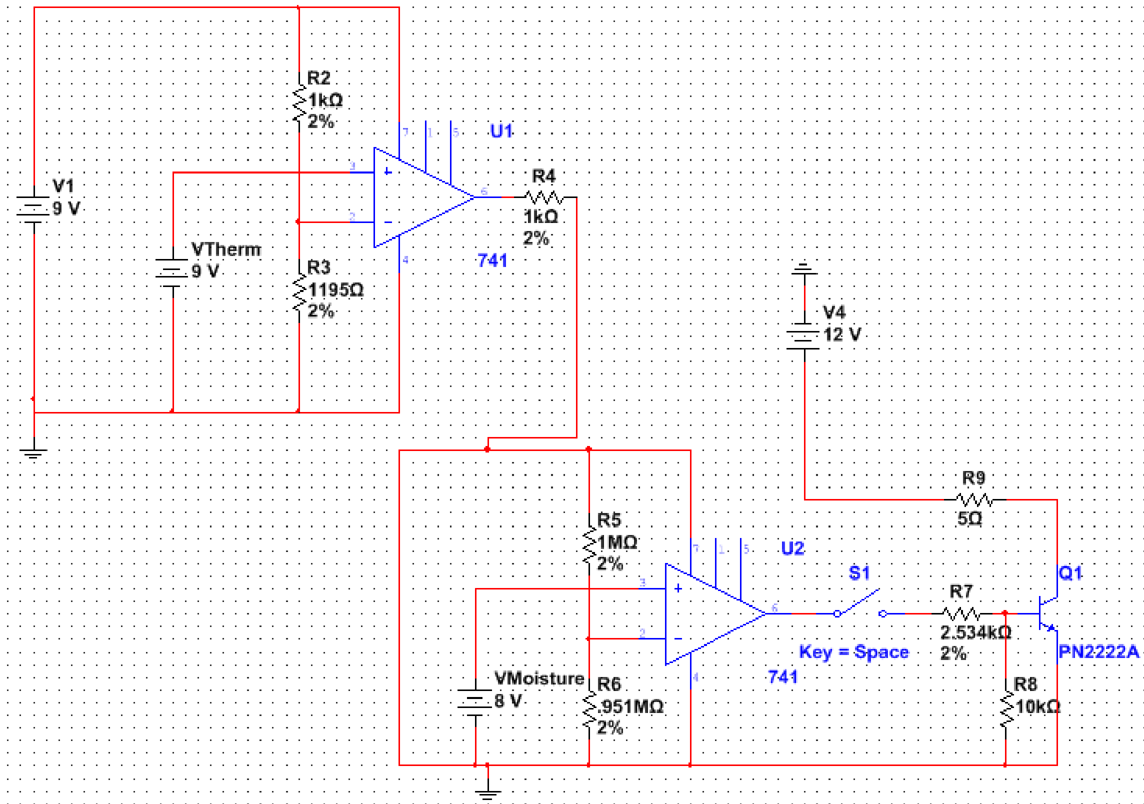

Figure 10: Entire Design Simulation for Moisture Sensor and Heat Circuit

In order to verify that this circuit performs as desired, each individual portion was separated, tested individually, and then compounded to each respective portion of the circuit. The following sections will describe, demonstrate and detail the results of each simulation.

5.1 Temperature Sensor and Voltage Comparator

To ensure that the thermistor selected and designed in Section 4 of this project will accurately satisfy our needs, we can first simulate a voltage comparator circuit. Then, we will substitute a voltage source in place of the voltage divider circuit for the thermistor. In its place, we can conduct a DC sweep across this new independent voltage source, and plot it against the output of the voltage comparator.

The figures below demonstrates the results of these simulations and sweeps. As noticed, the voltage output at Node 6 (the output of the comparator) increases suddenly to approximately 0V once the voltage substitution for R_{Therm}, V_{Therm}, approaches the calculated switching threshold of 5V.

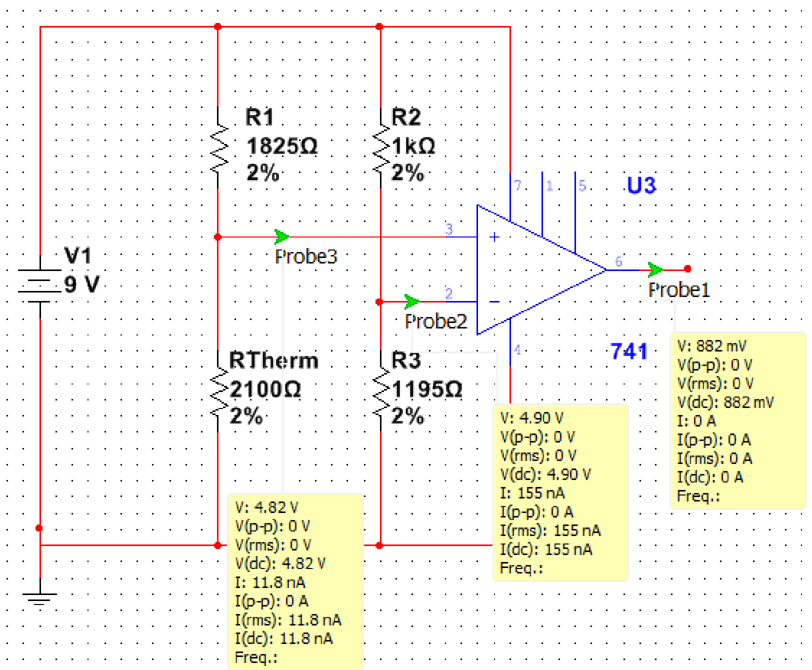

Figure 11: Probing of Voltage Comparator Output vs. Thermistor Resistance, Temp > +5°C

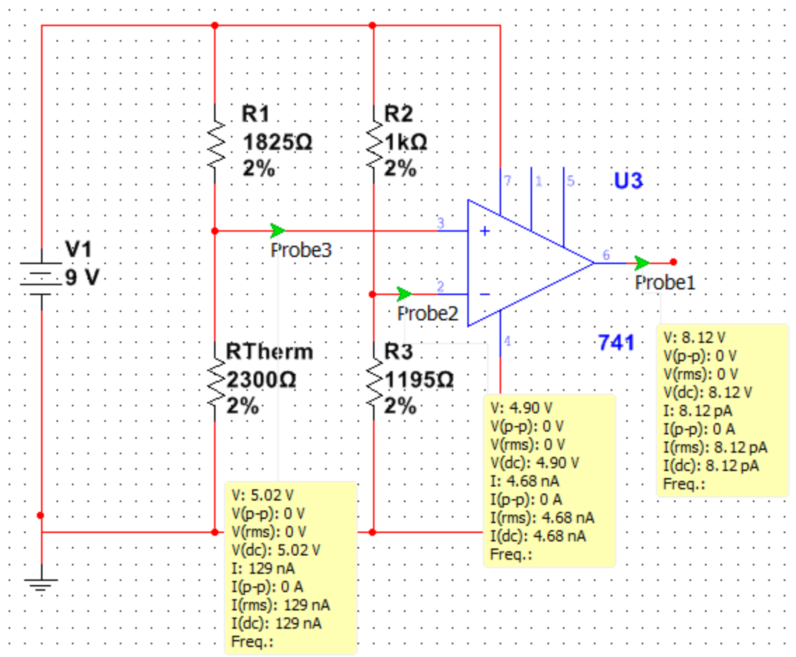

Figure 12: Probing of Voltage Comparator Output vs. Thermistor Resistance, Temp < +5°C

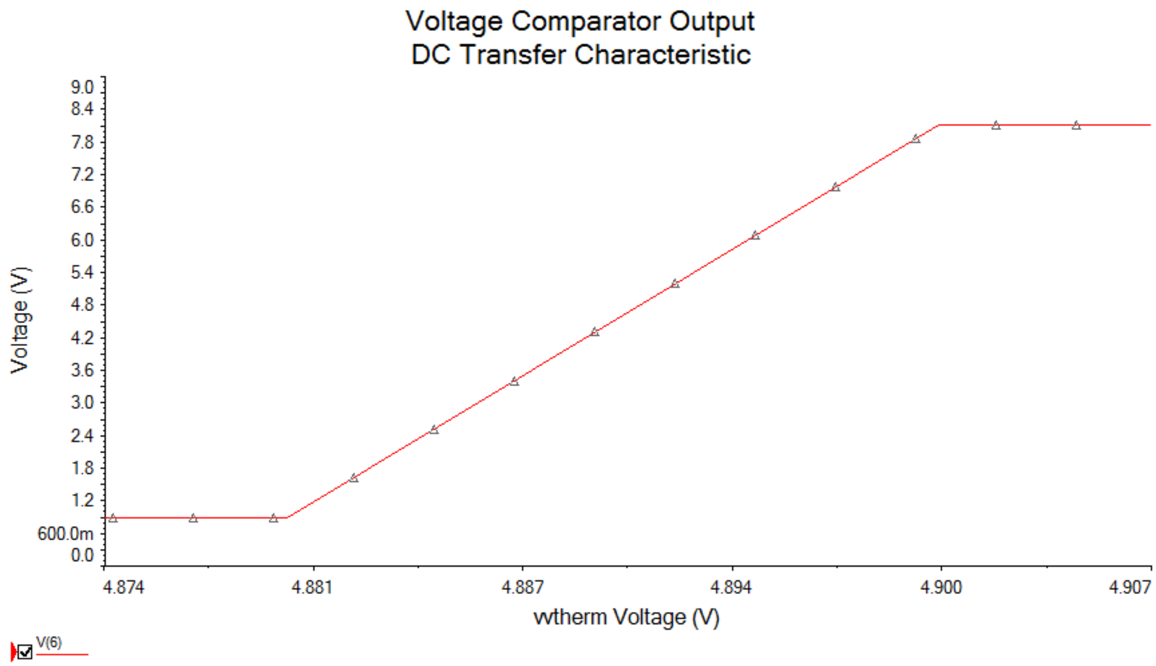

Figure 13: DC Sweep Result for V_{Therm} as R_{Therm} Substitute vs. Voltage Comparator Output

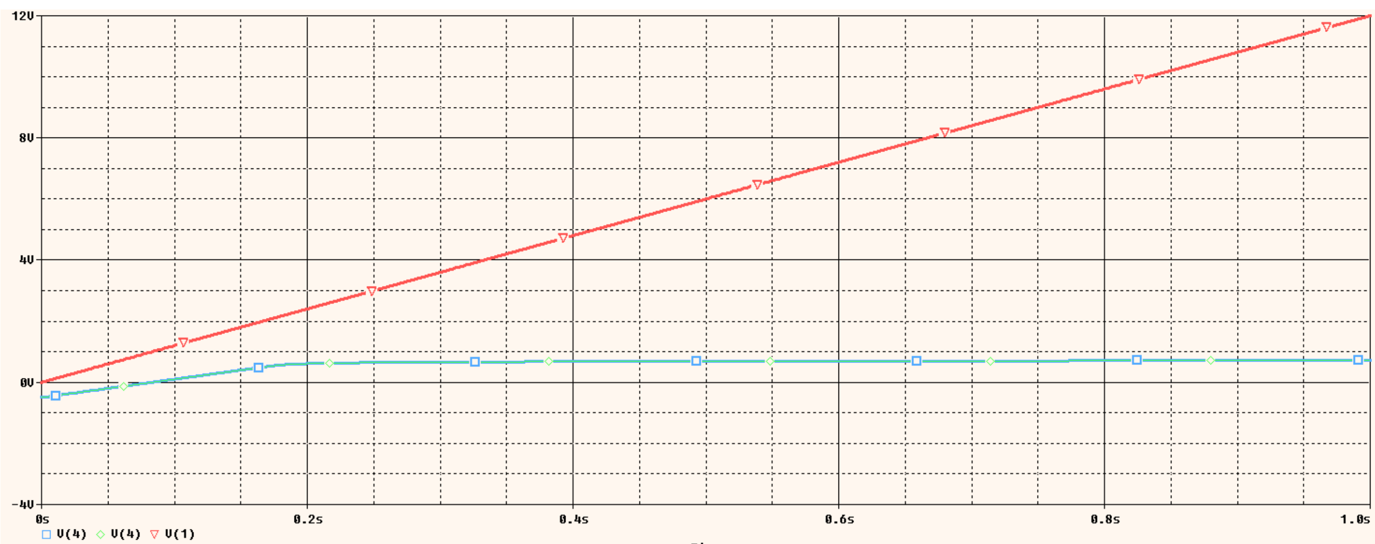

Figure 14: PSpice Transient Analysis of VTherm (Red) vs. Diff between VTherm and Voltage Divide

5.2 Moisture Sensor

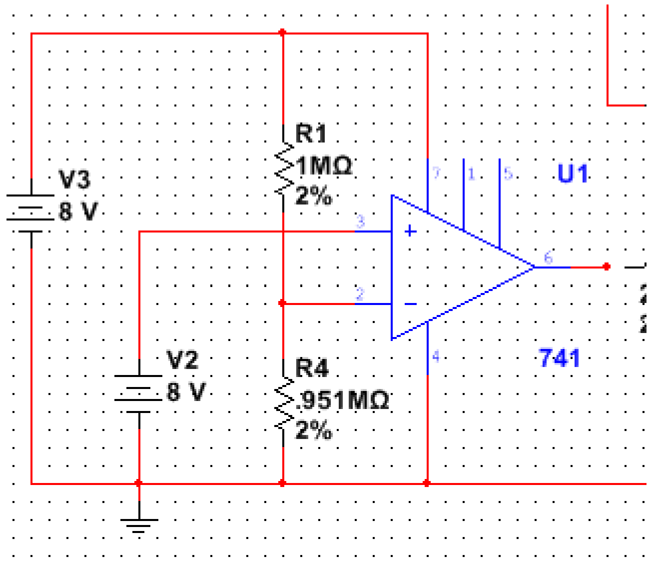

Figure 15: Moisture Sensor Circuit for Simulation

Once the voltage comparator outputs a high value of approximately 8V, the circuit can then proceed to measure for the presence of any moisture. To do so, we can replace the two moisture sensor probes with an equivalent, independent voltage source, V_2. In order to first separate this circuit from the comparator circuit, we will also place a source voltage V_3 to represent the output of the comparator voltage.

The independent voltage source V_2 will be connected to the positive pin of the comparator. This is because the presence of moisture has a representative resistance value that is directly proportional with the output, i.e. the output is high when the resistance across the moisture sensor probes is high. For the negative pin of the comparator, we can connect another voltage divider. This voltage divider must be again at a fixed voltage to dictate the minimum value the moisture sensor probes must reach before the comparator outputs a low signal. In order to avoid installing rail-to-rail busses for the comparator, we can again choose a voltage that is approximately in the halfway point of the input source voltage, 8V, which would be 4 V. Because the voltage at V_2 should not fall past this 4V, we will choose a fixed voltage of 3.9V for this voltage divider. We can choose two resistors of approximately the same value for this bridge, and will select high values in order to increase the sensitivity of this circuit. Therefore, the resistors chosen were 1M Ω and 0.951M Ω for R_1 and R_4 in the circuit, respectively.

To simulate this circuit, we can again run a DC sweep across the independent voltage source V_2. We can trace this sweep against the emitter pin of the NPN transistor, which will pull the current for high voltage values from the voltage divider circuit, by measuring the voltage at its node. Figure 16 demonstrates a graph capturing this sweep.

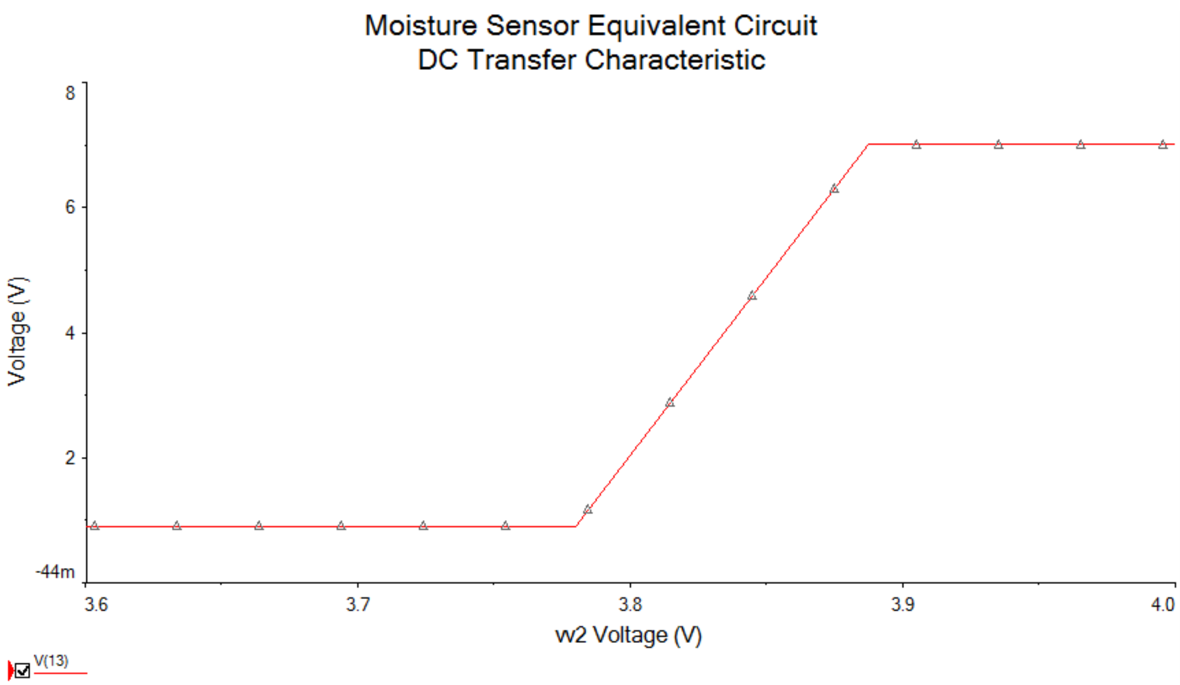

Figure 16: DC Sweep of Moisture Sensor Equiv. Voltage vs. Comparator Output

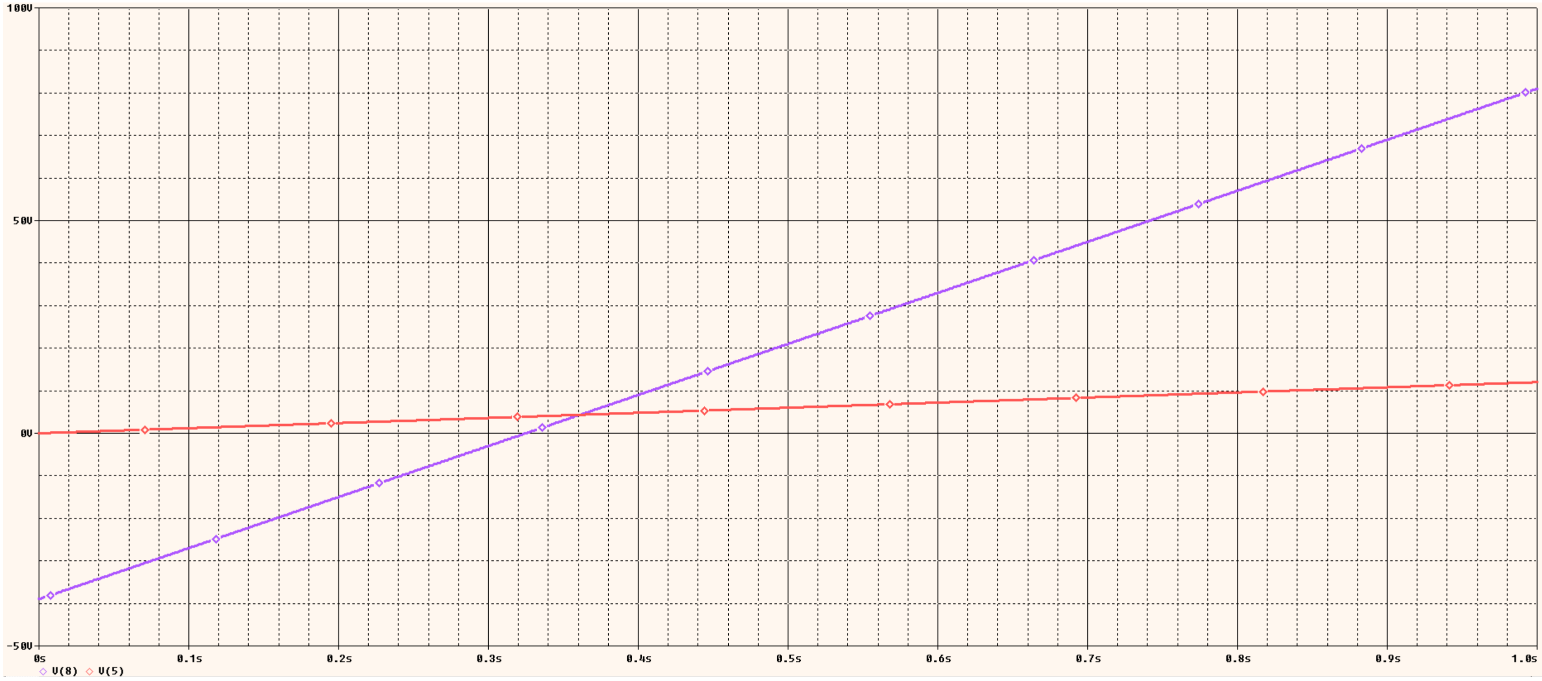

Figure 17:Transient Analysis of VMoisture vs. Diff between VMoist and Voltage Divider (3.9V)

5.3 Heating Device

The final portion of the circuit, once all other units have passed their established thresholds and have been activated, is the heating unit. This is comprised of a layer of NiChrome C wire that would be installed in the solar photovoltaic panel.

In order to effectively power the heating unit, we need to select a power supply that is capable of providing the minimum amount of power required for our heating unit. As our circuit will be using a 12VDC source requiring at most 5 A, we can use a 12V, 5AH lead battery.

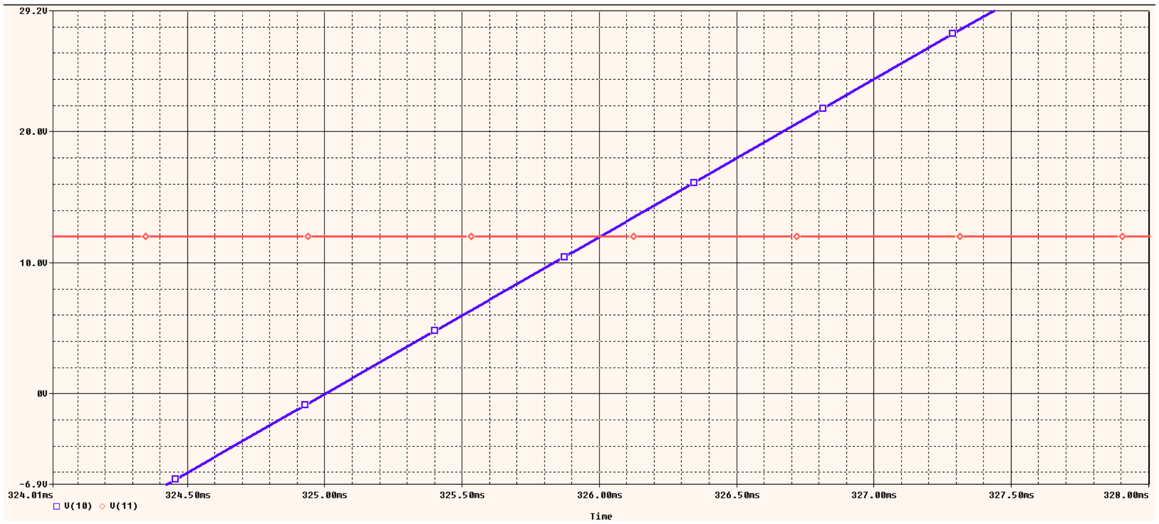

Figure 18: Transient Analysis of 12V Supply vs. Time when Switch Closes

7. Future Design Recommendations

Through the process of researching, designing, and simulating this project, it is only logical to consider other alternatives to the design that could possibly increase many features of the overall project. These features include cost reduction, accuracy, aesthetics, and others. This section will describe a few possible alternatives that are recommended for future editing, extension or reference of this project and its design.

7.1 Temperature Sensor Recommendations

An initial design recommendation for this project in the future would be to use existing and advanced temperature and humidity sensor models.

7.1.1 Combined Temperature and Humidity Sensor

These include integrated chip (IC) components that combine the readings for temperature and humidity. A controversial issue that arises with this design change, however, is that the original block diagram for this project required a decision circuit to first evaluate the temperature value before conducting humidity values. It is strongly recommended that, should this design feature be considered, to carefully understand the schematic and wiring diagram of the selected IC to ensure if the two readings can be evaluated in this combination.

7.1.2 Temperature Switch

Through researching possible components for the project, a part named a temperature switch was found that would perform the same function as the thermistor, comparator and Darlington circuit combined. One example of this is the Texas Instruments LM57 ±0.7°C Temperature Sensor with Resistor-Programmable Temperature Switch. This part packages: a digital-to-analog converter (DAC), for the external programmable resistors; a temperature sensor; two trip tests dependent on the output of the DAC and temperature sensor, built-in temperature hysteresis; and digital logic operators to analyze the output temperatures. Including this part would reduce the number of external components in our circuit by compacting essential pieces and processes into a small package. It would also be beneficial to utilize this part for operations requiring a strictly digital output. The disadvantage of this part would only be for those circuits using parts other than thermistors to measure temperature, such as temperature dependent sensors.

7.2 Moisture Sensor Recommendations

7.2.1 Moisture Sensor Connection – Kelvin Bridge

An optimal way to connect the moisture sensors would be through using a Kelvin bridge. An alternative to measuring the resistive differential between two electrolytic probes, the Kelvin bridge allows for a larger elimination of bias error through the inclusion of specific components to optimize the accuracy of recorded measurements.

The 4-wire Kelvin configuration is essential for this project due to the bridge's high sensitivity to the resistivity across wires. Since there is a small and constantly fluctuating amount of resistance in water, Kelvin sensing assists in the reduction of error in measurements by disregarding the resistance of electrical leads and contacts/connections. Kelvin sensing is also a great feature of this project as it is a low-voltage application, which will help in the voltage drop calculations of this circuit.

To connect this circuit, the stainless steel probe sensors, now insulated, are connected in parallel to two sets of two resistors connected in series. One set, which will be connected to an ammeter, serve as shunt resistors, which are low resistance resistors used to measure the current across the loop by means of the voltage drop. The line works as a short circuit, where current flows in the path of least resistance. This set of resistors' leads are connected to the rest of the circuit as closely as possible to prevent the creation of stray resistance. The other set of resistors, in parallel between the shunt resistors and the probes, will be utilized to measure the voltage across the probes. A supply voltage will be connected between the shunt resistors in order to utilize Ohm's Law and calculate the current across the circuit. Connecting them within the same loop as the other resistors will create stray voltage, which can affect the resistance measurement.

Within this project, the supply voltage, provided by another 9V DC battery, is activated by the switch mechanism described in the earlier section. The resistors of the Kelvin Bridge are not selected randomly; instead, they are based on the ratios between both sets of resistors, which need to equal/be proportionate to each other as closely as possible to neglect as much stray voltage as possible. Simply put, the voltage across the probes is balanced (or zero) when the ratios are equal. The resistance across the probes, which is a manipulation of Ohm's Law, is calculated as follows:

$$R_{probe} = \frac{Voltmeter}{Ammeter}$$

Where the voltmeter and ammeter values will not be explicitly displayed in this circuit, but are the measurements obtained as described above.

7.3 Heating Unit Recommendations

7.3.1 Heater Reconstruction

Another recommendation for future design includes remodeling the heating unit. The new base would be made of polyimide, a common polymer with high heat resistance. Polyimide was selected instead of silicone rubber as the heating requirements for this application will not reach high temperatures exceeding the maximum exposure temperature for polyimide (200° F). The polyimide will be used as a thermosetting, molded into a plastic and then etched with the appropriately selected foil. This mask would then be laser cut to fit the size of the metallic conductors on the solar panel, and would rest in the layer between the glass and the polymer sheet. If that would not be feasible, research can be conducted to evaluate the best polymer combination to ensure the safe and appropriate installation of the heating film and glass solar panel cover.

7.3.2 Heat Temperature Regulation

Presently, this circuit is designed to activate the Nichrome heating unit once the relay is successfully activated through the moisture sensors. An alternate, energy efficient method to regulate the amount of heat emitted by the nichrome circuit would be to apply a pulse with modulator from a microcontroller, which would be dependent on the amount of moisture present. This dependent factor would be dictated by the resistive difference amount measured, and would increase or decrease the nichrome circuit emission when the amount of moisture present is more or less, respectively.

Appendix

PSpice Simulation Code

```
** Temperature Sensor Circuit **

VTherm 1 0 PWL(0,0 1,12);

R12 1 0 1k;

VFix 2 0 4.9V;

E1 3 0 VALUE = {10 * (V(1) - V(2))};

RFix1 3 4 1MEG;

R1 4 0 1k;

D1 4 0 Dix

D2 0 4 Dix

.MODEL Dix D (RS = 1m BV = 100)

** Moisture Sensor Circuit **

R46 5 6 1k;

VMoisture 5 0 PWL(0,0 1,12);

VFix2 6 0 3.9V;

E2 8 0 VALUE = {10 * (V(5) - V(6))};

RFix2 8 9 1MEG;

R2 9 0 1k;

** Switch and Heater Circuit **

S 10 0 11 0 ZWIK
.MODEL ZWIK VSWITCH (RON = 1m ROFF = 10MEG VON = 0.1 VOFF =
0)

E3 10 0 VALUE = {100 * V(8)};
```

```
RBreak 8 0 100;

RHeat 11 12 5;

VSupply 12 0 12V;

.PROBE
.TRAN 1 1 0 1m UIC
.END
```

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