5-29-2021

Wildfire Prevention & Suppression System

Johnny Dimas Flores

Ansh Jetly

Antonio Lorenzo

SANTA CLARA UNIVERSITY

Department of Mechanical Engineering

Date: May 29, 2021

I HEREBY RECOMMEND THAT THE THESIS PREPARED
UNDER MY SUPERVISION BY

Johnny Dimas Flores, Ansh Jetly, and Antonio Lorenzo

ENTITLED

Wildfire Prevention & Suppression System

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Godfrey Mungal (signed elctronically)
Thesis Advisor: Godfrey Mungal, Ph.D.

Dražen Fabris 6/11/2021
Department Chair: Drazen Fabris, Ph.D.

Wildfire Prevention and Suppression System

by
John Dimas Flores, Ansh Jetly, Antonio Lorenzo

SENIOR DESIGN PROJECT REPORT

Submitted to
the Department of Mechanical Engineering

of

SANTA CLARA UNIVERSITY

in Partial Fulfillment of the Requirements
for the degree of
Bachelor of Science in Mechanical Engineering

Santa Clara, California

2021

Wildfire Prevention & Suppression System

Johnny Dimas Flores, Ansh Jetly, Antonio Lorenzo

Department of Mechanical Engineering
Santa Clara University
2021

ABSTRACT

The Bay area community has continually been at threat to wildfires. The current trend showed that wildfires would be an even more prevalent threat in the near future. Despite this, there still exists a lack of knowledge involving wildfire safety and protection for people's property. Current systems were found to be too expensive, needed constant maintenance, or access to isolated storage of 1,000+ gallons of water. Through research of misting systems, the effectiveness of mist as a radiation shield, and working with members of CalFire, it was determined that the system needed to meet the following parameters to be effective and meaningfully implemented: (1) cost under $5,000 to develop, (2) The ability to maintain a minimum of 40% relative humidity, (3) ease of use and setup, (4) independent from main electrical and water sources. This report explores the development and tests of a wildfire prevention and suppression (WIPS) system solution for Santa Cruz homeowners. Tests were conducted to determine defensible coverage, humidity increase rate, ideal mister size, and a complete WIPS system was developed and tested at a CalFire site. The proof of concept system was capable of delaying and mitigating damage to property and met the parameters listed above. The design was made from schedule 40 ¾ ID PVC pipe, with the system delivering 2.5 gallons per minute, capable of bringing the air surrounding the property to 80% humidity, for a cost of under $1,500.

Keywords: Wildfire, Protection, Humidity

ACKNOWLEDGEMENTS

The people listed below are individuals that contributed significant insight to the workings of the system, allowed access for testing, or aided with a breakthrough throughout the design process. Thank you to everyone!

We'd like to thank the resources that Santa Clara University provided us with, which include the main source of funding for the project through the Undergraduate Senior Design Grant from the School of Engineering, as well as the access to Rod Broome's machining lab.

Dr. Godfrey Mungal was the WIPS design team advisor that helped by giving us consistent direction and guidance throughout the process. He aided in managing budget as well as holding the team accountable for deadlines and processes for understanding. He also introduced key concepts that the team may have overlooked and reviewed the production of this thesis.

Ken and Lizanne Jensen invited us to their home and played a large role in influencing the final design of the WIPS system. They opened our eyes to the fact that a protection system can be easily created by an individual who cares enough. They were very kind and knowledgeable about the fire safety process and made amazing cookies!

Fire Chief Gonzalez was our connection at CalFire and aided in setting us up with additional interviews and a test site where we could safely test our system. Thank you also to the firefighting team that helped us actively test our system. The team was led by Fire Chief Tom Chevenell, with Captain Tom Kaska and firefighters Ryan Walter and Nina Lavelle helping out.

Thank you all very much for your contributions and continued support!

Table of Contents

List of Figures

List of Tables

1. Introduction

California has continually been threatened by wildfires since its founding. In 2020 some of the largest wildfires in the history of the United States ravaged Northern California, afflicting the Scotts Valley and Santa Cruz areas. In 2020 alone, there were 9,279 fire incidents with 4,197,628 total acres burned. There were 10,488 structures damaged or destroyed and at least 31 fatalities; causing an approximated $2.01 billion in monetary loss [1]. The Bay Area is particularly susceptible to wildfires given its variegated ecosystems ranging from the dry rolling hills of Morgan Hill, to the temperate rainforests of Santa Cruz, all vulnerable to wildfire. The current trend shows that wildfires will be a more prevalent threat in the incoming years [2], and if nothing is done to stop it or aid the fire department, the loss of buildings and life will affect the economy and quality of life in California. The purpose of our project is to bring better living situations to those who struggle with the threat of wildfires by applying our engineering backgrounds to find innovative and frugal methods to provide cheaper and more efficient methods of suppressing or preventing wildfires from severely damaging property.

> "Santa Clara University will excel in educating men and women to be leaders of competence, conscience, and compassion. By combining teaching and scholarship of high quality, an integrated education in the Jesuit tradition, and a commitment to students as persons, we will prepare them for professional excellence, responsible citizenship, and service to society, especially on behalf of those in greatest need." - *Santa Clara Strategic Mission Statement*

The first line of Santa Clara University's Strategic Mission Statement makes it clear that a key factor in an SCU education is for the students to be compassionate. This point is emphasized even more in the final sentence of the mission statement where it is said that Santa Clara University will prepare the students for serving their society, especially on behalf of those in greatest need. Our project directly aligns with this mission statement as our goal in working on this project is to help those in our immediate community i.e. the Bay Area and Santa Cruz Mountains. The people in these communities are in need after being directly affected by the SCU, CZU, and LNU fires. Some of our very own Broncos have lost their homes in these fires. 2020 has shown to the world exactly how much climate change is affecting the annual fire season, and it is clear that wildfires will continue to worsen every year. In an effort to help those most affected and help our immediate community, we have decided to create this project. The last point in the School of Engineering's Mission Statement deals with service activities that benefit humanity. It is clear that Santa Clara University is keen on producing not only smart and competent students but also humanitarians. This project will help neighbors in need.

1.1 Preliminary Research

Market Research

To get a better grasp on wildfire systems, the team looked into the market for systems that are currently available. The team used this information in order to gain an understanding of what subsystems/features were used by other companies and see what areas needed improvement. The main systems that were looked into are the FireBreak Protection System, FoamSafe System, and the Frontline System.

The FireBreak Protection System is a system that relies on a drum water source and several guns, or nozzles, installed on the property to pump immense amounts of water and a fire retardant called 'Phos-chek' onto the entire house and surrounding property in order to create a fire-resistant surface between the house and incoming flames. It is self-contained and uses compressed air in order to maintain efficient pressure within the system.

FoamSafe System is a completely self-contained system that activates when fires are sensed within the property. It coats the entire home in special foam and water for thirty minutes in order to prevent it from catching on fire. However, one of the biggest drawbacks is that you are required to have it specifically designed and installed for your home, which leads to prices being upwards of $20,000.

Frontline System is a wildfire suppression system that, similar to the others, coats the entire house in Class A foam and water. A big benefit of this system is that it is able to be activated through an app. However, it requires a manual trigger, which means if the resident is evacuated and doesn't know when the fire will hit their home, they won't know when to turn the system on.The main conclusions from this market research were the extremely high price that all of these systems have, their reliance on special forms of maintenance, and their use of Class-A fire retardant materials. A clear breakdown of these systems and additional comments on market research can be seen in Appendix A.

Interviews

In order to continue gaining a better grasp on consumers' needs and views, interviews were conducted with individuals that received evacuation notices, were actually evacuated, people working in firefighting services, and general individuals from the Bay Area. Through the interviews conducted, it was learned that the main reasons people don't own wildfire suppression are due to the fact that they don't know that they exist, or that the systems they know of are far too expensive. Current systems are in excess of $20,000. If $20,000 is spent on a suppression system to protect a $500,000 home, it means 4% of your home price was paid just for wildfire protection.

From the interviews with members of the FireSafe Council of Santa Cruz, the team's eyes were opened to the potential of creating a 'do-it-yourself' (DIY) system [3]. The team learned that the real reason wildfires are so prevalent is due to the fact that not many people have the knowledge regarding wildfires. No protection can be a full on preventative measure against a wildfire; it's too much heat. However, WIPS systems can take steps to fight against fires and buy as much time as possible against wildfires. Homeowners would also benefit from learning more about defensible space and clearances around their property. It was through interviews with these members of the FireSafe Council that the team decided that in order to affect the greatest change, the objective should be to create a working system to prove to homeowners that it is possible to protect themselves and then distribute that information.

The team also learned which parts of the home are the most important to protect when under threat of wildfire, as well as minute changes that can be made and considerations for design when dealing with a design that needs to withstand heat. It was also through interviews that the team recognized the possibility of using humidity to fight fires rather than directly extinguishing them [4]. Contact information of our interviewees is contained in the references section, and a breakdown of customer needs report is in Appendix B.

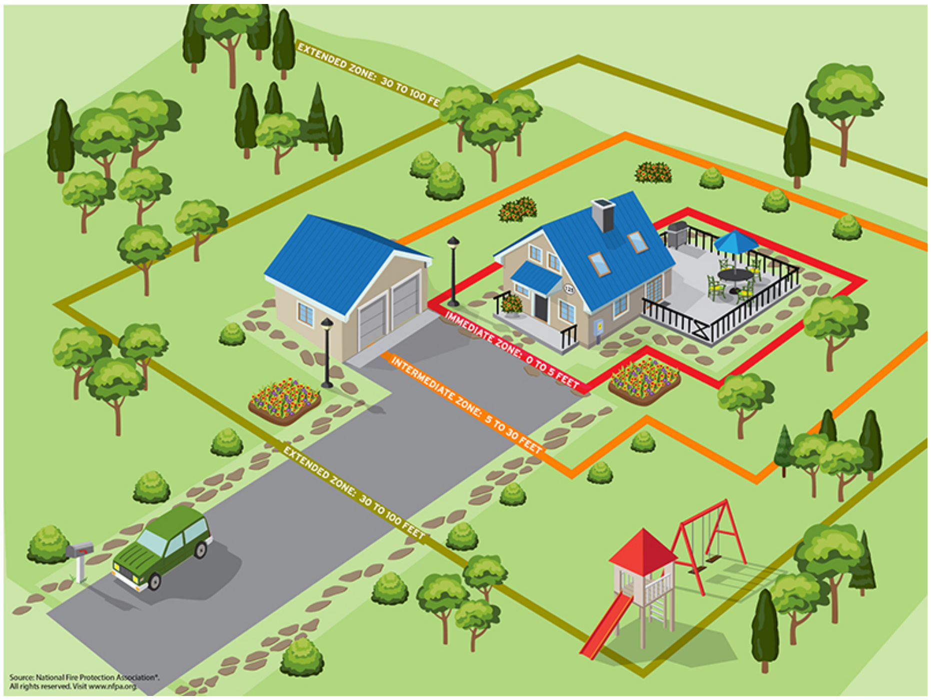


Figure 1.1: Example of defensible space around a property *(NFPA, reproduced without permission) [5]*

Review of Academic Literature

The team utilized a variety of literature for research, focusing on the main topics: Firefighting methods, characteristics of spray, and fire retardant materials. An entire list of literature used can be found in the references. Main takeaways from academic research was the math behind droplets that could be pushed out of a mister in a conical area in relation to pressure through the system, wildfire controls, and an understanding of Net Positive Suction Head (NPSH) and how to move the water from a lower area to a higher area.

One of the first pieces of information that the team was introduced to was a video by Dr. Jack Cohen, called "Your Home Can Survive a Wildfire" [5]. The video placed emphasis on similar topics that the firefighters mentioned in their interviews. They placed significant importance on what should be your initial step for protecting your home. Which was to be aware of defensible space and the effect that embers have on your home. Wildfires are most prominently caused by embers being blown from the main wildfire, to peoples' houses and igniting them. If people remain uneducated and disregard the dry foliage in their gutters, on their roofs, and around their homes, a WIPS system can only do so much. This is why in the video, Dr. Cohen gave clear instructions on how to maintain defensible space by taking the time to clear out dry foliage around the spaces of their house. When people think about wildfires, they expect 100 foot flames, but in reality, it only takes several pieces of ember that fit in your hand and the negligence of a homeowner.

The information from Dr. Cohen's video and the advice the team received through interviews pushed us to understand that the WIPS system we developed is the second step. The first step is the knowledge of fire safety and the importance of doing the little unglamorous parts of fire safety. It was imperative to emphasize cleaning out foliage, and changing the property mesh guards to 1/16th inch mesh before thinking about utilizing a WIPS system. By placing an emphasis on the basics, it also allowed the team to view a wildfire protection system as an additional measure of protection, and not an overwhelming method of protection to stop a wildfire.

From Alan Green's and Paul Cooper's report on the experimental characterization of wildfire sprinkler sprays using high-speed videography [6], the team was able to develop an understanding of the relationship between the diameter of the droplets resulting from a spray mist. Figure 1.2 shows the relationship between the Sauter-mean diameter, or the average particle size of the mist compared to the number or volume fraction of the droplets. This demonstrated that choosing the proper mister would have to match the intent of the system. The intent of the system was to increase the relative humidity of the area around the property, so that meant that finer droplets would be required in order to dissipate the latent heat of the environment rather than saturate the ground beneath. Firefighters emphasized the importance of fighting radiant heat and embers over grass fires in their interviews. With smaller droplets, the system places an emphasis on preventing wildfires through preventing embers rather than saturating the perimeter to protect from grass fires.

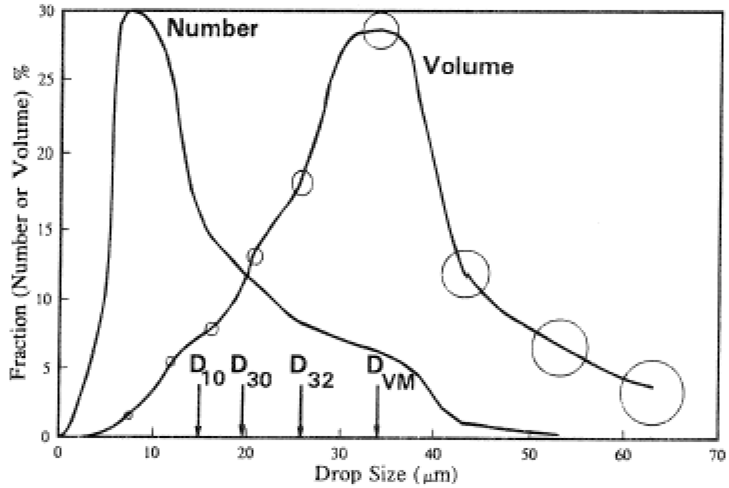


Figure 1.2: Relationship between Sauter-mean diameter and Number/Volume fraction *(reproduced without permission) [6].*

Dr. Martin's thesis in regard to Water Mist as a Radiation Shield [7] was used to develop an understanding of how effective water mist can be against the latent heat of a wildfire. Dr. Martin proves that water simply as a radiation shield can be effective against the radiation of a fire. This was one of the leading points that led to WIPS neglecting Class A foams as part of the system, as using a water mist can still be effective and more efficient in terms of water consumption.

The Academic literature was used extensively in order to better understand the situation regarding wildfires and obtain specific equations that the team will use to calculate and compare the efficiencies of their system. The equations will also be used to offer calculations on defensible space, perimeters, and other specifications.

1.2 Project Objectives

Through research, a more defined purpose was created and the following goals for the project were determined:

- Affordable
- Effective
- Replicable

Affordable means that the design should be able to be manufactured and sold at a price that is affordable to Santa Cruz residents. It should be less than 10% of a residents' average annual income. Effective means that the design should be one that protects the largest area of property for wildfires for the maximum amount of time, while minimizing water, power, and waste usage. Replicable means that the design should be one that is simple and easy to understand and recreate with minimal guidance and instruction. It also means that the materials and methods used to construct the design need to be ones that are accessible to the average person. The project objectives were translated into a hierarchy of needs as shown below in Table 1.1.

Table 1.1: Hierarchy of Needs

Primary Need	**Secondary Needs**	**Priority Level**
Affordable product	● Should be available to anyone regardless of socio-economic status ● Cheaper than the other existing products ● Relatively cheaper, yet effective materials	1
External Power Source	● The fire protection system should work if the power in the home goes out ● There should be a backup power to the system ● Should not entirely depend on electricity	2
External Water Source	● The product should be able to work without municipal water ● If there is no major source of water nearby, the system should still be effective	2
Easy to Install	● Self-installation capabilities ● Not too overly complex or space consuming design ● Should not take too long to install (within hours)	3
Durable Product	● The product should be weather-resistant ● The system should be fire-resistant ● It should withstand regular wear and tear ● Should be protected against rust ● Should not require constant maintenance	3

Universal Installation	• Applicable to various types of homes regardless of shape and size • Can be used on other buildings other than houses	4
Automated Activation	• There should be some sensor that detects a fire and activates the system depending on the proximity of the threat • Additional to manual activation	4
Sustainable/Eco-Friendly	• The product should not harm the environment • Non-harmful chemicals • Powered by clean energy • Does not waste any water	4
Aesthetic Design	• Should not make the home look uglier • Sleek design that blends in with home • Not immediately noticeable	5
System is Smart	• Connected to an external app that can control the wildfire suppression system • System can send alerts to user • Fire detection capabilities	6

1.3 Mission Statement

Our goal is to demonstrate proof of concept for an affordable, effective, and replicable independent wildfire protection and suppression system that will benefit those at risk in the greater Santa Cruz area with limited access to power and water when affected by disaster.

Mission Statement Breakdown	
Product Description	• An independent wildfire protection system capable of preventing or suppressing damage caused by wildfires
Benefit Proposition	• Decreased damage from wildfire • Cheaper than other systems • Easy to make in DIY style
Key Timeline Goals	• Product conceptualized in Fall 2020 • Product prototyped in Winter 2021 • Final testing and technical documentation in Spring 2021

Primary Market	● Homeowners ● Property owners
Secondary Market	● Agriculture markets
Assumptions	● Closed system ● System as a preventative measure ● Mesh improvement ● Clearing of defensible space

1.4 Team and Project Management

Project Challenges

This project experienced several challenges deriving from the focus of the project being affordability and efficiency. These challenges arose from the use of the water source management, budget, and test regulations.

The water source for our system was a challenge as many of the systems utilize several thousands of gallons of water in their system. We needed to try and minimize the amount of water in order to make it easier for users to install, as well as more convenient in general. We addressed this problem by using pumps and misters to maximize the pressure and use less water than other sprinkler systems.

We needed to find a test site and also create a testing environment. Recreating was unlikely to be possible, due to safety concerns, despite the benefit it would have had in testing the prototype. There were also constraints as to how realistic a scaled down test could have been, so while a quarter section of a full size model was more feasible, it was determined that it would be difficult to recreate the same types of flow losses we would see in a full model.

Budget

Budgeting was an issue, as we were only allocated $1,500 to manufacture our product. We also needed to create a test environment and build the actual system, so the team needed to prioritize certain parts of the product. Table 1.2 below shows the actual expenditure of the project, classified by category.

Table 1.2: Budget of Actual Expenditures

Subsystem	**Total Expenditures**
Power System	$149.99
Containment System	$500
Delivery System	$187.67
Electronics/Control System	$412.09
Tools/Equipment	$95.2
Misc.	$41.21
TOTAL:	$1,386.15

Timeline

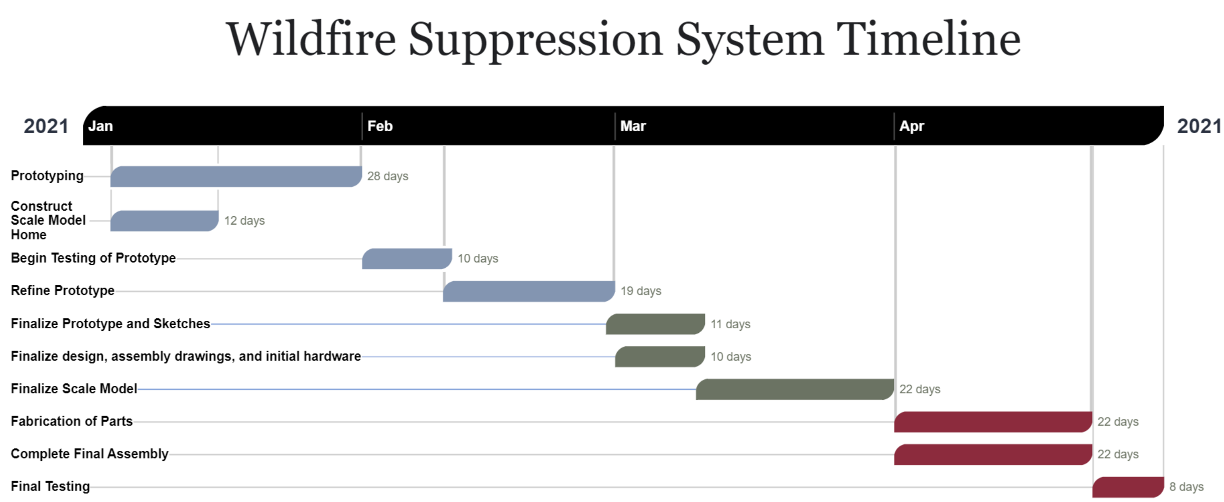


Figure 1.3: WIPS Project Timeline

Team Management

In order to be a successful team, proper management is necessary to not overwhelm the team. With a team of only three people, it was imperative to properly delegate tasks to separate members of the team. The team also met at a minimum of twice a week in order to ensure that the separate tasks were working towards the main goal. This allows the team to be productive individually and maintain the correct vision and understanding of the holistic goal. It allowed the people on the team to execute what they're best at without being held back by others while still being held accountable.

Safety Risk and Mitigation

The main safety risk when designing our system is testing it in a real-world scenario. We cannot just light a fire near a house that has our system prototype installed and hope that it works the first time. Furthermore, even if we were to test this product in a controlled environment, we still run the risk of injury if our system does not work as intended and we have to put out the fire ourselves. For this reason, we worked with CalFire as well as the local Santa Clara Fire Department to ensure that we were taking the proper precautions and were well equipped for any type of situation we encountered. We also used a scaled-down model of a home as well as a scaled-down model of our system to minimize any type of fire hazards.

Table 1.3: Risk and Control Measures

Risk	**Control Measure**
Fire-related incident	● Controlled environment ● Fire extinguisher ● Protective clothing
Shop-related incident	● Follow proper shop guidelines ● Wear protective gear ● Use appropriate shop hours

2. Project Design

This section contains preliminary systems-level design evaluations based on the criteria derived from the project objectives and mission statement. Consideration of the complete system functionality is included.

2.1 Systems-Level Explanation

Systems Level Sketch

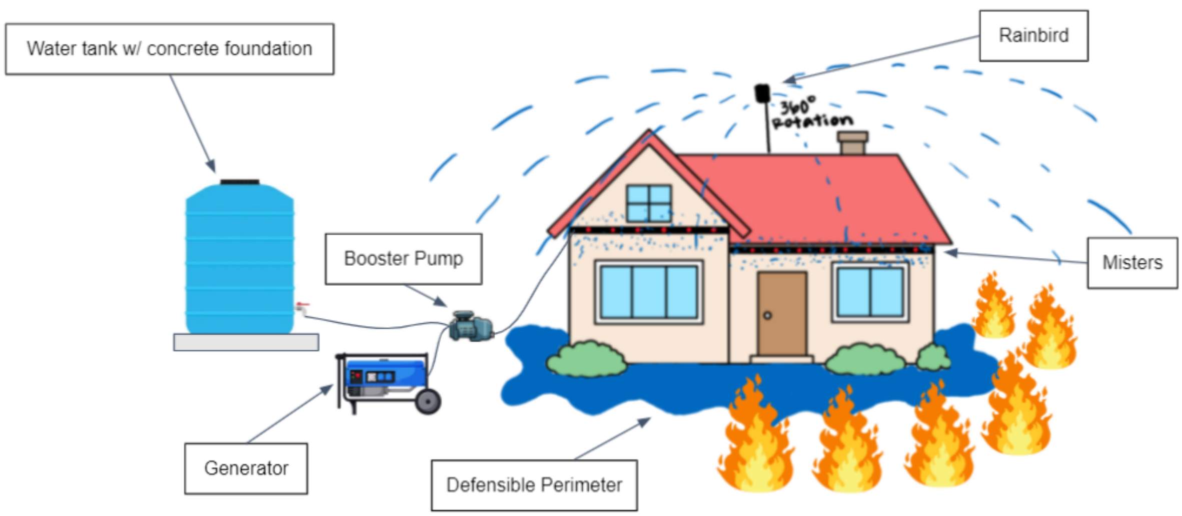


Figure 2.1: Original Systems-Level Sketch

Functional Analysis

This system utilizes nozzles attached to pipes in order to create mist. With the misters running, the intent is that the humidity of the air will increase, and the mist will also act as a radiation shield against the ambient heat of the wildfires. The surroundings will also become saturated so as not to ignite when presented with any grass fires. The system also has nozzles on the roof that rotate 360 degrees and spray water to prevent the roof and a 45+ foot radius surrounding the area from catching fire. While the Rainbird ™ nozzles prevent the roof from catching fire and provides a surrounding protective radius, and the misters saturate the surrounding walls, ground, and air with water, the 1/16th inch mesh which is compared to ¼ inch mesh in Figure 2.2 over the vents are what prevent the embers from entering the attic and igniting the insulation. For the misters and rainbird, the water is supplied from a minimum sized 500 gallon water tank, leading through hose tubing. The hose runs through a pump that is powered by a generator for additional psi and leads up to schedule 40 ¾ ID PVC piping. The PVC pipe is embedded with misters. When threatened by a wildfire or upon receiving notice of evacuation, the owner will turn on the system and leave their home. This allows the system ample time to begin saturation of the area and prevent ignition of the surrounding area of the property.

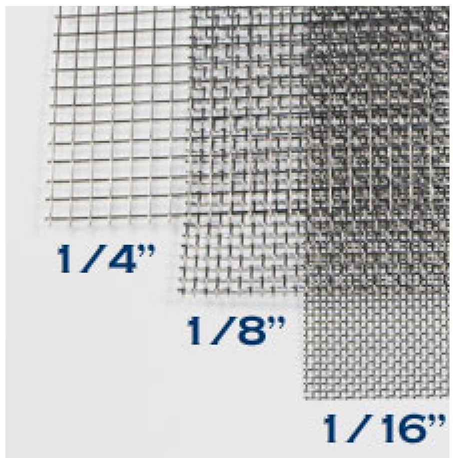


Figure 2.2: Comparison of ¼, ⅛, and 1/16th inch meshes

The system's main function is to prevent fires from reaching a property as well as put out a fire as quickly as possible if it does reach anywhere on the property. This is done using the misters and the Rainbird™. There are two other sub-functions that complement the main functions of the system, which are increasing the humidity of the surrounding air and hydrating any flammable materials surrounding the property. If the humidity of a certain area increases, the likelihood of a material catching fire diminishes due to the water content in the air increasing. Furthermore, a material becomes less flammable as it begins to get super hydrated. Once an object is saturated, the temperature of the fire has to increase drastically in order for the material to catch fire. Figure 2.1 shows the systems-level sketch that was created to visualize the idea. Whole product design specifications can be found later in the product specifications section. These are numbers that have been researched as needed in order for the system to function properly.

2.2 Product Specifications

In order to have a system that can effectively suppress wildfires, a system that is detached from power and water sources and can produce sufficient pressure to shoot water around the property is required. As seen below, specified numbers for water pressure, number of nozzles, volume of water, and shelf life, in order to be competitive. The numbers stated have been shown to efficiently suppress fires for properties that are approximately 600 sqft. The team has also included maintenance, shelf life, and installation times. These product specifications are close to the minimum, but in order to make our product marketable it is imperative to focus on the ease of use of the product as well as the price. It was important to establish specification numbers while making it affordable to the average person because that is the way to make the product available and effective to those affected by wildfires.

.

Table 2.1: Product Design Specifications

Elements/ Requirements	**Units**	**Target Range**
Market		
Cost	USD	2,000 - 3,000
Shelf Life	Years	5 - 10
Installation Time	Days	3 - 7
Product		
Pressure (Misting system)	PSI	20-30
Pressure (Nozzle System)	PSI	30-40
Water Volume Output (Misting System)	Gallons/min	0.025
Water Volume Output (Nozzle System)	Gallons/min	0.5 - 1.0

Liquid Capacity	Gallons	300 - 500
Foundation	sqft	25-40
Number of misters	Units/ft	1 - 2
Number of Rainbird nozzles	Units/1000 sqft	1
Pump	Horsepower	0.1-0.5
Generator	Watts	500-1000

Choosing the material for piping was also a consideration for the project. It was imperative that the pipe be made of a material that was accessible but would also be thermally resistant enough and able to withstand the pressures that would be sent through it. In order to maximize efficiency, the losses caused due to the pipe also needed to be minimized. A materials selection chart was created, shown in Table 2.2. A further list of materials and considerations can be found in Appendix C.

Table 2.2: Materials Selections

Function	Pipe for Wildfire Suppression system
Objectives	• Maximize Velocity in pipe ○ Maximize %droplet ○ Maximize Volumetric Flow Rate
Constraints	• No Burst Failure • No mechanical failure • No leaking

	• Inner Diameter < 1”
Free Variables	Choice of Material, Diameter

Using the materials selection chart as well as the stiffness and bursting pressures, Schedule 40 PVC pipe was chosen to be the pipe for the WIPS system. PVC is an accessible material to all people. Also, with increased temperatures, the modulus of elasticity doesn’t change critically until the ambient temperature of 80-100℃ shown in Figure 2.2. It was determined that the PVC pipe would not increase in flexibility and bend due to the weight of the water, adding flow losses, in the presence of increased temperatures. The bursting pressure that Schedule 40 PVC was considered. The maximum operating pressure for schedule 40 ¾” ID PVC pipe is 350-400 psi, which is about 10 times higher than the pressure that the system needs to operate at to be effective.

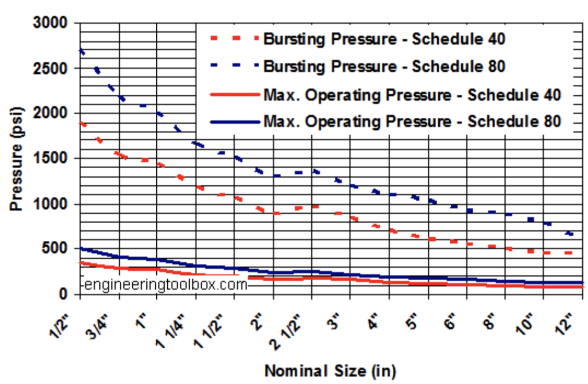


Figure 2.3: PVC Pressure vs. Nominal Size of Inner Diameter (ID) *(reproduced without permission) [8].*

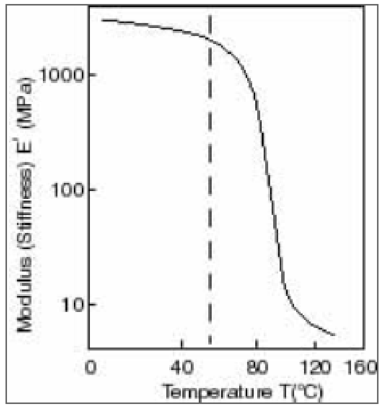


Figure 2.4: Schedule 40 PVC Modulus of Stiffness vs. Temperature *(reproduced without permission) [8].*

2.3 Design iterations

The team began approaching the design with the intent to have a system that extinguishes wildfires on a perimeter. However, the amount of water required and the drawbacks of using Class A foam material made it an unreasonable design choice. The choice to utilize misters was a fundamental one, as the system moved from coating materials in water to understanding the environment and utilizing the air's humidity in conjunction with saturated ground materials to accomplish the same goal. No ignition of material is equally as effective to extinguishing active fires when stopping a building from burning down.

An initial design is shown below in Figure 2.3. In a similar fashion to the final design, it was planned that piping would follow along the overhang of the property and have a 'waterfall' function that would saturate the walls and surrounding ground with water. In order to protect the roof, Class A fire-retardant foam would simultaneously be dispersed on the rooftop of the property. This design was not kept as the inefficiency of maintaining hydration within the class A foam posed a problem, as well as the prevalence of fires that are caused by embers, which the 'waterfall' function from the pipes would not stop as effectively as misters.

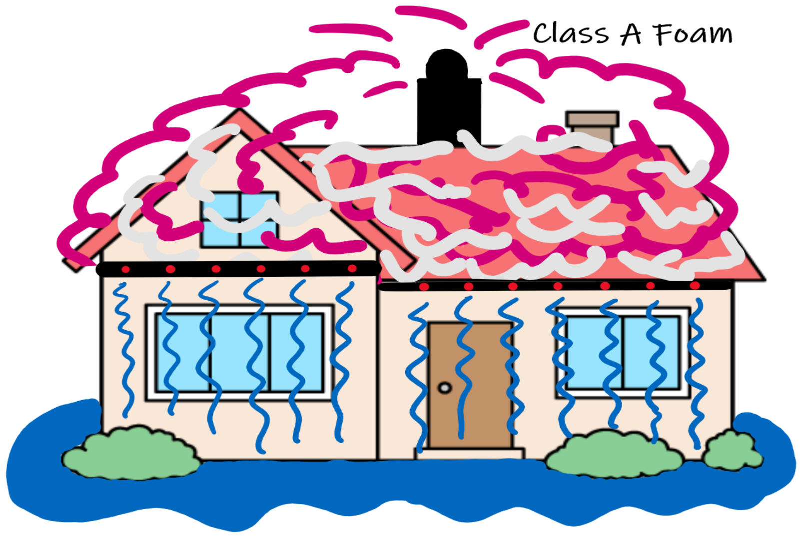


Figure 2.5: Class A Foam Design

Another design idea was to have exterior sprinkler systems strategically placed around the property to prevent fire from reaching the property. The intent was that a perimeter of mobile sprinklers would allow the user to customize the layout of the sprinklers to the respective fire. There was also the addition that by having a deployable sprinkler system would allow the owner to stow the sprinkler system safely away and out of sight when it wasn't fire season. This idea was dismissed when the need to take into account the fires due to embers. This design was not suited to acting as a way to mitigate latent heat while preventing embers from broaching the perimeter as well.

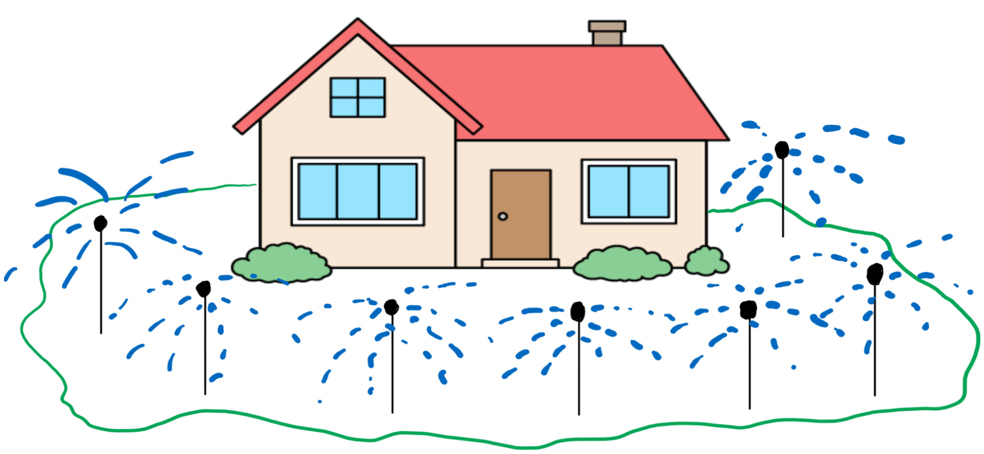


Figure 2.6: Mobile Sprinkler Design

3. Subsystems Design

This section contains descriptions on the subsystems which make up the whole WIPS system and identifies the individual components and functions that allow the system to function together and accomplish the project objectives and mission statement. Additional engineering drawings of the subsystems can be found in Appendix C.

3.1 Subsystem Components

The WIPS system design consists of five different subsystems. The subsystems are: water containment system, power system, water distribution system, water transportation system, and the electronic system. These subsystems are essential for this system to work. The water containment system consists of a 500 gallon water tank which ensures that our system is independent and not reliant on municipal water. The 500 gallon water tank can be swapped out with any size water tank or even a pool, however for our system, we chose to use a 500 gallon tank as it is cost and space effective. The second subsystem, the power system, includes the generator and the water pump. The generator is important because it ensures our system is independent and does not use municipal power. The pump is powered by the generator and ensures that the system has at least 30 psi which is the minimum running pressure for this system. The third subsystem is the water distribution system. This system includes the impact sprinkler (Rainbird ™) and the misters. This is the subsystem that outputs the water in such a way that the property is hydrated and protected. The combination of these parts working in conjunction with each other are able to distribute water in an efficient and optimized manner. The fourth subsystem is the water transportation system. This system deals with the piping used for moving the water from the pump to the misters and the Rainbird ™. The most important thing with this system is that the piping has a strong enough bursting pressure, is cheap, and can withstand a thermal load. The fifth subsystem is the electronics. For the purpose of our testing, our electronics consisted of a Raspberry Pi paired with multiple sensors so that real time information and data during testing was available.

3.2 Subsystem Selection

A 500 gallon water tank for our system based on the fact that it would allow our system to have a run time of around 3 hours and 20 minutes with the amount of water distributors we have. For our power system, we selected a booster pump that had somewhere between 0.5 and 1 horsepower. We required at least 30 psi for our system to run. Given that the volume of water in the water tank would already provide some pressure, an additional 30 psi from a pump would be sufficient to ensure that our system runs properly. Appendix C also shows all previous considerations for subsystems.

For our generator selection, we required something cheap, but something that would also be efficient. This generator chosen had the best cost to run time ratio. It utilizes a 20 lb propane tank rather than gasoline or oil.

The misters chosen were Ruofeng misters that alternate between 0.7mm and 0.8mm openings. Mister selection is further discussed in section 5.1.

The Rainbird ™ we chose runs at a base psi of 30 psi, and has a radius of 30-40 ft. This was also the cheapest impact sprinkler. These items were chosen based on their specs as well the low price associated with them.

Schedule 40 PVC ¾” ID was chosen to be the pipe for the WIPS system. PVC was significantly cheaper than brass or copper piping, and it was also more user friendly which made our system more accessible to the average homeowner.As talked about previously as well, the bursting pressures of schedule 40 PVC and schedule 80 PVC were taken into consideration. Schedule 40 is slightly lower than schedule 80, but the pressure in our system was significantly lower than the bursting pressure of either forms of PVC. Schedule 40 was then selected as it was more cost effective.

Mycodo is an open source software created by Kyle Gabriel for the Raspberry Pi to work with inputs and outputs to sense environmental factors. For this reason, we chose the software for our system to record and analyze data. Coupling the software with our experiments and sensors, we were able to optimize each component in our subsystems to keep the system reliable and effective. Each sensor we had was chosen due to its compatibility with the Mycodo software.

3.3 Water Containment

The water containment subsystem is designed to hold the entirety of the water used by the system. Having a water containment system is essential to ensure that the system does not pull from the municipal water. A water tank can be used, or an already existing water source such as a pool with a suction pump. For the purposes of our design, this tank was chosen with the following specifications:

Vertical Containment Tank

- 300-500 Gallons
  - Enough to run for 5 Hours
- 1 Outlet
  - Connection to misting system
  - Connection to Rainbird ™
- Built on 4-inch Concrete + Rebar foundation

Figure 3.1: Vertical Water Containment Tank *(reproduced without permission) [9]*

3.4 Power System

The power system is designed to provide the electricity for the system as well as translate that electricity into water pressure. A propane generator is used to power a water pump. The specifications for the two are shown below:

Power System

Pump

- Aiko Centrifugal Water Pump
- Exit Valve 1”x1”
- Model: WP-A-PKM60
- Power: 0.5 HP
- Weight: 13.5 Kg

Figure 3.2: Aiko Centrifugal Water Pump *(reproduced without permission) [10]*

Generator

- Baja 900-Watt Propane Powered Inverter Generator
- Runtime: 30 hours
- Power Source: 20 lb Propane tank

Figure 3.3: Baja 900-Watt Propane Powered Inverter Generator *(reproduced without permission) [11]*

3.5 Distribution System

The distribution system is designed to spread water in the most efficient and optimized way possible so that the system can saturate the greatest amount of space and create the greatest perimeter with the least amount of water wasted. In order to do this, misters and impact sprinklers are used. The specifications of the two are listed below:

Water Distribution

Misters

- Volumetric Output
  - 0.025 Gallons/min
- Pressure
  - 20-30 psi
- 1-2 misters per foot of pipe
- Brass Nozzle 10/24 Nozzle Thread

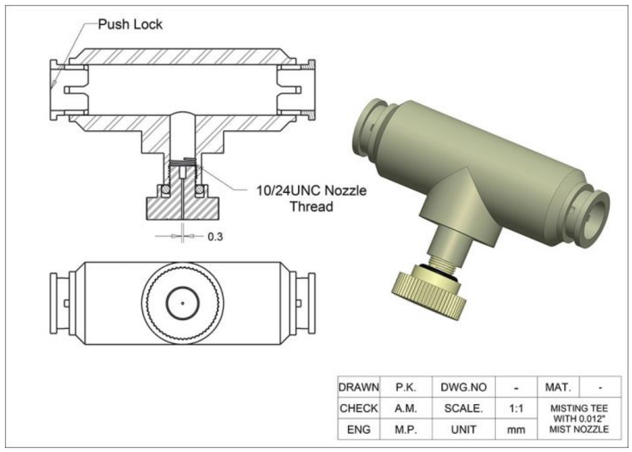


Figure 3.4: CAD and Drawing of Mister valve *(reproduced without permission) [12]*

Rainbird

- Impact Sprinkler
- Volumetric Output
  - 0.05 Gallons/min
- Pressure
  - 30-45 psi
- Coverage
  - 1 per 1000 sq-ft of roof

Figure 3.5: Rainbird Sprinkler Valve *(reproduced without permission) [13]*

3.6 Transportation System

The transportation subsystem is designed to transport the water from the pump to the impact sprinklers and the misters. It consists of different piping and valves. The specifications for the following are listed below:

Water Transportation

a. **Pipe**
   - Schedule 40 ¾" ID PVC Pipe
     - Material Selections in Section 2.2
   - Resistant to leakage
   - Resistant to corrosion

Figure 3.6: Schedule 40 ¾" ID PVC Pipe *(reproduced without permission) [14]*

System Activation

b. **Manual Valve**
   - Manual Valve Actuator MD30
   - Rotary Motion
   - Plastic Motion for grip

Figure 3.7: Manual Valve Actuator MD30 *(reproduced without permission) [15]*

4. System Analyses

This section discusses different analyses conducted on the CAD model of the system. This section describes the different simulations done in order to ensure pursuing a functional prototype would be feasible given the initial design. Simulation results proved that there would be minimal losses within the pipes and gave estimates for run time of the system.

4.1 CAD of System

In order to get a better understanding of how the system would be put together, the team created CAD models of separate pieces so that simulations could be run on them.

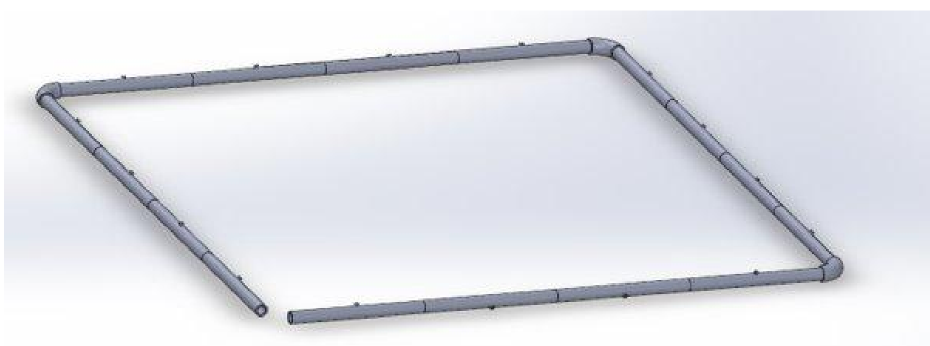


Figure 4.1: Isometric View of Piping System

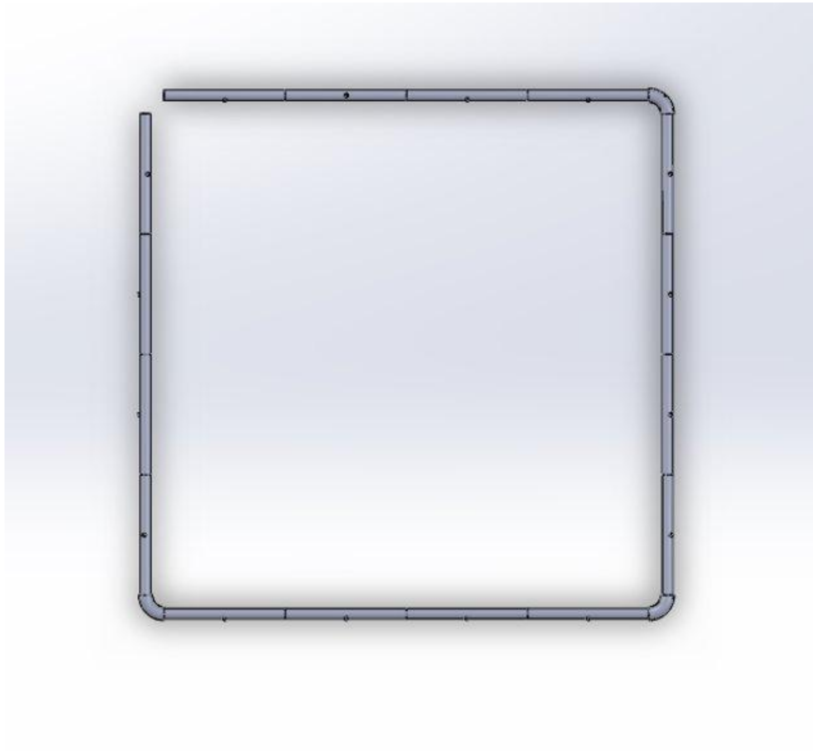


Figure 4.2: Bottom View of Piping System

The different pieces of the system such as the tank, the PVC piping, and the misters had to be made separately and assembled. This allowed for them to be removed or added from the tests accordingly.

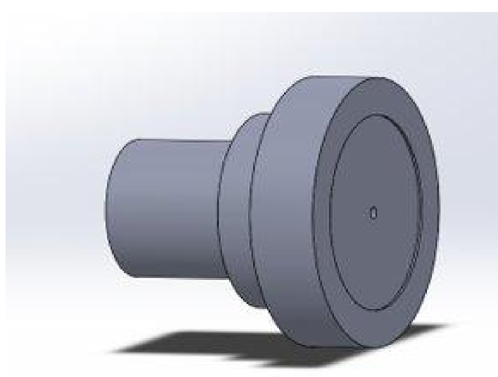


Figure 4.3: Close view of Mister

Figure 4.4: CAD of Water Tank

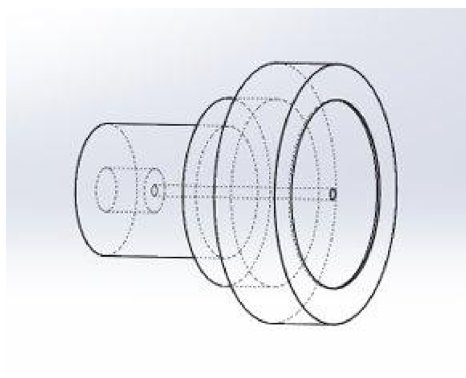


Figure 4.5: Line Drawing of Mister

4.2 Dynamic Flow Analysis

The simulations for the flow analysis were done several times with differently angled elbows. The simulations showed that the short radius elbow experienced higher losses at the corners because the water was hitting the end of the pipes and 'bouncing off' and being forced by the pressure of the water behind it. With longer sweeping elbows, the losses were much better.

Being able to include the misters in the simulation of the system showed us that the pressure losses due to the water leaving the misters were negligible and would not critically affect the flow of the system, given the spacing between the mister holes. The simulation demonstrated that the WIPS system would function at 30 psi without losing significant pressure due to the misters.

Screenshots of the simulations are shown below in Figures 4.6, 4.7, and 4.8.

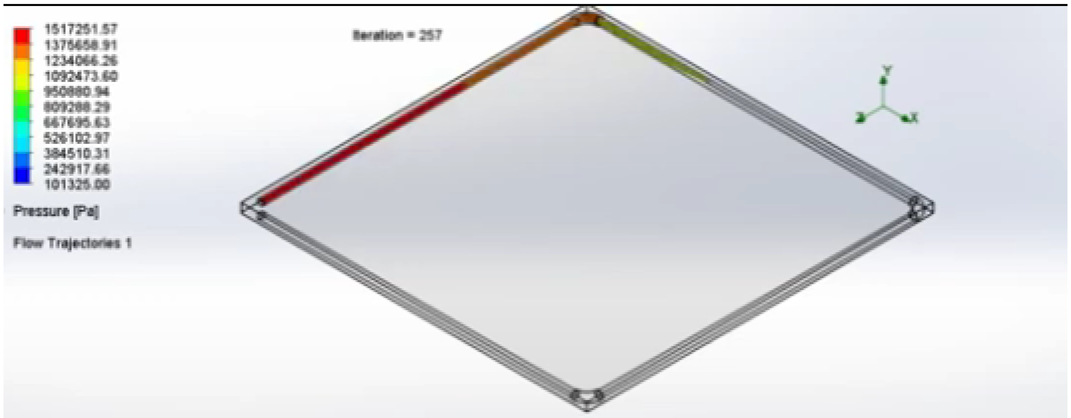


Figure 4.6: Full View of Water going through Piping System

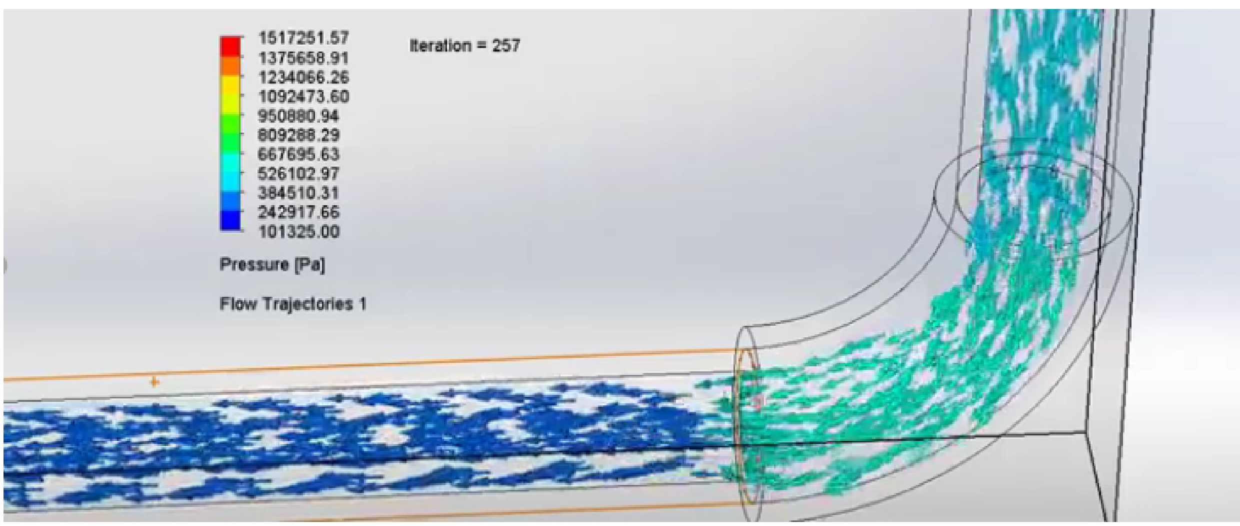


Figure 4.7: Close up of loss at an Elbow 3

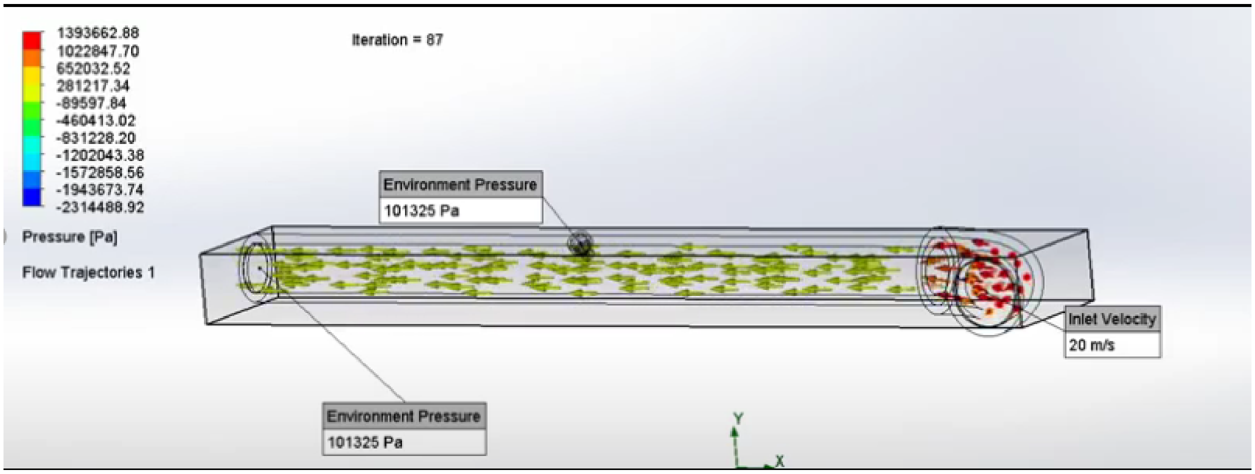


Figure 4.8: Close up of loss at Elbow 1

5. Subsystem Experimentation

This section addresses how the team specified parts of the subsystems in addition to the simulated models. This section goes into additional detail about how the subsystem design was completed and applied to the system.

5.1 Mister Specification

One of the first challenges that was realized during the fabrication of the piping system was the necessity to have the misters be on the same line, with the holes being drilled into the PVC at the correct angle. If the drill and tap were angled differently for each hole the misters would all have had separate coverages and therefore not have the same spray attenuation.

In Figure 5.1 it shows how the team was able to use an additional device to keep the drill and tap exactly perpendicular to the circular PVC pipe. The team used a Unistrut steel girder with holes in it to 'clamp' onto the PVC pipe. Bearings were then used to align the drilling and tapping sections. A line was also drawn on the PVC as a secondary measure to ensure that the holes were straight.

The alignment device ensured that the holes were along a straight line and that they were also drilled into PVC at the same angle.

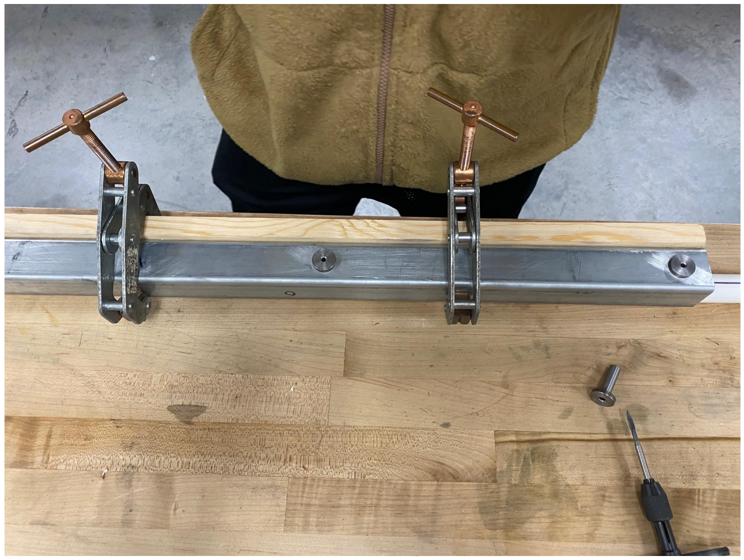


Figure 5.1: Device used to align mister holes

Once the holes were drilled and tapped in the PVC, the next step was to determine the mister that was going to be put into the holes. The team obtained 0.4, 0.5, 0.6, 0.7 and 0.8 mm sized misters. Every single mister type would have different characterization of spray, and therefore would have different rates of change in the humidity as well as coverage. The team tested this by constructing a miniature set up of piping as shown in Figure 5.2. The setup utilized the electronics system to record temperature and humidity, and paper was placed below the pipe in order to observe mister coverage.

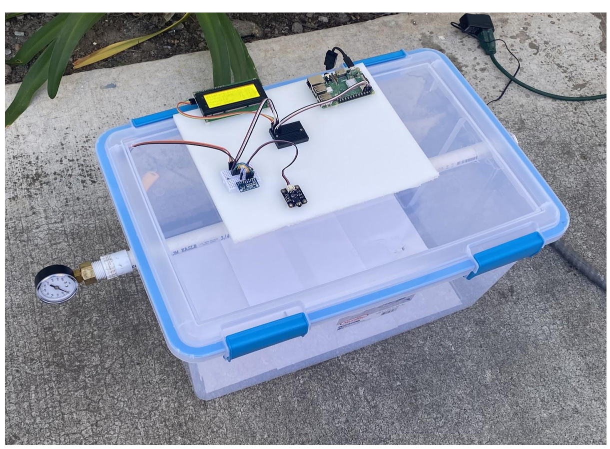


Figure 5.2: Mister nozzle size and coverage experiment setup

The pipe had only one mister hole in it, and the different sized misters were placed in the hole at separate times. Water was then allowed through the system and the humidity was monitored. The water was then turned off and the system was allowed to return to the natural level of humidity. The test was then run again with a different sized mister. The relationship between relative humidity and size of the mister openings are shown in Figure 5.3, taken by altering the open source software of Mycodo. Figure 5.4 show the paper that we placed underneath the pipe in order to measure the coverage of the misters.

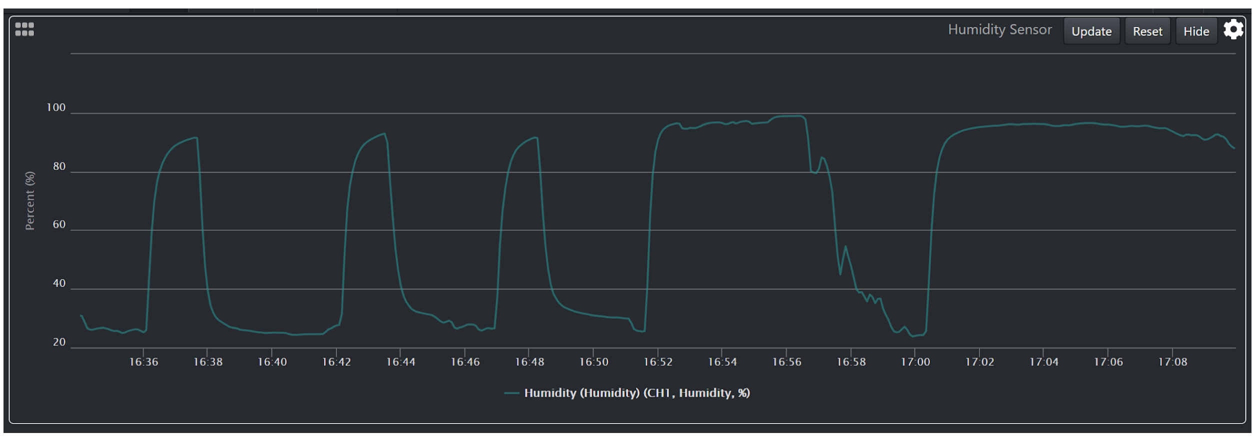


Figure 5.3: Mister test results with 0.4, 0.5, 0.6, 0.7 and 0.8mm mister openings

The 0.7 mm mister has the most rapid increase in relative humidity levels as compared to the other mister sizes, but the 0.8 mm nozzle has the largest coverage area from all the misters. For these reasons, the 0.7 mm and 0.8 mm mister nozzles were chosen to be implemented in an alternating fashion on the pipe system.

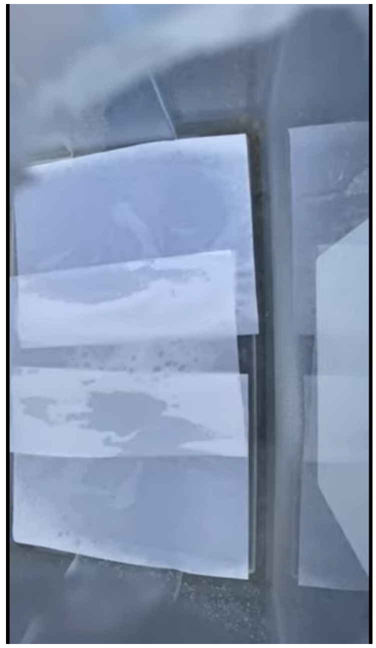


Figure 5.4: Inside View of Mister Coverage Experiment

Figure 5.5: Final mister setup in pipe

5.2 Pipe Flow Loss

The tests from the dynamic flow analysis showed that the regular PVC corners may not be the best method if the team was trying to reduce losses within the piping system. The team was able to purchase sweeping PVC elbows that were intended to be housing for electrical conduit rather than pipe, which had a longer, more sweeping radius compared to the shorter PVC elbows.

Tests on the full piping system were conducted to see how the pipes held up at a given initial pressure of 30 psi. Shown in Figure 5.6, the system was placed upside down, eliminating the need for water to travel upward, and the water was turned on. The system worked successfully, and the misters had no blockage, however sometimes the corners would be pushed apart. The bursting pressure of the PVC was well within the safety range, however the joints were not operating at the stated pressure, which led to the decision that PVC cement would have to be used at the conjoining ends during construction. The cement would just lead to a more solid construction of the full system, and mitigate any risk of the system falling into itself.

Figure 5.6: Full pipe set up

In order to determine how correct the flow simulation was about the elbow radii, the team ran a brief test on the difference in losses from the separate elbows.

Figure 5.7: Flow loss test with short radius elbow

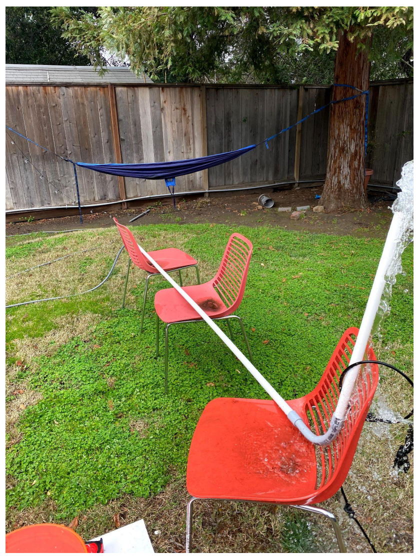


Figure 5.8: Flow loss test with long radius elbow

In Figure 5.7 and Figure 5.8 the team conducted a very simple test to compare the losses in the pipes. Water was run through a pipe with a single elbow, and placed against gravity. The resulting height of the water at the top of the pipe was then taken, and the average of the measurements was taken as a conclusion. The tests agreed with what was shown in the simulation, and the long radius elbow had a higher height following the elbow, which indicated that there were fewer losses and better flow in the longer radius elbow when compared to the short one.

5.3 Active Control/Electronics

The electronics on our system as well as the active controls within it were used to record and analyze data as well as automate our system. The Raspberry Pi had the Mycodo software installed on it, which allowed us to view data from the sensors in real time. Raspberry Pi had the ability to create functions for any electronics that were connected to it using the IoT relay. The team was able to create a code for the system to activate the misters whenever a connected sensor detects an incoming wildfire. Each of the sensors below were chosen due to their compatibility with the Mycodo software.

Controls Setup

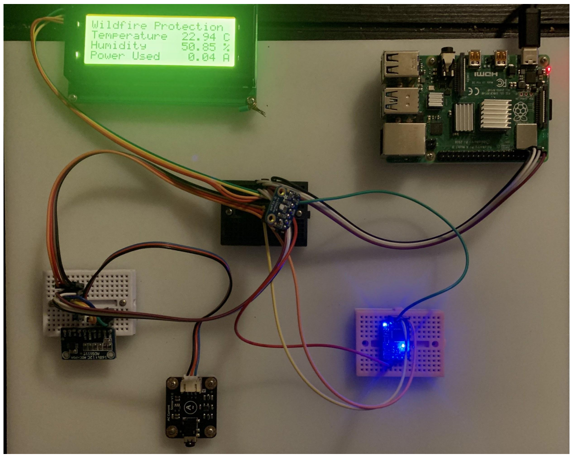


Figure 5.9: Raspberry Pi 4 System Connected to Electronic Sensors

Data Collection and Analysis

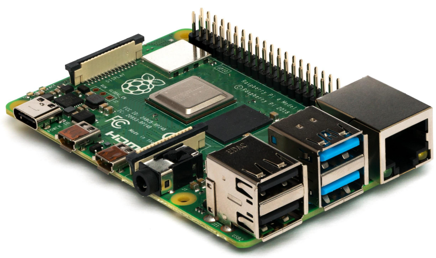


Figure 5.10: Raspberry Pi 4 *(reproduced without permission)* [16]

The Raspberry Pi 4, in conjunction with the Mycodo open software created by Kyle Gabriel, allowed us to monitor the live data being received from the sensors as well as compile the data into graphs. Using the data collected, we were able to create experiments and analyze which components would fit the system best. The displays below were the components and sensors used to give feedback to the microcontroller. The specifications for the components are shown below:

Data Display

- Interface: I2C
- I2C Address: 0x27
- Pin Definition: GND, VCC, SDA, SCL
- Back lit (Yellow with Black char color)
- Supply voltage: 5V
- Size: 60mm×99mm
- Contrast Adjust: Potentiometer
- Backlight Adjust: Jumper

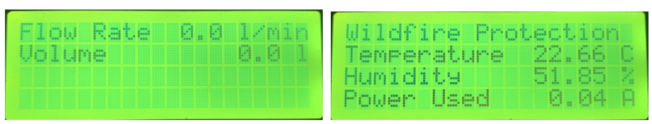


Figure 5.11: 20X4 LCD Display LCD Screen

Sensors

Environment Sensor

- 3.74 x 2.56 x 0.39 inches
- ±2% relative humidity
- ±0.3°C accuracy
- I2C interface
- 3V or 5V compliant
- Weight: 0.8g

Figure 5.12: Adafruit Sensirion SHT31-D Temperature and Humidity Sensor *(reproduced without permission)* [17]

Flow Sensor

- Tinned lead connector
- Accurate to ± 5%
- Minimum flow rate 19 L / min (5 GPM)
- Maximum flow rate 114 L / min (30 GPM)
- Weighs 796.5g
- Operating temperature -29º C to 100º C (-20º F to 212º F)
- Max operating pressure 1378.95 KPA (200 PSI)
- Max viscosity 200 SSU

Figure 5.13: ¾" Atlas Scientific Flow Meter *(reproduced without permission)* [18]

Power Sensors

- Input Voltage (VCC): 3.3V-5.5V
- Interface: Gravity Analog (PH2.0-3P, analog voltage output 0.2-2.8V DC)
- AC Voltage Input Range: 0-1V (AC RMS)
- Relative Error: ±4%
- Dimension: 32×27 mm /1.26×1.06 in
- Weight: 5g

Figure 5.14: ADS1115 Analog-to-Digital ADC PGA Converter *(reproduced without permission)* [19]

Automation

- One circuit, 4 outlets, 2x NC, 2x NO
- Includes surge suppression, debounce, safety breaker
- Weight: 1.12 lb

Figure 5.15: IoT Relay - Enclosed High-power Power Relay *(reproduced without permission)* [20]

Mycodo software allowed the team to relay certain functions to sensors connected to the IoT Relay (which was also connected to the Raspberry Pi). This included automatically actuating the system based on wildfire detection, or relative humidity levels. The program uses Python, which is shown in Figure 5.15, and utilizes multiple sensors at once in order to optimize the response time of the system.

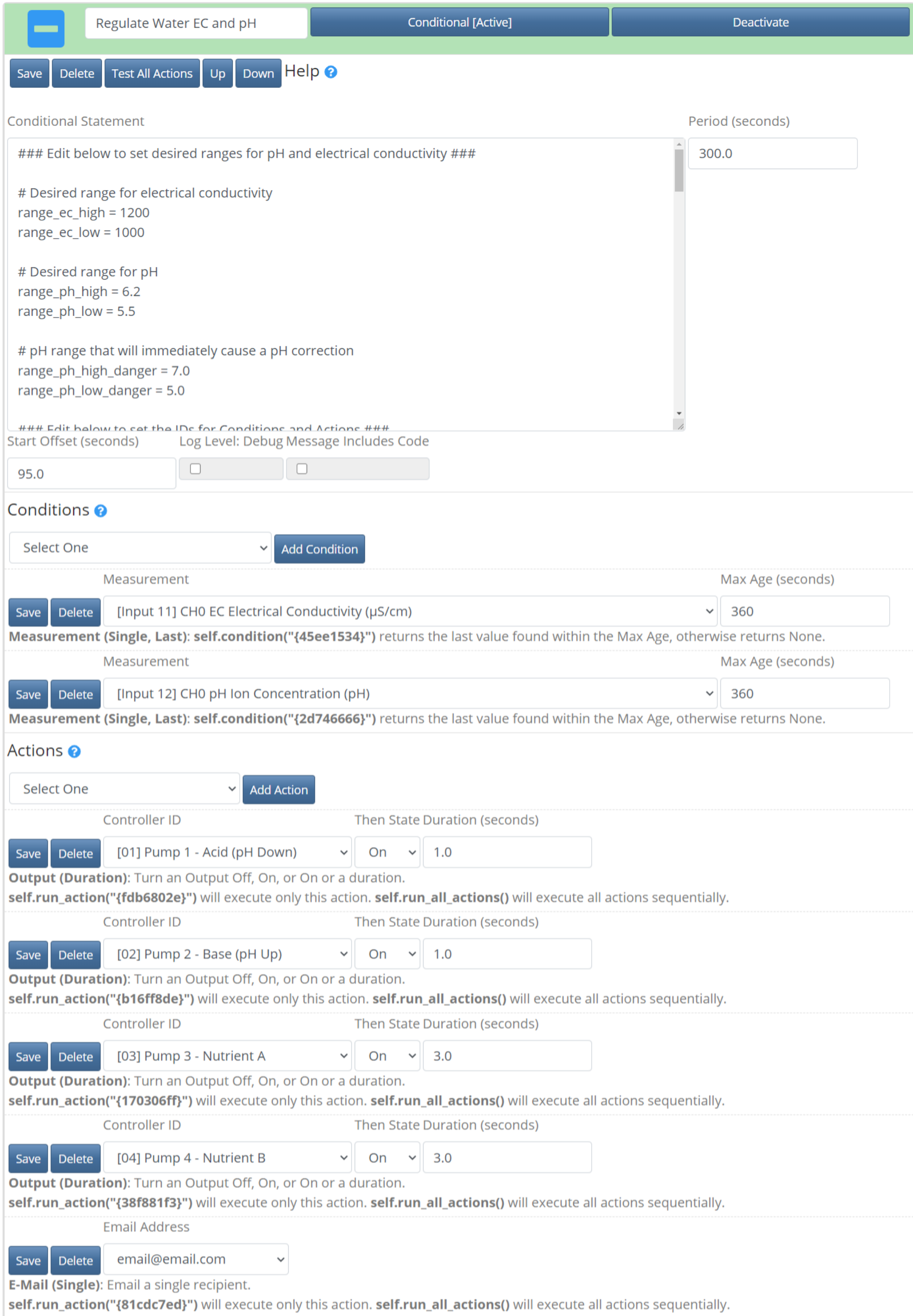


Figure 5.16: Example of Mycodo program being used to regulate electrical conductivity and pH levels of a plant growth system

Full Schematic of Electronics

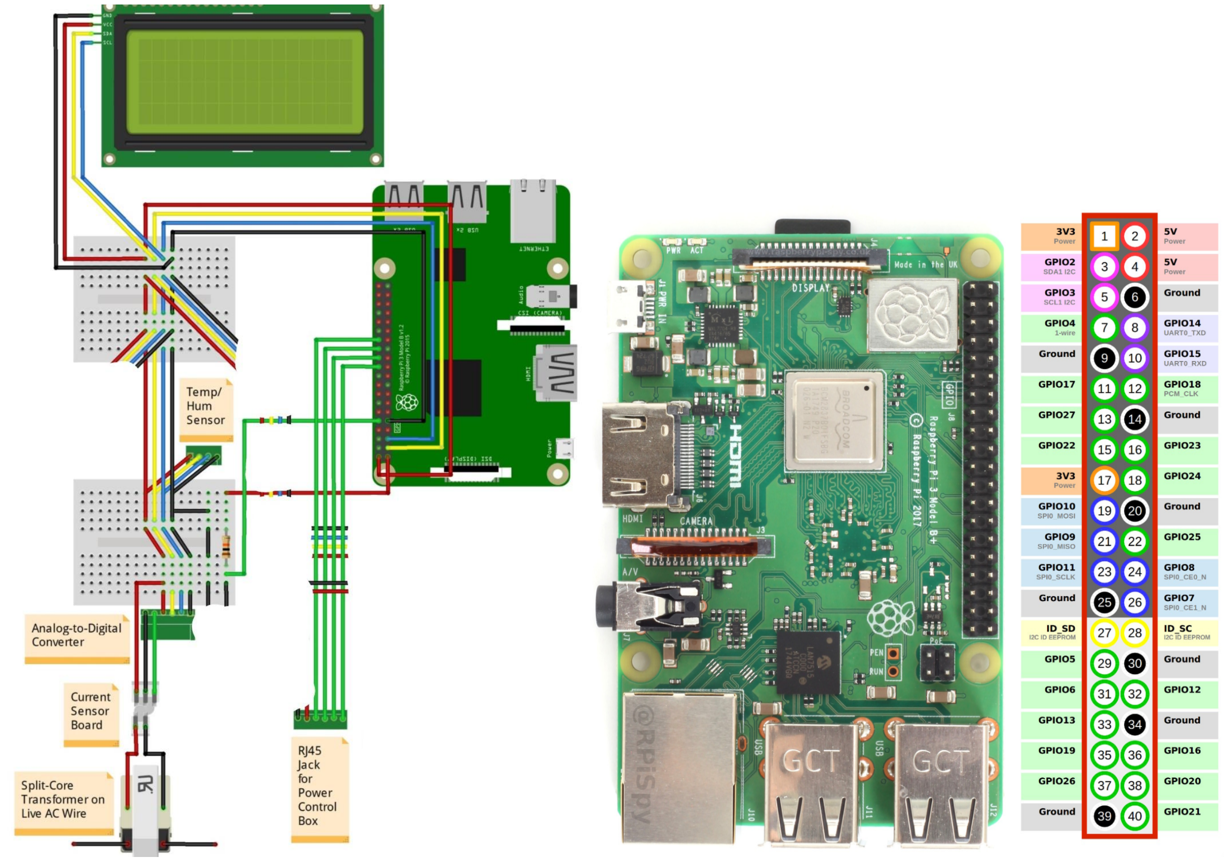


Figure 5.17: Schematic of Sensors attached to Raspberry Pi and Raspberry Pi layout

6. System Integration and Testing

This section discusses the full system testing that was performed and the results from the test. This section includes the test plan that was conducted as well as system build cost and materials along with the results and discussion derived from the test.

6.1 Experimental Procedure

Goal: The intent behind this test is to see if the misters themselves will be able to act as a relevant radiation shield against the fires that the firefighters will be simulating against the shed, as well as the embers that the shed will be exposed to. It is with the intent to record what is happening and also determine a strong defensive perimeter and see the effectiveness of the system.

Execution: The execution of this test plan will be conducted in four phases. Preparation, Transport, Testing, and Recovery. Preparation phase began on 02/15/21 and ended on 03/30/21. The preparation phase consists of making sure all materials have been prepared and are ready to be transported. This phase also includes the preparation of the test site and confirming the times with Fire Chief Gonzalez. The transport phase begins in the morning of 03/30/21 and ends upon arrival at the CalFire site on 03/30/21. This involves loading all the prepared tools and materials into the car and driving it up to Bonny Doon CalFire test site. The Testing phase begins on arrival and ends once the testing commences. This phase first involves the team arriving several hours before the testing is scheduled to begin. Upon arrival, the team will begin reassembly of the pipes and begin screwing in the connector rods and o-rings onto the shed. The pipes will be cut to size and assembled. Once assembled, they will be cemented together to ensure no leakage and no problems to occur due to pressure during the test. Once everything is prepared to the size of the shed, the firefighters will come and attach a water and electricity source to the system. Once the sensors are transmitting and we are recording data, the firefighters will turn on the water and allow for 5 min of run time along with simulated embers. This test will be run several times, and measurements of humidity in the area, as well as the saturated area around the site will be recorded. Feedback will also be taken from the firefighters along with their observations. The recovery phase begins once testing has been concluded. This merely involves cleaning up and taking the pipes and connectors off the shed and bringing them back to Santa Clara. The recovery phase also includes analyzing and investigating the findings from testing and making the appropriate changes to the system before moving on to testing as an independent system.

6.2 Results

The team arrived at the CalFire Bonny Doon station with all the necessary materials. The first step to testing was setting up the 8ft x 16ft shed with the PVC pipes. The team screwed in all the fastenings and O-rings to hold the PVC in place. Stainless steel tape was also used on the 16ft length as a third support in order to prevent potential flexion from the PVC, adding to additional flow losses. Once the pieps were in, they were rotated to the appropriate angle away from the shed and cement was used to fasten the corners and join the lengths of PVC. The rainbird was emplaced on top and connected using the split hose connector. The pressure gage was emplaced rather than a cap to get pressure readings of the system. Images of the set up on the shed are shown below in Figure 6.2. The electronic setup was connected and plugged into a CalFire generator. The water was supplied from a CalFire engine at 31 psi to simulate basic household water sources or the low end of the pressure from a 500 gallon tank with an exit of a one inch diameter.

8 ft x 16 ft Shed. 1ft overhangs.

Figure 6.1: Shed set up of full system test

A test run without any fire was conducted. The humidity increased on the sensors in live time, but due to connectivity issues, the results were unable to be recorded onto a laptop for posterity. Additionally, during the test, the humidity sensor encountered some problems and would not change readings. The belief is that water was directly sprayed onto the humidity sensor causing the system to short.

The test was then run with a fire placed 5 feet away from the plywood shed. The wildfire was simulated by igniting sets of wooden palettes, as shown below in Figure 6.3. The entire test was done under the supervision of a team of firefighters.

Figure 6.2: Test in progress with fire

The system ran for 30 minutes. During this time the team monitored the water usage and the resulting damage caused by the palette fire. Shown in Figure 6.4, the palette fire was able to leave scorch marks after only 30 minutes of blazing 5 feet away from the plywood. The system was fully effective, however, due to the small size of the droplets, the wind played a larger effect than expected, moving some of the mist towards a different direction than intended.

Figure 6.3: Shed surroundings after test

The firefighters were impressed with the system as there was a clear slow to the rate of ignition of the palettes once the WIPS system was turned on. In interviews with them following the test, they commented on how the system would be far more effective as a preventative measure, which is our intent, rather than a fire that has successfully made it up to the property line. This is another reason that they stress the importance of having proper defensible space and a 100 ft clearance from the house. Another important note is that the Rainbird ™ has a radius of 35-45 ft, so it was unable to affect the palette fire that was already so close to the shed. In the test, the system was also turned on after the fire was set, which is unrealistic as the intent is that the system is turned on upon notification of a wildfire threat, not when the wildfire is at the doorstep. The firefighters brought up additional considerations such as the fact that most properties are not built with plywood, which is extremely flammable, and would likely also be painted which would make the homes slightly more fire resistant. This means that the system would have demonstrated higher effectiveness if we had the chance to make the shed a little more home-like. Through this test it was also determined that the WIPS system used 2.5 gallons per minute, which would offer 3 hours and 20 minutes of protection using a 500 gallon water tank. This is important to note because most people in Santa Cruz already have water sources far larger than 500 gallons, or even pools on their properties. If the system was connected to a pool, which on average is 11,000 gallons, the WIPS system would offer protection for more than 70 hours to the users' properties.

7. Business Plan

This section discusses the current state and objectives of the project as a product. This section addresses why this project is not going to be a marketable product and patent search and classification for the WIPS system. The section also includes the cost analysis of the whole project.

7.1 Goals and Objectives

Initial research brought clarity to the WIPS Project by showing us that fire safety knowledge, and not a marketable WIPS system, was the key to developing a safer environment. The entire goal of the project was to increase fire safety awareness and provide a proof of concept that people could take steps to protect their own homes. This project as a proof of concept has been successful, and the final product is one that shows people how to follow the steps that we took, as well as additional fire safety information that they should keep with them if they want to stay safe.

7.2 Cost Analysis

The following tables in this section demonstrate how the goal of creating a $1,500 system was completed. It also shows how we believed we would have difficulty in terms of funding, but were actually very impressed with how we were able to budget our costs and find aid from external sources.

Table 7.1: Expected funding and expenditure

Item	Description	Quantity	Price/Cost
Income			
School Funding	Undergraduate programs funding	-	$1,500
Dr. Mungal (if necessary)	Potential	-	$1,000
Expenses			
Materials for Shed	(8 sheets of 4’x8’ Plywood, 200’ 2x4)	-	$263.60
Water Tank	Vertical epoxy lined water tank. OD 30 in. with angle leg support. Max. Temperature: 180°F (daily usage)	48”D x 71” : 500 Gallons	$1,278.00
Foundation for Water Tank	Foundation. 4	25 sqft	$150.0
Pump and Generator	0.5 hp water pump and 900 Watt Generator + Propane	-	$297.00
Piping	Schedule SDR 11	140 ft	$301.00

	CPVC 3/4 in. Piping		
Nozzles	Fire Nozzle, 1.5 in inlet size	8 units	$98.40
Anti-Siphon Valve	DASASVF075 - ¾ in. FPT Threads	2 units	$54.98
TOTAL	-	-	$2,443.13

Table 7.2: Actual expenditures needed to create the WIPS system

Item	**Model**	**Quantity**	**Total Price ($)**
¾” ID PVC	SCH 40	6 x 8 ft	21.36
Conduit Elbow	SCH 40	4	4.60
Hose Connector	SCH 40	1	3.44
Hose Splitter	Melnor	1	9.98
Hose	HDX	2 x 50ft 1 x 15ft	29.91
Misters	RuoFeng	44 x 0.7mm 44 x 0.8mm	54.76
PVC Primer + Cement	Oatey	1 Primer 1 Cement	7.97
PVC Cap	SCH 40	1	0.69
PVC Connector	SCH 40	5	2.20
Impact Sprinkler	Rainbird	1	8.97
Conduit Hangers	Oatey	4	9.98
Piper Hanger Strap	Oatey	1 x 10ft	2.97
Thread Sealant Tape	Husky	1	1.98
Metal Adapters	Everbilt	5	51.97
Valve	Everbilt	1 x ¾ in.	19.74

Pump	SAER-USA	1 x 30 PSI	149.97
Generator	Champion	1	479.00
Water Tank	Norwesco	1 x 500 gallons	427.60
Wood Screws	Everbilt	1	9.48
		Total Price:	**$1,296.57**

7.3 Patent Classification

Within the patent offices, there are three types of patents: Utility, design, and plant patents. WIPS falls under the utility patent category as it is a frugal improvement of a safety process, and utility patents "may be granted to anyone who invents or discovers any new and useful processes… or any new and useful improvement thereof" (US Patent and Trademark Office).

There are two forms of classifications that the United States Patent and Trademark Office (USPTO) acknowledges. The Cooperative Patent Classification (CPC) System and the United States Patent Classification (USPC) System. WIPS is a product that utilizes misting pipes, impact sprinklers and independent water sources, in addition to electronics that act as actuators and monitors for the safety and effectiveness of the system. Under the CPC System, WIPS would fall under the 'F - Mechanical Engineering; lighting; heating; weapons; blasting'.

Within the 'F' classification in the CPC, WIPS can be further classified under subcategories such as F15D, F17D, F16K and F16P. WIPS is a system that involves the construction and cohesion of separate mechanical systems that come together to provide a safer environment for the user through the use and manipulation of fluids and pressure. F15D is a subclassification for systems that utilize fluid dynamics or any methods or means for influencing the flow of gases or liquids. F17D is a subclassification for systems that involve pipes and pipeline systems. F16K is a subclassification for systems that utilize valves. F16K is less applicable as the classification seems to be referring specifically to a patent involving an improvement on a valve, whereas WIPS is a system that uses a valve in the holistic system. F16P involves "Safety Devices in

General” (USPTO), so the WIPS system that is intended purely for the safety of users and their property fits well into the F16P subclassification.

The classification for the WIPS system under the USPC System is different and less varied. WIPS could fall under either the main Class 169 ‘Fire Extinguishers’ or Class D29 ‘Equipment for Safety, Protection, and Rescue’. WIPS is not intended to act as a fire extinguisher, although it can act as one. The intent is that WIPS is a preventative system that is used to enhance safety by saturating and raising the humidity of a perimeter and in worst case scenarios act as a radiation shield against the heat of a wildfire. This is why WIPS would have to be further sub classified under Class 169 sub class 45 for ‘processes of preventing fire’. In regard to equipment for Safety, WIPS falls under Class D29 sub class 129 as an element/attachment for fire protection and safety.

Review of Prior Art

Patent searches of current or pending claims for wildfire or fire suppression lead to a variety of methods and ideas relating to WIPS. Many involved aerial systems and mounts, handheld or portable systems, as well as specific sprinkler heads/releases and individual parts that would be mounted onto a full suppression system. The reason for the patents of individual parts derives from the fact that no house or property is identical. With respect to the bureaucracy of intellectual property and wording that is needed for a patent claim, if one was to claim a patent for a specific system type that is based on a single house, it is possible for claims to be stolen with slight adjustment in regard to the property or area that the ‘new’ patent would be covering.

The individual parts make claims of increased coverage and protection for preventing fires. In the patent reports, the considerations that they made are very similar to those of WIPS, as the intent is always to answer the question of how to prevent fires. In this thinking, the claims of increased coverage, rates of liquid expenditure, and actuation are all considered. One of the patent claims was very similar to an early iteration of WIPS. It was an “Automatic fire extinguishing system with gaseous and dry powder fire suppression agents” patent from the European Patent Office. It was a patent for an item that could act similarly to a grenade and be thrown onto an affected area and extinguish the area using chemicals. Although the delivery is very different, the team considered using fire suppression agents to mix with the output of water from our system to increase the ability of WIPS. The decision to eliminate fire suppression agents from the system design was due to the safety of the house and the emphasis on the agents to stay hydrated in order to have effectiveness.

One of the patents found was a “Speed controlled rotating sprinkler” US Patent #5377914. The device that this patent is for is actually one that is utilized in our system. WIPS utilizes the rotating sprinkler, or ‘Rainbird’ as a part of our system that is used to saturate 30+ feet around the intended perimeter. In order to prevent wildfires from affecting the property, WIPS increases the humidity and saturates the perimeter. The Rainbird does not increase the humidity due to the amount of water that it utilizes and the water droplets that it creates, but it aids in creating 360 degree coverage of the property and saturating the area. WIPS differs clearly from the sprinkler as it is a full system, and the fact that WIPS is intended to be a fire prevention and protection system whereas the Rainbird is intended for irrigation practices.

Through the iterations of WIPS, one of the goals was to automate the actuation of the misters and sprinkler systems. A patent that was approved in 2020 is US10758758B2, which was the Remote control of fire suppression systems. This was one of our first considerations as the team ideally wanted the user of the system to not have to be present within the property for the system to work. In order to address this problem, the idea for actuation based on the humidity of the property was introduced to WIPS. This allows for the user to turn on the generator and simply leave the property. The remote control of fire suppression systems patent was the idea that the user should be able to monitor and control their system through wifi and a smartphone. This differs from WIPS, as the intent is to have the system be completely automated by having valve control based on the temperature surrounding the property as well as the relative humidity. The way that WIPS is automated also allows for frugal use of the water source as if the relative humidity of the property goes above 80%, the system turns off to save water.

Misting pipes, impact sprinklers, or independent water sources are not new concepts. Our product is not a new or revolutionary idea, rather it is a collection of already existing parts, being used in an effective manner to decrease the chance of losing a house in a wildfire. Based on this preliminary patent search, it is clear that patents do exist for individual parts such as “rainmakers” or “impact sprinklers” , as well as PVC and misters. However, there was no patent on a full system similar to ours. That is most likely because the patentability of a full system similar to ours is quite low since similar products exist. These similar products show that this was a tried and tested method for adding some sort of protection to one’s house in a wildfire. In addition to the patentability of this product being low, this design project has moved more in the direction of using this prototype as a proof of concept. Our goal is to create an educational and instructional pamphlet that the average homeowner can look at to construct a similar system for their house. Because our product is essentially a pamphlet promoting fire safety, frugal innovation, building this system, and safety management, it is not something that would require a patent.

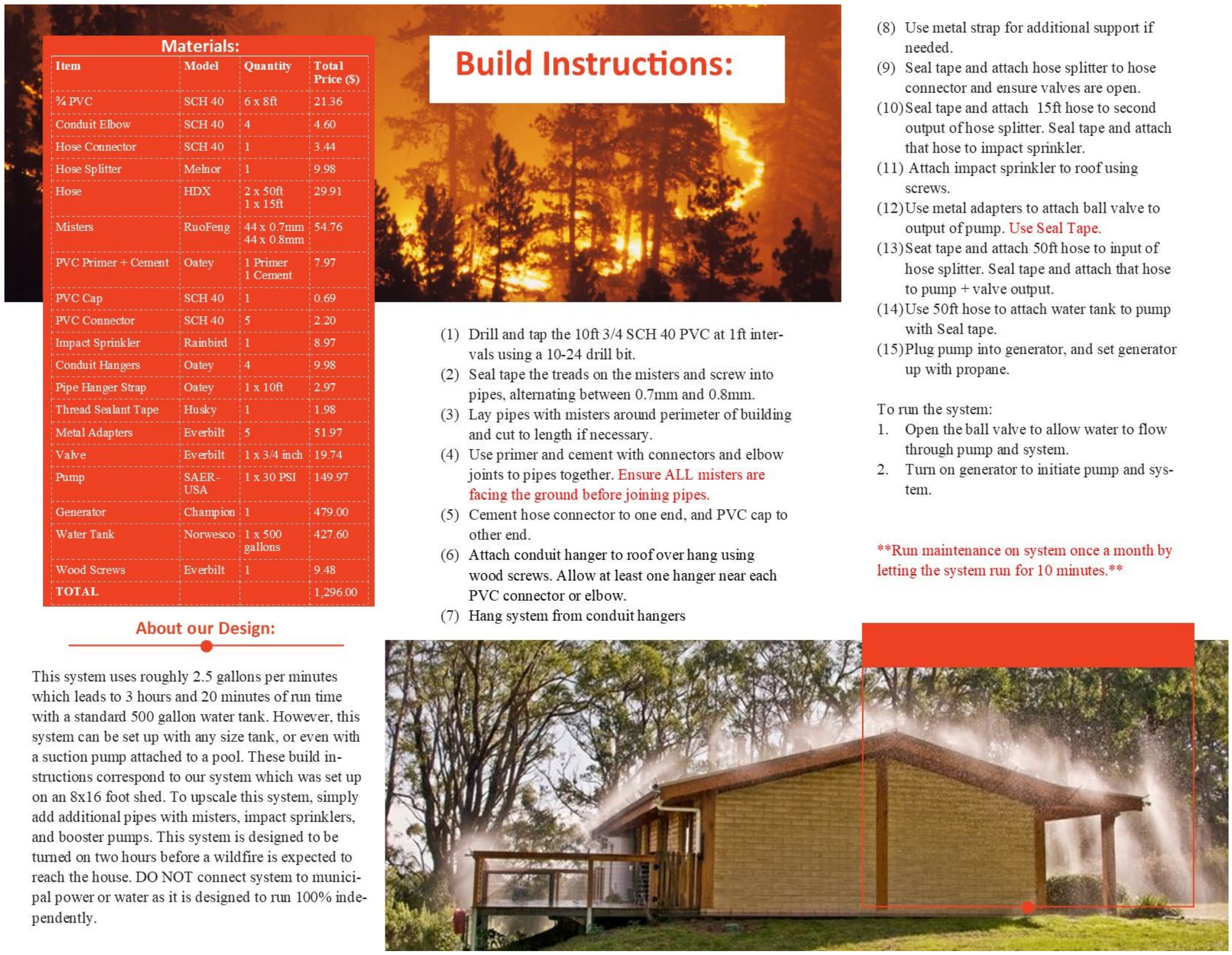
7.4 Product Description

Once a 100ft defensible space around the property has been maintained, all foliage removed and pushed away from the immediate areas of the house, and the meshes to protect the inside of the house have been replaced with a 1/16th inch mesh, the WIPS system is the next step. This system utilizes misters and impact sprinklers fed from a water tank to increase protection for a property. The system uses nozzles attached to pipes in order to create mist. With the misters running, the intent is that the humidity of the air will increase, and the mist will also act as a radiation shield against the ambient heat of the wildfires. The surroundings will also become saturated so as not to ignite when presented with any grass fires. The system will also have nozzles on the roof that rotates 360 degrees and spray water to prevent the roof and a 45+ foot radius surrounding the area from catching fire. The water is supplied from a minimum sized 500 gallon water tank, leading through hose tubing. The hose runs through a pump that is powered by a generator for additional pressure and leads up to schedule 40 ¾ ID PVC piping. The PVC pipe is embedded with misters.

7.5 Final Product

The most feasible and effective way to share this system/idea with the general public is to create a pamphlet. Wildfire protection systems already exist but the two main problems are that people are not educated about this issue and don't even realize that these products are on the market, and the second issue is that the products are far too expensive with prices reaching over $20,000 for a single system. By creating a pamphlet, we are able to easily distribute this information to a greater population. Additionally, we are able to mitigate any extra cost as this pamphlet contains build instructions for the user to build their own system.

Figure 7.1: Front side of Fire Safety Pamphlet



Materials:

Item	Model	Quantity	Total Price ($)
¾ PVC	SCH 40	6 x 8ft	21.36
Conduit Elbow	SCH 40	4	4.60
Hose Connector	SCH 40	1	3.44
Hose Splitter	Melnor	1	9.98
Hose	HDX	2 x 50ft 1 x 15ft	29.91
Misters	RuoFeng	44 x 0.7mm 44 x 0.8mm	54.76
PVC Primer + Cement	Oatey	1 Primer 1 Cement	7.97
PVC Cap	SCH 40	1	0.69
PVC Connector	SCH 40	5	2.20
Impact Sprinkler	Rainbird	1	8.97
Conduit Hangers	Oatey	4	9.98
Pipe Hanger Strap	Oatey	1 x 10ft	2.97
Thread Sealant Tape	Husky	1	1.98
Metal Adapters	Everbilt	5	51.97
Valve	Everbilt	1 x 3/4 inch	19.74
Pump	SAER-USA	1 x 30 PSI	149.97
Generator	Champion	1	479.00
Water Tank	Norwesco	1 x 500 gallons	427.60
Wood Screws	Everbilt	1	9.48
TOTAL			1,296.00

About our Design:

This system uses roughly 2.5 gallons per minutes which leads to 3 hours and 20 minutes of run time with a standard 500 gallon water tank. However, this system can be set up with any size tank, or even with a suction pump attached to a pool. These build instructions correspond to our system which was set up on an 8x16 foot shed. To upscale this system, simply add additional pipes with misters, impact sprinklers, and booster pumps. This system is designed to be turned on two hours before a wildfire is expected to reach the house. DO NOT connect system to municipal power or water as it is designed to run 100% independently.

Build Instructions:

(1) Drill and tap the 10ft 3/4 SCH 40 PVC at 1ft intervals using a 10-24 drill bit.
(2) Seal tape the treads on the misters and screw into pipes, alternating between 0.7mm and 0.8mm.
(3) Lay pipes with misters around perimeter of building and cut to length if necessary.
(4) Use primer and cement with connectors and elbow joints to pipes together. Ensure ALL misters are facing the ground before joining pipes.
(5) Cement hose connector to one end, and PVC cap to other end.
(6) Attach conduit hanger to roof over hang using wood screws. Allow at least one hanger near each PVC connector or elbow.
(7) Hang system from conduit hangers
(8) Use metal strap for additional support if needed.
(9) Seal tape and attach hose splitter to hose connector and ensure valves are open.
(10) Seal tape and attach 15ft hose to second output of hose splitter. Seal tape and attach that hose to impact sprinkler.
(11) Attach impact sprinkler to roof using screws.
(12) Use metal adapters to attach ball valve to output of pump. Use Seal Tape.
(13) Seat tape and attach 50ft hose to input of hose splitter. Seal tape and attach that hose to pump + valve output.
(14) Use 50ft hose to attach water tank to pump with Seal tape.
(15) Plug pump into generator, and set generator up with propane.

To run the system:

1. Open the ball valve to allow water to flow through pump and system.
2. Turn on generator to initiate pump and system.

Run maintenance on system once a month by letting the system run for 10 minutes.

Figure 7.2: Backside of Fire Safety Pamphlet with Build Instructions

8. Engineering Standards and Realistic Constraints

8.1 Engineering Standards Breakdown

NFPA 13, 13R

Standard for the Installation of Sprinkler Systems

This a set of standards for the design and installation of automatic fire sprinkler systems. Our system is made to operate as an automatic fire sprinkler system so it would be important to meet the industry's benchmark requirements. With standards set in place for the sprinkler system aspect of our product, we can ensure that it will work properly and provide coverage/protection against incoming wildfires.

NFPA 22

Standard for Water Tanks for Private Fire Protection

Our system contains a water containment system. It would be very helpful to have a standard for the types of water tanks that we would use depending on the size of the home/system. It would give us a criteria to meet for water tank designs, construction, installation, and maintenance. These standards are also specific to fire protection systems so it would fit well with our project.

ISO 9001

Quality Management Standard

This standard deals with the quality of products coming from a company/business of any size. It would be important for us to follow these guidelines because we need to ensure that our product is of equal quality wherever it is applied. There is no room for error when it comes to protecting homes from such a violent disaster like a wildfire. Our system and its components need to meet a certain criteria of quality in order to save homes and maybe even lives.

ISO 1101

Geometrical product specifications

Our product should be able to be reproduced using our specifications. Having a standard for the way we design our system would be extremely useful for its production. When making our system there will also be set tolerances that the product will have to meet in order to guarantee that it works efficiently. It is important to have a standard for the schematics of the system as we are trying to give customers the opportunity to save money by building the system themselves. All systems put together by customers should operate similarly and effectively.

ISA-TR84

Automation Asset Integrity of Safety Instrumented Systems

These standards cover the criteria for systems that detect abnormal situations and switch on in order to get back to a "safe" state. As we try to automate our system, it would be essential to meet these standards in order to provide continuous protection and support to our customers. We need to develop a method to detect an incoming wildfire and turn on the system in order to help save the home our product is attached to. This could be possible through the use of temperature sensors, infrared sensors, or access to local wildfire alerts that turn the system on when a wildfire is detected.

8.2 Economic Factors

Although the team is not planning on putting the WIPS system as a consumable product, the economic factors revolving around wildfire protection are immensely beneficial. By demonstrating engineered standards for a system that can effectively protect their homes, residents would no longer need to go out and purchase $20,000+ protection systems. If an individual in Santa Cruz already has access to an independent water supply system or source, with a little hard work they can recreate the system for under $1,000, depending on how large their property is. Our system and pamphlet demonstrate that there we have produced a cost effective solution for something that should be a basic right. The disparity between the $20,000 for a current protection system and the price of about $25/ft of perimeter that the home has is a success that shows that everyone should be building their own WIPS system following our design. Additionally, California suffered over $2 billion in monetary loss in 2020 alone. As shown in Figure 8.1, the cost associated with fighting fires is also increasing. With more people taking the initiative and putting up their own systems, the hope is that it will aid in reducing the amount of monetary loss as well as the needed costs to fight against the fires.

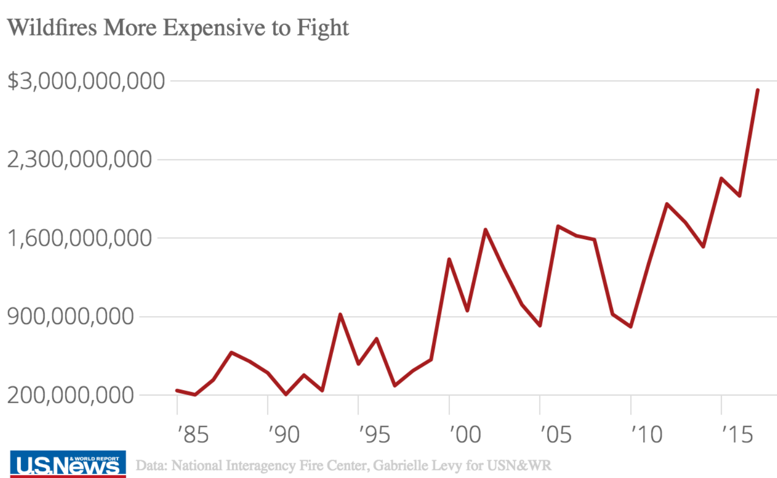


Figure 8.1: Professional cost to fight fires by year (2016) (*reproduced without permission)* [21]

8.3 Societal Influence

Over the last 20 years, the changes and unpredictability with weather has led to wildfires burning more acres of land across the United States as shown in Figure 8.2. By giving people the ability to defend their homes for an affordable price, the number of acres and properties burned should decline if the outreach is strong enough. Additionally, if people report the fact that they have a WIPS system on their property, it can aid firefighters in understanding and predicting paths to fires so that they can be more proactive and less reactive towards fires in their areas. This would mean that the efforts put towards fighting the fires can be more effective and means that damage to areas of land and property can be kept to a minimum.

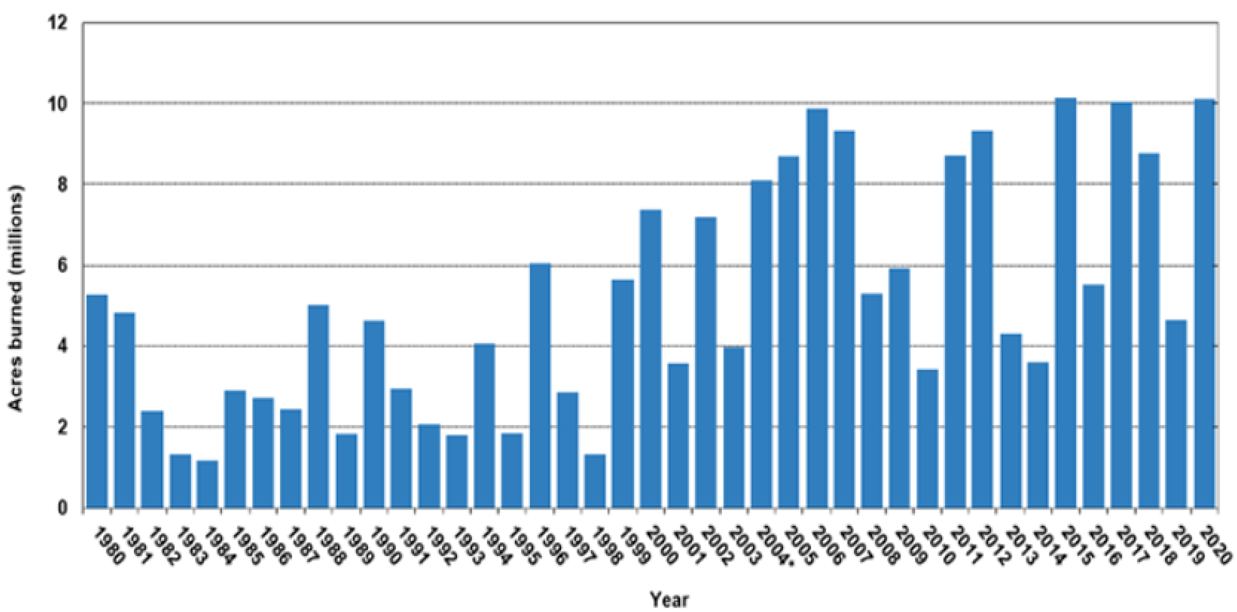


Figure 8.2: Number of Acres burned in the United States 1980-2020 (*photo reproduced without permission)* [2]

Through interviews with people that are actively affected by fires as well as members of the firefighting community, we realized that the main problem is the lack of knowledge that surrounds fighting fires. By providing people with an understanding of defensible space and the knowledge on how to invest in their own ability rather than a pricey system, we hope that more people will be able to take the initiative into fighting a problem that affects not only themselves, but also their neighbors and their surrounding communities. It is imperative to educate people that protection is as simple as upgrading meshes to 1/16th inch mesh and clearing dead vegetation around the house to create a defensible perimeter.

8.4 Environmental Impact

Wildfires quickly consume homes, businesses, and other structures. Wildfires can burn up to one acre every five seconds, the entire time releasing toxic smoke that pollutes the environment. With wind, the toxic chemicals can be carried for thousands of miles. By introducing a system that tries to protect the number of properties that go up in flames, the impact on the environment can be extremely beneficial. Rather than having ash that includes scorched chemicals that are contained within plastic and paint, the ideal scenario is one that has structures left standing, which leads to less chemicals in the atmosphere.

In regard to the natural environment, it is true that the ecosystems revolve around the cycle of wildfires occurring. However, current wildfires still have intense blazes and are destructive. The loss of natural vegetation, and the inability to have topsoil that has the proper nutrient retention and water infiltration can be detrimental to the wildlife contained in the ecosystem. Depending on the species, they may struggle to survive with a lack of natural vegetation. With more WIPS systems in place, it is possible that wildfires will not be able to cross over certain lines, providing a natural ‘stopping’ point for the wildfires - therefore keeping a balance between what nature intended and all out destruction.

8.5 User Experience

The user experience when looking at our pamphlet is quite simple. The idea is that people will raise awareness and develop an understanding of what steps they should take in order to make their homes more fireproof. Detailed build instructions were included on the pamphlet with specifications on how to make the system effective. All the materials are easily accessible through online purchase or a department store near the resident.

When using the system, the process should be as easy as turning the generator on and allowing water flow through the system. The system will then turn on and proceed to increase the humidity and saturate the surroundings of the property. The team was not able to fully automate the process, but the system should still be effective for 3 hours for every 500 gallons of water. The user is then able to leave and return to their property when danger has passed over their respective communities.

8.7 Health and Safety

The WIPS system allows for people to feel safer in their own homes despite the threat of wildfires. It should allow people to be comfortable in using it as well, as it only uses water and no additional chemicals such as Class A foam. The only concern would be if fire does still get onto the property as the increased temperatures could lead to slight degradation of the PVC and the release of some fumes. This is unlikely though, as the PVC will have water running through it simultaneously, which will prevent extreme failures within the piping.

Overall the WIPS system is safe. The user should be able to easily follow the guided instructions and safely install all the portions of the system, there should be no risk to anyone's safety. The largest concern would be a lack of specification during the instruction and someone hurting themselves in the build process. The WIPS system is here to promote a culture of maximum fire safety and awareness.

9. Summary and Conclusions

This section comments and evaluates the design decisions made during the engineering process. It takes into consideration the results following the tests conducted and the feedback of the firefighters and advisors following the test. This section also includes feedback on additional work that can come from this project and methods of improvement.

9.1 Design Evaluation

Our goal was to build a system that would be affordable, effective, and replicable. This would allow the majority of individuals affected by wildfires to be able to go out and purchase the materials needed to recreate the system easily and protect their home without having to worry about whether their craftsmanship would hold up or not. By providing a proof of concept that a system like the WIPS system can be effective and replicated for under $1,500, it opens the door for homeowners to feel comfortable going out and following the WIPS design. With our goals in mind, the WIPS group was able to provide a final structure that was made out of PVC piping, 0.7 and 0.8 mm misters, a Rainbird ™, and general hosing components. By keeping the materials and parts limited to those found at retail and online stores, we were able to maintain low costs and satisfy our goal of keeping the materials accessible. Our design was made with Santa Cruz residents in mind, but the design would still be effective for areas that are generally affected by wildfires.

The design successfully activated in our tests and demonstrated results in water consumption and ability to slow down ignition. We were able to successfully move the water using only 31 psi. There were no instances of bursting or leakage from the system, and the system was effective by using only 2.5 gallons of water per minute. The system still required manual actuation, and there were problems with the controller and sensor arrays that were intended to measure temperature and humidity.

The system as a whole was an overarching success. There were less measurements than we wanted to have taken due to the problems with the controller and sensor array, but the team was still able to effectively demonstrate that there is potential for a DIY WIPS system that can aid in fighting against wildfires and enhancing the protection of the users' homes. There was significant success in the piping, power, and distribution systems, but we believe that improvements can always be made.

9.2 Design Improvements

The most notable point of improvement comes from the humidity sensor failing us in a full system test. The assumption was that the humidity sensor could withstand some form of water as the intent is that it interacts with water to take measurements. However, when exposed to increased amounts of moisture, it is believed that the sensor shorted causing us to be unable to take additional measurements. The failure of the humidity sensor also prevented the system from being completely automated for an additional water saving method. Through the use of a microcontroller, it would have been possible to add an additional component to actuate the pump. It would have been possible to activate the pump when the relative humidity of the property dropped below 40% and turn off the system when relative humidity reached above 80%. Through this form of actuation, it would allow for the system to save more water and therefore last longer. This means that if the ambient temperature wasn't enough to evaporate through the amount of moisture in the air at the given time, the system would save water for when the fire moves closer or becomes a more imminent threat.

Another improvement that could have been made to the system would have been to change the angle of our misters. In our mister angle testing, we looked for the angle with maximum coverage, which was 45 degrees away from the parallel of the wall. This allowed for maximum ground coverage without interference to our characterization of spray and change in relative humidity. However, in the test, it was shown that this actually meant that if the wind was strong enough, the water that wasn't directly saturating an object or going into the atmosphere, it would be carried away. In order to prevent this and guarantee some form of protection an improvement would be for the line of exit from the mister would be parallel to the angle of the wall, as shown below in Figure 9.1. By doing this, the coverage around the house from the misters would be smaller, but there would be a guarantee that mist would hit the walls, saturating the walls in some form. This would be an additional measure against scorching and embers.

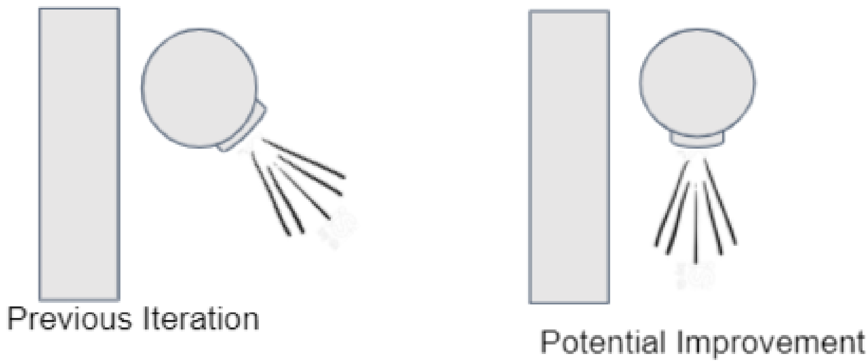


Figure 9.1: Mister angle improvement

References

Sources

[1] California Department of Forestry and Fire Protection (CAL FIRE). "Stats and Events." *Cal Fire Department of Forestry and Fire Protection*, www.fire.ca.gov/stats-events/.

---

[2] "Wildfire Trend Statistics." *Facts + Statistics: Wildfires*, Insurance Information Institute, 2021, www.iii.org/fact-statistic/facts-statistics-wildfires#:~:text=About%2010.1%20million%20acres%20were,structures%20and%20killing%2031%20people.

---

[3] Jensen, Lizanne: Fire Safe Council of Santa Cruz Vice President, (831) 425-7001, lizkenjensen@gmail.com

Providing information on fire safety protocols specific to Santa Cruz as well as a personal design for a make-shift wildfire suppression system.

---

[4] Torres, Ruben: Fire Chief of Santa Clara Fire Department, (408) 615-4900, Fire@santaclaraca.gov

Providing fire safety protocols for the city of Santa Clara as well as helping to provide a suitable location for testing prototypes.

---

[5] Cohen, Jack, NFPA. *Your Home Can Survive a Wildfire*. *YouTube*, YouTube, 9 Nov. 2015, www.youtube.com/watch?v=vL_syp1ZScM.

---

[6] Green, Alan, and Paul Cooper. "Experimental Characterization Of Wildfire Sprinkler Sprays Using High-Speed Videography." Atomization and Sprays, vol. 29, no. 5, 2019, pp. 381–402., doi:10.1615/atomizspr.2019031403.

This article looks at different tests to check the effectiveness of different types of sprinkler heads on wildfires. It examines 6 different types of sprinkler heads and uses high-speed videography to determine which is the best at putting out a fire.

[7] Martin, Daniel A. “The Use of a Water Mist Curtain as a Radiation Shield.” *Lund University*, Lund, 2015, pp. 1–78.

[8] Timm, Peter. “What Temperature Range for PVC Pipe?” *Hunker*, www.hunker.com/12615706/what-temperature-range-for-pvc-pipe.

[9] “Water Tank.” *National Tank Outlet*, www.ntotank.com/500gallon-norwesco-darkgreen-vertical-water-tank-x5060989?gclid=Cj0KCQjwktKFBhCkARIsAJeDT0iDLxzsBlE9cS1KFUw0QpbwdwJiSfK5HzVGcbdQEYIeD796jhpsfd4aAuDHEALw_wcB.

[10] “Aiko Water Pump 2’ X 2’ 2Hp: Model : WP-HCPF-70.” *Aikchinhin*, www.aikchinhin.sg/products/aiko-water-pump-2-x-2-2hp-hcpf-70.

[11] sunset-135, et al. “Propane Inverter Generator Baja 900W Portable Clean Long Lasting 46396020192.” *EBay*, EBay, 11 Feb. 2020.

[12] “Drawings of Valve.” *CP*. https://www.caddetails.com/cad-drawings/oc/valves?sort=0.

[13] “Rainbird Sprinkler.” *Rainbird.* https://www.store.rainbird.com.

[14] “PVC Pipe”. *Coburn’s*. https://www.coburns.com/products/plastic-pipe-tubing/46901906-8-in-x-20-ft-pvc-dwv-pipe-schedule-40-plain-end.

[15] “Manual Valve Actuator.” *NI Product*. https://www.nriparts.com/products/na-na-valve-parts-and-accessories/415942

[16] “Raspberry Pi 4.” *Pimoroni*. https://shop.pimoroni.com/products/raspberry-pi-4?variant=29157087445075

[17] “3251 Adafruit” *Mouser Electronics.*
https://www.mouser.com/ProductDetail/Adafruit/3251?qs=DJieTMTAD3WAE3SOd7%2FRQw%3D%3D&mgh=1&gclid=Cj0KCQjwktKFBhCkARIsAJeDT0hOs296sEJb3It6udjP69pRMGi2HvuXJ_S5_TSdpCrJjW_u-yJ7194aAq0TEALw_wcB

[18] “Atlas flow meter.” *Atlas Scientific.* https://atlas-scientific.com/probes/3-4-flow-meter/

[19] “ADC PDG Converter.” *Amazon.*
https://www.amazon.com/ZYAMY-Ultra-Compact-Development-Ultra-Small-Low-Power/dp/B0777JTNM1

[20] “IoT Relay.” *Amazon.*
https://www.amazon.com/Iot-Relay-Enclosed-High-Power-Raspberry/dp/B00WV7GMA2

[21] Levy, Gabrielle. “Wildfires Are Getting Worse, And More Costly, Every Year.” *U.S. News & World Report*, U.S. News & World Report, 1 Aug. 2018, www.usnews.com/news/data-mine/articles/2018-08-01/wildfires-are-getting-worse-and-more-costly-every-year.

[22] Hulsted, Bjarne Paulsten, et al. “Fixed Firefighting Systems - Water Mist Systems.” Oct. 2004, pp. 1–15., doi:10.3403/bsen14972.

[23] Lutz, Ota. “The Science of Wildfires - Teachable Moments.” *NASA*, NASA, 15 Sept. 2020,

An article on the review of the growing importance of stopping wildfires. The article talks about how wildfires are continuing to grow in occurrence and bring notice to how necessary working on a method to save people’s homes against wildfires are.

[24] Thompson, Matthew, Silva, Francisco, Calkin, David, and Michael Hand. “A review of Challenges to Determining and Demonstrating Efficiency of Large Fire Management”.Xiao,

Deqin, et al. “A Wireless Multi-Sensor Network Deployment Framework for Wildland Fire Detection.” 2012 Dallas, Texas, July 29 - August 1, 2012, 2012, doi:10.13031/2013.41939.

A scholarly article that details a wildfire detection system that does not use a camera, an infrared sensor system, or a satellite system, unlike current fire detection systems. It outlines a wireless multi-sensor network that is more reliable and effective than other fire detection systems.

---

[25] “Fire Extinguishing Media. Foam Concentrates.” *BSI Standards Limited*, 2020, pp. 1–33., doi:10.3403/00945110u.

This article discusses the essential properties and performance of liquid foam concentrates in the extinguishing of fires started from class A fuels (ie. solid, organic materials, wood, paper, rubbers, etc.)

---

[26] Chuang, Yu-Chun, et al. “Flame-Retardant Agent and Fire-Retardant Fabrics Reinforced the Polyurethane Foam: Combustion Resistance and Mechanical Properties.” Journal of Sandwich Structures & Materials, vol. 22, no. 7, 2018, pp. 2408–2420., doi:10.1177/1099636218798152.

Examines three differently composed polyurethane (PU) composites and compares them using a variety of tests. The conclusion of the article is that PU foam composites are an effective flame-retardant material that could be applied to vehicles, construction, vegetation, and commercial products.

---

[27] Rodríguez y Silva F, González-Cabán A (2016) Contribution of suppression difficulty and lessons learned in forecasting fire suppression operations productivity: a methodological approach. Journal of Forest Economics 25, 149–159.

An article on the difficulty of suppression regarding wildfires. The article also comments on how forecasting wildfire can lead to the control and understanding of the spread of wildfires.

---

[28] Mack, Marco: Deputy Fire Marshall for Aptos/La Selva Fire Department, marco.mack911@gmail.com

Good source of information for fire safety protocols, tips, and training.

---

[29] Aramaki, Scott: Evacuated Resident, (669) 418-9211

Provided general understanding of what their experience regarding wildfires was like. Provided insight on their knowledge of wildfire suppression systems, and their expectations of wildfire suppression systems.

---

[30] Zendejas, Ozsie: Santa Cruz Resident, (831) 265-9193

Provided general understanding of what their experience regarding wildfires was like. Provided insight on their knowledge of wildfire suppression systems, and their expectations of wildfire suppression systems.

---

[31] Santiago, jesus: Evacuation Notice Recipient, (831) 978-4733

Provided general understanding of what their experience regarding wildfires was like. Provided insight on their knowledge of wildfire suppression systems, and their expectations of wildfire suppression systems.

Appendix A - Existing Products

The FireBreak Protection System is a system that relies on a drum water source and several guns, or nozzles, installed on the property to pump immense amounts of water and a fire retardant called 'Phos-chek' onto the entire house and surrounding property in order to create a fire-resistant surface between the house and incoming flames. It is self-contained and uses compressed air in order to maintain efficient pressure within the system.

FoamSafe System is a completely self-contained system that activates when fires are sensed within the property. It coats the entire home in special foam and water for thirty minutes in order to prevent it from catching on fire. However, one of the biggest drawbacks is that you are required to have it specifically designed and installed for your home, which leads to prices being upwards of $20,000.

Frontline System is a wildfire suppression system that, similar to the others, coats the entire house in Class A foam and water. A big benefit of this system is that it is able to be activated through an app. However, it requires a manual trigger, which means if the resident is evacuated and doesn't know when the fire will hit their home, they won't know when to turn the system on.

Specifications of Competing Wildfire Suppression Systems

Specification	**FireBreakPro.**	**FoamSafe System**	**Frontline**
Manufacturer	FireBreakPro.	Wildfire Protection Products & Services	Frontline Wildfire Defense Systems
Home Coverage	Outdoor Areas Only.	Other than Outside of house, 100 Sqft of defensible space	Outdoor Areas Only.
Price	$400 minimum. $25/standard head, Not including Water and power system	>$20k	$4-6 per square foot
Accessibility	Call to determine pricing and installation	Call for quote and purchase	Call for quote and purchase

Installation Type	Call to install	Call to install and for more information	Call to install
Water Source Size Required	Min. 550 Gallons		N/A
Water Volume/min	N/A	N/A	N/A
Power Source	Self-contained. Compressed Nitrogen. Solar power	Solar-powered	Connected to home power source, but has a built-in backup power source
Water Source	Self Contained. External tank	pool, pond, spa, reservoir, or they will provide you with a tank	Municipal, well, pool, or water tank options
Fire Retardants	Compressed Air Foam Systems. Water to Foam ratio is 1:10. Phos-check	Special foam	"Class A" foam
System Activation	Self - Activation (remotely or through phone call)	Automatic	Self-activation (remotely or through the app)
Ease of Use	Turns on with a phone call or Handle	Automatic and Manual activation	Turns on with one button, pretty easy
Sustainability	Fertilizer based, will promote plant growth	Foam is environmentally friendly. No need for clean up	Environmentally friendly, biodegradable foam
Sensors?	Self-activation/ Phone activation. Fire scout Sensor, but doesn't come with system	Yes, automatic	Self-activation (remotely or through the app)
Weather Tolerant	Yes	Yes	Yes

Suppression v. Prevention	Suppression	Suppression and offers preventive services	Suppression and prevention (cuts off embers before they get into your home)
SMART System?	No	No	App allows you to activate system wherever you are
Appearance?	Single sprayer, with huge connection for water tanks	Large nozzles that spray the outside of the house	Discreet, with thin pipes lining exterior of home
Shelf Life/ Lifetime	No specifics, but is checked every year	25 years (for foam)	Not specified
Indoor vs. Outdoor	Only Outdoor. Uses Phos-Check, so cannot protect insides	Outdoor	Outdoor (Home exterior)

Appendix B - Customer Report

Customer Report

The team has noticed some flaws within currently available systems that we intend to address.

One of the biggest concerns that our team noticed was that the vast majority of these systems require manual activation. Whether it be through a manual switch, handle, or phone call, the systems that we looked at require someone to notice that a fire is nearing the house to be turned on. In order to improve upon this design, we want to incorporate a form of fire detection system that can distinguish between barbecue fires and fires that can cause damage to someone's home. We don't want to require individuals to have to be the ones to notice the threat to their homes. We believe that automatic detection can be more reliable and have a wider radius that will lead to earlier notice and a higher probability of saving lives and households.

Another issue that our team realized with current systems is the pricing. We realize that it is expensive to develop these types of systems, but we believe that the ability to save someone's home should be available to anyone and not just the wealthy. The systems should be able to adapt to any home, easy to install, and still effectively save the home.

Potential Improvements to Current Systems:

- Automatic fire detection systems
- Reduction of how much water is necessary
- Cheaper (yet just as strong) materials used for piping
- Cheaper overall costs
- Self-installation option
- Discrete/customizable
- Self-sufficient, reliable power source
- A method that doesn't involve dousing the entire home/property

We have decided to focus our project on the Santa Cruz, CA area because it has been heavily impacted by the wildfires, especially when it comes to people's homes. Our group is looking to help protect the homes of these residents in a cheap, effective manner. Although homes are very important, there are also many small businesses that could be negatively impacted by these wildfires as well. Keeping the Santa Cruz homes and businesses in mind, our potential customers would be the residents and business owners of Santa Cruz, CA.

Potential Customers:

- Homes
- Small businesses
- Farms
- Vineyards
- Open-air businesses (Floral shops, local businesses in Santa Cruz)
- Fire stations (Firefighters can buy the system and use their knowledge to install them in homes they know are the most prone)

Appendix C - Subsystem Iterations

Previous Subsystem Specifications

1. **Water Delivery Subsystem**

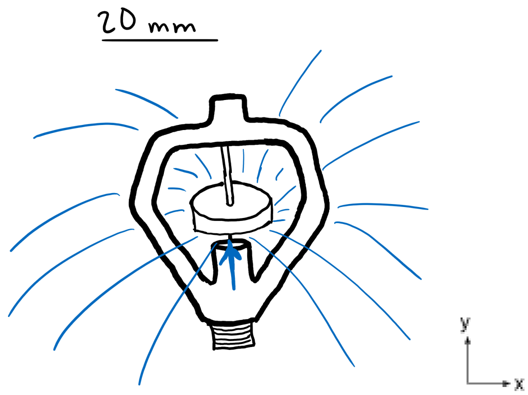


Figure 1: 20 mm nozzle with a circular cover to evenly disperse water. The circular cover is mobile on the y-axis

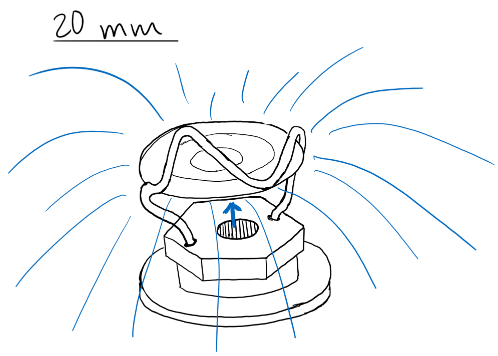


Figure 2: 20 mm nozzle. This nozzle has a larger circular cover that would rise with the wiring. This would create a flatter spread and offer more protection to the pipe.

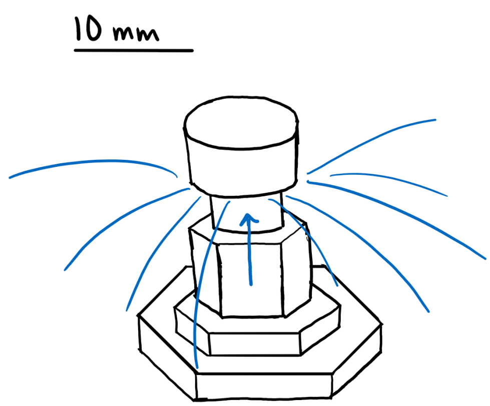


Figure 3: 10 mm nozzle. This nozzle would always be partially exposed. This would make it cheaper but less appealing. The effectiveness would be the same however it could be subject to damage over time

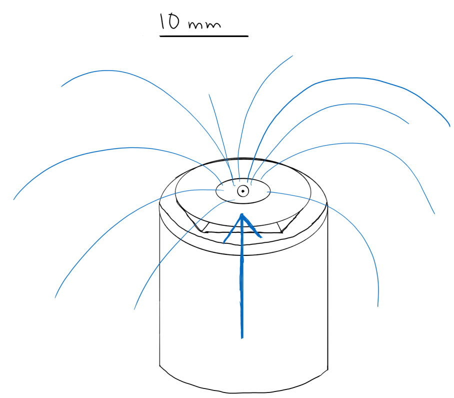


Figure 4: 10 mm nozzle. This nozzle would be fully encased in a cylindrical cover. It would pop out when being used.

2. **Water Containment Subsystem**

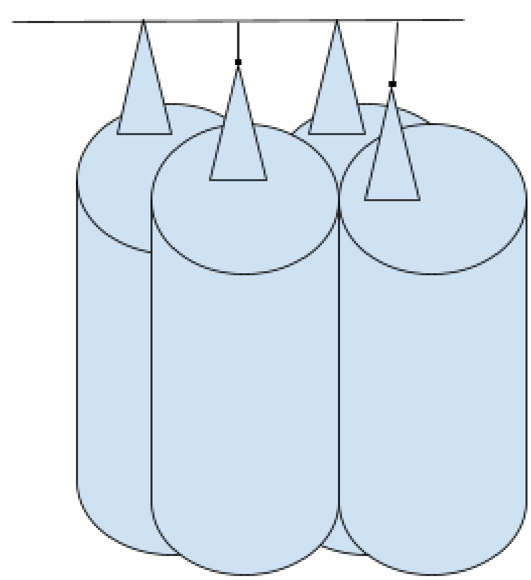


Figure 5: Multiple tank system. Two of the tanks contain water, and two tanks contain fire retardant foam. This would allow a multi-stage process for protecting the house and property.

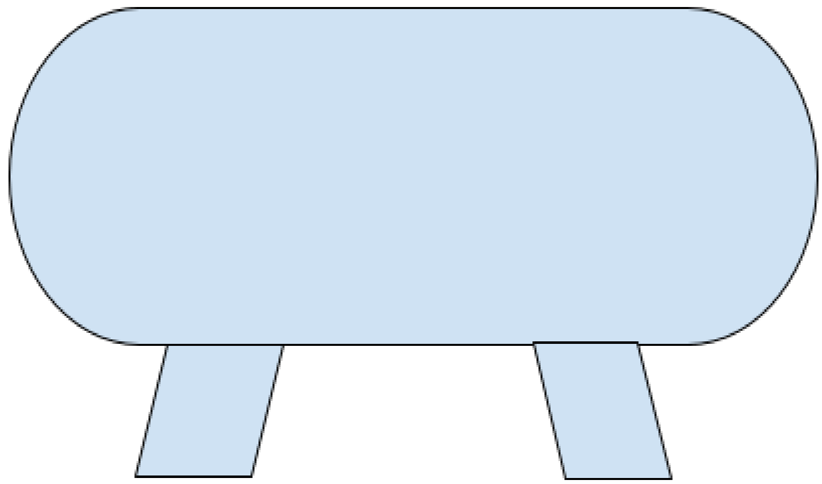


Figure 6: Horizontal Pressurized tank. This is a tank that would come pre-pressurized by us with fire retardant foam inside. This tank would function similarly to an upscaled fire extinguisher.

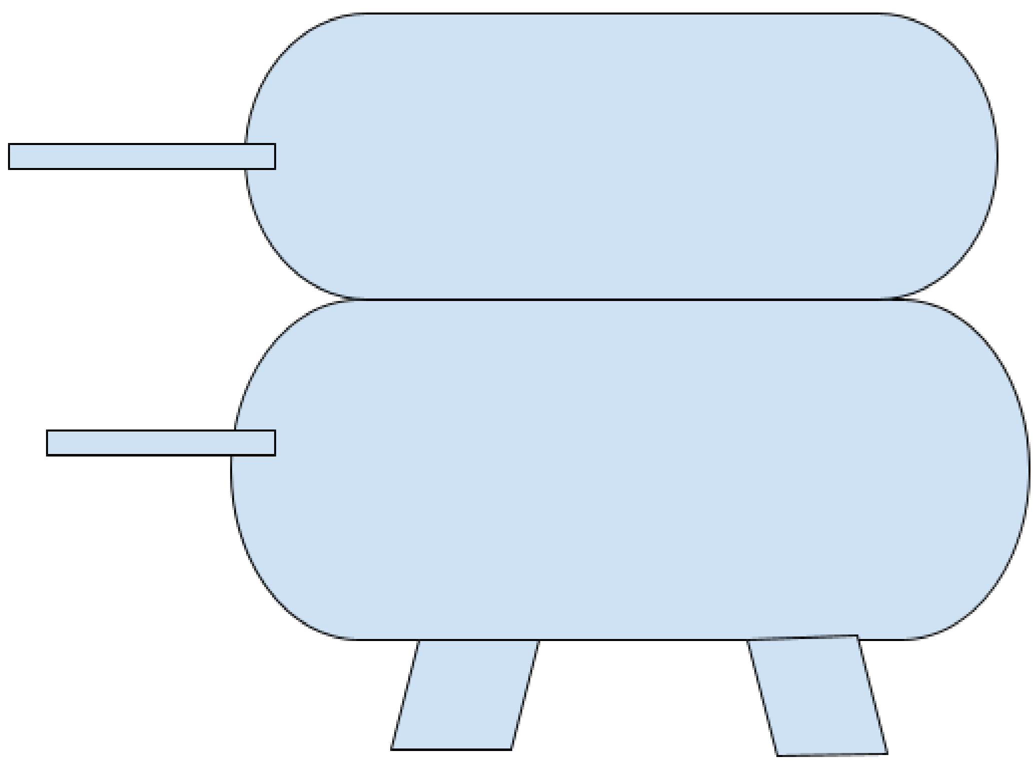


Figure 7: Horizontal pressurized air and water tank. This is a tank that would be pressurized once installed in the home with air. One tank would contain compressed air and the other would contain water. The two would mix and create a mist at the nozzles.

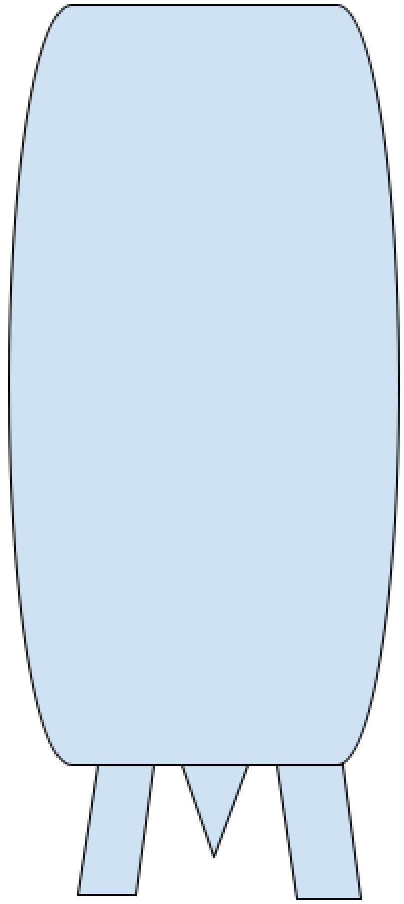


Figure 8: Gravity powered water tank. This setup is a gravity-powered system where the tank would be located somewhere higher, possibly the attic, and the sensors would simply release the water. Gravity would carry the water through the pipes and to the nozzles.

3. **Power Supply Subsystem**

No electricity

Figure 13: No electricity used. Utilize pressure or the force of gravity to lead water into the sprinkler system

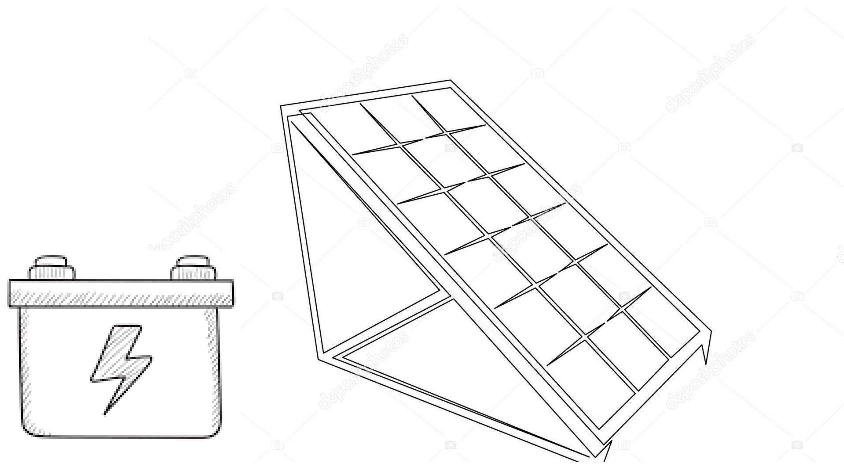


Figure 14: Lithium-ion battery paired with a compact solar energy panel that could attach to the roof. Long-lasting and reliable power that can be accessed by the system at any time, regardless of daylight.

Figure 15: Pre-charged stand-alone battery that would be good for a single-use. Will hold a charge for at least 5 years.

Figure 16: Battery that is permanently hooked up to the electricity grid of the house. This would allow for usage even if the power goes out. This is also the simplest solution involving electricity.

4. **Water Transportation Subsystem**

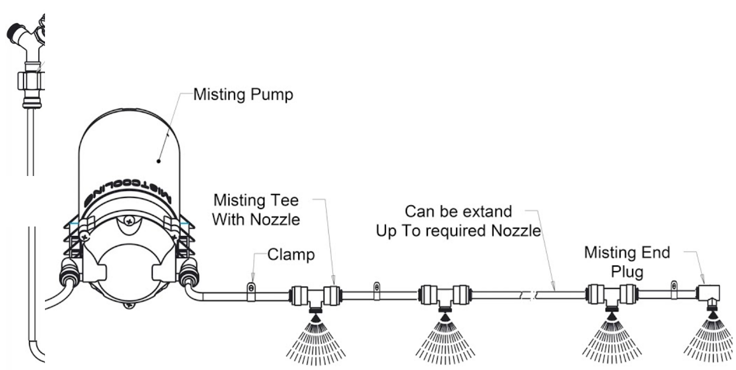


Figure 17: Solid piping running from the water source, through the pump for pressure (if not gravity fed) directly to misters/nozzles. Piping will utilize tee, wye, cross, and elbow fittings as needed.

Figure 18: Solid piping running along all outer areas, with flexible tubing from the main water source toward the misters/delivery system. This system allows for more flexible access and a variety of positioning for delivery systems. Creates an opportunity for keeping the water line consolidated with the movement of the delivery system.

5.

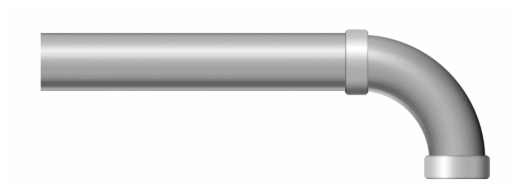


Figure 19: PVC Piping. Cheap material and rigid. Resistance to corrosion is high and lacks the need for maintenance. Easy to obtain and adjust. Resistant to ignition and easy installation. Slightly higher friction coefficient, creating more turbulent flow. Susceptible to leakage between connections depending on desired water pressure.

Figure 20: PEX Piping. Slightly more expensive than PVC. Flexible material allowing for easy maintenance and adjustment. Leak resistance is high. However, requires protection if used outside as UV can damage the plastic layers. May be ideal for parts of the system, but not ideal for moving high volumes of water.

Figure 21: Galvanized Piping. Zinc coating to increase corrosion resistance, but still not for any potable water. Good for transporting large amounts of water with minimal friction losses. More expensive as a metal. Threading allows for easy installation.

6. **System Activation Subsystem**

Figure 22: Manual activation. This method would be the easiest and is the easiest to maintain. The drawback is that it would have to be manually activated by someone in the house/surrounding area which is counterintuitive against the safety of wildfires.

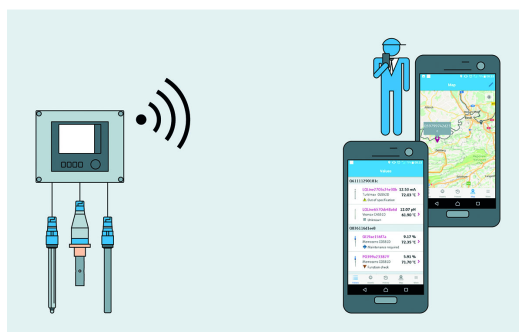


Figure 23: Smart System/wireless activation. This method would act as a manual activation but requires communication between the system terminal and an app.

Figure 24: UV sensor-activated control. This method would use UV sensors to sense the intensity of heat/light signatures that are unique to wildfires and would alert the system to begin cycling.

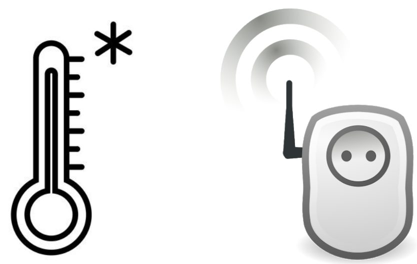


Figure 25: Temperature sensor-activated control. This method would utilize sense temperatures in nearby areas and activate the system as a preventative measure. This requires one-way communication and temperature sensors.

Appendix D - Defensible Perimeter Calculations

Defensible Perimeter.

determined Needed Relative Humidity = 60%.

Given $T_{\circ}$ during wildfire ≈ 50°C (ref. Fire Chief Gonzalez)

$\therefore$ 56.94 g/kg $\left[H_2O\, g / kg_{air} \right]$ Air = 1.2929 kg/m³.

$\therefore$ water in air for 60% humidity = 56.94 · 1.2929 = 73.62 g/m³.

$\therefore$ Diagram

$\therefore$ Perimeter = 60m.

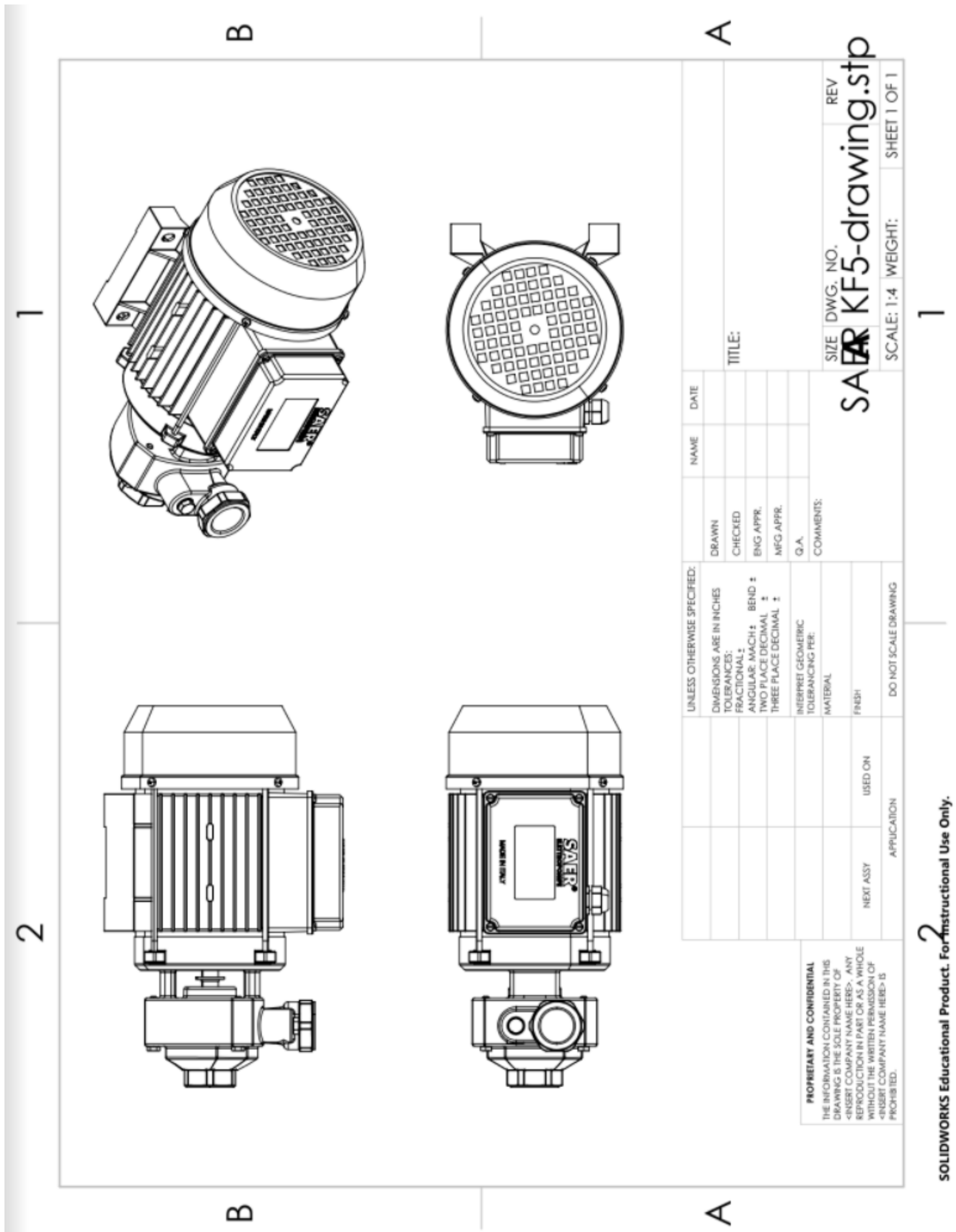
$\therefore$ 73.62 g/m³ · 60 m² = 4.417 kg of water in air.

$\therefore$ 4.417 kg = 4.417 L = 1.166848 gall/t = ṁ.

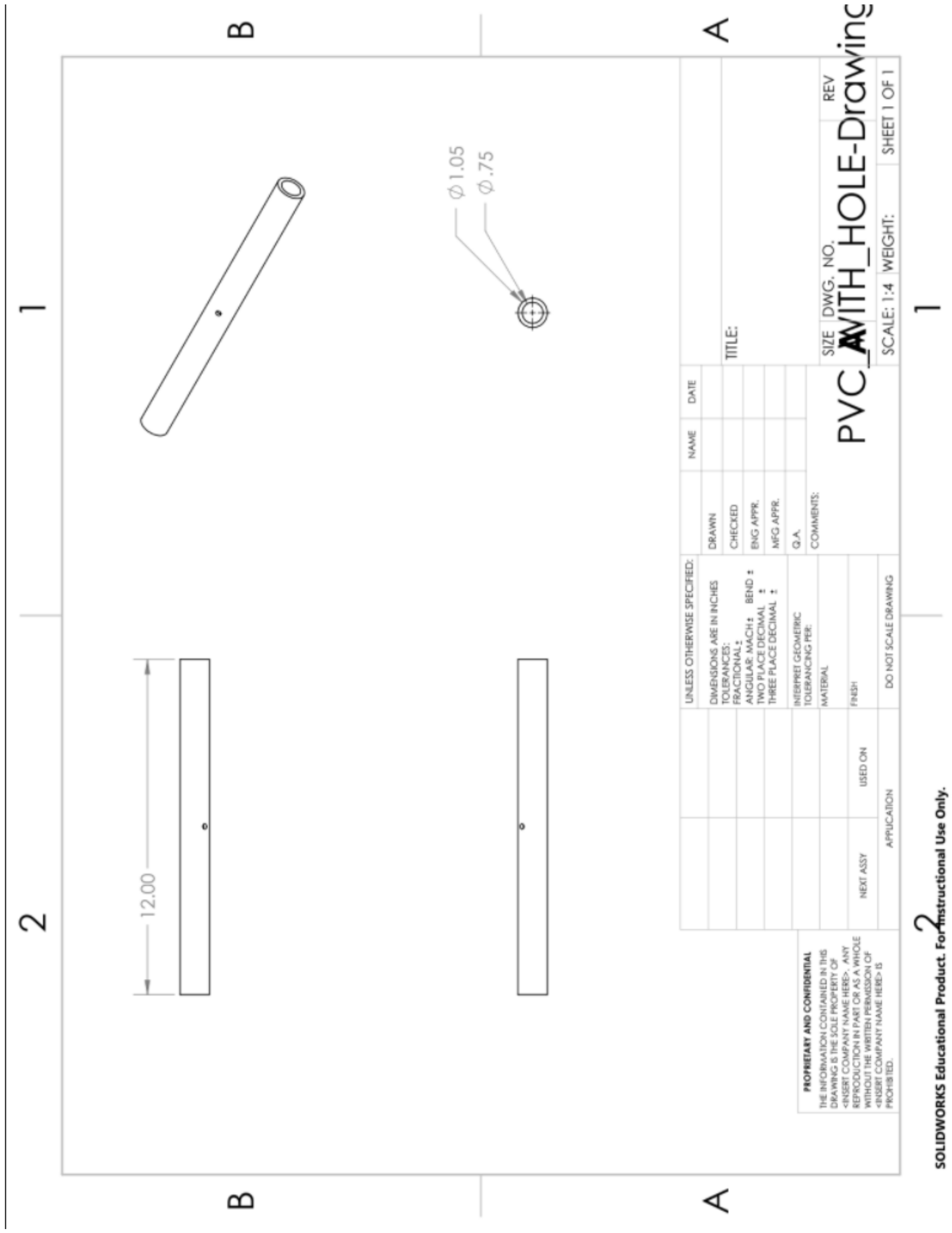
$\therefore$ In order to maintain defensible perimeter of 1 m for model house,

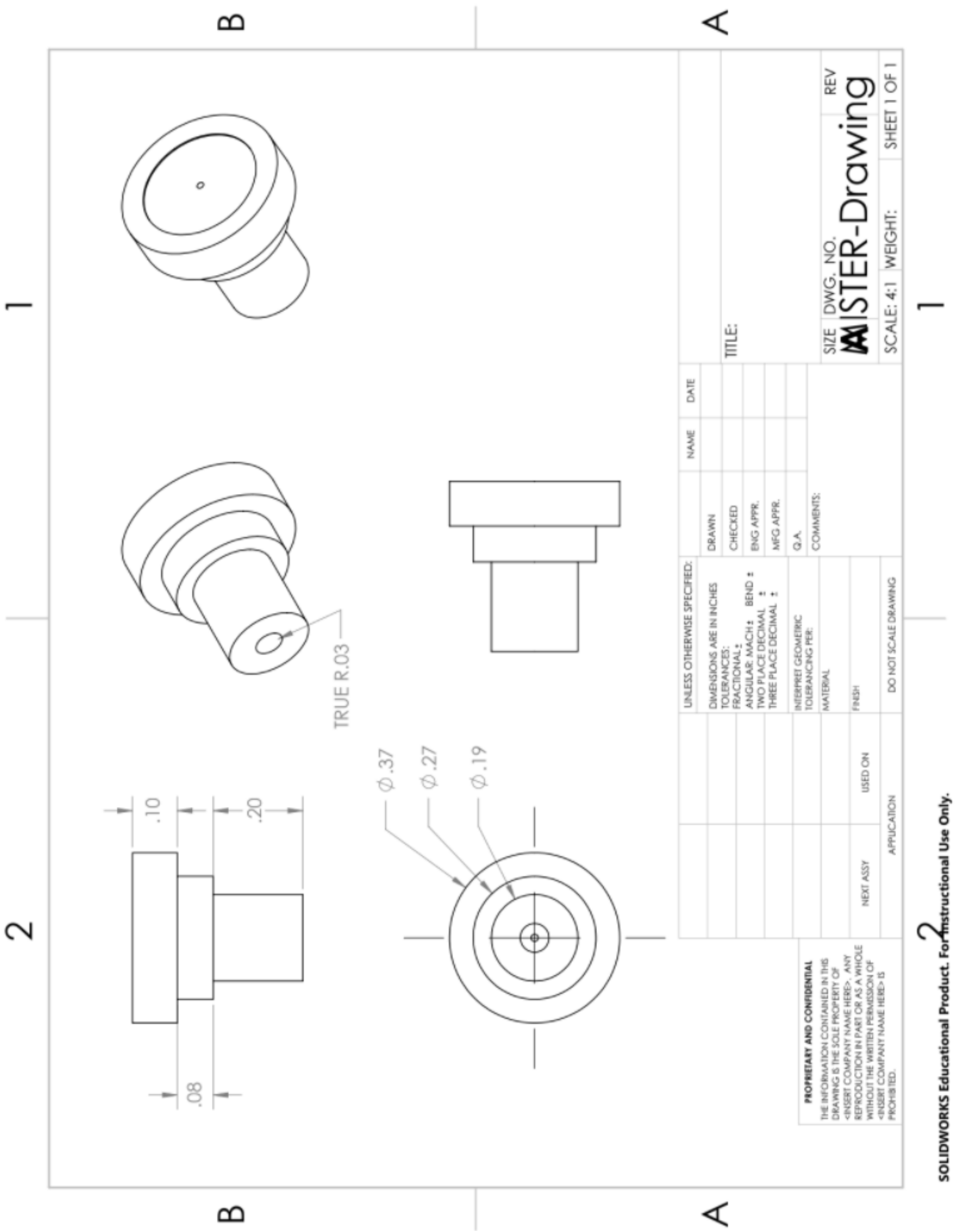
require 1.166848 gall/t. (60% humidity for m² around 60m house).

Appendix E - Engineering Drawings



KF5-drawing.stp
TITLE:
SIZE
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
DO NOT SCALE DRAWING
SOLIDWORKS Educational Product. For Instructional Use Only.


12.00
Ø1.05
Ø.75
2
1
B
A
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
PVC_WITH_HOLE-Drawing
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


2
1
B
A
.10
.20
.08
Ø.37
Ø.27
Ø.19
TRUE R.03
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
A
MISTER-Drawing
REV
SCALE: 4:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
SOLIDWORKS Educational Product. For Instructional Use Only.

Appendix F - Experiment Conditions and Details

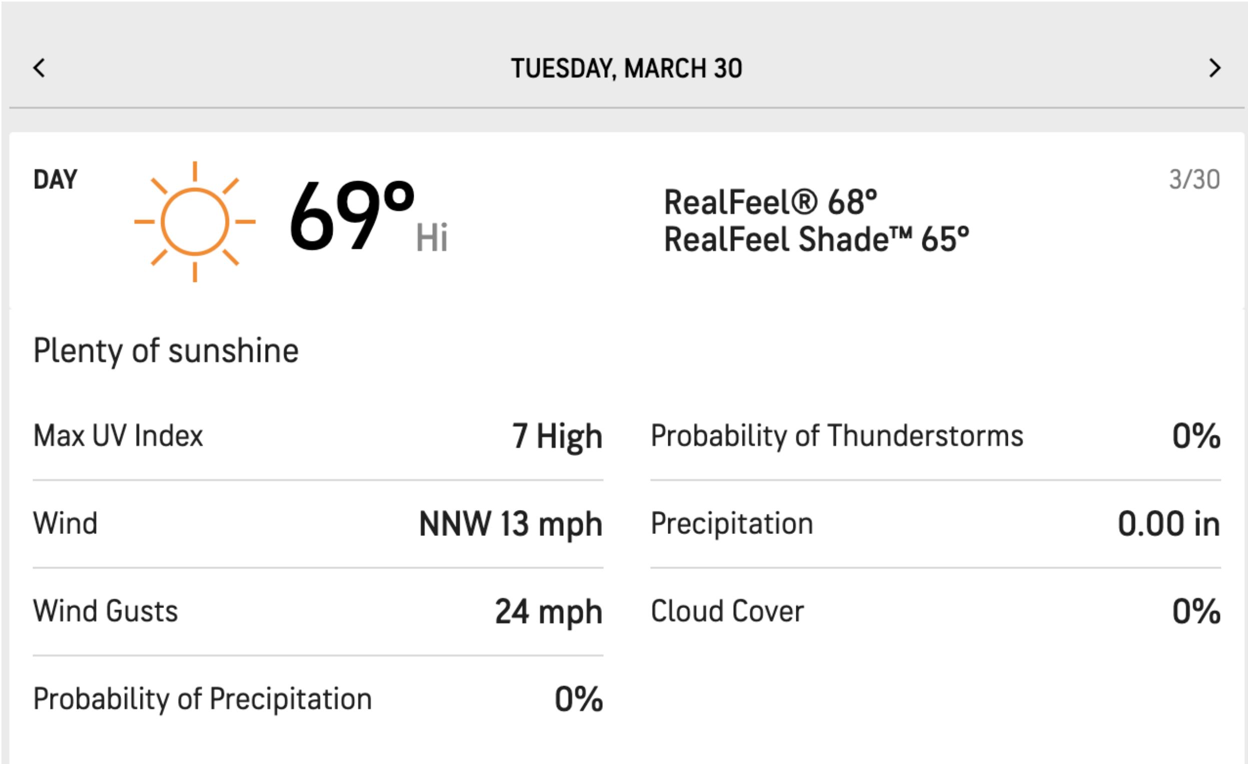


Figure 6.1: Weather on the day of the test

Transport Plan: Disassemble PVC, bring in sections in one car. Ansh - Responsible for construction pieces; Johnny - Responsible for electronic pieces; Antonio - Responsible for Connectors, tools, and miscellaneous items. All items are able to be brought up in one car on the same day.

Checklist of Things to Bring:

- PVC Pieces x 6
- PVC Elbow Connectors x 4
- PVC Straight Connectors x 8
- PVC Cutter x 1
- Cap Piece x 1
- Duct Tape 30ft x1
- PVC Cement x 1
- Misters 7mm x 40 (only 30 inserted)

- Misters 8mm x 40 (only 30 inserted)
- Hose Connector x 1
- Pressure Gage x 1
- Electronic Pieces (Miscellaneous, attached to board) x 1
  - MotherBoard x 1
  - Display x 1
  - Protective Case x 1
  - Humidity, Flow, Current Sensor, x1, respectively
- Camera x 1
- Measuring Tape x 1
- Handheld Power Drill x 1
- Handheld Saw x 1
- Copper O-rings x 4
- Threaded Rods and Pieces x 4
- Steel Tape 10ft x 1

Appendix G - Senior Design Conference Slides

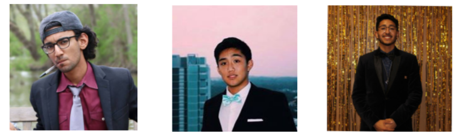
SANTA CLARA UNIVERSITY
School of Engineering

Wildfire Prevention & Suppression System

John Dimas Flores, Ansh Jetly, Antonio Lorenzo

Santa Clara University 1

Introductions



Ansh Jetly '21	Antonio Lorenzo '21	Johnny Dimas Flores '21
Team leader	Antonio	Johnny
Mechanical Engineer Santa Clara University	Mechanical Engineer Santa Clara University	Mechanical Engineer Santa Clara University

Santa Clara University 2

Santa Clara Mission Statement:

Mission: Santa Clara University will excel in educating men and women to be leaders of competence, conscience, and compassion... we will prepare them for professional excellence, responsible citizenship, and service to society, especially on behalf of those in greatest need.

- Service to Society
- Change in Local Community
- Demonstration of Engineering
- High Professional Standards

Santa Clara University

Background Information

In 2020 alone...

$2.089 Billion USD
Monetary Loss

2, 155, 852
Number of Acres Burned

~120,000
Total Evacuation Orders

10,488
Buildings Destroyed

Santa Clara University 4

WIPS Mission Statement

Our goal is to demonstrate proof of concept for an affordable, effective, and replicable independent wildfire protection and suppression system that will benefit those at risk in the greater Santa Cruz area with limited access to power and water when affected by disaster.

Affordable   Effective   Replicable

Santa Clara University 5

Current Systems

Other systems exist but have issues

- Some systems cost over $20,000 + installation
- Dependent on municipal water and energy
- Contain foams that can be harmful to the home and difficult to remove

Santa Clara University 6

Research

- **Interviews**
  - Affected/at-risk Individuals
  - Santa Cruz Fire Safe Council
  - Firefighters
- **Literature**
  - Effect of Wind in Wildfires
  - Characterization of Spray
  - Mist as Radiation Shield
  - Class A Foams

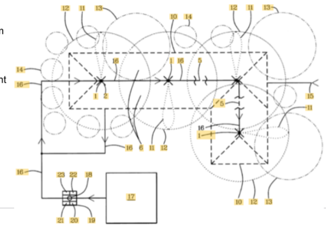
Santa Clara University 7

Patent Discussion

Title: Wildfire Protection System
Patent No.: US6360968B1
Date Granted: 2002-03-26

Description: Intent of this patent is to act as protection for buildings against wildfires.

- Rotating sprinklers
- Removable compact
- Water delivery system



8

Takeaways - Interviews

- **Lawyer**
  - Cost factor
  - Legal repercussions
- **Affected Individuals/ Fire Safe Council members**
  - DIY ability
  - Potential design ideas
- **Firefighters**
  - Fire Safety Knowledge
  - Role of Humidity
  - System independence

CAL FIRE

Santa Clara University 9

Takeaways - Key Literature

- **Dr. Jack Cohen - "Your Home Can Survive a Wildfire"**
  - Protection against embers
  - Wind in relation to wildfires
- **Green, Alan, and Cooper, Paul. "Experimental Characterization Of Wildfire Sprinkler Sprays Using High-Speed Videography."**
  - Sauter-Mean diameter
  - Mister importance
- **Martin, Daniel. "The use of a Water Mist Curtain as a Radiation Shield"**
  - Attenuation of Spray
  - Effectiveness against Radiation
- **"Fire Extinguishing Media. Foam Concentrates"**
  - Use of Class A Foams
  - Specifications of Class A foams and fire retardant

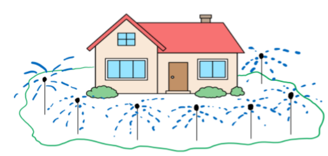
Santa Clara University 10

SANTA CLARA UNIVERSITY
School of Engineering

Santa Clara University 11

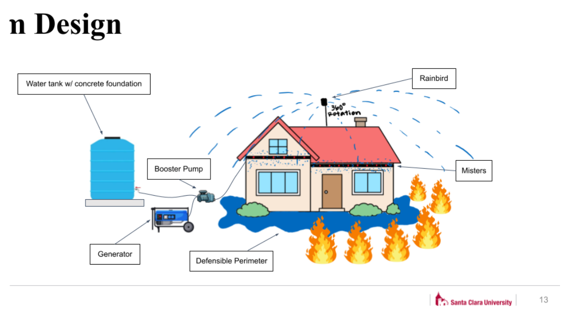
Previous Iterations

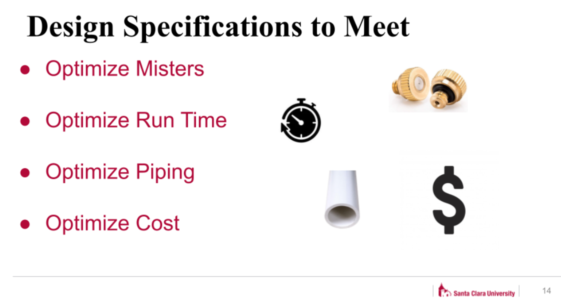
Piping would follow along overhang of property and saturate walls and surrounding ground with water. Class A fire-retardant foam would simultaneously be dispersed on the rooftop of the property.

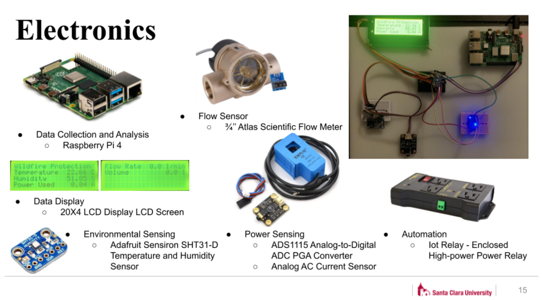


Exterior sprinkler system strategically placed around property to prevent any fire from reaching the house.

Santa Clara University 12

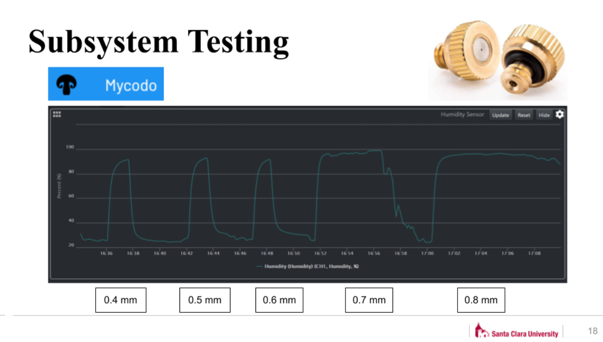

n Design
Water tank w/ concrete foundation
Rainbird
360° rotation
Booster Pump
Misters
Generator
Defensible Perimeter
Santa Clara University
13


Design Specifications to Meet
Optimize Misters
Optimize Run Time
Optimize Piping
Optimize Cost
Santa Clara University
14


Electronics
Flow Sensor
¾" Atlas Scientific Flow Meter
Data Collection and Analysis
Raspberry Pi 4
Data Display
20X4 LCD Display LCD Screen
Environmental Sensing
Adafruit Sensiron SHT31-D Temperature and Humidity Sensor
Power Sensing
ADS1115 Analog-to-Digital ADC PGA Converter
Analog AC Current Sensor
Automation
Iot Relay - Enclosed High-power Power Relay
Santa Clara University
15

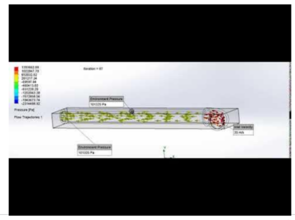

Subsystem Testing
Santa Clara University
16


Subsystems Testing
Santa Clara University
17


Subsystem Testing
Mycodo
0.4 mm
0.5 mm
0.6 mm
0.7 mm
0.8 mm
Santa Clara University
18

Subsystem Testing

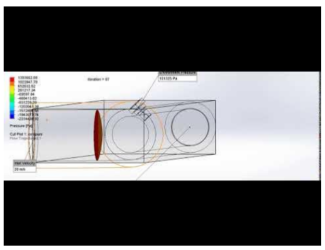
Flow Simulation Research - SolidWorks



- SCH 40 Pipe
- Single Bend
- Single Mister

Made with SolidWorks

Flow Simulation Research - SolidWorks

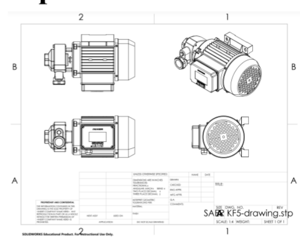


Made with SolidWorks

Subsystems and Components

Specifications:

- SAER KF-3 Booster Water Pump
- Power: 0.75 HP
- Flow: 954 GPH
- Max Working Pressure: 90 psi
- Max Suction Lift: 17 ft.
- Max Total Head: 203 ft.
- Dimensions: 11.3 x 5.3 x 7.1 [in.]
- Weight: 24 lbs.



Subsystems and Components

Specifications:

- 500 Gallons
  - Enough for system to run for 2.5 hours
- Vertical Tank
- 1 Outlet
  - Connection to Misters
  - Connection to Rainbird ™
- Build on a 4-inch concrete & rebar foundation

Subsystems and Components

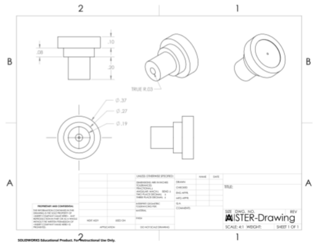
Specifications:

- Baja 900-Watt Propane Powered Inverter Generator
- Runtime: 30 hours
- Power Source: 20 lb Propane tank

Subsystems and Components

Specifications:

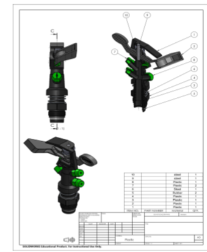
- 0.025 Gallons/min
- 0.7mm and 0.8mm
- 30 psi
- 1 per foot of pipe
- Brass Nozzle
- Alternating mister sizes along the pipe



Subsystems and Components

Specifications:

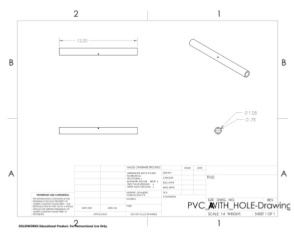
- Impact Sprinkler
- 2.11 Gallons/min
- 30-45 psi
- 1 per 1000 sq-ft of roof
- 30-45 ft radius



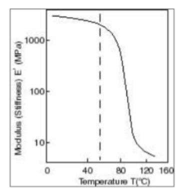
Subsystems and Components

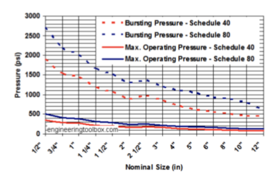
Specifications:

- Schedule 40
- ¾ ID PVC Pipe
- Majority of system

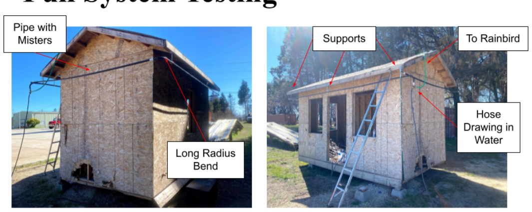


Pipe Characteristics





Full System Testing



8 ft x 16 ft Shed. 1ft overhangs.

Testing

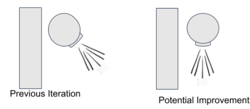
Results and Discussion

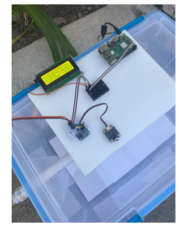
- System was effective in protecting surrounding grass area
- Preventative system against fires
- Theoretical - 3.36 gallons per minute → 2 hr 30 min of protection
- Practical - 2.5 gallons per minute → 3 hr 20 min of protection
- 35 ft defensible perimeter

Santa Clara University 31

Potential Improvements

- Use more suitable sensors
- Full automation from generator to pump
- Water conservation by automating sensors
- Misters angled for more coverage





Santa Clara University 32

Total System Cost

Item	Model	Quantity	Total Price ($)
¾ PVC	SCH 40	6 x 8ft	21.36
Conduit Elbow	SCH 40	4	4.60
Hose Connector	SCH 40	1	3.44
Hose Splitter	Melnor	1	9.98
Hose	HDX	2 x 50ft 1 x 15ft	29.91
Misters	RuoFeng	44 x 0.7mm 44 x 0.8mm	54.76
PVC Primer + Cement	Oatey	1 Primer 1 Cement	7.97
PVC Cap	SCH 40	1	0.69
PVC Connector	SCH 40	5	2.20
Impact Sprinkler	Rainbird	1	8.97
Conduit Hangers	Oatey	4	9.98
Pipe Hanger Strap	Oatey	1 x 10ft	2.97
Thread Sealant Tape	Husky	1	1.98
Metal Adapters	Everbilt	5	51.97
Valve	Everbilt	1 x 3/4 inch	19.74
Pump	SAER-USA	1 x 30 PSI	149.97
Generator	Champion	1	479.00
Water Tank	Norwesco	1 x 500 gallons	427.60
Wood Screws	Everbilt	1	9.48

Total: $868.97 without water tank
$1,296.57 with water tank

Santa Clara University 33

Pamphlet

Santa Clara University 34

35

36

Acknowledgements

★ Dr. Godfrey Mungal
★ Ken and Lizanne Jensen
★ Chief Gonzalez
★ Ryan Walter (firefighter)
★ Nina Lavelle (firefighter)
★ Captain Tom Kaska
★ Chief Tom Shevenell
★ Engine 1767 Bonny Doon Station

Dr. Mungal

Chief Gonzalez

Ken and Lizanne Jensen

Engine 1477 posing as Engine 1767

Santa Clara University 37