H.E.A.T.²

Heat Emitting Automatic Temperature Square

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Abstract**—Snow and ice can be very dangerous weather conditions in some parts of the world. People spend a lot of time shoveling and the Department of Transportation hires plows to clear roads and lay salt down to keep conditions safe. This can be a very time consuming process and the salt left on roadways deteriorates the bottom of cars. A Computer and Electrical Engineering project, the H.E.A.T. Square is an automated pavement solution to remove snow and ice off driveways, walkways or roadways and keep conditions safe. The H.E.A.T. Square utilizes a temperature and humidity sensor to detect when snow and ice are on the pavement, when detected the integrated Atmega328 triggers a relay to turn on the heating system. When the pavement reaches a temperature well above freezing the Atmega328 will turn off the relay and heating system. The H.E.A.T. Square has a built in strip of LEDs that are used as an indicator for the state of the system.**

Index Terms**—Microcontoller, Humidity Measurement, Thermistor, Printed Circuit, Accuracy, Heating, Temperature Control**

I. INTRODUCTION

Living in a world of never ending growth in technology processes such as shoveling and laying salt can be a thing of the past. The objective for this project was to design and create a highly functional project that can change the way colder climate places handle snow and ice removal. This project is a 1ftx1ft square that will represent the pavement on a driveway, walkway or roadway. The square was constructed of an external wooden structure with pavers on the top. This project utilizes a temperature sensor, a humidity sensor, heating element and LEDS. The sensor data is processed by an Atmega328P, if the sensor data represents snow and ice conditions the Atmega turns on a relay to power the heating system. The heating system melts the snow and ice on the surface of the square and a surface mounted thermistor is used to measure the temperature of the pavement. When the surface temperature of the square reaches fifty degrees Fahrenheit the Atmega will turn off the relay and heating element. The LEDs are used as indicators to let the user know what state the system is in.

II. SYSTEM COMPONENTS

A. ATmega328P Microcontroller

The ATmega328P Microcontroller is the ideal microcontroller for this project with respect to writing, loading, and testing the code used in this to control the inputs and outputs, as well as the ease of access for inserting it into the PCB. The specific ATmega328P chip used was the 28 dual in-line pin (DIP-28N) which gave more than the necessary pinouts for the hardware. The ATmega328P (DIP-28N) microcontroller chip comes as the default microcontroller on the Arduino Uno, which allows for the code and sensors to be easily tested and breadboarded, utilizing Ardiuno's IDE to view the outputs of the sensors. The microcontroller can then be removed from the Arduino used for testing and placed on the PCB for the final product. As well as being the same microcontroller, the pin-out allocation numbers between the Arduino and a standalone ATmega328P on the PCB were made to be identical and required no major redesigning in the code.

The ATmega328P is equipped with 8 digital I/O and 6 analog A/O, more than what is necessary for H.E.A.T.²'s hardware. Four pins were allocated for the Wi-Fi module that did not make the final product. One of the digital pins are used for the DHT11 humidity sensor's inputs that get polled every 2 seconds due to limitations of the DHT11 humidity sensor The second digital I/O acts as an output HIGH signal to the relay for when conditions are met. The third digital I/O that is used is for the WS2812B LED Strip. The microcontroller is always sending an output to the WS2812B LED Strip depending on which of the four states the system is in. The sole analog I/O used is for the temperature reading given by the NTC 3950 Thermistor, which also had its data polled every two seconds due to the DHT11's limitations.

B. DHT11 Relative Humidity Sensor

There were three different types of humidity sensors applicable for this project, resistive, Capacitive and thermal humidity sensors. Figure 1 below compares the important parameters for these sensors.

Sensor Type	Thermal Humidity Sensor	Capacitive Humidity Sensor	Resistive Humidity Sensor
Range	0-100%	0-100%	5-90%
Accuracy	Absolute Humidity	Relative Humidity	Relative Humidity
Cost	High	Moderate	Low
Power	Constant source	Constant Source	Constant Source

Calibration	Must be calibrated before use	Some calibration necessary	No calibration necessary

Figure 1: Humidity Sensor Comparison

For this project's application it was determined that a capacitive relative humidity sensor would be the best humidity sensor. The capacitive Relative humidity sensor was chosen because it is a cost effective accurate humidity sensor capable of measuring humidity from 0-100%. The humidity sensor chosen was the DHT11 Relative humidity sensor. This sensor uses a pull up resistor and an NTC thermistor to sense the humidity in the air. The sensing capacitor has two electrodes with a dielectric moisture layer between them as the humidity or moisture changes, the capacitance will also change. One of the pros for this sensor is it is capable of sensing both humidity and temperature, so although there is a separate thermistor temperature sensor specifically for the surface temperature of the tile, this sensor will be able to sense the outdoor air temperature. Another advantage to the DHT11 humidity sensor is it can produce a digital output making it very easy to interface with the Atmega chip. This humidity sensor has a temperature range from 0 degrees celsius up to 50 degrees celsius and a humidity range from 20% humidity up to 80% humidity with a +/-10-15% accuracy. During the operation and testing of this project the DHT11 humidity sensor was found to be very accurate and worked without any issues.[1]

C. NTC 3950 Thermistor

There were three different types of temperature sensors applicable to this project, the Resistance temperature detector (RTD), thermistor and thermocouple. Figure 2 below compares the important parameters for each of these sensors.

Sensor Type	**RTD**	**Thermistor**	**Thermocouple**
Accuracy	0.1-1C	0.05-1.4C	0.5-5C
Temp. Range	-200-650C	-100-325C	200-1750C
Linearity	Linear	Exponential	Non-Linear
Noise	Rarely susceptible	Rarely susceptible	Very susceptible
Power	Constant source	Constant source	Self-powered
Cost	High	Low-moderate	Low

Figure 2: Temperature Sensor Comparison

The thermistor was chosen because it is a very accurate sensor that has a low susceptible to noise, a quick response time and low to moderate cost. The thermistor chosen for this project was the 3950 Negative Temperature Coefficient Thermistor, the temperature range for this thermistor is -55-165C the 3950 thermistor is accurate to +/- 3 degrees and has an IEC sensor rating of IP68k meaning it is dust and waterproof making it a good choice for outdoor use. The 3950 thermistor translates a resistance value into a temperature value, the higher the resistance the lower the temperature. The NTC thermistor was connected in a voltage divider circuit to translate the resistance value into a voltage provided to the Atmega chip. During the operation and testing of this project the 3950 thermistor was found to be very accurate and worked without any issues.[2]

D. WS2812B LED Strip

Utilizing lighting was one of the key indicators that puts this product above others already in the market. There are a multitude of options when it comes to type of lighting technology and how to control it, but the decision to use an LED strip came pretty easily due to the ease of use and the ability for it to get programmed directly into the Atmega328P chip that is used. The product chosen for this was the WS2812B LED strip. This is an RGB color changing LED strip with 4 ports. VDD is the power supply, DOUT is the control data signal output, VSS is ground, and DIN is the control data signal input. Each LED is 20 mA for red, 20 mA for green, and 20 mA for blue making the maximum output to be 60 mA at full brightness. The strip for each tile has roughly 50 LEDs which would require 3 Amps worth of power. There are a few great design aspects for this product which led to the decision to choose it. First is that the VDD, VSS, and DOUT for each LED closest to the power is connected to the VDD, VSS, and DIN respectively of the next LED in line already. This allows for soldering just the 3 connections at the first LED per strip and that is it. Secondly, each LED is individually addressable via programming in the Atmega chip meaning both the dim setting and color settings can be set for each LED individually.

In terms of design and integration with the HEAT² system, there were two things to consider. First was noise on the data input line. The product manufacturer suggests using a 330Ω resistor to reduce that noise. Second was that the external voltage signal needed to be smoothed out, so a 100µF capacitor was added between the power supply and ground to do so [3].

E. 5V Single Channel Relay Module

The HEAT² system utilizes multiple voltage potentials to operate correctly, so having a way to use a low voltage signal to control a large voltage potential in a safe and effective way is ideal for the proper function of the HEAT² system. This is where a relay module exceeds in performance. The relay we chose to use operated on 5V, which made it simpler to incorporate into the already existing 5V power supplied to the PCB. Once powered, the power indicator LED will be green and once the relay activates the relay status indicator LED will be red. Interfacing the module was straight forward, with an input side and output side. The input side has 3 pins, VCC (relay power supply +), GND (relay power supply -) and IN (signal trigger input). In addition the IN can operate on a low level trigger, or high level trigger which gives us more flexibility on how to send a control signal, we chose to go with the high level (5v) signal to activate the relay. The output side of the relay consists of 3 pins as well. NO (normally open pin), COM (relay common pin) and NC (normally closed pin).

In terms of design and integration with the HEAT² system, there were two things to consider when choosing the right relay. First the ability to handle max voltage load and current draw of the heating element (120VAC/4.2 amps). This relay module which has a maximum load: 250VAC/10A does just that. Second, is preventing noise from the AC signal from interfering with control signals on the input side. The relay module we chose to use comes with an opto isolator (optical coupler) that prevents high voltages from modifying the system receiving the signal. This allows 2 circuits to transfer electrical signals while keeping them electrically isolated from each other using a short optical transmission path. [4]

F. WarmlyYours Snow Melting & Heating Cable (43')

The heating element can be considered the most important component in the HEAT², due to the fact that all components work together to safely and effectively bring power to the heating element to allow proper functionality. This is why choosing the right heating element is very important and all other components would be built around this. The *WarmlyYours Snow Melting & Heating Cable* will be used for three main reasons: budget, performance and ease of use.

As far as performance goes for the 43' long heating cable used, it draws 4.2 amps at 120VAC, which pairs excellent with the relay of choice which can handle 120 VAC and a max current load of 10 amps. Since this cable will be in the upper half portion of the HEAT², it is necessary for the heating cables to be able to flex and bend without compromise to performance. This allows a maximum run up to 10.75 sq. ft with a 3" spacing giving a uniform heat transfer through the foundation sand up to the surface of pavers.

Having an easy and safe way to install the heating cables was a top priority as well, the HEAT² needed a heating cable that did not need extra drivers or other devices to power it, and the *WarmlyYours Snow Melting & Heating Cable* was perfect due to its 120VAC operational voltage. This cable came with three wires that are wired to a distribution block, which in turn is connected to a waterproof male inlet. The black wire line, yellow is neutral and the yellow with green stripe is ground. This helped pave the way for the entire HEAT² voltage power supply in terms of using the mains 120VAC home outlet to bring power into the HEAT² and distributing the voltage internally of the HEAT² to the other components. [5]

III. System Concept

A. Hardware Block Diagram

Figure 3 below shows the hardware block diagram for the H.E.A.T² system. The main component of this system, the heating element, requires a 120V input signal and needs up to 50W per square foot of power to operate. Because of that, the voltage input for the heating cable will be from an AC voltage mains power outlet. Since the goal for this product is to operate automatically, a triac relay is used rather than a manual relay. This relay receives a signal from the MCU to turn the heating cable on and off depending upon the state of the system. All of the other devices in this system require much lower voltages, so there is an AC/DC converter to go from 120V to 5V, and a DC/DC converter to go from 5V to 3.3V. As seen below, the LED, MCU, and Moisture Sensor all require 5V as the input power and the only device requiring 3.3V is the temperature sensor. As for communication, the MCU is connected to the moisture and temperature sensors as a means of receiving the signals, and it is connected to the LED and the relay to send signals.

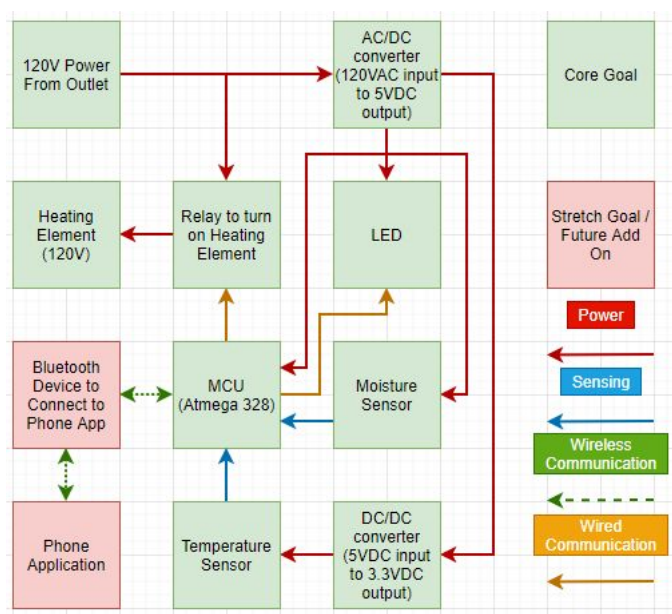

Figure 3: System Block Diagram

B. Software Block Diagram

Figure 4 below shows the software block diagram for the H.E.A.T² system. The ATmega328P microcontroller has 4 inputs, two in and two out. The microcontroller reads inputs from the thermistor and the humidity sensor and determines which of the four modes it should be in. It then sends the corresponding color data to the WS28128B LED Strip to make it reflect the current mode. If both the thermistor and humidity sensor satisfy the conditions required for snow or ice, the signal is sent to the relay module which will then turn on the heating cable.

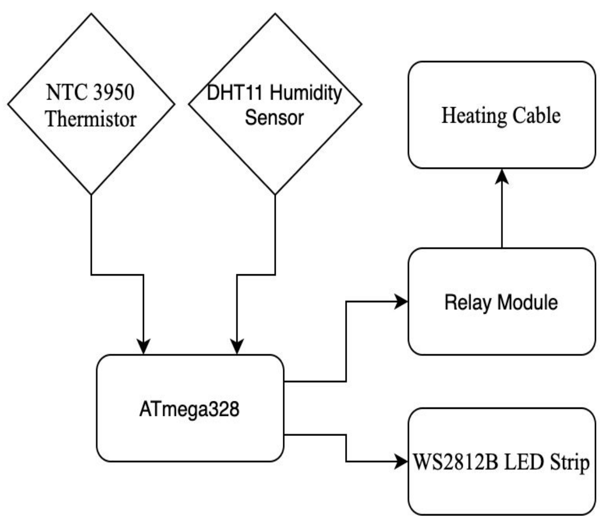

Figure 4: Software Block Diagram

C. Truth Table

There are 4 different states that the system can be in at any time, and only one of them turns the relay on which then turns on the heating cable. The two inputs for the system are the temperature sensor and the humidity sensor, and the output is the Relay. Based on those 3 components, an AND gate is used as a means of operation as shown in Figure 5 below. However, as mentioned in previous sections, the lighting is another output factor. It is not as simple as just on and off since the LED strip being used is an RGB color changing strip. Creatively, there are countless ways that the LED can be programmed. It can flash different colors, it can have a themed sequence, it can simply be programmed to be a certain color depending on the state, etc. To simplify the testing and easily demonstrate the functionality of the system, the LED strip is programmed to be white during state 1 of the system, blue during state 2, green during state 3, and red during state 4.

System State	LED Color	Humidity Sensor	Temperature Sensor	Relay
1	White	0	0	0
2	Blue	0	1	0
3	Green	1	0	0
4	Red	1	1	1

Figure 5: System Truth Table

IV. System Design

A. Software Design

The software design of this system relies on the sensor data given by the DHT11 Humidity Sensor and the NTC 3950 Thermistor. Any operation the microcontroller does is controlled by these two variables as shown by the Figure 5 truth table.

1) *Logic Implementation*

The actual logic for the H.E.A.T² system's codebase is enclosed entirely within an infinite loop that checks the values of the two sensors every two seconds, dictated by a timer sleep function, as this is one of the limitations with the DHT11 Humidity Sensor[1]. The analog value that the thermistor gives is of resistance across the thermistor compared to the standard 10K resistance required to make this measurement. It takes multiple reading samples over the two seconds and finds the averaged value so that a random spike in temperature doesn't adversely affect the system. This is then translated into temperature in Celsius using a series of equations and then used in the conditionals in conjunction with the reading given by the humidity sensor[6]. Within each of the four conditionals is a loop for iterating through the LED strip's individually addressed LEDs. Each loop contains a function that will change the LEDs color to the specified RGB value if it is in a new state, otherwise the color displayed will remain the same. Only in one of the four modes does a conditional send a digital HIGH signal to the relay module to turn on the heating element, and that is when the temperature and humidity values match the conditions required for snow or ice to form on the H.E.A.T².

2) *Libraries & Energy Efficiency*

The codebase utilizes the DHT library which is required by the humidity sensor to accurately interface with the microchip on the sensor itself. It also uses the FastLED library to interface with the WS2812B LED Strip. This allows easy control over the LED strip's RGB values, and when to turn them on and off. With the ability to manage the RGB values on the LED, the value can be lowered to decrease the brightness of the LED. Since each LED on the strip is individually addressed, this allows the strip to skip every other LED when they are powered on. Both of these options allow the LED strip to consume less power when connected, saving on energy costs.

B. *Hardware Design*

1) PCB Design

The hardware design of this system for Printed Circuit Board purposes consists of the microcontroller circuit, 2 internal systems, and 5 external systems.

The microcontroller that is used is an Atmega328P chip. For prototype purposes an arduino Rev 1 was used, and the schematic for that is open source. Serial communication was not needed so the devices used for serial communication were removed from the final PCB design. The main components that remained were the crystal oscillator, a few capacitors, 1 inductor, and a couple of resistors. Figure 6 below shows the schematic and how it is connected.

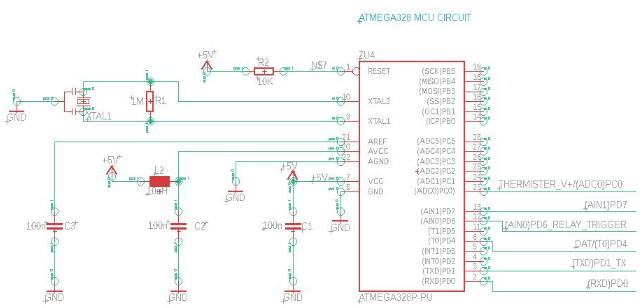

Figure 6: Atmega328 MCU Circuit for PCB

A voltage regulator circuit is the first of the 2 internal systems on the PCB. Arduino uses a texas instruments chip that converts the 5V input that powers the PCB to a 3.3V output. The part number is LP2985-33DBVR. This is not an adjustable output chip so no external resistors are needed to complete this system. The second internal system is a green status light that indicates when the PCB has active power. This is a simple circuit that has a 100µF capacitor between the 5V input and ground and 2 1KΩ resistors in parallel with each other between 5V and the LED itself. Figure 7 below shows the schematic for the 2 internal systems.

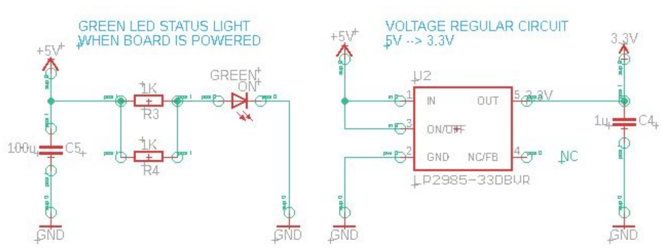

Figure 7: Internal PCB Systems

Of the 5 external systems, first is the AC/DC converter. The AC/DC converter used is a Mean Well IRM-60-5ST. The device itself was similar in size to the PCB. For that reason, the screw mount terminal version was used rather than PCB mount to keep the PCB size compact. It takes AC voltage in and sends out V+ at 5 volts. The 60 amp version was used so that roughly 15 slave tiles could be used per master control tile with the PCB and the AC/DC internal. The majority of power that the AC/DC provides is taken up by the LED strip, so a conservative maximum of 75% power would put the LED amperage at 45 for 15 tiles, well within the range of the AC/DC output. For schematic design purposes, a 100nF capacitor was used between 5V and ground to smooth out the voltage input signal.

The next two external systems are the sensors, both the thermistor and the humidity sensor. The humidity sensor has 3 connections: 5V, data input, and ground. There is a 1KΩ resistor between 5V and the data input line, so that resistor is soldered and traced on the PCB. For the thermistor, there are two connections and the device is polarity free. The two connections are V+ and ground. It receives power from a 3.3V power source. The 3.3V power source is acquired via a DC/DC converter that is discussed more below. In between the 3.3V power source and the connector pin is a 10KΩ resistor soldered and traced on the board prior to the output connector.

The 4th external system is the LED strip. Similar to the humidity sensor it has just 3 connections: 5V, data input, and ground. The difference between the LED connection and the humidity sensor connection is that rather than the resistor getting connected between the 5V input and the data input line, the resistor which is 330Ω is placed between the output of the Atmega chip and the connection to the LED data line.

The last part of the external systems is the relay to turn the heating system on and off. As discussed in the system component section, it has 3 connections to the PCB: 5V, data, and ground. Then it also has AC in and AC out with a relay that turns AC power on and off depending upon what voltage the data line from the PCB is receiving (5V or 0V).

Figure 8 below shows the 5 external system schematics.

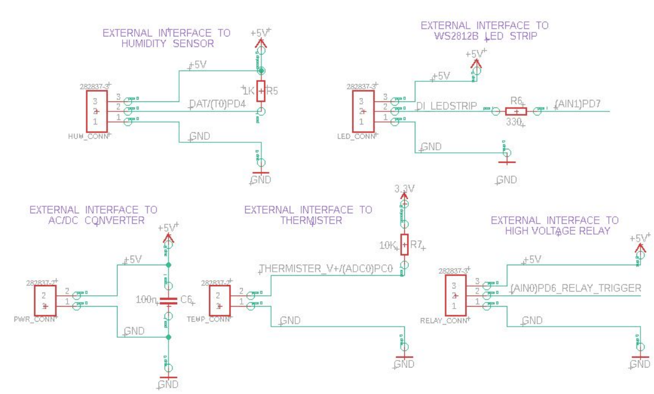

Figure 8: External Systems

Once the schematic was simplified into the sections above, it was time to design the PCB layout. All of the connector outputs were through hole wire to board terminal block type and they were all on one side of the board. For the atmega chip, the goal was to bootload the chip on an arduino and transfer the chip to the PCB. Therefore, a 28 pin dip socket connector was soldered to the board so that the atmega chip could be removed easily for reprogramming and testing purposes. Lastly for the PCB, there were 2 planes created, one for 5V and one for ground. Vias were placed throughout the board to connect to ground. Other than that, the board was able to be designed into a single layer via placement optimization. Figure 9 below is the final PCB configuration.

One final note regarding the PCB layout: using a wifi module was a stretch goal for this project in order to connect the system to a phone app. It was accounted for in the PCB; however due to COVID and the fact that the group was unable to meet in person more than just a couple of times, it was not something that was obtained before semesters end. With that being said, the PCB had accommodations for it so it will be shown in the PCB layout below.

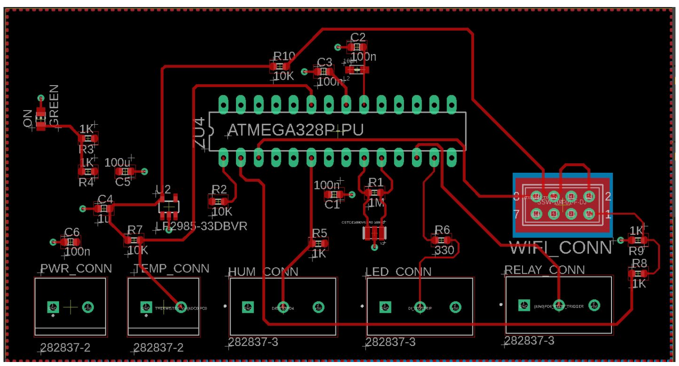

Figure 9: PCB Layout

2) Power Distribution and Heating Cable

Bringing power to the heating cable was the main goal of the HEAT², however it is essential that this is done safely due to the high voltages involved. The main voltage supply will come from the home outlet which is typically 120VAC and plug directly into the HEAT² waterproof inlet via a typical household extension cord. The voltage that enters the inlet port will then be fed to a distribution block. This Distribution block will have five connection ports, two will be for Neutral (isolated from each other in the distribution block), two for Line (physically connected with a jumper lead), and 1 for the safety ground.

One wire will go from the first neutral connection on the distribution block to the relay's common pin using a black wire. From the relay's NO (Normally open) pin, a yellow wire will go back to the distribution block’s second neutral port, (when the relay activates during the right conditions, this is how the heating element gets connected to the mains voltage supply). A flexible industrial grade wire (red) is used in the second neutral port to extend directly to the heating element's Neutral yellow wire, which incorporates a crimped connection. To finish the Heating element connection, the black wire (Line) and the yellow with green stripe (Ground) goes to their respective port on the distribution block both using a flexible industrial grade wire (red) with a crimped connection to extend to the distribution block. The power to the AC/DC convertor will come from a white (line) wire and a black (neutral) from the distribution block. This will allow the PCB to always have power when the HEAT² has been plugged in. Figure 10 below shows the electrical cavity tray that has the power inlet at the bottom left, distribution block bottom center, AC/DC convertor (not shown top right, PCB top center, relay module top left. The heating cables shown on top of the unit are under pavers and in between the foundation sand, (the excess cables are routed out the back).

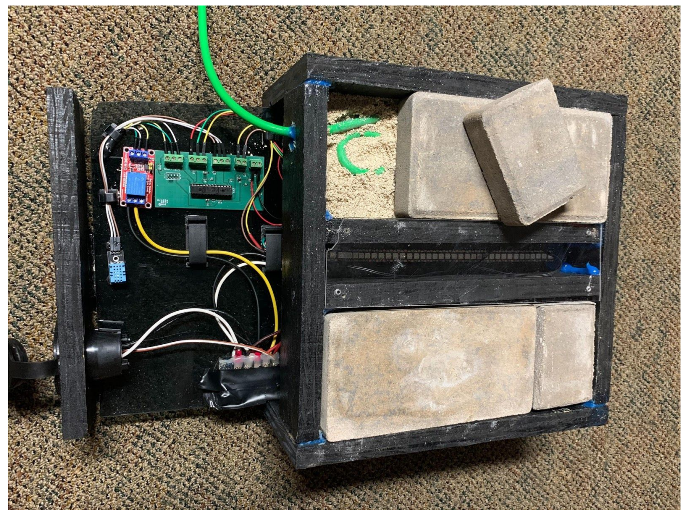

Figure 10: Electrical Cavity Tray

The heating cable comes with 43’ of cable that heats up, but the electrical wires are insulated from the heat and does not conduct heat from the heating cable itself, in this way we can route the electrical wires into the electronics cavity and connect to the distribution block in the process stated above. The heating cable itself is flexible, and able to bend which makes it possible to route multiple runs under a paver for maximum heat transfer. To hold the heating cables in place during the routing procedure a metal bracket mesh was used, 2 brackets on each side to run cables thru. This method holds the cables securely and keeps them from touching, which can create possible extreme heat spots on the cable itself. Once routed, foundation sand is used to pack in between, under and over the heating cable, this will help transfer heat from the cable to the surface of the pavers.

3) Housing Design

The HEAT² structure was designed to be a simple 1ft x 1ft square, that can be easily stacked and transported by any handler. The design needed to be strong in construction to withstand harsh weathers while giving users access to various components.

The HEAT² has an outer dimension of 12”L x 12”W x 6”H.

Looking from the top view of the HEAT², the outer walls will be a wood frame construction that encloses the pavers which mentioned in the previous section are on top of foundation sand and the heating cables. The Temperature sensor will be mounted flush in the wood frame thru a dedicated drilled hole for the sensor and its wires. The middle of the HEAT² will have a plexiglass that covers the LED strip, which is mounted to another section of wood that separates the electronics cavity from the heating element. When the wooden frame is first constructed and put together, a thick bead of Silicone Gasket will be placed in all potential areas that will be prone to leaks. The silicone gasket used is able to resist high temperatures up to 500 degrees Fahrenheit, while giving a leak proof seal. Looking at Figure 11 below shows the top view of the HEAT².

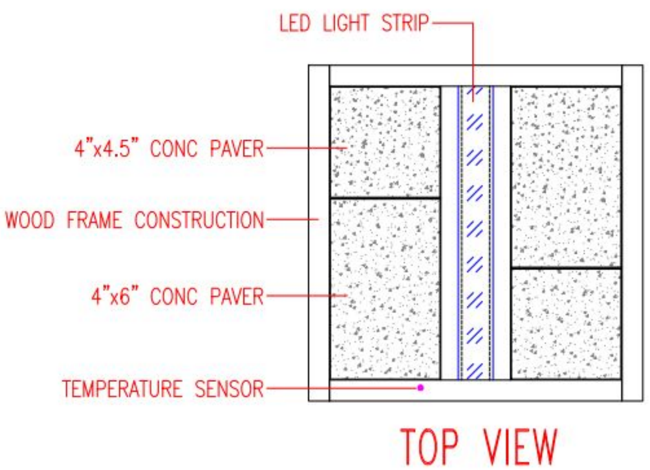

Figure 11: Housing Top View

The side view from back of the HEAT² will include a waterproof inlet on the electronics compartment drawer. This electronics compartment will be able to slide in and out to allow testing, parts replacement or service to components. The electronics are completely separated from the heating element by a section of wood above the compartment that holds the foundation sand, cables and pavers. Inside the electronics cavity will be a tinted plexiglass that mounts all the electronic components securely to, with various clips for wire management. Figure 12 below shows the side view of the HEAT².

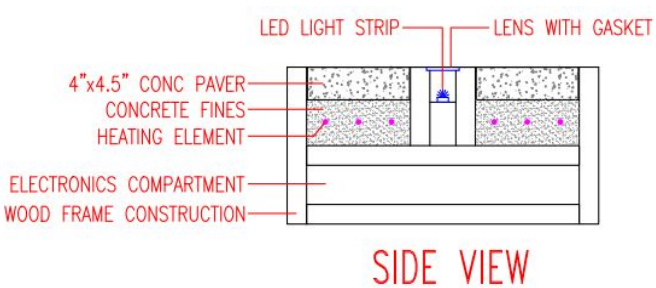

Figure 12: Housing Side View

The final assembly of the HEAT² prototype used 3/4" thick plywood for the frame construction. The unit uses multiple U shaped brackets to hold the LED wood separators to the middle section with screws that were pre drilled to prevent wood splitting. The middle section and outer section is held in place with a variety of nails and screws. An excess hole is drilled to allow the remaining cables to exit the HEAT², where it can go into another unit. The HEAT² is painted with a black textured coating. Figure 13 below shows the final product, the HEAT².

Figure 13: Final HEAT² Product

V. Conclusion

In conclusion, we have decided that a smart tile heating system using the listed catalog of equipment is feasible for its purpose and can be built to meet requirements relatively efficiently. Ideally, the end product will not be too expensive or complicated to set up and installed. We hope that the smart tile heating system will be able to satisfy the end user through automated snow and ice melting and prove to be a reliable and durable product given the expected weather conditions the smart tile heating system is meant to operate in. While the H.E.A.T² may have its own unique constraints that can sometimes make tasks more difficult than it needs to be, it offers quite a few benefits that are economical, and pro environmental.

The smart tile heating system should allow the end user the comfort of automating the management of their driveway conditions. The smart tile heating system will give the end user the time and energy that they would have otherwise spent shoveling snow or picking ice out of their driveway back, while also allowing them to turn off the device if the user would like to save energy or let the snow lay by simply unplugging it.

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