GNG 1103

Design Project User and Product Manual

Modular Heated Sidewalk Cover

Submitted by:

Wolf Fifth - Team #12

Al Howaid, Mohammed

Cvejic, Emily

Selivanov, Mykhailo

Topcuoglu, Yasin

Kayijuka, Imena-Sacha

April 10th, 2021

University of Ottawa

Table of Contents

List Of Tables

List Of Images

List of Acronyms and Glossary

Acronym	Definition
BOM	Bill of Materials
UPM	User and Product Manual
EH	Electrical Hazard
WB	Weather Box
GFCI	Ground Fault Circuit Interpreter
MHSC	Modular Heated Sidewalk Cover

Table 1. List of Acronyms

Introduction

This User and Product Manual (UPM) provides the information necessary for proper setup and use of the to effectively use the Modular Heated Sidewalk Cover, MHSC. This UPM contains all the important information concerning prototype documentation, system overview, maintenance and general setup. This document should be consulted before installing the product, as it will explain the necessary steps and precautions. This document should also be consulted for general maintenance, and error behaviours. By following the steps accurately as described in the UPM, the product will be able to continue functioning properly and accurately.

This document will first discuss the product overview explaining its properties and functions. The overview briefly explains the cautions and warnings as well. Next, the document will explain how to set up the MHSC and how to use the product. These sections will ensure that the MHSC is correctly installed and operated. The document will also explain the troubleshooting and maintenance. This portion of the document is important to ensure that the mat is properly maintained in order to reduce the risk of malfunction and increase the product longevity. The user is also provided with proper information on how to contact the help team for questions about the MHSC. This document then explains the product documentation about the prototypes, explaining the necessary tools and materials needed for each prototype. Finally, the document explains the future recommendations for the product.

1 Overview

The University of Ottawa spends over 1.5 million dollars in snow removal operations annually in an attempt to keep sidewalks safe and clear of snow and ice. This solution however, is not the most viable, long-term answer since rock salt damages the surrounding infrastructure and environment. Rock salt decreases the lifetime of buildings. It also harmfully affects the soil, landscape and the wildlife that live on campus. These consequences lead to extra money being spent on repairs and landscape maintenance caused by the deteriorating effect of rock salt.

A proposed solution is having a modular heated sidewalk. Although attempts have been made in the past, they were not the most feasible solutions. By meeting with our client, our team was able to gather a comprehensive list of the customer statements. We then translated these statements into needs. Other needs were also gathered through the benchmarking of other products. These needs are given priority ratings in order to come up with a final problem statement for this issue and begin the design process.

The client has expressed many needs and concerns regarding this problem. These needs are grouped in four main categories: typical uses, likes, dislikes and concerns.

The typical uses include the ability to fit the mats throughout campus, and remove them in the summertime. The user also expressed a need for safety of those using it, and that the mats do not cause danger for those walking on it. Since this mat would be placed all around campus, the client would like that the mats are easy to clean and repair as well.

The likes of the customer are aspects that they would like to see, but aren't necessarily mandatory to the success of the design. The customer would like a solution that is long term and scalable and would be able to build more modules throughout the years.

The dislikes of the customer as aspects that the customer has explicitly said they wouldn't like to see in the final design. The client would like to spend less money on snow removal techniques than they currently are spending. They would like a solution that is less harmful to the campus environment and infrastructures.

The customer has also expressed multiple concerns in the final design that are important to consider as well. These include water drainage and safety, as well as considerations for power consumption and implementation costs.

These statements can be appropriately organized in a table, associating the statement with the need.

Question	Client Statement	Interpreted Need
Typical Uses	The proposed solution should be able to fit across campus in different sized areas	The sidewalk is scalable
	The solution must be able to be removed in the summertime	The sidewalk can be stored
	Must be safe for use and durable against the elements	The sidewalk is durable
	The solution should be easy to clean and maintain and perform repairs	The sidewalk is easy to maintain
	Shouldn't be dangerous for those walking on it	The sidewalk is safe for pedestrians
Likes - What the customer would like to see	We should be able to create more modules of the sidewalk	The sidewalk is modular
	We want a solution that is viable and long term	The sidewalk is durable
	The surface of the product must not be slippery	The sidewalk has traction

Dislikes - What the customer could do without	Spend less money on snow removal. (Currently spending 1.5 million dollars annually)	The sidewalk is affordable
	Traditional methods damage infrastructure	The sidewalk is not destructive to its surroundings
	The excess water can cause flooding	The sidewalk has drainage
Concerns	The short term cost is relatively high	The sidewalk is affordable
	There needs to be a place for the water to drain	The sidewalk has drainability
	Heated sidewalks often require a good deal of energy	The system is energy efficient
	The system has not to be an obstacle for People walking when there is no snow	The system is safe for pedestrians

Table 2. Client Statements Translated Into Needs

After consideration and grouping of these needs, they could be rated with an importance from 1-5.

Needs Grouped	**Rating (1-5) 5-most important**
The system is energy efficient	4
The system is safe for pedestrians	5
The sidewalk is scalable	4
The sidewalk has drainage points	3
The sidewalk is affordable	3
The sidewalk is modular	5
The solution is portable	3
The system is accessible	5

The solution is durable	3
The solution is easy to maintain	4

Table 3. Prioritization of Client Needs

The HeatStreet Pro is built to withstand all circumstances as well as to be effective and safe. At an affordable price, the HeatStreet Pro brings a lot to the table. First of all, it has a self automated central control system which, without the aid of human interaction, knows when to turn the heating on and off depending on the weather conditions. This is done with a rain/snow sensor, temperature sensor, and an arduino microcontroller which is paired with relays. The software that is loaded on the microcontroller has cases that tell the heating to either turn on or off. Simply the system turns on when temperature is below freezing point, or when there is rain/snowfall detected. The system is put into what's called a weather box, which essentially protects and contains all the electric components. It has exposed lights which indicates to the user whether the system is on or off. This weather box is a huge benefit because it reduces costs since everything is well protected which greatly reduces risk of damage to components. Also a series of the sidewalks can be controlled by a central system instead of individually, which reduces cost of electronic components.

The HeatStreet Pro is modular and scalable. Units of the sidewalk can be connected to each other to create a series of sidewalks as mentioned before. These can then be simply disassembled to be stored away for the summer or when they are not in use. The connections are simple, safe and durable as well which is another one of the benefits of the HeatStreet Pro. It has magnetic connections which prevent the units from slipping away from each other. All connections within the HeatStreet Pro are also watertight to ensure that there are no electrical issues and that the risk of electrocution is greatly reduced.

The HeatStreet Pro is built by considering all types of people. Therefore, it is a very inclusive product and takes accessibility seriously. The HeatStreet pro comes with end pieces that have a slight ramp so that people riding things such as wheelchairs, walkers, scooters and anything else can easily get on and off the sidewalk.

The HeatStreet Pro is built with quality, grippy material that is also environmentally friendly. The material is a sturdy rubber material that is recyclable that is very cheap to obtain, again reducing cost. The grip provides traction where the sidewalk contacts the concrete, and for the people walking on it the top side has grip to avoid slipping. The top part also has channels to allow water channeling which prevents water puddling, hence reducing risk of slipping. The mated parts are also well sealed, to again ensure that water does not seep in to prevent electrical problems.

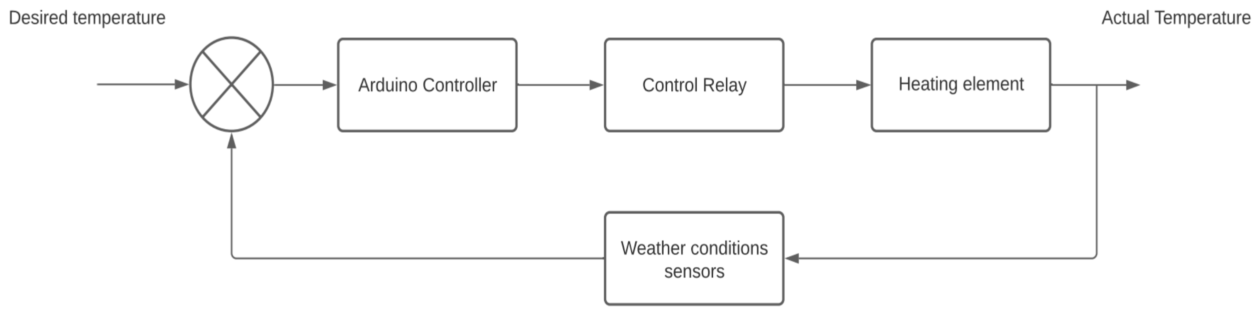

Figure 1. Block Diagram

1.2 Cautions & Warnings

Since the mat is going to use electricity near water , care must be taken while using and setting up the mat.

Ice accumulation - In case of electrical failure or defects, a unit may not be capable of heating, leading to ice accumulation.This might also occur when the temperature hovers around 0. This ice accumulation can also lead to a lower friction on the mat surface, making it easier to slip and fall on the mat.

Water accumulation - In case of obstruction, the water channeling can fail and can flood the sidewalk or cause puddling. Care should be taken when choosing the placement of the mats.

Slip and fall - Ice accumulation or water accumulation due to failure in heating or draining can pose a risk to slipping and falling. Care and precautions should be taken when observing for ice accumulation.

Electrocution - In case of a failure in the watertight electrical connections or the sealing, an electrocution risk is raised if water comes in contact with the electric components. This could be avoided by regular maintenance and placement care.

2 Getting started

The following subsections will provide a brief, and general walkthrough of the system from initiation to exit of the Heatstreet Pro.

2.1 Set-up Considerations

The control unit will act as the main input device for the mats. The unit is able to control up to fifteen mats in series and will need to be configured according to the weather conditions of the surrounding area. The mat itself will be the output device, and will not require any special configuration other than the appropriate maintenance described in this manual.

2.2 User Access Considerations

It is important to note that the control unit has a built in system that acts as a two-step activation. If the temperature requirements are met, but the mat does not detect any snowfall or rainfall, then the control unit will not allow the mat to activate. The same logic applies if the mat detects rainfall but does not meet the specified temperature threshold.

It is thus important for users to properly configure the settings with an Arduino program to match the appropriate weather conditions of their environment for maximum efficiency. The control unit has its default settings to be configured for the Ottawa-Gatineau region, meaning that the temperature threshold for activation is below 0℃ along with a rainfall coverage of 60%.

2.3 Accessing the System

The system will come with a built in control unit. The control unit permits the whole system to act as an automated system. The user will be required to configure the proper configurations with an Arduino program to match their given environmental conditions. Once this is complete, the user will send the information to the Arduino control box which will save and run the program every time the system is plugged in to a power supply.

Should the system be cut from its power supply, the user will simply need to reintroduce a new power source or reinstate the previous power supply to reactivate the system. The control unit's code will have been saved regardless and thus reconfiguration will not be required.

While the programming will be saved within the mat, rendering a second configuration obsolete- it is recommended for users to recheck the Arduino Programming on the control unit for any unexpected changes that may have occurred.

2.4 System Organization & Navigation

The system is separated into two separate categories: the control unit and the mat. Navigation will occur purely into the first.

The system is separated into two separate categories: the control unit and the mat. Navigation will occur purely into the first.

Control Unit - The control unit is composed of a temperature sensor, an Arduino board and a rainfall/snowfall sensor. The users will need to use an Arduino software to navigate between the sensors' configurations.

The Mat - The mat itself is composed of a rubber mat, magnetic connections, and a heating system inbetween. When two or more mats are placed together, the magnetic connections on either end of the mats will need to be joined for the mats to align together. Additionally, the inner cable embedded within the mats will also need to be connected to ensure that the mats stay within a series instead of two separate entities.

2.5 Exiting the System

To properly shut down the system, the user needs only to unplug the power source and wait a recommended period of 5 to 10 minutes for the heating system to cool down. Afterwards, the mat can be disconnected from one another and stored within proper conditions. The control unit itself will turn off along with the disconnection from the power source and will need to be stored in a safe environment.

3 Using the System

The function of this device is to create the effect of a heated sidewalk without altering the structure of the walkway. To reduce the risk of slip injuries that happen due to ice formation.

The product is extremely user friendly designed to be plug and play. The mats are to be set-up in the location that they are needed ensuring that inter-mat connections are properly set-up

Proceed to placing the WB in a location exposed to the eliminate—to ensure correct readings of the rain and temperature sensor. After securing the WB in place, connect it to a power source—120V. If the WB is successfully connected to power it will be indicated by the solid amber light. If the light is not on please go to section 4 to troubleshoot the error.

When the WB is successfully connected to power. Proceed to connecting the WB to the mat using the provided cable.

Ensure that you connect an end piece ramp or the system will not function. The WB will indicate that the heating system is functional by a flashing red light.

3.1 Weather Box

Power ON: This is indicated by a solid amber light.
Heating system ON: This is indicated by a flashing red light

4 Troubleshooting & Support

This section will describe the recovery procedures. This section should be consulted concerning general maintenance and device malfunctions. It is important to read this entire troubleshooting and support section before attempting to repair any components on the mat.

4.1 Error Behaviors

The control unit might malfunction in different ways. It is important to identify these problems early on, as to reduce the possibility that these problems might cause permanent damage to the circuitry or the surface material of the mat.

This section describes some of the common problems that might occur, and details the correct steps to take in order to resolve these problems.

> *Mat doesn't turn on when it is snowing* - The control unit needs to be calibrated to match the current weather conditions in the local area. Otherwise, the preset conditions will be the default settings for the mat which may cause adverse effects depending on the location of the user. If, for example, the mat is used in an area where the temperature is often around 0, it is advised to set the heating threshold to a higher temperature to prevent freezing.
>
> *The mat has a layer of ice on it* - The heating mat might cause ice accumulating if the temperature hovers around 0. This can be fixed by changing the temperature threshold to a higher temperature.
>
> *There is water accumulation* - The mat is designed so that water does not accumulate on the surface of the mat. This could happen however, if the mat is placed at the bottom of a slope, the melting water will accumulate at this bevel. It is advised to not place the mats at the bottom of a sloping surface if water accumulation is evident.
>
> *The mat is not turning on* - The mat internal connections are soldering and heat shrunk in order to ensure proper functioning of the device, so it is safe to assume that there are no internal connection problems. The mat not turning on can be due to many different factors. It is important to perform a general check and ensure that all the connections are connected to a power supply. A green light should appear on the WB. If this is not the case, it is advised to contact our help team.
>
> *The control box is not working* - Due to the complexity of the control box we recommend replacing the control unit with a new one. The user is free to work on the control unit using parts from the BOM or equivalent along with the proper equipment required. Some of the sensors might burn out due to overuse. The temperature sensor, for example, might begin to malfunction after repetitive temperature fluctuations. This sensor can be replaced if the maintenance crew is aware of the proper electronic handling

requirements and safety protocols. It is advised to turn off the WB as well as disconnect it for the power before attempting to perform any maintenance on any of the components. The circuit diagrams should be consulted and the worker should ensure they have all the necessary components before attempting to replace a component. It is advised to order the same components from the same manufacturers as specified in the BOM, to account for all the correct electrical characteristics.

4.2 Special Considerations

It is important to note before starting any maintenance on the mat, that there is a large voltage that passes through the mat. This means that the person performing the maintenance should know how to handle electrical components properly, and adequate electrical safety precautions should be practiced. If there are any concerns about performing maintenance on the mat, contact the technical support team at 1-800-100-1000 or by email at support@WFMat.com.

Whenever beginning to perform any type of maintenance on the mat, including seasonal cleaning, it is necessary to ensure that the device(s) are disconnected from a power source. This is used as a precautionary measure to reduce electrocution or device malfunction.

It is recommended to wear Electrical Hazard, EH, rated safety boots whenever performing maintenance on the mat. These boots are specially rated to prevent electrocution from up to 600 volts. Our mat is only using 120V, therefore these boots will be effective.

Regular maintenance checkers should be performed on the cables themselves to ensure there is no cable deterioration that could cause electrocution when exposed to water. The cables used in this design are waterproof, but still pass current and voltage and could be dangerous when exposed to water.

GFCI should be used to interrupt the electrical circuit in any case of shock due to water exposure. These can be installed easily to replace a regular outlet.

4.3 Maintenance

In order to lower the chance of a larger malfunction or failure, regular maintenance should be done on the system. This includes but is not limited to the following:

Seasonal Cleaning - The mats should be cleaned at the end of each season that the mat is deployed and working. This ensures that there is no accumulation of dirt, debris or salt that could potentially damage the rubber surface of the mat. Cleaning the mat should be done by first brushing off the mats of all dirt, then gently rubbing the surface with a mixture of warm water and dish soap. This will ensure the mats are properly cleaned and can be stored safely after adequate drying.

Weekly Inspection of the Mat - A simple weekly inspection of the mats could avoid larger problems accumulating in the future. This inspection can quickly be done by ensuring that there are no holes or burns on the surface of the mat. This inspection should also check the cables to ensure the mats are still connected and that the cables are not submerged in water accumulation or puddles.

Monthly Inspection of the Weather Box - Since the weather box does not pose as much of an imminent danger to the user in case of a malfunction. The inspection should check whether the cables are still connected correctly, as well as make sure there is no damage to the WB itself, such as holes. The rain sensor should not be covered in snow if it is not snowing, our design takes this into consideration, but for any reason, there is snow accumulation, the inspector should brush this off to make sure the mat continues to function properly.

N.B.: Any maintenance mentioned below performed without the explicit confirmation from the support team, will result in a void of the product warranty. Please see Section 4.4 for more information.

Necessary steps should be taken if one of the elements of the mat fail or get damaged.These steps are outlined by the type of failure.

Rubber Mat - If the top part of the mat fails due to heavy use or unnatural circumstances, the mat can be split into two halves, where the top part could be replaced with a replacement. Given the nature of the mat, it would not be ideal to replace the bottom portion as it would need to be readjusted to fit with the circuitry applied to it, as well as the magnets. Nonetheless, both parts of the mat can be replaced with suitable material, though the top part will be more sustainable in the long run.

Heating System - Incase of a failure of the heating system or any other electrical component embedded into the mat we recommend buying a replacement mat. The user is free to to work on the mat using part from the BOM or part with equivalent specifications, but the circuitry involved may prove complex if not handled with the proper equipment.

Arduino | Software - The user can connect the arduino in the control unit to a computer and edit the software using the arduino program. The original code is included at the end of this document and can be reuploaded to the device if the user suspects some malfunctioning. Using this method, the user could troubleshoot to pinpoint the source of the problem, assuming they are familiar with Arduino type programming. Editing the code of the control unit can increase the effectiveness of the mats, by specifying the desired temperature range to adapt the mat to. This is a useful feature to change depending on the season, conditions or any patterns in the local area of the user.

4.4 Support

For any emergency, or in the case of a fire or electrocution, please contact 911.

For general assistance with the mat itself, please direct any questions or concerns to our support team at support@WFMat.com. You might be asked to provide a serial number or order number in order for the support team to provide assistance, please include this in your email. The support team can be reached out to concerning problems or malfunctions with the mat. It is advised to contact the team before attempting any maintenance on the mats. The support team will be able to properly assist you and maintain the warranty on the product.

For immediate assistance, contact our toll free 24 hour help center at 1-800-100-1000. Questions relating to the immediate functionality or device failures can be directed to our help center.

It is also possible to contact the manufacturer of certain components as well. This will help provide accurate details about sensors themselves.

If there is malfunctioning for the rain sensor or temperature sensor, the manufacturer of the component can be contacted. ABRA is an electronics distributor in Montreal, Quebec. They can be contacted concerning any faulty or malfunctioning sensors. They can be reached by phone at 1-800-361-5237.

If there are concerns for the electrical wiring, the Emerson company could be contacted. The Emerson Canada representative is located in Richmond Hill, Ontario. They can be reached by the phone number 1-905-762-1010.

In any case, it is important to mention the nature of the experienced problem, as well as including photographs whenever possible. This will allow for a smoother process to solve the problems.

5 Product Documentation

5.1 Prototype I

Prototype I focused on a general overview representation of the system. This prototype featured a physical comprehensive model to showcase the design of the system. This allowed for us to gain a better idea on component placement and setup of our design.

5.1.1 BOM

Item	Description	Manufacturer	Cost (CAD)	Quantity	Total (CAD)
Cardboard	Scrap cardboard pieces	N/A	Free	X 2	$0
Magnet pack	Neodymium rectangular magnets to hold the mats together, pack of 10.	Abra Electronics	$6.99	x 1	$6.99
Headers	A nut and screws with a flat head	N/A	Free	x 4	$0
Peace of cloth	A Peace of rectangular fabric	N/A	Free	x 1	$0
Wires	Some scrap wires	N/A	Free	x 1	$0
LED	LED light	N/A	Free	x 1	$0
				Total	$6.99

Table 4. Prototype I BOM

5.1.2 Equipment list

Heat gun, soldering iron. Adhesive, exacto knife,wire stripper/cutter, voltmeter, wires, heat shrink tubing

CAD software for designing a 3D model and a mock-up circuit.

5.1.3 Instructions

Since this was our team's first prototype, we focused on creating a basic proof of concept. using readily available materials. We based our model after our chosen conceptual design. This mat prototype was created physically and using CAD to help us better understand and invent our concept, something we can show our clients. Also we created our electrical circuit to eliminate some doubts in the circuit design to understand how the control system would control the mat.

5.1.4 Testing and Validation

There were four tests associated with the first prototype. Our first prototype was a physical model, and showed a general overview of the product. Because of this, the tests done during the first phase were mostly analytical and numerical

Test #1 Visualization: The first test done was the creation of a physical and analytical model to depict the final product. This prototype was made to represent a smaller scaled version of the modular heated sidewalk. The prototype is physical, made of simple materials. This device helped our team get a better idea of the design overview for the modular heated sidewalk. Through the physical first design, we were able to decide on the placement of the sensors and components. The results of this test were recorded using images and helped us further convey our solution to the client.

Figure 2. The model is made using a visually similar material. The lower left corner on the surface of the mat features a hole to be able to hold the temperature sensor. The lower right corner shows how the temperature sensor would be incorporated into the mat, sticking out of the side. This is shown with an LED.

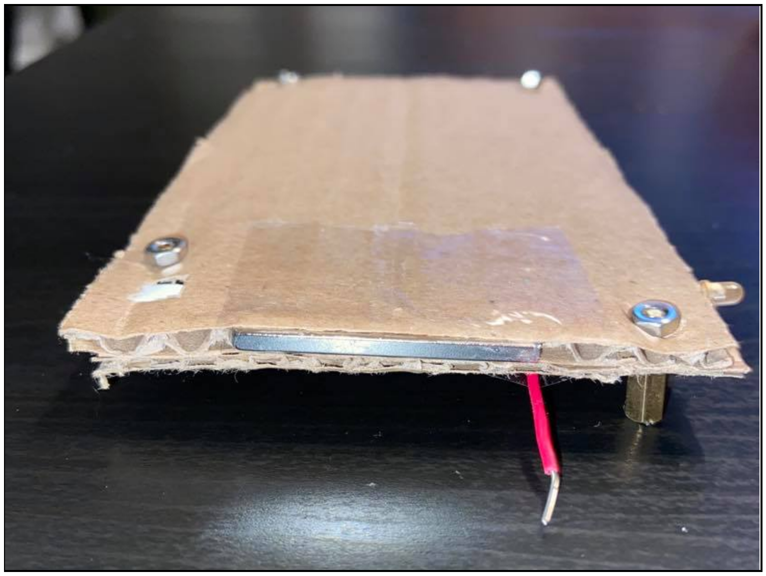

Figure 3. This side view of the sidewalk prototype shows many of the important features. The headers keeping the mat lifted are to simulate the use of a screw connection to the sidewalk. The heads of these would be recessed into the mat for the final product, and might be omitted altogether if the strength of the magnet is strong enough to hold the mats together. The magnet is featured in this side view as well. It is integrated into the side of the mat, and will be held there. These magnets will provide ease of connection between the mats. The wire sticking out of the mat is to represent the electric cable that will allow the mats to be modular and interconnected. This cable will be sealed with a heat shrink cable to make it waterproof.

Figure 4. This view shows the connection of the sidewalks using the magnet connection.

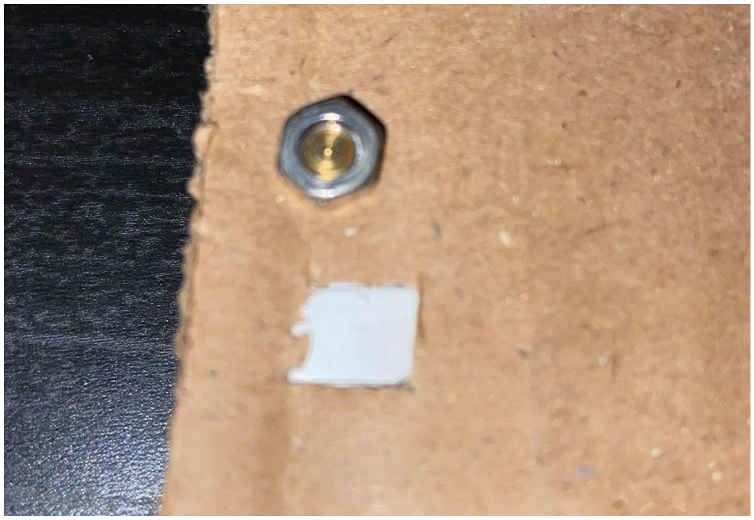

Figure 5. This view shows where the rain sensor will be implemented on the mat. A square surface would need to be cut from the material of the mat in order to properly integrate the sensor.

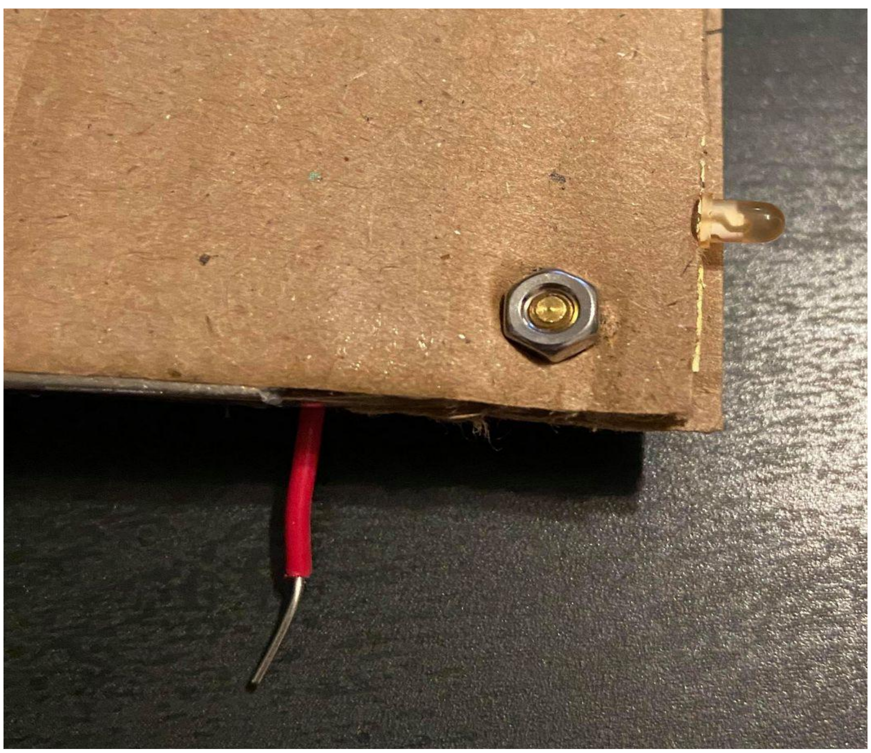

Figure 6. This view shows the temperature sensor. This will be placed flush with the edge of the mat in the final design. In the same corner, the wire represents the connective wire that will allow the mats to connect.

Figure 7. The internal components of the mat.

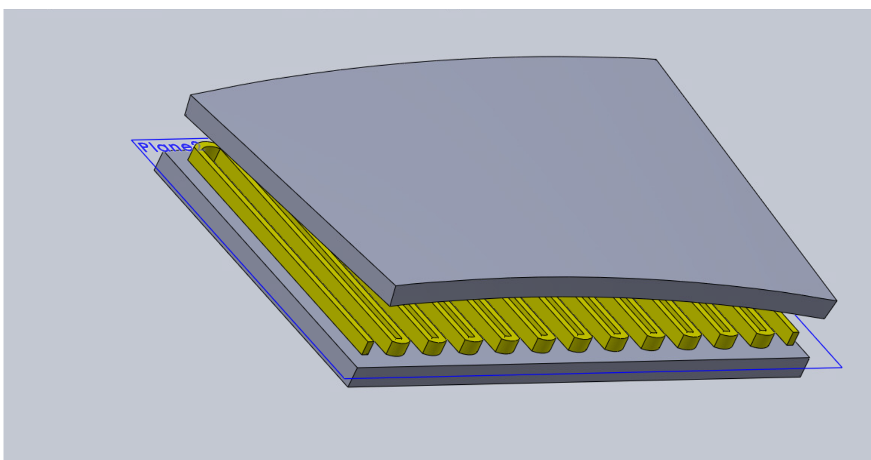

Figure 8. CAD design of the modular heated sidewalk. The heat trace is shown in yellow.

Test#2 Circuit Test: The second test was created by using a numerical model of the circuit using Multisim. The results obtained indicate the final product electrical specifications.

Arduino

Power supply: AC-DC converter with output: 5Vdc, 1A

Microcontroller max load for all pins: 0.2A

$P = V\,x\,I = 5\,V\,x\,0.2\,A = 1\,W$

Heat trace circuit

Current draw of 12 feet of heat trace @ 120 Vac = 0.7A

$P = V\,x\,I = 120\,V\,x\,0.7\,A = 84\,W$

Figure 9. Electric Calculations

Test#3 Weight Test: The third test was to calculate the final weight of the mat.The results are stored in a table and help us see if the final weight is within the design specification parameters.

Item	Weight (lbs)
Cable	1.20
Top Surface	2.50
Bottom Surface x2	4.27
Rain Sensor	0.22
Temperature Sensor	0.01
Arduino Uno	0.05
Magnet (x2)	0.02
Wires & Electrical Components	0.20
Total Weight	**12.74 lbs**

Table 5. Weight

Our results for the analytical weight test fell well under our limit of 20 lbs, and weight only 12.74lbs. This will allow our device to be light and transportable.

Test #4 Cost: The final test for type first prototype was the numerical calculation of the final cost for the mat. The price of each component is recorded in a table and helps determine if the cost of the mat is ithin the design specifications.

Item	Description	Manufacturer	Cost (CAD)	Quantity	Total (CAD)
Rain Sensor (SENS-52)	Rain detector to be used on each unit	Abra Electronics	$6.91	x 1	$6.91
Heat Trace Cable	Electrical heating system, for the sidewalk	EasyHeat	$43.23	x 1	$43.23
Magnets	Neodymium rectangular magnets to hold the mats together, pack of 10.	Abra Electronics	$6.99	x 1	$6.99
Winterized mat	This material will be used as the top part of the mat.	Canadian Tire	$10.00	x 1	$10.00
Temperature Sensor (DS18B20)	Waterproof temperature sensor to be used on each unit	Dallas Semiconductor	$3.48	x 1	$3.48
Stair Tread	This material will be used as the top part of the mat.	TECHNOFLEX	$4.99	x 2	$9.98
				Total	$80.59

Table 6. Cost of Materials for Prototyping

5.2 Prototype II

Prototype II mostly focuses on the internal control system of the heating mat. This prototype featured a prototype for the control system with the use of the sensors and the various other electrical components. This allowed for various tests to be done on the functionality of the control system. This prototype also featured a simple physical prototype for the overall setup of the mat. This allowed for simple tests such as grip and traction tests to be carried out. Additionally, this prototype was crucial for finalizing the type of circuit and system that would be used, especially after the client meeting. Using simulation software, the difference between parallel, and series circuits were tested in order to determine the better option for this issue. On top of that, instead of integrating sensors into each mat the team decided to go with a weather box that would contain one control unit that would control a line of sidewalks. This would simplify maintenance, reduce costs, and increase reliability. Therefore, this prototype was crucial for the further development and finalization of the final design that would be used.

5.2.1 BOM

Item	Description	Manufacturer	Cost (CAD)	Quantity	Total (CAD)
Heat Trace Cable	Electrical heating system, for the sidewalk	EasyHeat	$43.23	x 1	$43.23
Magnets	Neodymium rectangular magnets to hold the mats together, pack of 10.	Abra Electronics	$6.99	x 1	$6.99
Winterized mat	This material will be used as the top part of the mat.	Canadian Tire	$10.00	x 1	$10.00
Stair Tread	This material will be used as the top part of the mat.	TECHNOFLEX	$4.99	x 2	$9.98
ESP8255	For wireless connection	Sparkfun	$6.95	x 1	$6.95
				Total	$77.15

Table 7. Estimated cost per unit of mat

Item	Description	Manufacturer	Cost (CAD)	Quantity	Total (CAD)
Rain Sensor (SENS-52)	Rain detector to be used on each unit	Abra Electronics	$6.91	x 1	$6.91
Temperature Sensor (DS18B20)	Waterproof temperature sensor to be used on each unit	Dallas Semiconductor	$3.48	x 1	$3.48
ESP8255	For wireless connection	Sparkfun	$6.95	x 1	$6.95
				Total	$17.34

Table 8. Estimated cost of weather box

5.2.2 Equipment list

Heat gun, soldering iron, Adhesive, exacto knife, wire stripper/cutter, wires, heat shrink tubing, computer.

5.2.3 Instructions

The first subsystem is the control system. This subsystem requires the use of the sensors which can be found in the BOM as well as electrical components such as wires, arduino and wires. The system is set up as the diagrams and photos below show. The code that is also included is then uploaded to the arduino.

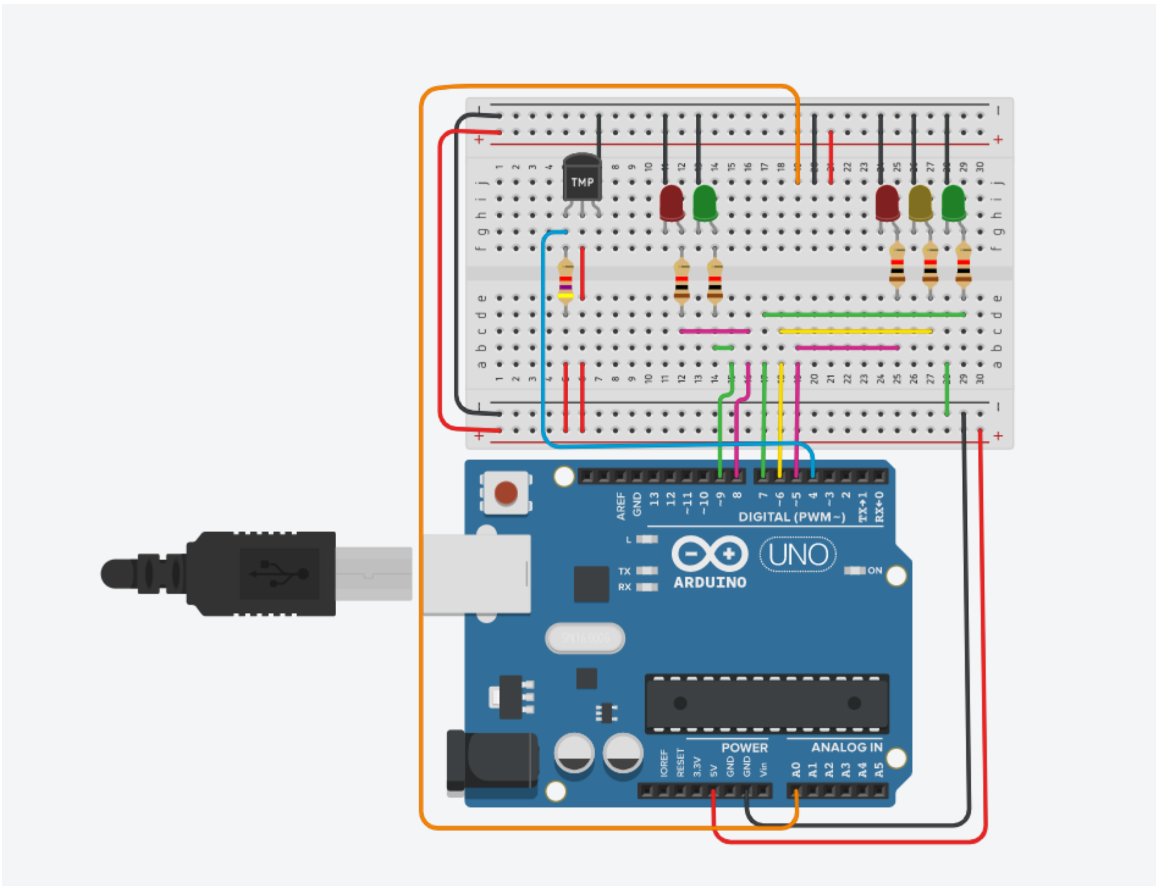

Figure 10. Circuit diagram for arduino and sensor connections. The three cables in the center of the breadboard (orange, black and red) correspond to the connection pins of the rain sensor headers.

After setting the system up by following the diagram in Figure 5, it should resemble the set up below that is shown in Figure 6.

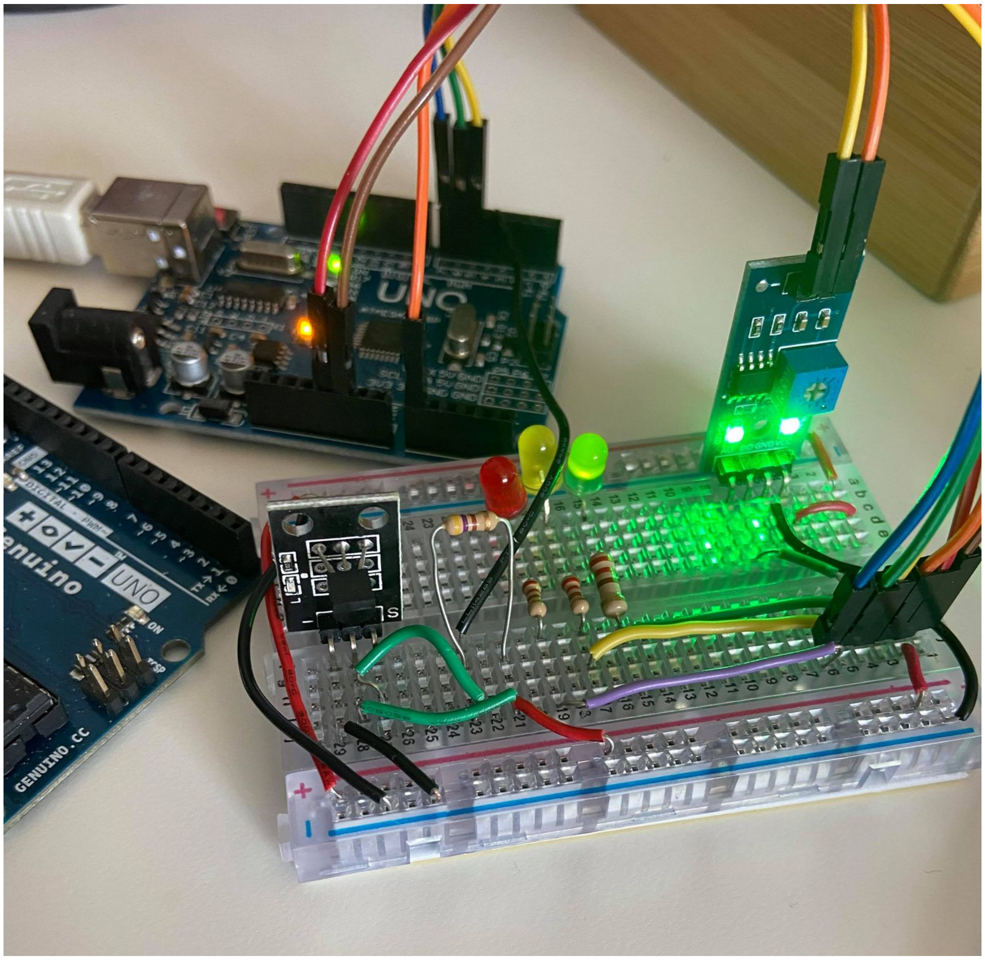

Figure 11. Control system set up

The following figures display the code that is uploaded to the control system.

rain_sensor §

```
/*************************************************************************************
 * Title: rain_sensor.ino
 * -----------------------------------------------------------------------------------
 * Description -  to use in the modular sidewalk project. This code uses a sens-52
 *                rain/snow sensor.
 * Date         Version    Changes
 * ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 * 03/10/2021   1.0.0      Code creation
 * 03/11/2021   1.0.1      Tuned device to specific values
 * 03/12/2021   1.0.2      Tested and fixed errors
 * 03/13/2021   1.1.0      Implementation of LEDS
 ************************************************************************************/
// Variable Declarations
int greenLed=5;
int yellowLed=6;
int redLed=7;

void setup() {
 Serial.begin(9600);
 pinMode(greenLed,OUTPUT);
 pinMode(yellowLed,OUTPUT);
 pinMode(redLed, OUTPUT);
}

void loop() {
 Serial.println(analogRead(0));

 if (analogRead(0)<600){                          //Case 1 - Snowing hard, heating at full capabilities
  Serial.println("It is snowing hard");
   digitalWrite(yellowLed,LOW);
   digitalWrite(greenLed,LOW);
  digitalWrite(redLed,HIGH);
 }

 else if(analogRead(0)<900) {                     //Case 2 - Snowing medium, heating at medium capabilities
  Serial.println("It is snowing");
  digitalWrite(greenLed,LOW);
  digitalWrite(yellowLed,HIGH);
  digitalWrite(redLed,LOW);
 }

 else if (analogRead(0)>=900){                    //Case 3 - Not snowing, heating off
 Serial.println("It is not raining or snowing");
  digitalWrite(greenLed,HIGH);
  digitalWrite(yellowLed,LOW);
  digitalWrite(redLed,LOW);
 }
  delay(2500);

}
```

Figure 12. Arduino code for rain sensor

temp_sensor

```
/*******************************************************************************************
 * Title: temp_sensor.ino
 * ---------------------------------------------------------------------------------
 * Description -  to use in the modular sidewalk project. This code uses a sens-73
 *                temperature sensor.
 * Date         Version    Changes
 * ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
 * 03/10/2021   1.0.0      Code creation
 * 03/11/2021   1.0.1      Testing and debugging
 * 03/13/2021   1.1.0      Implementation of LEDS
 *******************************************************************************************/

//Library inclusions
#include <OneWire.h>
#include <DallasTemperature.h>

// signal of the temperature sensor connected to pin 4
#define DATA 4

OneWire oneWire(DATA);

int greenLED=5;
int redLED=7;

DallasTemperature sensors(&oneWire);

void setup(void)
{
  Serial.begin(9600);
  pinMode(greenLED, OUTPUT);
  pinMode(redLED,OUTPUT);
  sensors.begin();
}

void loop(void){
  sensors.requestTemperatures();

  Serial.print("Celsius temperature: ");
  Serial.println(sensors.getTempCByIndex(0));

  if(sensors.getTempCByIndex(0)<0){
    Serial.println("Heating on");
    digitalWrite(redLED,HIGH);
    digitalWrite(greenLED,LOW);
    delay (1000);
  }

  if(sensors.getTempCByIndex(0)>=0){
    Serial.println("Heating off");
    digitalWrite(redLED,LOW);
    digitalWrite(greenLED,HIGH);
  }
  delay(1000);
}
```

Figure 13. Arduino code for temperature sensor

Following the setup of the control system, it is also combined with the mat by wiring in the heating cable to the relays that are connected to the arduino.

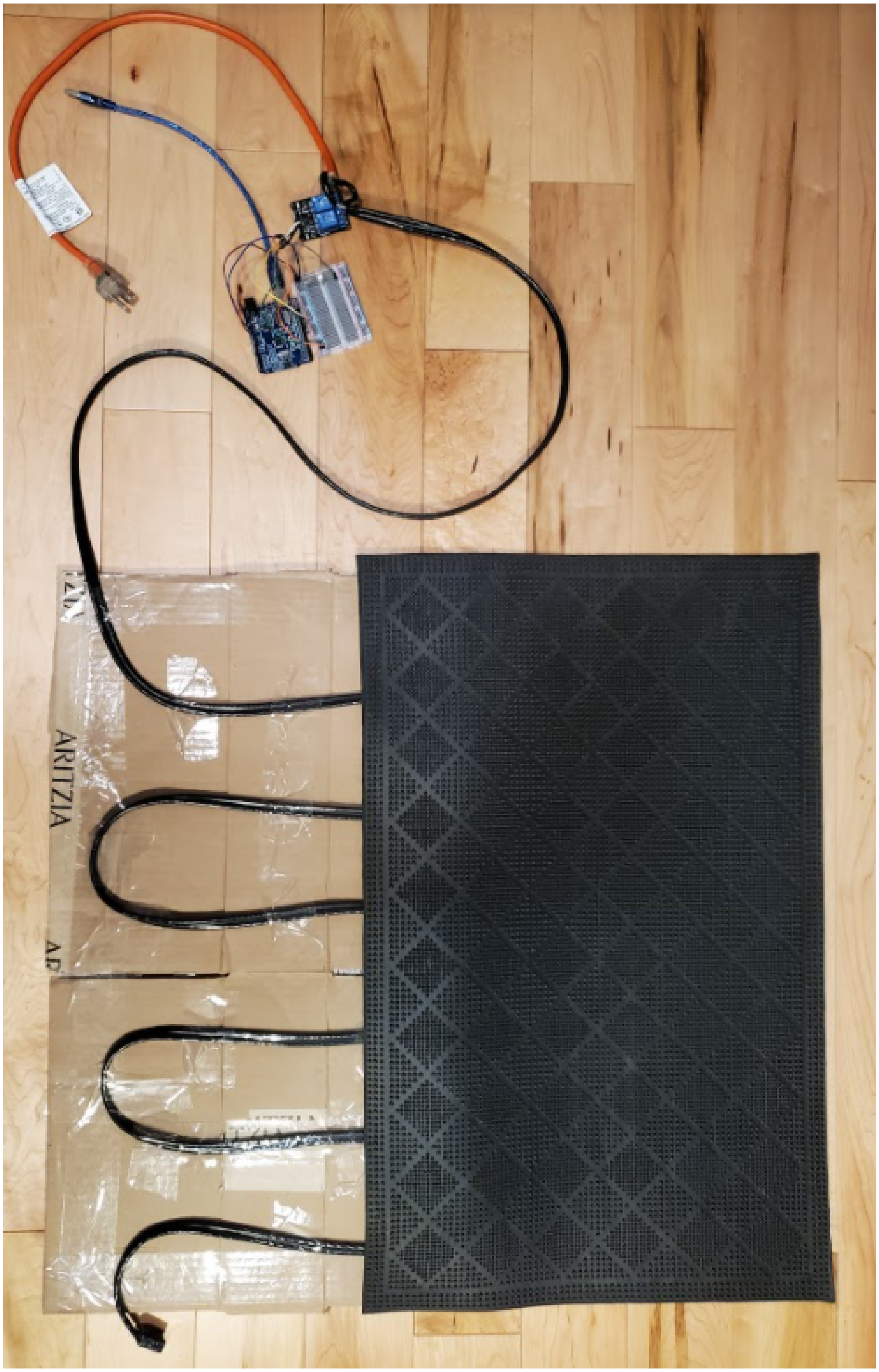

Figure 14. Prototype II

5.2.4 Testing and Validation

In the testing phase for Prototype II, there were multiple tests that were done being either physical or analytical.

Test #1: The first test is a test of the sensor. It is done by simulating slush/rain/snow on the sensor. This was done by squirting water droplets on the device. By fine tuning the ranges on the arduino code, three cases were set; snowing hard, snowing and not snowing. Each of these cases were represented with a coloured LED. These are red, yellow and green, respectively.

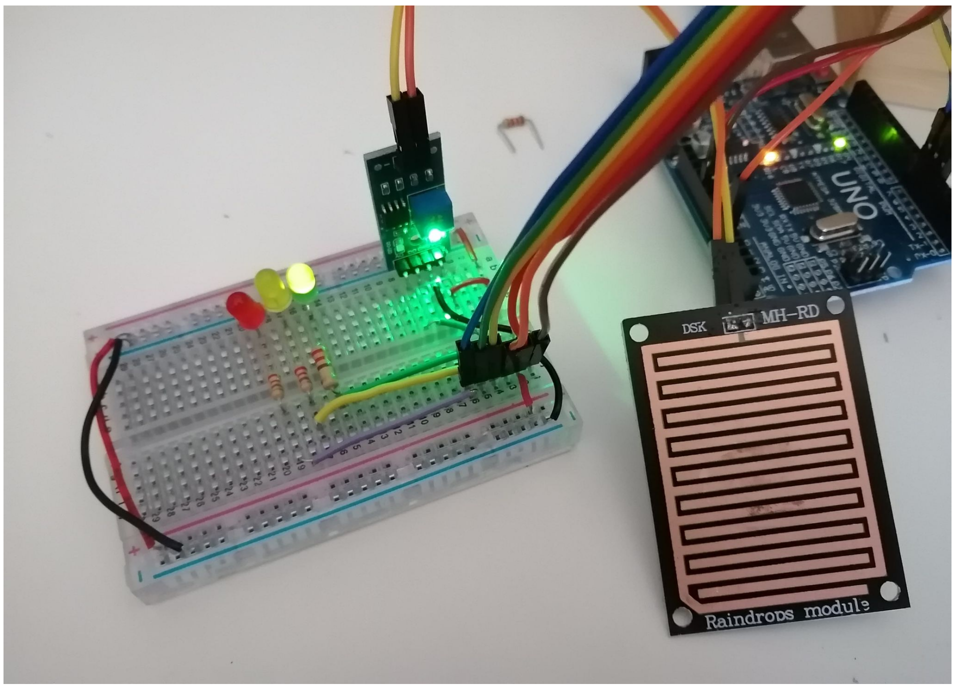

Figure 15. There is no snow on the sensor, the green LED is on

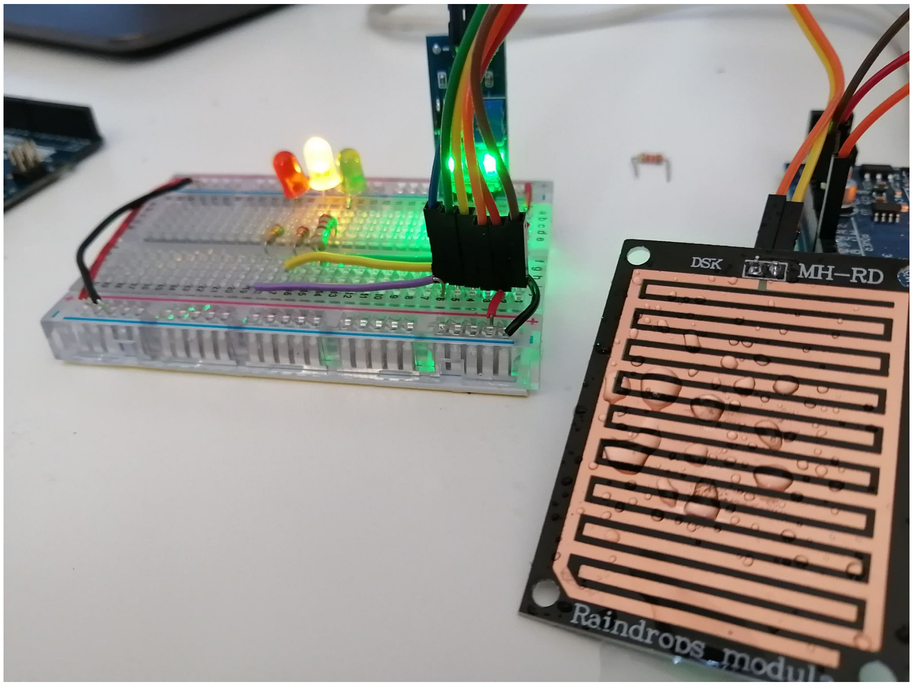

Figure 16. There is a minimal amount of snow on the sensor, the yellow LED is on

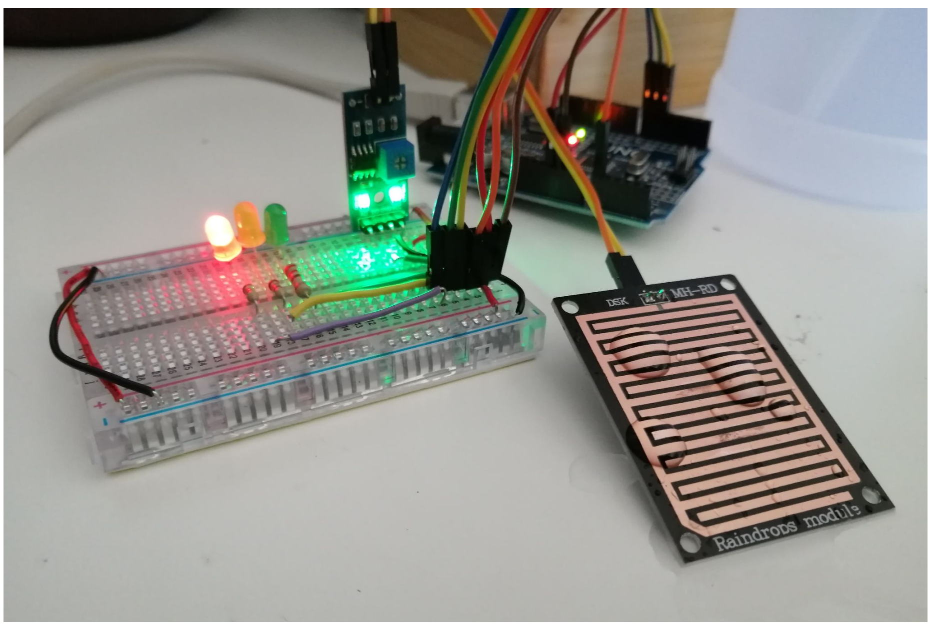

Figure 17. There is a large amount of snow on the sensor, the red LED is on

```
It is snowing
728
It is snowing
735
It is snowing
584
It is snowing hard
994
It is not raining or snowing
1002
It is not raining or snowing
1004
It is not raining or snowing
1007
It is not raining or snowing
1007
It is not raining or snowing
1009
It is not raining or snowing
1007
```

Figure 18. The serial monitor showing the state of the rain sensor.

Test #2: This test is an analytical and experimental test. It is similar to the previous test, however in this case it is the temperature sensor that is being tested. The use of two LEDs showed the temperature range. When the temperature was above 0℃, the green LED was lit. When the temperature was below freezing, and the heating device would need to be turned on, the red led was lit. The temperature sensor was also tested outside, where the local temperature was -4℃ during the time of testing. The sensor worked perfectly in this weather, and the red LED turned on when the temperature was below 0℃. Note that the temperature sensor is rated to read temperatures below -55℃.

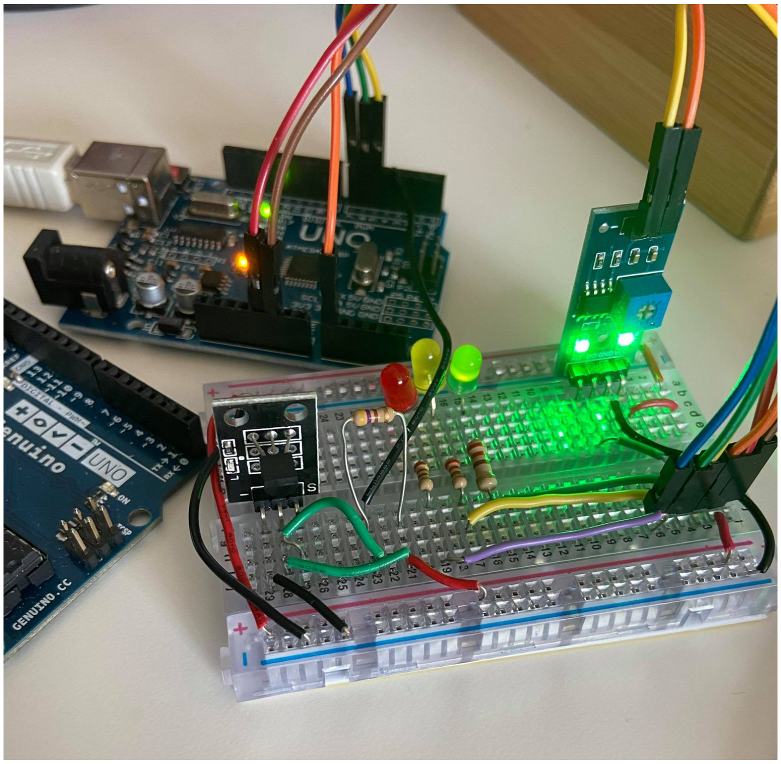

Figure 19. The temperature sensor reading the ambient room temperature which is above 0oc. The green LED is on.

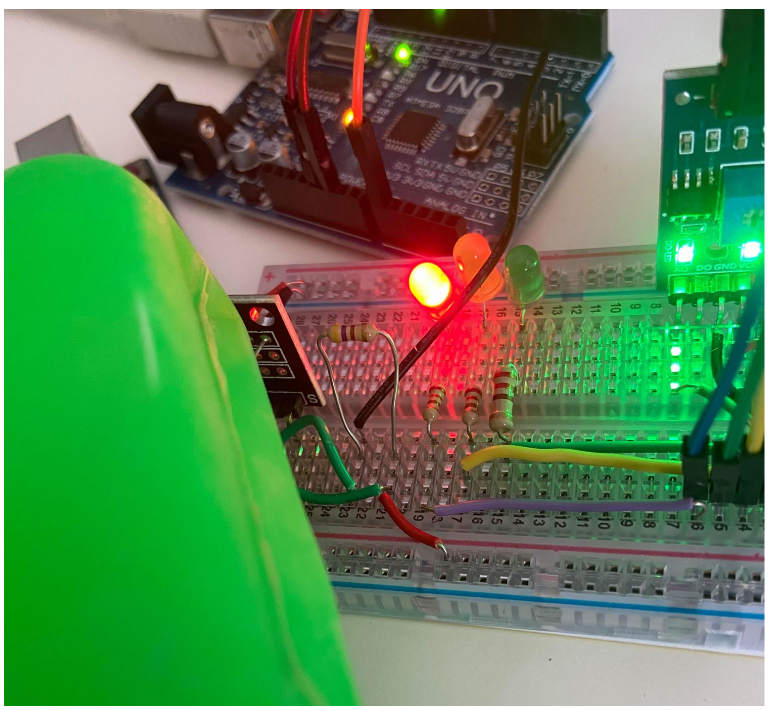

Figure 20. A cold pack applied to the temperature sensor to reduce the temperature to below freezing. The red LED is lit.

```
Celsius temperature: 17.81
Heating off
Celsius temperature: 17.81
Heating off
Celsius temperature: 17.50
Heating off
Celsius temperature: 16.44
Heating off
Celsius temperature: 15.75
Heating off
Celsius temperature: 15.25
Heating off
Celsius temperature: 14.81
Heating off
Celsius temperature: 14.44
```

Figure 21. Sample serial print out of the temperature sensor readings.

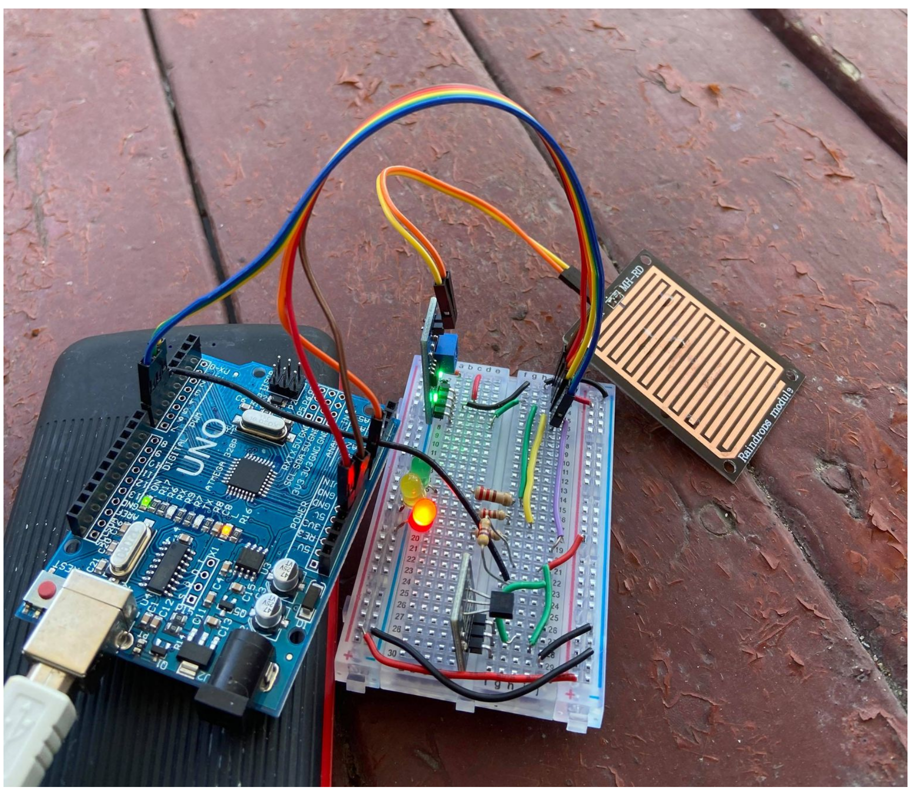

Figure 22. The red LED is on when the temperature sensor is placed outdoors in below freezing temperatures.

Test #3: This next test focuses on the grip and traction of the sidewalk. It comprises an experimental and analytical test as the grip/traction is tested experimentally then also analyzed with various calculations. In this experiment, the principle of friction during impending motion was used. Impending motion refers to the state of a body when it is about to move. Therefore, an angle at which the shoe was about to move was recorded in order to help us calculate the coefficient of friction of the mat and the shoe.

The mat was placed on a flat rigid top. The top was secured from any movements except the tilt motion to ensure more accurate measurements. Then, the angle of the tabletop was increased to a point when the shoe started moving. The experiment was conducted 4 times for dry and wet conditions to minimize measurement errors.

Figure 23. Grip test

Figure 24. Traction test

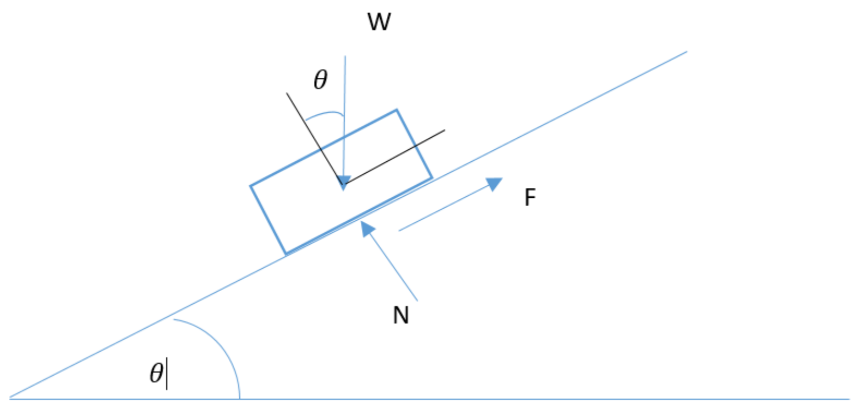

Figure 25. Free Body Diagram

$$F_{friction} = \mu N$$

μ – Friction coefficient

N – Normal force

$$\sum R_x = 0 \;=> F_{friction} - W sin\theta = 0$$

$$\sum R_y = 0 => \; N - W cos\theta = 0$$

$$N = W cos\theta$$

$$\mu N = W sin\theta$$

$$\mu W cos\theta = W sin\theta$$

$$\mu = \frac{W sin\theta}{W cos\theta} = tan\theta$$

Figure 26. Free Body Diagram

Experiment Number	DRY surface	WET surface
1	34°	30°
2	33°	31°
3	34°	30°
4	35°	32°

Table 9. Measured angle for dry and wet surface for impending motion

Friction coefficient for dry surface:

$$Average\ angle = \frac{34 + 33 + 34 + 35}{4} = 34.00°$$

$$\mu = \tan 34.00 = 0.675$$

Friction coefficient for wet surface:

$$Average\ angle = \frac{30 + 31 + 30 + 32}{4} = 30.75°$$

$$\mu = \tan 30.75 = 0.595$$

Difference between traction coefficients:

$$\%\ change = |(\mu_D - \mu_w)/\mu_D| * 100\% = 11.9\%$$

From the experiment data, we can observe that when the rubber mat is wet, the traction coefficient decreases only by 11.9% which makes the mat very efficient under wet conditions.

Mechanical properties of the material are disregarded. The heating system will always maintain a constant (above zero Celsius) temperature of the mat so it will not affect the material traction properties.

Test #4: This final test is a simple simulation. The team was stuck on whether to create a system so that the mats are connected in series or parallel. This test was conducted using TinkerCad simulation, by using a power supply that provides 120v and 5A. The mats were simulated by using resistors, each mat draws 20MΩ:

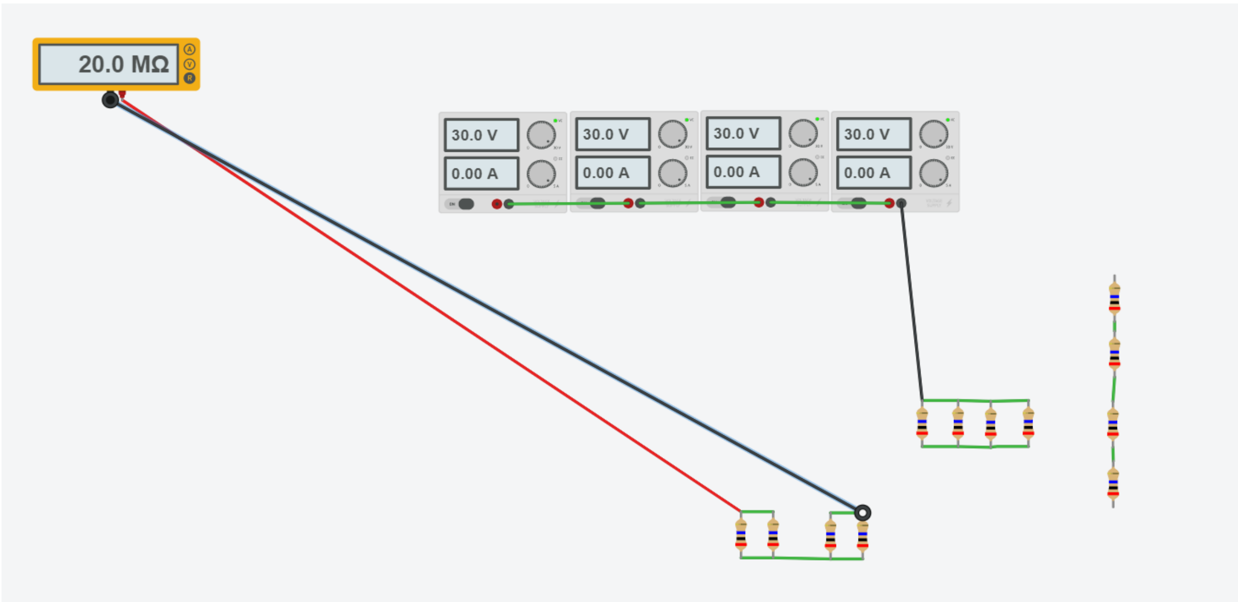

Figure 29. Circuit testing

Circuit type	Voltage	Resistance	Current	Voltage measured coming out
4 mats in series	120v	80MΩ	1.5μA	66.7v
4 mats in parallel	120v	5MΩ	24μA	114v
2 pairs of parallel mats in series	120v	20MΩ	6μA	100v

Table 10. Circuit Testing results

As table 8 shows, the parallel configuration had the most voltage measured out which would be ideal for the efficiency of the system. Therefore, as a result of this experiment it was determined that the parallel configuration would be the optimal type of circuit.

5.3 Prototype III

Prototype III focuses on the whole product and brings all subsystems together. This prototype is a physical and comprehensive prototype. Since it is a physical and comprehensive prototype, this prototype is a very accurate presentation of what the final product would be. The tests during this prototyping phase focuses mostly on the overall functionality of the systems and whether or not the subsystems are properly working together.

5.3.1 BOM

Item	Description	Manufacturer	Cost (CAD)	Quantity	Total (CAD)	
Rain Sensor (SENS-52)	Rain detector to be used on each unit	Abra Electronics	$6.91	x 1	$6.91	https://abra-electronics.com/sensors/sensors-temperature-en/sens-52-raindrop-sensor-module.html
Carbon Heating Film	Radiant heating system of the sidewalk	QuietWarmth	$59.98	x 1	$59.98	https://www.homedepot.ca/product/quietwarmth-1-5-ft-x-5-ft-120v-floor-heating-system-for-laminate-vinyl-and-floating-floors-7-5-sq-ft-/1001611786
Magnets	Neodymium rectangular magnets to hold the mats together, pack of 10.	Abra Electronics	$6.99	x 1	$6.99	https://abra-electronics.com/electromechanical/magnets/mag-n-50-50x5x3mm-neodymium-rare-earth-rectangular-magnets-pack-of-10.html
Stair Tread	This material will be used as the top part of the mat.	T.A. DRUMMOND	$3.69	x 2	$7.38	https://www.rona.ca/en/t-a-drummond-18-in-stair-tread-fv5040brn18-00975207
Temperature Sensor (DS18B20)	Waterproof temperature sensor to be used on each unit	Dallas Semiconductor	$3.48	x 1	$3.48	https://abra-electronics.com/sensors/sensors-temperature-en/one-wire-waterproof-temperature-sensor-ds18b20.html
Control Relay (non-latching)	250Vac switching voltage,	Songle	$3.07	x1	$3.07	https://abra-electronics.com/electromechanical/relays/pcb-mtg-20a-30a/sla-05vdc-sl-c-relay-5vdc-spdt-30a.html
				Total	$87.81	

Figure 30. BOM for Prototype III

5.3.2 Equipment list

PPE:

- Gloves (heavy duty pair and rubber pair)
- Safety glasses

Hand tools:

- Screwdriver set
- Wire crimping set
- Pliers and cutters

Power tools:

- Power drill + drill bits
- Heat gun

5.3.3 Instructions

Mat assembly:

1. On the base mat, lay out heattrace in snake-like shape with input and output located as shown below.
2. Secure the heattrace with metal brackets
3. Splice in female on the input side (in the right) and male for the output side

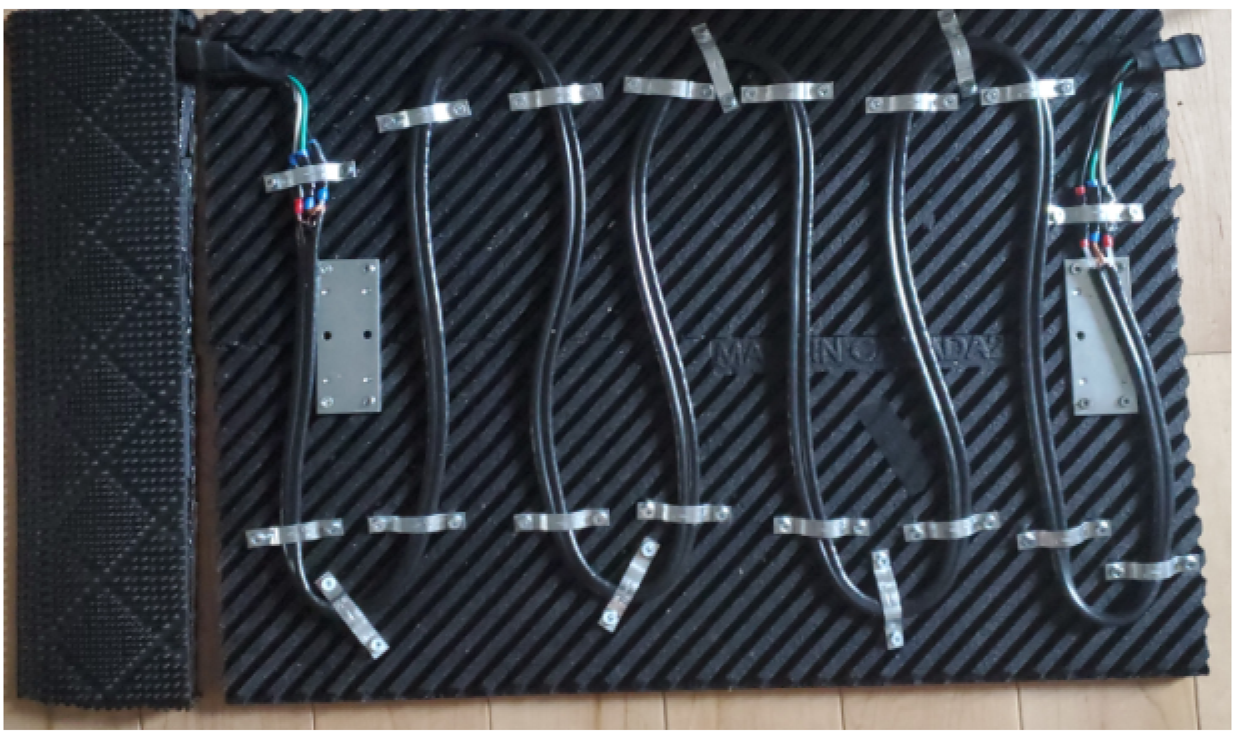

Figure 31. Integrated heat trace

4. Cover the assembly with a cover mat
5. Place and secure 2 magnets on each side of the mat as shown below

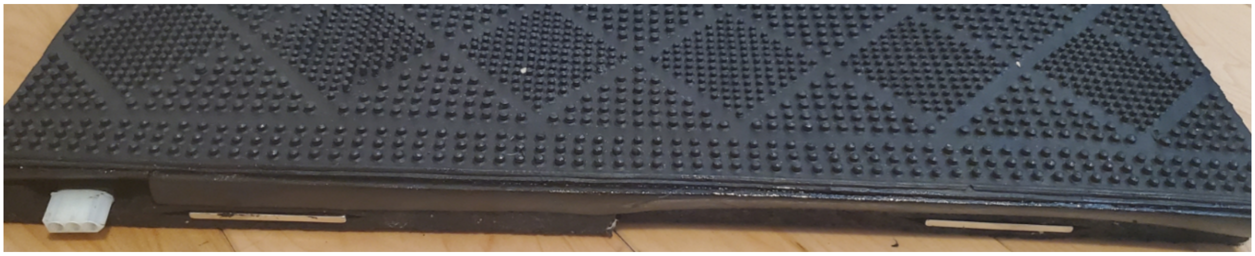

Figure 32. Mating surface of the mats

Ramp:

1. Cut a strip of the base mat material
2. Trim top layer to create an angle
3. Mount top layer
4. Place magnets as shown in the mat assembly section

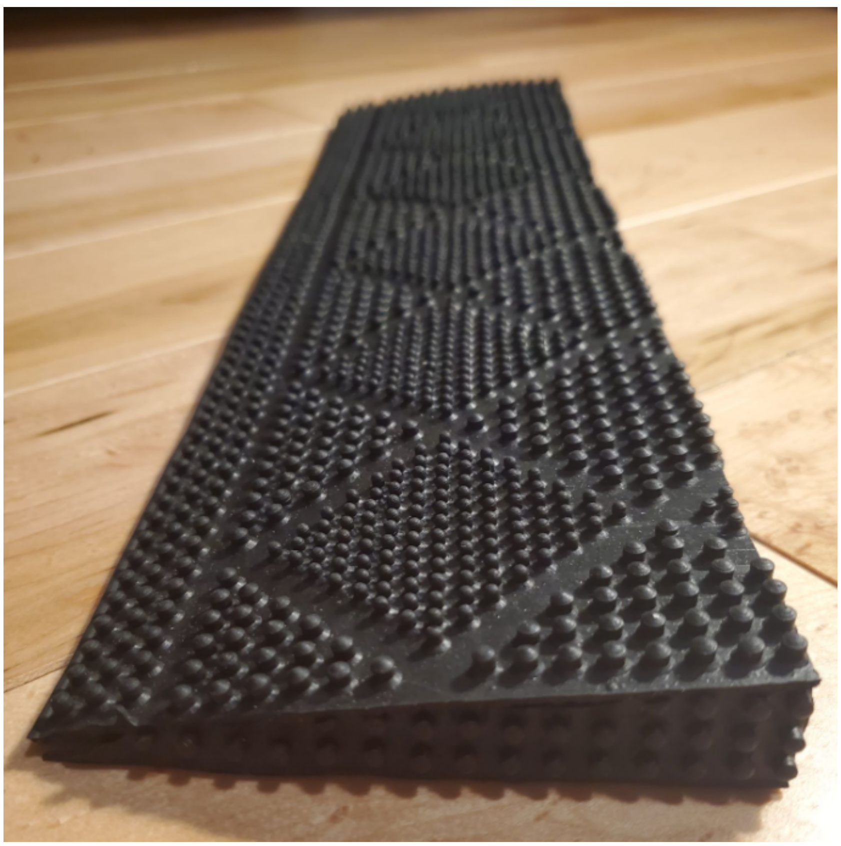

Figure 33. Ramp

Weather Box:

1. Mount temperature and rain sensor
2. Mount yellow and red LED indicators

Figure 34. Top view of the WB

3. Install Arduino Uno and Relay module as shown below
4. Wire in AC-DC converter to supply power to the controls (white block)
5. Connect sensors and light indicators to corresponding terminals
6. Place female connector on the input side and male on the output side of the box
7. Wire in the power output to Relay 1.

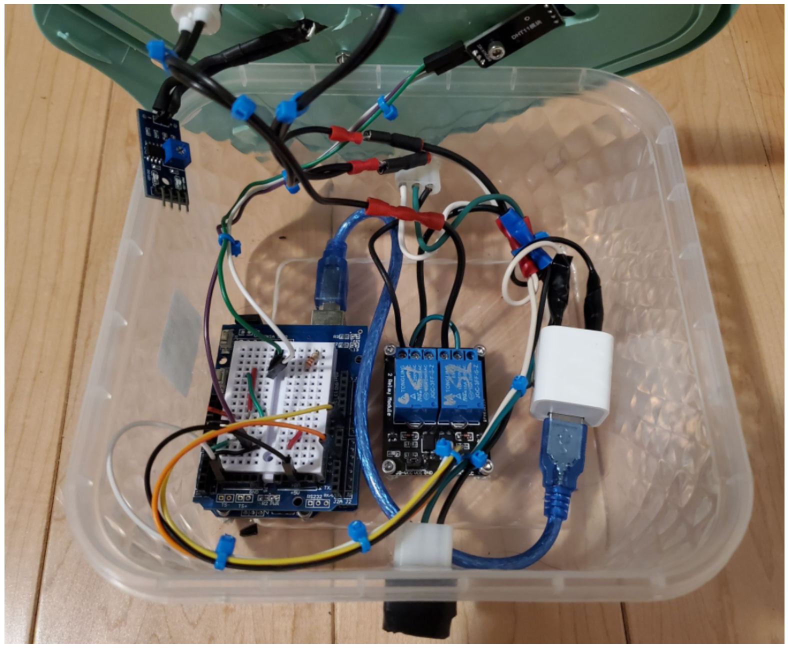

Figure 35. Internal view of the WB

5.3.4 Testing and Validation

1. Tested the magnet connection between mat assembly and the ramp. The test showed that the attachment between the mat and the ramp were strong enough to stay held together.

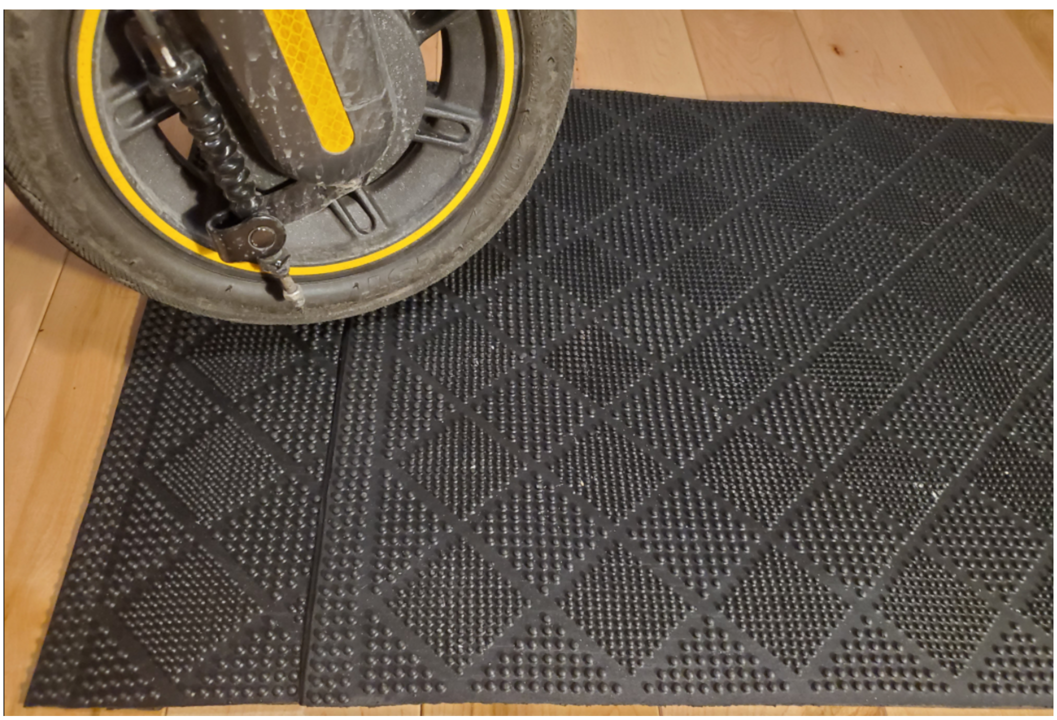

Figure 36. Wheeled transport test over the magnetic connection

Figure 37. Walk test over the magnetic connection

2. Tested the surface temperature of the mat while it was operating. This test was done in the house and was taken 10 minutes after the heating cable was on.

Figure 38. Mat surface temperature when activated

3. Tested the hardware by simulating different scenarios and thresholds for the software. This allowed us to view and validate the working ability for obscure conditions that the mat would be subjected to.

```
It is snowing
728
It is snowing
735
It is snowing
584
It is snowing hard
994
It is not raining or snowing
1002
It is not raining or snowing
1004
It is not raining or snowing
1007
It is not raining or snowing
1007
It is not raining or snowing
1009
It is not raining or snowing
1007
```

Figure 39. Control response to condition changes

6 Conclusions and Recommendations for Future Work

6.1 Lessons learned

Throughout the design of this product, our team learnt many valuable lessons to take into consideration for future projects. One of the main lessons learnt was to ask and challenge each other's ideas. This process allows for great brainstorming practices and helps us detect possible problems earlier on in the design process. By asking and challenging each other's ideas in a constructive way, we are also all able to get a fullscope of understanding encompassing the project and each other's ideas. By doing so, we ensure that we are all on the same page concerning subsystems and design changes, increasing our chances of success as a team.

Another lesson learnt was the value of inter task dependencies. By making these dependencies clear, or reducing the need for inter task dependencies, we are able to create a project and subsystems that run more smoothly and help us work more in parallel rather than in series. It is important that, when working with tight deadlines, no one is waiting around for another teammate to finish their work. Thankfully, our team worked great together and there was never any difficulty communicating. All team members helped each other out and we were able to lower this need for series task dependencies.

Another important lesson that we learned was the importance of accessible tools and machines. Since this product was made during lockdown, many of the school labs and tools were unable to be used during the creation of the project. This raised some confusion and lack of guidance for our team members as to how to go about creating this mat without proper tools and machines. Thankfully,we were able to create a working product. However, things will be done much differently if we had constant access to tools and components at the school labs.

Finally, our team learnt the importance and value of good teamwork. Thankfully, our team was able to communicate very well and maintain weekly meetings. We were all on the same page concerning level of expectations and high standards. This helped us focus primarily on the project at hand, rather than focus on working well as a team.

6.3 Recommendations for future work

There are many things that we would have liked to include in this project to improve multiple features of our design. Unfortunately, due to our time and monetary constraints, not all the possibilities were feasible, and some of these improvements needed to be abandoned. If the deadline for this project were to be extended, there are many things that we would have liked to add to the functionality and overall design of the heated sidewalk cover.

For one, the use of a wireless connection system between the mats and the weather box would be beneficial. This would allow the price per mat to be drastically reduced, as well as improve the scalability of the mats. Since there would be less connections, we would be able to produce the mats at a much larger scale. In order to render the mats completely wireless, the use of ESP8266 wifi modules would be used. These devices would receive transmitted signals from the weather box, stating the outside temperature and whether it is raining. With the use of wifi modules, it would be possible to create a webpage that would contain all the sensor information as well.This will allow the information to be accessible to the maintenance crew tasked with snow removal. Through this webpage, the user can choose to turn the devices on, if for example,they know of the predicted weather for tomorrow. This website will also allow for the users to change the threshold temperature for the temperature sensor to better suit the mat to their needs based on the local weather patterns and conditions. The website will also allow for the maintenance crew to set the rain sensor threshold to a lower value, meaning that more snow should fall before the sensor is turned on, or to a higher value. All these settings will allow for our device to be more customizable and increase the range of applicable uses for our product.

It would also have been interesting to see the use of multiple sensors in the WB. This would allow for more accurate power usage as well as valuable campus information. The use of multiple sensors would allow for a large influx of information pertinent to the weather and temperature of the campus. Devices such as a humidity sensor, or UV sensor could be used to more accurately control the mat, but also to provide information to students about the status of the campus environment. This data can be used to analyze environmental patterns in the area, and advise students concerning the environmental status.

It is also important for our device to be openable in order to provide accurate maintenance. Unfortunately during this project, we did not have enough time to fully integrate this subsystem into our design. By allowing for the mat to open, our device will be easier to maintain and troubleshoot. It will also prolong the longevity of the device. However, since our mats themselves are so low cost, we omitted this feature during our first design in order to focus on the functionality. Entire replacement of the mat might be simpler, safer and more cost effective than performing maintenance and part replacement on the mat.

Embedded heated cables would be another feature that we focus on for the future development of this mat. These embedded cables will be more comfortable to walk on, while also helping to properly dissipate the heat throughout the entire surface of the mat. This can be done with access to the right tools by creating ridges for the cables in the rubber.

7 APPENDIX I: Design Files

Document Name	**Document Location and/or URL**	**Issuance Date**
Team Contract	https://docs.google.com/document/d/11eSynrv3xyBdY-ejD76gZ9y7ZG6MQ69bD4gSlcHKdTk/edit	January 24th, 2021
Needs Identification and Problem Statement	https://docs.google.com/document/d/1vpsQI3CsaUTfYz2oOOcPps_4JywZSh2jMw38XmS9SPk/edit	January 31st, 2021
Design Criteria and Target Specifications	https://docs.google.com/document/d/1QvdJFdW6FvKYdnYoxMZqZpImlzY0Lw-Pej1UYH7PqSk/edit	February 7th, 2021
Conceptual Design	https://docs.google.com/document/d/1VFJuYsswRheV7fXatmvpnxgWakAOgTs7IeL5NJV-tO4/edit	February 21st, 2021
Project Schedule and Cost	https://docs.google.com/document/d/1OsRL2Y4czPI1aur7G-3xpRF6ysH_Oo653Q-4DaldmDo/edit	February 28th, 2021

Prototype I and Customer Feedback	https://docs.google.com/document/d/1TDHm-AYQTUMytCywUoMHSsweJ2aoEocBIQGZgHHGjhQ/edit	March 7th, 2021
Prototype II and Customer Feedback	https://docs.google.com/document/d/1rGDGOEFPtIJ9wc9ueEJumgSMc3YztItgYDWqGYAfyts/edit	March 14th, 2021
Prototype III	https://docs.google.com/document/d/17pg3zLHm4z6LPKzy7fs1iBlpGSrY4b4-JWnsZclFAAQ/edit	March 28th, 2021
MakerRepo	https://makerepo.com/yasintopcuoglu/803.gng1103f12wolf-fifth	March 28th, 2021

Table 11. Referenced Documents

8 APPENDIX II: Other Appendices

Code:

```
/*********************************************************************
*
   Title: temp_sensor.ino

----------------------------------------------------------------------
-   Description -  to use in the modular sidewalk project. This code
uses a sens-73
                  temperature sensor.
   Date          Version     Changes

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~
   03/10/2021   1.0.0       Code creation
   03/11/2021   1.0.1       Testing and debugging
   03/13/2021   1.1.0       Implementation of LEDS
*********************************************************************
/

//Library inclusions
#include <OneWire.h>
#include <DallasTemperature.h>
```

```
#include <dht.h>
dht DHT;
#define analog_pin A1

OneWire oneWire(DATA);

int greenLED = 5;
int redLED = 7;
int cable = 4;
int heaton = 8;

DallasTemperature sensors(&oneWire);

void setup(void)
{
  Serial.begin(9600);
  sensors.begin();
  pinMode(greenLED, OUTPUT);
  pinMode(redLED, OUTPUT);
  pinMode(cable, OUTPUT);
  pinMode(heaton, OUTPUT);
}

void loop(void)
{

  int chk = DHT.read11(analog_pin);

  Serial.print("Celsius temperature: ");
  Serial.println(DHT.temperature);
  delay(2000);
  Serial.println(analogRead(0));

  // Temperature lower than 0oc and snows - it is on
  if (DHT.temperature < 1 || analogRead(0) < 400) {
    Serial.println("Heating on");
    digitalWrite(cable, HIGH);
    delay(1200);
  }


  if (DHT.temperature > 1 && analogRead(0) < 400) {
    Serial.println("Heating on");
    digitalWrite(cable, HIGH);
    delay(60);
  }

  // Temperature higher than 0oC and not snow - it is off
  if (DHT.temperature >= 0 && analogRead(0) >= 400) {
    Serial.println("Heating off");
    digitalWrite(cable, LOW);
    delay(500);
```

```
  }
  delay(100);
  heatmaton();
}
void heatmaton()
{
  while(!(DHT.temperature >= 0 && analogRead(0) >= 400)){
    digitalWrite(heaton, HIGH);
    delay(1500);
    digitalWrite(heaton, LOW);
    delay(1500);
  }
}
```