# Automated Frozen Pipe Burst Prevention System

## ECE 445 DESIGN DOCUMENT – SPRING 2023

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Project #22

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# Contents

# 1. Introduction

## 1.1 Problem

Frigid temperatures like those during the winter here in Illinois run the risk of inducing frozen & thus burst pipes. Just this past winter break, our apartment got an email regarding several units on our floor that had unfortunately had their pipes burst as a result of the winter storm.  This is an issue that plagues not only college students like us, but many residents across the country. An estimated average of over 250,000 homes each year will suffer damage from frozen and burst pipes. The damage is estimated to be in the $400-500 million each year. To further highlight the fragility of frozen pipes, even a rupture as small as an 1/8th of an inch can release up to 250 gallons of water per day.

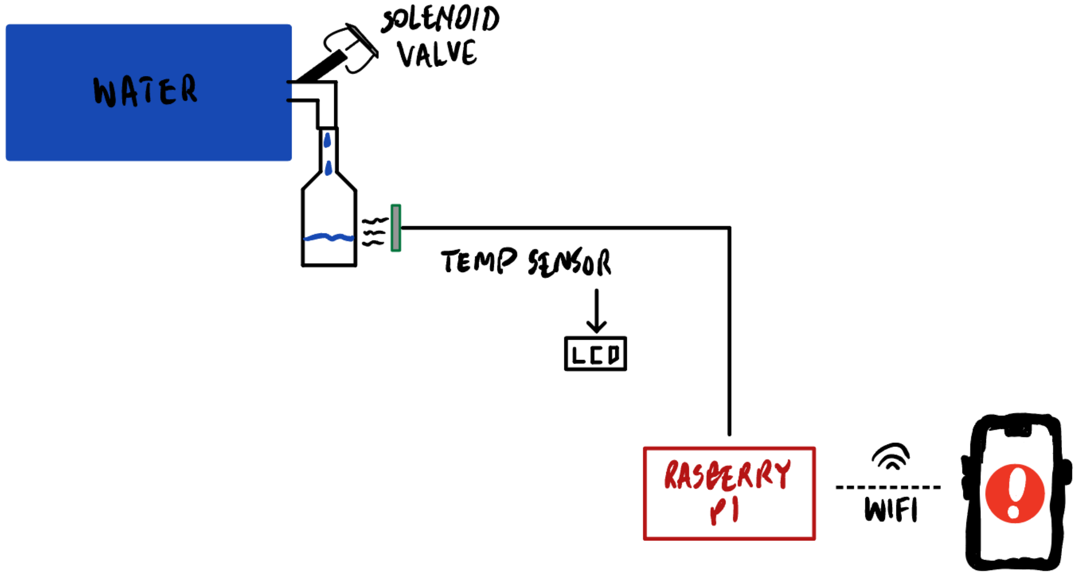
## 1.2 Solution

Current methods to help alleviate this issue have proven insufficient and/or have left room for improvement. Common current methods to prevent frozen pipes include maintaining a set temperature of at least 55 degrees fahrenheit in the home, running a trickle of cold water from faucets with exposed pipelines, and adding insulation or heat cables along the pipelines. Other methods such as the use of antifreeze are considered harmful for the environment, wildlife, and humans.

The former 3 are a good place to start but what happens when a resident forgets to set the temperature or leave the faucets running? Even if the resident were to take these measures, the utilities costs that one would incur and energy wastage that would occur appears to be excessive and inefficient. In addition, situations where the resident is away from the residence for an extended period of time and cannot return in a timely manner further exasperate this issue.

Our proposed solution is creating an automated system that alerts the resident via a notification to their smartphone that a pipe is at risk of freezing and therefore further at risk bursting if left unattended. The notification subsystem will be triggered by the subsystem involving the temperature sensor. In addition, a third subsystem will be utilized to open a valve that would allow cold water to trickle through the pipe. The combination of these two features enables the resident the ability to take further action by buying them time as well as automating certain preventative measures such as allowing water to trickle through the pipe which helps prevent the pipe from freezing.

## 1.3 Visual Aid

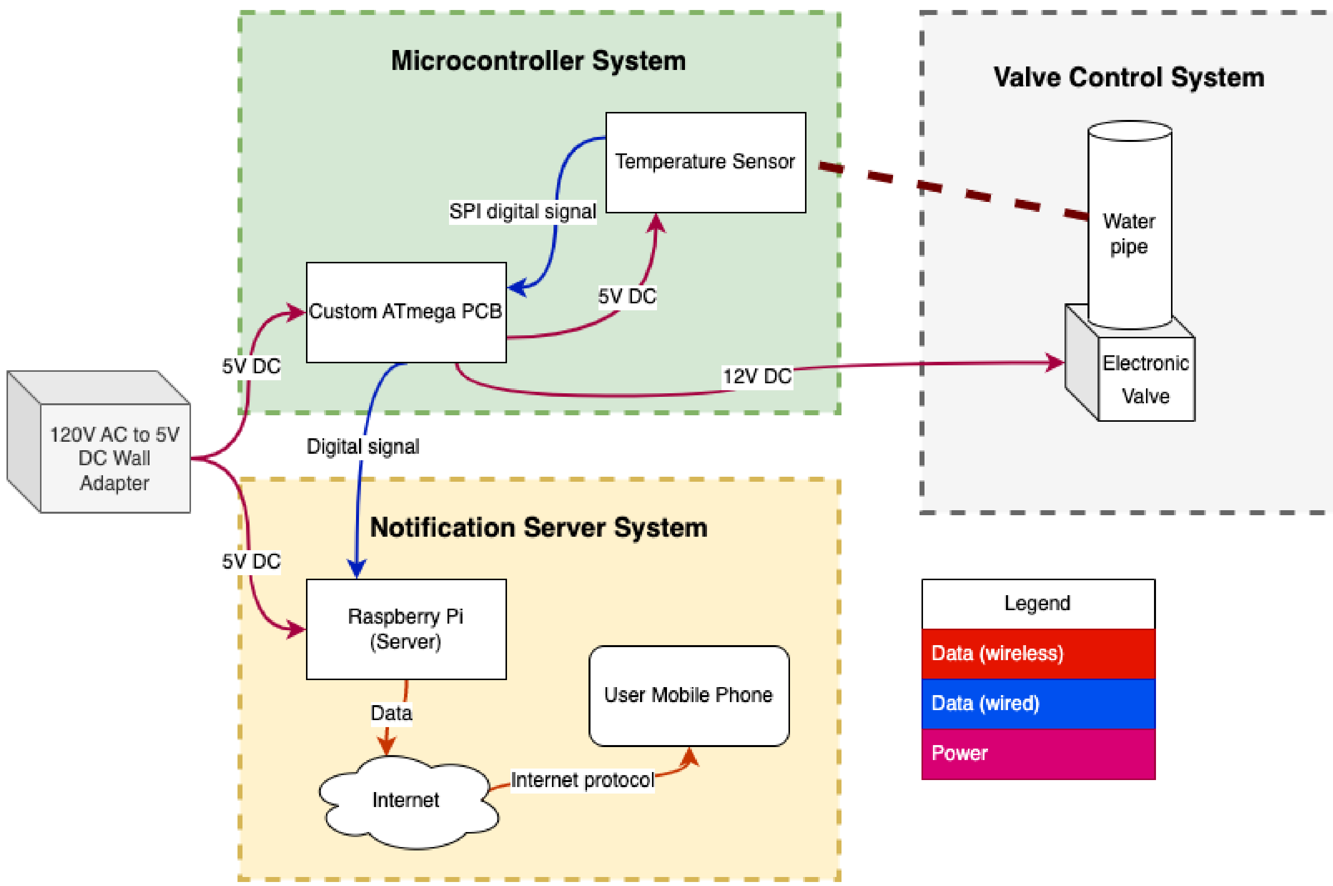



## 1.4 High-Level Requirements

1. System is triggered only when the temperature sensor output reads between 13.0-14.0 °C.
2. 1 push notification is sent to the mobile device using wifi upon receiving low temperature reading.
3. 75 mL of water is deposited to the pipe over the course of 5 seconds so that the movement from trickling water prevents the pipe from freezing. As the solenoid valve is ½", this may require adding an additional filter to the valve opening to reduce flow rate.

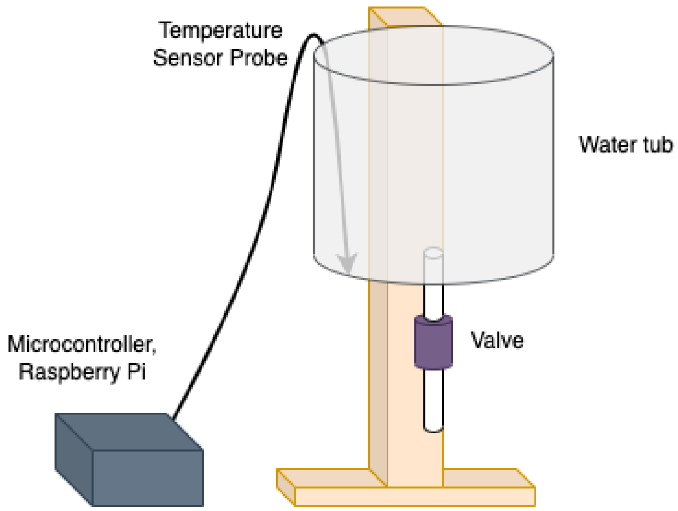
# 2. Design

## 2.1 Block Diagram



## 2.2 Physical Design

Note: Dimensions are not included in the below diagram because the setup has not yet been physically constructed, and the design will be finalized with the machine shop once all necessary parts have arrived.




The above diagram shows the layout of the primary physical components of our project setup. The plastic water tub will be suspended aloft by a wooden frame to allow the pipe and valve to be connected to the exterior of the bottom, which will allow water to flow out of the reservoir and to the valve due to the gravitational water pressure. The temperature sensor probe will be routed over the top of the tub, and placed at the bottom, to most accurately represent the temperature of the water present in the pipe.

## 2.3 Microcontroller Subsystem

The microcontroller subsystem is instrumental for bridging the physical and electronic/software elements of our project together. The core of the microcontroller subsystem is the ATmega328P microcontroller integrated circuit, which will be programmed to read the input signal from the temperature sensor, and send signals to the relay to open the valve and the Raspberry Pi to send out the notification. The ATmega328P and its related components will be soldered to our custom printed circuit board (PCB), which will then interface with the Raspberry Pi 4 I/O and the temperature sensor digital output, as well as the LCD screen. It will be necessary to program the microcontroller via the USB 3.0 Type A port and the Arduino IDE software [6].

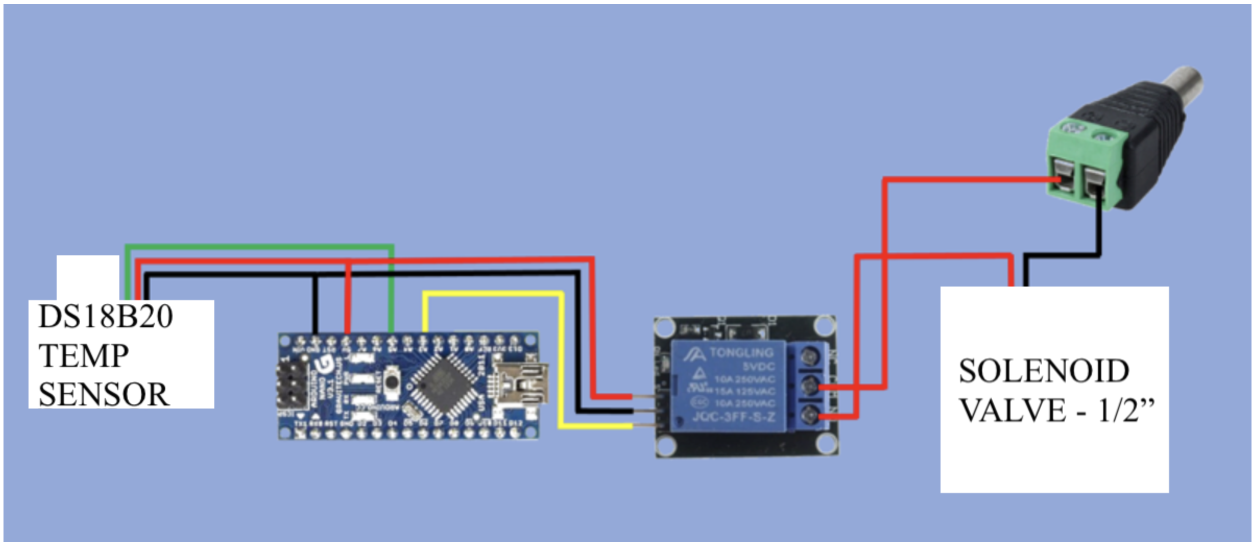
The microcontroller will be triggered by the DS18B20 digital thermometer only when it has provided an input signal of having reached a threshold temperature range between 13-14 degrees Celsius to account for the expected tolerance of +/- 0.5 degrees Celsius. This threshold was carefully chosen to ensure that the system will be triggered before crossing the suggested pipe-safe temperature of 55 °F (12.7778 °C).

## 2.4 Valve Control Subsystem

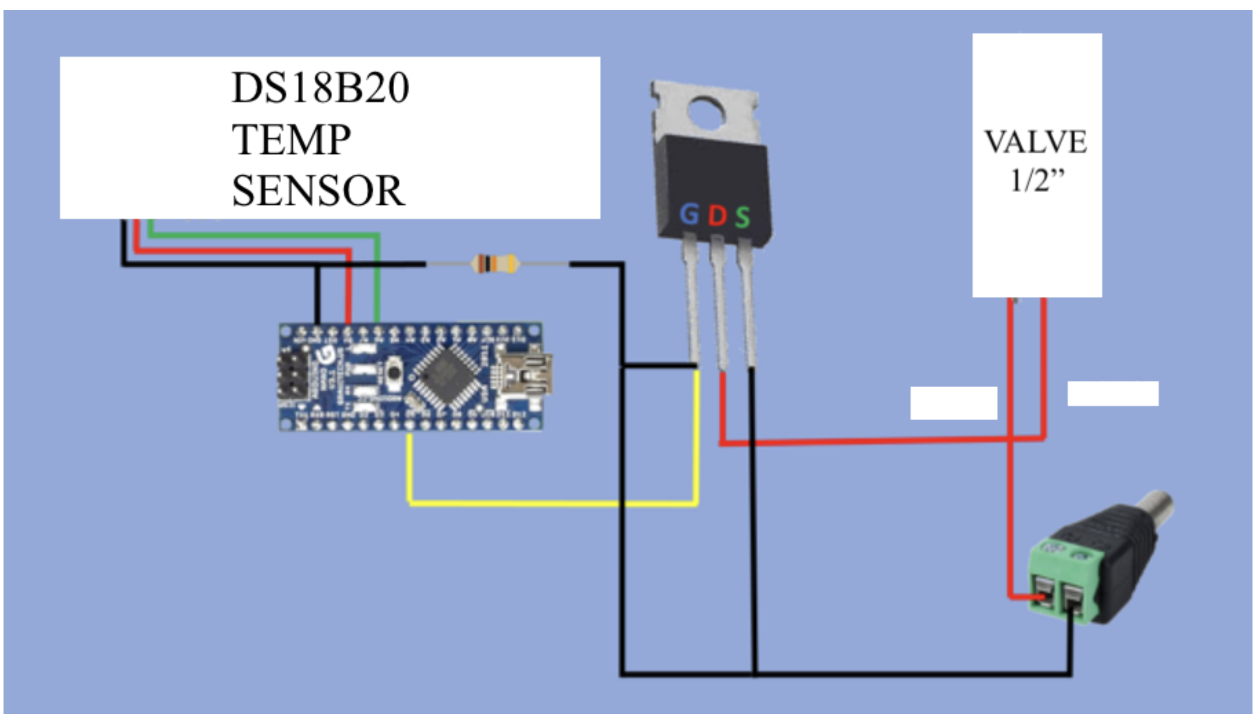
A safe temperature to avoid pipes bursting is 55° F [5]. Using this as a threshold temperature, when the ATmega328P microcontroller receives output below 55° F from the Waterproof Temperature Sensor (DS18B20), the 12V DC solenoid valve will move to release water into the pipe for a set period of time (-5 seconds). By doing so the water temperature in the pipe will be warmer and allow the user more time to implement a more assured method like turning up the thermostat.

**Subsystem Requirements:**
1. Solenoid valve must be able to communicate with the ATmega328P microcontroller to release water into the pipe for ~5 seconds.
2. Must be plugged into a 12V adapter connected to a 5V one-channel relay module or NPN transistor that is also connected to the ATmega328P microcontroller. ATmega328P (5V) alone is not powerful enough.

In order to deposit water, the valve will communicate with the PCB and the temperature sensor wired to the microcontroller. As the ATmega328P operates at a max voltage of 5V and the valve requires 12V, a middle component is needed to electromagnetically allow the 12V through when the temperature sensor says so. To make this, a relay or NPN transistor will be used. Both options act as a switch that will close so the valve can connect to its power supply.




If using a relay, shown in the image above, we will wire the temperature sensor to one of the digital input pins of the ATmega328P. The relay, which will electromagnetically switch power to the normally closed solenoid valve based on the threshold temperature, will also be connected to the microcontroller on one side, and to the valve, connected to 12VDC, on the other side. [1]



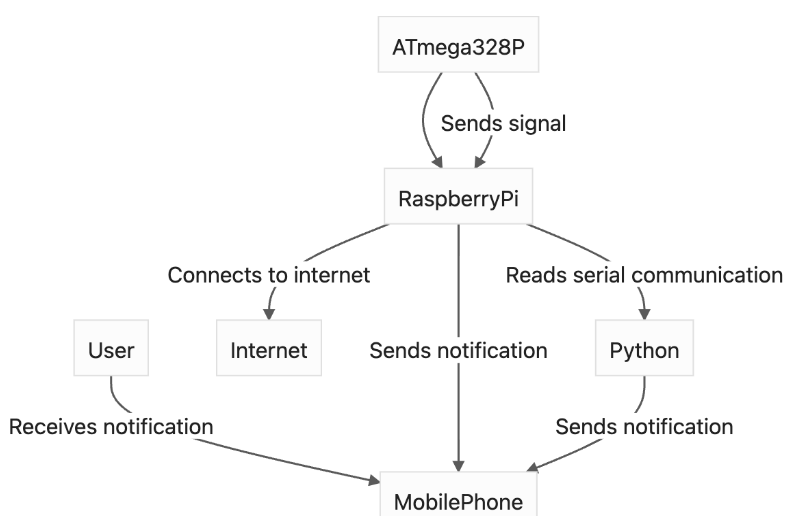
If using a transistor, depicted above, the temperature sensor will still be connected to the microcontroller through one of the ATmega328P digital pins, but now the 3 pin NPN transistor will have its drain pin connected to the solenoid valve and the source valve connected to the 12VDC source. [2]

Currently, we have found it difficult to locate the correct relay module that is not from a third-party site and so the transistor is an equal alternative. While using the transistor has concerns of overheating, it doesn't have moving parts like the relay, whose lifespan can be shortened as the friction of switching the power supply on repeatedly wears down the moving parts inside. Additionally, the transistor will also not see enough uses for us to worry about overheating. [3]

## 2.5 Notification Server Subsystem

To augment the user experience and interactivity of our system, a software implementation will be used to give the user of the device a notification on their mobile phone when the freezing prevention system is triggered. The Raspberry Pi 4 Model B single-board computer will be configured as an internet-connected server in order to deliver the notifications over the internet protocol.

The Raspberry Pi will interface with the ATmega328P via its I/O pins to detect the triggering, and is able to communicate with the internet using the on-board 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless capabilities. Although the code has not yet been implemented, we will likely use Python to read the serial communication coming from the microcontroller into the Raspberry Pi, and a Python push notification API to send notifications over the web to the user's mobile device.



## 2.6 Requirements and Verifications Table

| Component | Requirements | Verification |
|---|---|---|
| One-Channel Relay Module | 1. Provide 12 VDC +/- 10% from a 10.8 VDC-13.2 VDC<br>2. Can operate current within 0-200mA (90mA) | 1. Measure output voltage using an oscilloscope to ensure output voltage is within 10% of 12V.<br><br>2. Using a multimeter, connect leads to the coil terminals of the relay and measure. Output resistance should read 50-120Ω( 62.5) (Safe Relay Resistance). |
| DS18B20 Temperature Sensor Probe | 1. System should only be triggered between a temperature of 13.0-14.0 degrees Celsius accounting for the +/- 0.5 tolerance of the DS18B20 Digital Thermometer | 1. Measure the temperature of the water in the reservoir using an alternate thermometer when the system is triggered to ensure that it is within this threshold range. |
| ATmega328p Microcontroller | 1. Receive temp sensor input and output to display at 3.3 - 5VDC. | 1. Connect LCD and DS18B20 to ATmega. Program chip with code for display and check if data is transferring within the 750ms DS18B20 conversion time. Use an oscilloscope to check operation happens at 3.3 - 5VDC. |

## 2.7 Tolerance Analysis

Gauging the temperature of water in the reservoir is critical to the success of our project as the prevention system as a whole is contingent upon alerting the microcontroller to alert the resident of the potential of a pipe freeze via a push notification and trickling water through the pipe as soon as the threshold temperature has been reached between 13.0-14.0 °C. This range has already accounted for the tolerance of the DS18B20 Digital Thermometer of +/- 0.5 °C by ensuring the threshold temperature never falls below the suggested pipe safe temperature of 55 °F (12.7778 °C). The DS18B20 Digital Thermometer is also designed to measure temperatures from - 55 °C to +125 °C and maintains its tolerance within -10 °C to +85°C.

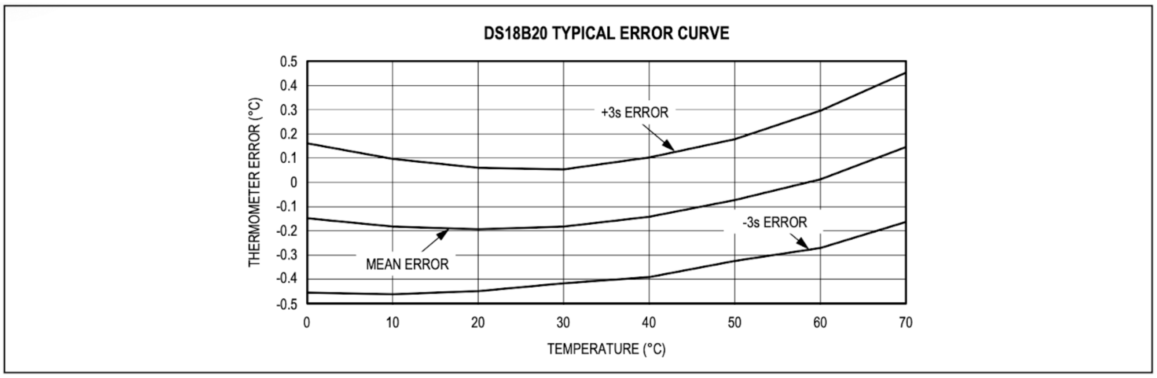



Figure 1. Typical Performance Curve

*The above figure displays the typical performance curve of the thermometer ranging from 0 to 70 °C [8]*

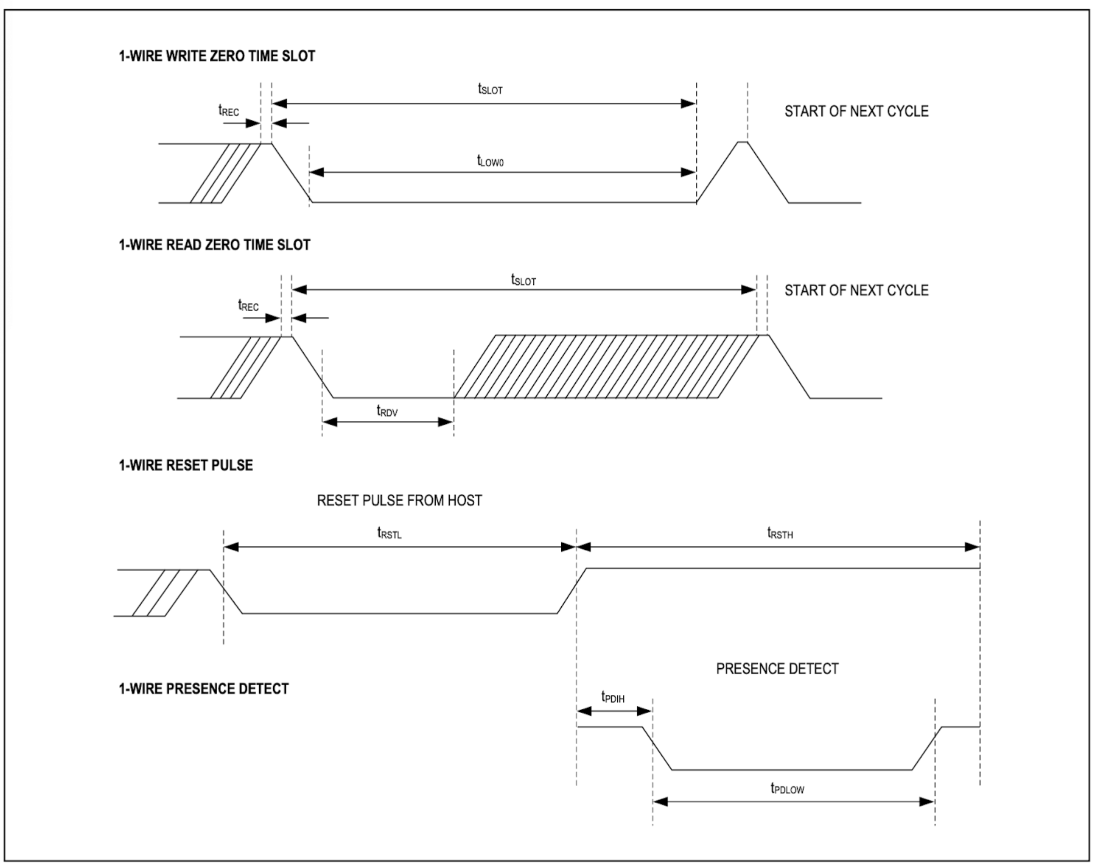



Figure 2. Timing Diagrams

*The above figure corresponds to the timing diagrams of the thermometer [8]*

Based on this quantitative analysis, we determine that this microcontroller and temperature sensor subsystem can be feasibly implemented. If the temperature sensor is receiving a consistent 5.0V DC and within the operating limit tolerance, it will be able to output accurate measurements with minimal error range. Additionally, we will pair the temperature sensor with a 4.7kΩ pull-up resistor between the signal and power pins in order to keep the data transfer stable. A typical gold-banded resistor has a ± 5% value tolerance, which is sufficient for our purposes. As such, the microcontroller will feasibly be able to interface with the temperature sensor and send the signals to open the valve accordingly, as well as meet its requirements.

# 3. Cost and Schedule

## 3.1 Cost Analysis

### 3.1.1 Labor

Using an hourly wage of $45:

[$45/hour] x 2.5hrs/day x 60 days to complete = $6750/person
$6750/person x 3 people = $20,250 Total

### 3.1.2 Itemized List of Components and Costs

| **Description** | **Manufacturer** | **Quantity** | **Price** | **Link** |
|---|---|---|---|---|
| ATMEGA328P-AU IC MCU 8BIT 32KB FLASH 32TQFP | Microchip Technology | 1 | $2.86 | **Link** |
| LCD MOD 32 DIG 16 X 2 REFLECTIVE | Lumex Opto/Components Inc. | 1 | $10.68 | Link |
| 2N2219A NPN TRANSISTOR | Microchip Technology | 1 | $6.94 | Link |
| QWIIC SINGLE RELAY | SparkFun Electronics | 1 | $13.95 | Link |
| CRYSTAL 16.0000MHZ 20PF TH | IQD Frequency Products | 1 | $0.48 | Link |
| IC USB FS SERIAL UART 28-SSOP | FTDI Ltd | 1 | $4.80 | Link |
| USB TYPE-A 3.0 CONNECTOR, RIGHT | Switchcraft Inc. | 1 | $1.50 | Link |
| CONN HDR STRIP SOLDER 6POS GOLD | Mill-Max Manufacturing Corp. | 1 | $3.84 | Link |
| CONN HDR DIP POST 14POS GOLD | Aries Electronics | 1 | $4.87 | Link |

| | | | | |
|---|---|---|---|---|
| DIODE GEN PURP 1KV 1A DO41 | Diodes Incorporated | 1 | $0.20 | Link |
| USB TO TTL CONVERTER (CP210) | DFRobot | 1 | $4.90 | Link |
| LED 5MM VERTICAL GREEN PC MNT | Dialight | 2 | $1.81 | Link |
| WATERPROOF DS18B20 DIGITAL TEMPE | Adafruit Industries LLC | 1 | $9.95 | Link |
| PLASTIC WATER SOLENOID VALVE - 1 | Adafruit Industries LLC | 1 | $6.95 | Link |
| GROVE - OLED DISPLAY 0.96" (SSD1 | Seeed Technology Co., Ltd | 1 | $5.50 | **Link** |
| RASPBERRY PI 4 MODEL B 4GB SDRAM | Raspberry Pi | 1 | $55 | **Link** |
| IC REG LINEAR 5V 800MA SOT223-4 | Texas Instruments | 1 | $1.41 | **Link** |
| 6 - 10 PIN CROSS CONNECTION ADAP | Olimex LTD | 1 | $2.12 | **Link** |
| DIODE SCHOTTKY 20V 500MA SOD123 | Onsemi | 1 | $0.38 | **Link** |
| RES 10K OHM 5% 1/4W AXIAL | Stackpole Electronics Inc | 3 | $0.10 | **Link** |
| RES 100 OHM 5% 1/2W AXIAL | YAGEO | 2 | $0.17 | **Link** |
| CAP CER 22PF 50V C0G 0402 | TDK Corporation | 2 | $0.10 | **Link** |
| CAP CER 0.1UF 4V X7T | TDK Corporation | 5 | $0.11 | **Link** |
| **TOTAL - IF ALL PARTS BOUGHT NEW** | | | **$141.34** | |

While we do not have an exact value for labor hours, our initial discussion with the machine shop suggested the construction would not take very long. We will discuss a time frame once the parts they need arrive (valve and container).

### 3.1.3 Sum of costs into a grand total

The total cost for this project, including 10% tax for components and excluding the machine shop estimate is 1.1*141.34 + 20,250 = **$20,405 Total**

## 3.2 Schedule

| Week | Task | Person |
|---|---|---|
| February 19 - February 26 | PCB Design | Benedicta |
| | Order parts for prototyping | Neha, Ethan |
| | Visit Electronics Service Shop for free components | Benedicta |
| February 26 - March 5 | Work on Push Notification with Raspberry Pi | Neha, Ethan |
| | Finish PCB Design | Benedicta |
| | Design Review | Everyone |
| March 5 - March 12 | Continue Notification Subsystem | Neha, Ethan |
| | **PCB Order March 7th** | Benedicta |
| March 12 - March 19 | Spring Break | Everyone |
| March 19 - March 26 | Breadboard Prototype | Benedicta |
| | Valve <- Sensor -> LCD Code | Neha |
| | Push Notification | Ethan |
| March 26 - April 2 | Fix PCB Issues | Benedicta |
| | Valve <- Sensor -> LCD Code | Neha |
| | Push Notification, Soldering | Ethan |
| | **PCB Order March 28th** | Benedicta |
| April 2 - April 9 | Finalize Assembly | Benedicta, Neha |
| | Integration Tests | Ethan |
| April 9 - April 16 | Fix Any Existing Bugs | Everyone |
| April 16 - April 23 | Mock Demo | Everyone |

| | | |
|---|---|---|
| April 23 - April 30 | **Final Demo** | Everyone |
| April 30 - May 7 | Final Presentation<br>Final Paper | Everyone |

# 4. Ethics and Safety

We will be avoiding ethical breaches by abiding by the IEEE Code of Ethics throughout our development process. Our project inherently attempts to create a sustainable alternative to current frozen pipe prevention measures by minimizing the usage of resources such as water and heat to what is needed (I.1. IEEE Code of Ethics). In addition, the three of us will be seeking the expertise and guidance of our professor, TA, as well as the faculty at the machine shop for constructive criticism of our technical work. The maintenance of our individual lab journals will serve as a basis for recording accurate measurements of our data which will serve as the basis for our claims (I.5. IEEE Code of Ethics).

Taking our project into consideration, one aspect that may be considered unsafe is the close proximity our electrical parts (PCB, Raspberry Pi) will need to be to the water reservoir and pipe for accurate measurements. We plan to mitigate this risk by utilizing waterproof/water-resistant components when possible and utilizing proper enclosures and encasing for components that are not (I.1. IEEE Code of Ethics).

In order to maximize safety while developing, testing, and demonstrating our project, there are a few safety precautions and procedures that we must follow. Firstly, we must exercise extreme caution when handling water around electrical wall outlets and other high-voltage equipment. Although our project should not involve high volumetric flow rates or excessive splashing of water, we must also ensure that our setup is positioned in such a way that it is out of range of electrical equipment or other water-sensitive objects. Aside from the presence of water, our project is relatively static and does not itself require any high amounts of power or dangerous chemicals. [7]

# 5. Citations

[1] Chris BCR. "Controlling a Solenoid Valve with Arduino." BC Robotics, 2 Dec. 2021, https://bc-robotics.com/tutorials/controlling-a-solenoid-valve-with-arduino/.

[2] Mratix. "2N2219 NPN Transistor." Components101, https://components101.com/transistors/2n2219-transistor-pinout-equivalent-datasheet.

[3] "Relays vs. Transistors: Which Is the Correct Choice?" Free Online PCB CAD Library, 7 Feb. 2021, https://www.ultralibrarian.com/2021/02/09/relays-vs-transistors-which-is-the-correct-choice-ulc#:~:text=A%20relay%20can%20be%20used,with%20AC%20signals%20as%20well.

[4] Annual reports. Illini Success. (n.d.). Retrieved February 23, 2023, from https://illinisuccess.illinois.edu/annual-reports/

[5] Farrell, M. H. J. (n.d.). *How to prevent your pipes from freezing*. Consumer Reports. Retrieved February 23, 2023, from https://www.consumerreports.org/home-maintenance-repairs/how-to-keep-pipes-from-freezing-a2277945570/

[6] ATMEGA328P to PC serial communication using Usart Tutorial. ATmega328P to PC Serial Communication using USART Tutorial | xanthium enterprises. (n.d.). Retrieved February 23, 2023, from https://www.xanthium.in/how-to-avr-atmega328p-microcontroller-usart-uart-embedded-programming-avrgcc

[7] *IEEE code of Ethics*. IEEE. (n.d.). Retrieved February 23, 2023, from https://www.ieee.org/about/corporate/governance/p7-8.html

[8] *DS18B20 programmable resolution 1-wire digital thermometer - farnell*. (n.d.). Retrieved February 24, 2023, from https://www.farnell.com/datasheets/1917635.pdf