Implementing a New Drying Oven at Pacific Can

A Major Qualifying Project

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In Partial Fulfillment of the Requirements for the Degree of Bachelor of Science

By:

Joseph Atchue________________________________

Kyle Chang________________________________

Gilberto Hernandez__________________________

Khoa Tan__________________________________

Project Advisors:

Professor Jianyu Liang______________________

Professor Amy Zeng________________________

Contents

Table of Figures

Table of Tables

Abstract

The largest aluminum can manufacturer in China, Pacific Can's production line washes up to 1500 cans per minute while its oven only dries 1200 cans per minute. Our team collaborated with students from Beijing University of Chemical Technology to optimize Pacific Can's oven to dry an additional 300 cans per minute. A prototype drying oven was designed and built and a scaling analysis was performed to prove that it is feasible for use by Pacific Can.

Acknowledgements

We would like to thank the following:

From Pacific Can:

- The workers who assisted us in building our prototype drying oven,
- Ms. Linna Zhu for being our liaison from Pacific Can, providing us with necessary information, and organizing our visits,
- Pacific Can for making this project possible and giving us the opportunity to visit and work in your factory

Beijing University of Chemical Technology (BUCT):

- Professor Li and the BUCT student team who helped us along with our project and assisted us in gathering the necessary materials for our prototype,
- The student volunteers for being so hospitable to us during our stay and showing us around Beijing

Worcester Polytechnic Institute (WPI):

- Professor Jiangyu Liang and Professor Amy Zeng for advising our project and helping us grow as a team and individuals,
- The faculty and staff at WPI and the Interdisciplinary and Global Studies Department (IGSD) for providing us with the opportunity to work on this project

Authorship

Abstract - Drafted by Joseph Atchue

Executive Summary - Drafted by All

1 Introduction - Drafted by Khoa Tan

2 Background

- **2.1 -** Drafted by Joseph Atchue
- **2.2 -** Drafted by Joseph Atchue
- **2.3 -** Drafted by Joseph Atchue
    - **2.3.1 -** Drafted by Joseph Atchue
    - **2.3.2 -** Drafted by Joseph Atchue
    - **2.3.3 -** Drafted by Joseph Atchue
    - **2.3.4 -** Drafted by Joseph Atchue
    - **2.3.5 -** Drafted by Joseph Atchue
- **2.4 -** Drafted by Joseph Atchue
    - **2.4.1 -** Drafted by Joseph Atchue
    - **2.4.2 -** Drafted by Joseph Atchue
    - **2.4.3 -** Drafted by Joseph Atchue
    - **2.4.4 -** Drafted by Joseph Atchue
- **2.5 -** Drafted by Joseph Atchue
    - **2.5.1 -** Drafted by Joseph Atchue
    - **2.5.2 -** Drafted by Joseph Atchue
    - **2.5.3 -** Drafted by Joseph Atchue

2.5.4 - Drafted by Joseph Atchue

2.6 - Drafted by Joseph Atchue

2.6.1 - Drafted by Joseph Atchue

3 Methodology

3.1 - Drafted by Joseph Atchue

3.2 - Drafter by Joseph Atchue

3.3 - Drafted by Joseph Atchue

3.4 - Drafted by Gilberto Hernandez

3.4.1 – Drafted by Gilberto Hernandez

3.4.2 – Drafted by Gilberto Hernandez

3.5 - Drafted by Khoa Tan

3.5.1 - Drafted by Khoa Tan

3.5.2 - Drafted by Khoa Tan

3.5.3 – Drafted by Khoa Tan

3.6 - Drafted by Joseph Atchue

3.7 - Drafted by Joseph Atchue

3.8 - Drafted by Joseph Atchue

4 Results and Analysis

4.1 - Drafted by Khoa Tan

4.2 - Drafted by Gilberto Hernandez

4.3 - Drafted by Gilberto Hernandez and Khoa Tan

4.3.1 - Drafted by Khoa Tan

4.3.2 - Drafted by Gilberto Hernandez

4.3.3 – Drafted by Gilberto Hernandez

4.4 - Drafted by Joseph Atchue and Khoa Tan

4.4.1 - Drafted by Khoa Tan

4.4.2 - Drafted by Khoa Tan

4.4.3 – Drafted by Joseph Atchue

4.5 - Drafted by Joseph Atchue

5 Conclusions and Recommendations

5.1 - Drafted by Joseph Atchue

5.2 - Drafted by Gilberto Hernandez

5.3 - Drafted by Joseph Atchue and Kyle Chang

5.3.1 - Drafted by Kyle Chang

5.3.2 - Drafted by Kyle Chang

5.3.3 - Drafted by Joseph Atchue

5.4 - Drafted by Joseph Atchue and Kyle Chang

5.4.1 - Drafted by Joseph Atchue

5.4.2 - Drafted by Joseph Atchue and Kyle Chang

Appendices - Drafted by All

Edits - Edits for style, grammar, and content were made by All

Executive Summary

Problem Statement

Food and beverage industries from around the world partner with packaging companies in order to increase their profits. For example, the aluminum can is a common container for beverage products. Beverage aluminum cans are made of about 70% recycled contents, three times higher than either glass or plastic bottles. Additionally, about 54.5% and 64.3% of aluminum cans are recycled by consumers and by the industry, respectively (The Aluminum Association, 2016).

Major beverage corporations, such as Coca-Cola and Pepsi, have continued to make use of aluminum cans because it conserves costs. Currently, worldwide a total of 200 billion cans per year were manufactured, or 6,700 cans per second (The World Counts).

Our sponsor, Pacific Can, is one of Asia's main can producers, being both innovative and sustainable with its production. Over the last 20 years, Pacific Can has aimed to maintain its principles defined in its acronym SCPTT: Serving our customers, Commitment to quality, Product variety and innovation, The environment, and Team spirit. They have been successful in the adaptation of new technologies that have replaced the 3-piece can with the 2-piece can (Pacific Can, 2011). They are constantly researching new methods in order to reduce the costs of production and to make their processes more sustainable, including their drying process.

Our team is tasked with improving Pacific Can's older of its two drying ovens in order for it to increase its drying rate from 1,200 cans per minute to 1,500 cans per minute. The goal is to design and build a prototype of a new drying oven for use by Pacific Can to increase its productivity, and also to reduce costs and improve sustainability.

Goal and Objectives

Pacific Can's greatest need, and our overall goal for this project, is to design and build a prototype of a new and more productive drying oven to replace the older production line's drying oven. Previous WPI MQP teams have tackled problems for the company to optimize their oven, so we analyzed their designs as well as the current design of the older drying oven in order to improve upon them. We propose that our goal can best be achieved through the completion of these four objectives:

- The analysis of Pacific Can's current drying process;
- The analysis of the results and recommendations of previous MQP teams;
- Experimentation with cans using our prototype drying oven;
- Design of a workable and sustainable model that can be implemented by Pacific Can;
- Scaling up to the industrial level.

Methodology

Our four objectives were achieved using the following methods. We analyzed the current drying oven in use by Pacific Can and used that as a base in which to build off with our own ideas. We also analyzed previous MQP designs and took their recommendations into account, making improvements along the way. We used previous and current designs in order to design our own drying oven using CAD/SolidWorks, and then bought the necessary materials to build a prototype with the help of Pacific Can's engineers. We then experimented using our own prototype and 20 numbered cans in order to gauge the drying oven's productivity in terms of drying percentage.

After our design, building, and experimentation, we analyzed the energy needed to scale up the project as well as building material and cost-effectiveness. Each of the methods were completed in a timely manner thanks to our team's following of a Gantt Chart detailing our project's timeline.

Results & Analysis

After building the prototype we started experimenting. Our prototype was built based on Pacific Can's current drying process and added on last year's MQP drying oven. The energy source for Pacific Can's current oven is natural gas, and we have replaced that to infrared (IR) ceramic tubes in our prototype to save energy while obtaining a similar result.

The procedure of the experiment is as follows: First, 20 cans are numbered and weighed to obtain their original mass. Second, we wet the cans and weighed them again. Third, the cans went through the oven and were weighed after they were dried. We compared the weight of the cans before and after to calculate the percentage of water that was evaporated during the drying process. We completed six trials in total by wetting and drying the cans in different methods.

- The first trial dried 5 cans at a time in 4 sub-trials at varying speeds; the sub-trial's drying percentages were 80.25%, 99.10%, 36.89%, and 67.36% at 1:57, 1:57, 0:32, and 1:26 respectively.

- The second trial dried 5, then 15 cans in 2 sub-trials at varying speeds; the drying percentages were 71.88% and 96.59% at 1:30 and 1:55 respectively.
- The third trial dried 20 cans at once with a drying percentage of 94.09% at 1:55.
- The fourth trial dried 20 cans at once after they received an additional spray to each can's inside; the drying percentage was 76.89% at 1:55.
- The fifth trial dried 20 cans at once after being submerged in water; the drying percentage was 93.70% at 3:40.
- The sixth trial dried 20 cans at once with both the air-dry and the underside infrared tubes from last year's team activated; the drying percentage was 97.78% at 3:20.

Our drying oven prototype was designed using SolidWorks and built with the help of Pacific Can's engineers. The new concept that we proposed this year include implementing a heat exchanger, IR ceramic tubes, and an evaporator. IR ceramic tubes are able to save up to 30% more energy than the traditional infrared tubes. We decided to incorporate a heat exchanger because last year's design was not able to take out the excess moist air. The evaporator can help suck out the water vapor even better than without one.

Scaling up calculation was performed, and energy calculation showed that a total of 951 IR tubes needed to dry extra 300 cans per minute. The number of the tubes could be lower as the calculation was a rough estimated without precise measurement and the cans only withstood 240°C. Material analysis proved that brick and concrete were the two most suitable among all common materials due to their high thermal resistance, melting point and low price. However, brick was more easily shaped than concrete was, our team finally recommended using brick for the design instead of concrete. According to the analysis of cost-effectiveness, the capital cost was up to 25,608 yuan, while the profit of the increased production is 1,273.91 yuan per hour. From that, the payback time was 20.11 hours, which was even less than a full time operating day.

Conclusions & Recommendations

We recommend that Pacific Can adopt our team's new drying oven design to their current drying process in their older production line to increase productivity from 1,200 cans per minute to up to 1,500 cans per minute. Our team's drying oven design uses innovative and entrepreneurial techniques to make it more productive, environmentally-friendly, and less expensive to build and operate than their current drying oven.

Our team also incorporated new drying processes into the new drying oven design, namely a heat exchanger and infrared ceramic tubes. The heat exchanger will be able to circulate the hot and moist air to keep a continuous flow throughout the drying process. The infrared ceramic tubes are cheaper to operate than natural gas, and they are also more environmentally-friendly and easier to control than natural gas.

There were some constraints that our team was presented with during the course of the seven-week project. One of the these was the language barrier, which was helped somewhat by having a native-speaker on our team. Another constraint was the restricted access to information via the internet, which was remedied through the use of a VPN. The seven-week time period of the project was also a large constraint, restricting our research and designs to a limited number of iterations. A final constraint to our project was the difficulty in obtaining materials to build the prototype with, which was helped through the assistance of Pacific Can and the Beijing University of Chemical Technology (BUCT) student team.

Our team's drying oven design is very effective in drying cans, as determined through our experiments, but there is still work that can be done to improve the drying process. We recommend that future MQP teams buy or build an evaporator, to be able to take out most of the moist air that circulates back into the heating room. We also recommend that future teams better design the vent to more evenly distribute the air inside the drying oven, therefore drying the cans more thoroughly.

1 Introduction

The food and beverage industries partner with packaging companies, and become some of the most profitable industries in the world. These packaging companies are one of the main keys leading to their profits with their manufacturing and production of containers such as cans, boxes, bottles, etc. However, these types of production chains generate a tremendous amount of waste, polluting the air, water, and ground. Awareness of pollution has reached consumers and big corporations, and actions have been taken to lessen their carbon footprint.

The beverage industry in particular, has adopted the aluminum can as its main method to contain their products. Companies and customers prefer cans when it comes to multi-packets and non-alcoholic beverages. Additionally, aluminum cans are made of about 70% recycled contents, three times higher than glass or plastic bottles. Furthermore, about 54.5% and 64.3% of aluminum cans are recycled by consumers and by the industry, respectively (The Aluminum Association, 2016). These facts have driven many big beverage corporations (such as Pepsi and Coca-Cola) to continue their focus to aluminum cans to conserve costs. However, manufacturing a total of 200 billion cans per year, or 6,700 cans per second (The World Counts), can cause beverage corporations to overload their other productions. This reason has led to the rise of third-party companies that primarily produce aluminum cans for establishing business relations with beverage companies. Our sponsor, Pacific Can, is one of Asia's main can producers that tries to not only innovate the production, but also keeps it sustainable.

Over the last 20 years, Pacific Can has always tried to maintain its principals defined as the acronym SCPTT (Serving our customers, Commitment to quality, Product variety and innovation, The environment, and Team spirit). They have successfully adapted new technologies in the replacement of the 3-piece can with the 2-piece can (Pacific Can, 2011). With the success in their products, Pacific Can not only has the ability to compete with other advanced companies in developed countries, but also maps itself on the global market with its variety of can types for their customers' needs. Additionally, Pacific Can is researching methods to reduce the cost of the production and to make the process more sustainable.

The drying process is one of the company's areas where it wishes to improve. After Pacific Can manufactures its cans, they are bathed to rid them of impurities before going into a drying oven. Groups of Worcester Polytechnic Institute (WPI) undergraduate students have been asked and sponsored to improve the oven's efficiency and cost-effectiveness.

Based on previous results and designs, our team has picked up on research from previous WPI students and decided on the objectives for our project. The first objective is to indicate the optimal conditions to operate the drying units. The second objective is to scale up the design to an industrial level. To achieve these objectives, literature review will be discussed for understanding of the heating unit. After that, methodology section will map out the steps on how the literature and understandings can be applied and tested. The next section will be the results explaining the final design and findings followed by the conclusion, which includes our own opinions about the project.

2 Background

In order to move forward with our project's experiments, designs, and final results and recommendations, we first had to do some background research on any necessary processes and the science of technological aspects that planned to implement. We also analyzed the previous findings, experiments, designs, and recommendations of the two previous MQP teams who have tackled this specific project. We looked into innovative entrepreneurial practices and engineering processes, as well as the use of infrared and heat exchanger technologies, convection and radiation as energy transfer sources, and the use of various drying technologies and techniques throughout different industries.

2.1 Innovation & Entrepreneurial Practices

Systematic innovation can be defined as "the purposeful and organized search for changes and the systematic analysis of opportunities such changes might offer for economic or social innovation." (Andre Kearns, 2009) Innovation always begins with analyzing opportunities at hand, and is simple and focused in order to find an optimal solution for a design or process. Innovation should start small, aimed at just one solution that focuses on fixing a "weak link" in an otherwise efficient and working process. In our case, our team is tasked with coming up with a more productive drying design or process to replace Pacific Can's older air-dry blower.

Entrepreneurship deals with the entrepreneur who searches for change, responds to it, and exploits the change as an opportunity (Andre Kearns, 2009). Many entrepreneurs deal with designing, launching, and running a new business venture, but in our project's case, we must use innovation to propose a new and more efficient business venture for Pacific Can to take on as their own. Our design will aim to be both environmentally-friendly and productive: two things that Pacific Can are looking for in their new drying process. We will study and analyze previous MQP reports in order to draw useful ideas in our attempt at a feasible drying process.

Furthermore, an environmentally-friendly process will benefit Pacific Can because it will take less energy for the company to run it. It will also be more cost-effective because the air-dry blower that the company already has in place will not have to be run at such high temperatures, thus saving energy and money through our new proposed drying process.

We will keep an entrepreneurial mindset as we work through some of the innovative ideas that we will propose to Pacific Can. We will choose the most productive and sustainable design or process that we will come up with, propose it to Pacific Can, and even mention the possibility of its use in their other facilities.

2.2 Manufacturing & Drying Processes of Other Industries

Most of the aluminum can manufacturers in the world use the same manufacturing process (Aluminum Beverage Can, 2017). The process is called a two-piece drawing and wall ironing process, beginning with an aluminum ingot that is cast to be 30 inches (76 cm) thick, which is then rolled into a sheet. The sheet is then cut into a circle, which is called a blank, thus forming the bottom and the sides of the can for later on in the process. Each of the blanks are 5.5 inches (14 cm) in diameter. The aluminum blank is then cut and “drawn” (pulled up) to form a cup that is 3.5 inches (8.9 cm) in diameter. The cup is drawn yet again to form a body that is put into a lubricated body maker, where it is cut to its desired size. Prior to being capped with a lid, the can is put through both a washing and drying process.

Most aluminum can manufacturers use a six-stage washing cycle for their cans. The first two steps of this washing cycle consists of a wash in hydrochloric acid, sulfuric acid, or a patented solution of the company's choosing. The final four steps of the washing cycle consist of washing the cans with deionized water. The next step is the drying process.

Different drying processes exist for different aluminum can manufacturers, but most of them fall into one of two types of dryers: either hot-air dryers/blowers or ovens. Each of these two drying processes can reach anywhere between 170 degrees Celsius to 200 degrees Celsius or higher. Pacific Can currently uses a hot-air dryer/blower that fluctuates between 170 degrees Celsius and 240 degrees Celsius.

2.3 Engineering Concepts

Throughout the course of this project, our team utilized various engineering techniques and skills in order to achieve our objectives, and then our final goal. We decided to include this section based on its inclusion in previous MQP reports on this project, and we have concluded that it can only help us with our project by including it.

2.3.1 Engineering Design Process

The engineering design process is a series of steps taken by engineers that can help them come up with solutions to a problem, often involving the design of a product or process (The Engineering Design Process, 2002). The steps of this process are outlined as followed:

1. Define the problem that you must find a solution to.
2. Do background research on all necessary topics that will need to be covered in order to solve the problem.
3. Specify any requirements that have been laid out to you.

4. Come up with ideas for solution evaluate them, and choose one to proceed with.
5. Come up with a solution.
6. Test that solution to see how well it compares to the previous design or process.
7. Results are then communicated/relayed to the person or company that sought out your help with their problem.

See Chapter 4 for how each step is carried out specifically. Through the use of this process, our team will be able to organize our ideas and carry them out to completion to figure out how useful they are in helping Pacific Can with their problem.

2.3.2 Systems Thinking

Systems thinking can be defined as the understanding of the interdependence of structures within a dynamic system of systems (What is Systems Thinking?, 2017). An example of this idea is an ecosystem: an ecosystem needs air, water, movement, plants, and animals to work together to either survive or perish (Gaia, 2017). Some have to live and some have to die in order to keep the system (in this case, the ecosystem) in working order. To relate this back to Pacific Can, our team must take into account the other processes involved in the manufacturing process when thinking up ideas that would not only affect the drying process, but also other parts of the manufacturing line as well.

2.3.3 Design of Experiments

Designing experiments involves a systematic method that is used to determine the relationship between factors affecting a process and the outcome, or outcomes, of that process (K. Sundararajan, 2000). In short, this method is used to determine cause-and-effect relationships. Information is also needed in order to manage process inputs to optimize output. There are certain statistical tools and experimentation concepts that should be understood about Design of Experiments (DOE).

Controllable input factors are “those input parameters that can be modified in an experiment or process.” For example, cooking rice requires the correct quantity of water and the correct quantity and quality of rice. Uncontrollable input factors are “those parameters that cannot be changed.” Going back to the rice example, the temperature in the kitchen as the rice cooks cannot always be controlled. Responses or output measure are “the elements of the process outcome that gauge the desired effect.” The responses of the cooked rice example are its taste and texture.

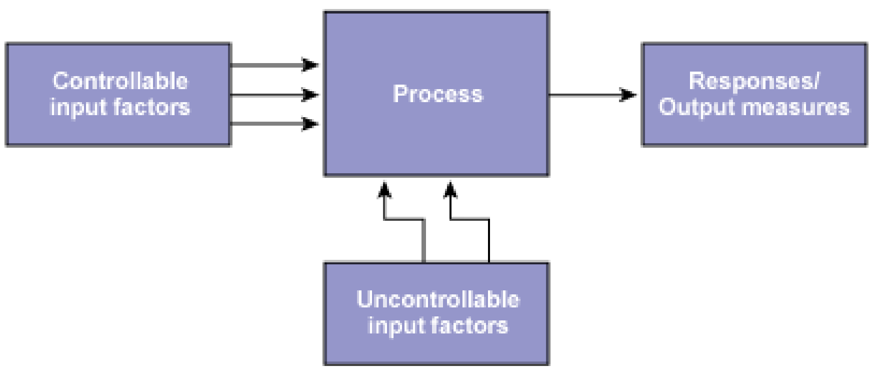


Figure 1: Design of Experiments (K. Sundararajan, 2000)

The approaches to an experiment for analysis is threefold (What is Design of Experiments (DOE)?, 2017):

- **Blocking** occurs when a factor is too costly or just impossible to randomize, allowing the restriction of randomization by carrying out the trials with one setting of the factor, and then all the trials with the other setting.
- **Randomization** refers to the order in which the trials of an experiment are performed, allowing for the elimination of effects of unknown or uncontrolled variables.

- **Replication** is the repetition of a complete experimental treatment, including the setup of the experiment.

Experiments are an important part of finding a solution to a design or process problem that requires a new, innovative way of working, so it is important for our team to follow these guidelines when designing experiments for the purpose of finding a solution to Pacific Can's drying process predicament.

2.3.4 Cost-Benefit Analysis

In order to determine a new, viable drying process for Pacific Can, part of the solution must include a savings from the previous drying process, which is where a cost-benefit analysis comes in. A cost-benefit analysis begins with the identification of the costs and benefits of both the current process and the new process that is to be recommended (David Frederick, 2011). Next, the costs and benefits are calculated for both the current and the new processes. Aggregate costs and aggregate benefits are then compared between the old and the new processes. Just as a side note, future costs include both up-front costs and any future costs caused by the implementation of the new process. An ROI (return on investment) equation, which is based on efficiency, revenue, or market share, can be used to more accurately calculate future revenue.

$$\text{ROI} = \frac{(\text{Gain from Investment} - \text{Cost of Investment})}{\text{Cost of Investment}}$$

Figure 2: Return on Investment Equation (Return on Investment, 2017)

A timeline should also be made of the predicted future costs and benefits to specifically define expectations and to manage the costs and revenue impacts on the operations.

2.3.5 Sustainability

Sustainable development made its debut in 1992 by Gro Bruntland, former Prime Minister of Norway and the Chair of the Bruntland Commission, at the United Nations Conference on Environment and Development (The Importance of Sustainability in Engineering Management, 2016). Sustainable development can be defined as the "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs." Sustainability, to shorten the term, influences economic, social and environmental development today through its use by world leaders. Engineering management has a real need to adopt sustainability in this day and age because of the "increasing pressure on air and water, arable land, and raw materials."

Advantages of adopting sustainable engineering and business practices, which I am sure the managers and engineers at Pacific Can would be keen to listen to, are as follows:

- Adding value to the owner;
- Reducing operation costs;
- Reducing complaints;
- Increasing the market value of building.

In order to become more sustainable, as is the case for Pacific Can, a company needs to become more energy and mass efficient, in addition to lowering their environmental emissions, which our project aims to do for Pacific Can.

Sustainability is especially needed in China because of its extremely quick shift from being an agrarian society to becoming a blossoming urban and consumption-centered society (Richard Brubaker, 2014). China's environmental degradation is almost exclusively caused by its harmful and wasteful industrial practices, but it continues because it is also the cause of China's great economic development. For the time being, China is more focused on "accessing and managing the resources that its cities will need to grow, while reducing the emission that are contaminating its air, water, and soil." Sustainable engineering can make China become more energy-efficient, which it desperately needs, and our team can help China reach that goal just a little bit by making Pacific Can's drying process more sustainable and cost-effective.

2.4 Infrared Energy

Infrared radiation has many variations and uses in various applications. Infrared radiation can be used for military, civilian, astronomical, and even medical purposes. But for our purposes, we are going to focus on infrared radiation's ability to heat things up very quickly and very efficiently. Since infrared radiation can heat up very quickly and efficiently, it is also a viable drying process in many industrial settings, which is good news for both us and Pacific Can.

2.4.1 Infrared Applications

Infrared (IR) light is the electromagnetic radiation that has longer wavelengths than those of visible light, which would be from about 0.74 micrometers to 300 micrometers (Infrared Waves, 2017). The frequency of infrared light is thus 1-400 THz (Terahertz), accounting for much of the thermal radiation emitted by objects near room temperature. Much of the sun's energy that reaches the Earth is in the form of infrared radiation, emitting 527 Watts of power. There also exists a delicate balance between what is emitted and what is absorbed, when it comes to infrared radiation, which makes the Earth's climate particularly sensitive to it.

The uses of infrared radiation are many and varied. It is used in such fields as industrial, scientific, astronomical, medical, and even military (Infrared Waves, 2017). Infrared light is used in night-vision devices to allow people to observe things in the dark without being detected themselves. For astronomical purposes, infrared wavelengths allow for the observation of objects that are obscured by interstellar dust. Infrared imaging cameras are used to detect heat loss in insulated systems, to observe changing blood flow in the skin, and also to detect overheating of an electrical apparatus. In the military, it is used for target acquisitions, surveillance, night vision, homing and tracking. Cosmetically speaking, infrared radiation can penetrate the skin up to 3-4 millimeters (mm), warming the body and the skin by stimulating blood circulation. In addition to that, it can also release dead cells from the skin, expel harmful toxins from the body, helps with weight loss, improves the ease of digestion of fatty tissues, opens up skin pores and purifies them, and makes skin more elastic and smooth.

2.4.2 Infrared Heating

There are many types of infrared tube heaters, but through our analysis of previous MQP reports, we have decided to move forward with quartz tube heaters. Quartz tube heaters are able to turn on and off very quickly, which is a useful property when it comes to a manufacturing line and saving money and energy (Quartz Tube & T3 Halogen Lamps, 2017). Infrared heating uses radiation as its source of heat transfer, and it transfers 200 W of power per 1 linear inch. To go along with its ability to turn on and off quickly, quartz tubes can also heat up and cool down very quickly, thus saving energy and money (Why Choose Solaira Infrared Technology, 2015). These specific types of tubes can reach up to 1600 degrees Fahrenheit (871.11 degrees Celsius), and have a radiant efficiency of 60%. The most commonly used heater is the 1.5 kilowatt (kW) heater, which would cost only $0.11-0.27 per hour (which at the current exchange rate would be about 0.75-1.83 yuan per hour). These heaters are also very sustainable, because they do not require very much energy, and they also do not emit any carbon monoxide or nitrous oxide gas. Minimal maintenance and no required ventilation because of no fumes also saves even more money.

2.4.3 Radiation Heat Transfer

Infrared heaters use radiation as its form of heat transfer. Radiation is the form of heat transfer that uses electromagnetic waves, most commonly in the infrared region (Radiation Heat Transfer, 2017). This type of heat transfer comes about through the thermal agitation of its composing molecules, and an example of radiative heat transfer comes from the sun. The equation for radiation heat transfer is as follows:

$$\dot{Q} = \varepsilon \sigma A \left(T_{hot}^4 - T_{cold}^4 \right)$$

$\dot{Q}$ Rate of heat transfer

ε Surface emissivity

σ Sthepan Boltzmann constant

Figure 3: Radiation Heat Transfer Equation (Radiation Heat Transfer, 2017)

With the difference in T being the difference in temperatures between the material of higher temperature and the material with the lower temperature. A is the surface area of the material that is receiving the radiation energy. The surface emissivity coefficient depends on the type of material and the surface temperature of the material. The Stephan-Boltzmann constant is 5.6703*10^-8 W/(m^2) *(K^4). The rate of heat transfer (Q) is the amount of energy per unit time (J/s).

2.4.4 Infrared as a Viable Drying Process

As stated previously, infrared radiation can be used as a viable heating source, and is becoming ever more popular in industrial manufacturing processes; i.e., curing of coatings, forming of plastics, annealing, plastic welding, and print drying (What is Infrared Drying, 2017). Infrared heaters are able to add to and even replace convection ovens and contact heaters. These infrared heaters consist of infrared light bulbs, a heat exchanger, and a fan that blows air onto the heat exchanger to disperse the heat.

Infrared heating, or infrared drying, involves heat transfer through the process of radiation between a hot element and a material at a lower temperature that needs to be either heated or dried (Infrared Waves, 2017). There is no intermediary element, such as air or water, that is needed in order for the infrared radiation to heat up or dry another material. The infrared system uses either gas emitters or electrical lamps as its hot elements, aligned in order to create a heating surface. The efficiency of infrared heaters makes it a logical choice for use in industrial production processes, such as drying, preheating, curing, scorching, and etc. The advantages of using infrared heater instead of conventional drying and heating systems are:

- Infrared requires no direct contact with the material to be heated or dried;
- There is a high drying/heating rate with the material that is to be heated;
- Infrared radiation can be focused where it is specifically needed;

- Infrared emitters can be adjusted to fit the material properties and geometry that is to be heated;
- There are great cost savings because it is very efficient overall and the optimal lifetime of infrared heaters.

All of the advantages that go along with using infrared heaters make it a logical choice to move forward with as an addition to Pacific Can's current drying process.

2.5 Heat Exchangers

In addition to the use of infrared heaters in our design for a new drying process for Pacific Can, we also incorporated a type of heat exchanger into the final design. Our initial idea for this came about because our design is basically an improvement on the old oven, which was a type of heat exchanger. Our research on heat exchangers and their applications gave us a better idea on how to improve the old oven. Heat exchangers are also used in industrial drying processes, which was a deciding factor in its incorporation into our final design. The type of heat transfer that heat exchangers use is convection, which will be used in conjunction with radiation heat transfer, used by infrared heaters.

2.5.1 Heat Exchanger Applications

Heat exchangers, more specifically industrial heat exchangers, are equipment designed in order to exchange or transfer heat from one medium to another (STI Group, 2014). The primary purpose of a heat exchanger is to heat up an element or to cool it down. Industrial heat exchangers have a very broad range of industrial applications. They are used as components in air conditioning and heating or cooling systems. There is a certain degree of heat that must be present in industrial processes in order for them to function; however, great care must be taken to keep these processes from overheating. Heat exchangers are used within many industrial plants and factory heat exchangers to keep machinery, chemicals, water, gas, and other substances within safe operating temperatures.

Heat exchangers can also be used to capture and transfer steam or heat exhaust that is released as a byproduct of a process or operation so that steam or heat can be put to better use elsewhere, thereby increasing efficiency and saving the company energy, and therefore money as well. This is where the application of a heat exchanger can be useful in the design for a new and improved drying oven in Pacific Can’s factory.

There are different ways in which different types of heat exchangers function, but all heat exchangers function to directly or indirectly expose a warmer medium to a cooler medium, or in other words, exchanging heat. The parts of a heat exchanger can include tubes housed in some type of casing, heat exchanger fans, condensers, belts, coolants, additional tubes and lines, and other components and equipment that can be used to increase heating and cooling efficiency to improve flow.

Heat exchangers are also classified into one of four metrics:

- The nature of the heat exchange process;
- The physical state of the fluids;
- The heat exchanger’s flow arrangement;
- The design and construction of the heat exchanger.

The first classification of heat exchangers deals with whether or not the substances between which the heat is being exchanged come into direct contact with each other or not; whether or not a physical barrier separates the substances or not, such as walls or tubes. Direct contact heat exchangers rely on conductive heat transfer, while indirect heat exchangers rely on convective or radiative heat transfer. The second classification of heat exchangers deals with the physical states of the hot and cold fluids, for example, liquid-gas, liquid-solid, or gas-solid. The third classification of heat exchangers deals with the arrangement of the hot and cold fluid’s flow within the heat exchanger. There are three types of flow arrangement: parallel, countercurrent, and cross. Parallel-Flow heat exchangers have the hot and cold fluids enter the heat exchanger from the same end and flow parallel to each other. Countercurrent-Flow heat exchangers have the hot and cold fluids enter the heat exchangers from opposite sides and flow toward each other. Cross-Flow heat exchangers have the hot and cold fluids enter the heat exchanger at different points and as they travel throughout they cross paths at different points, often at right angles. The fourth and final classification of heat exchangers deals with the design and construction of the heat exchanger, which can vary depending on its application and the space in which it will be used.

2.5.2 Heat Exchangers in Industrial Drying Processes

There are various temperature levels and drying principles used in industrial dryers. Some of the most common types of industrial drying processes involve the heating of air with steam, gas or hot water that is then circulated over the wet product (Industrial Heat Pumps, 2017). The air that dries the wet product picks up moisture from said wet product, increasing its humidity and also the energy contained within the steam, making it a useful heat source. The standard procedure is to exhaust this humid air in order to dehumidify it, and by using a heat pump, heat can be extracted from the humid air. The air is then cooled down and dehumidified, leaving the extracted heat to be increased in temperature and used to heat the dryer. A heat pump, being a part of a heat exchanger, thus serves two purposes: heating the dryer and dehumidifying and recirculating the air. Efficiency of drying can be very high through the use of a heat pump in conventional industrial air drying processes.

A heat pump dryer used in an industrial drying process is described below:

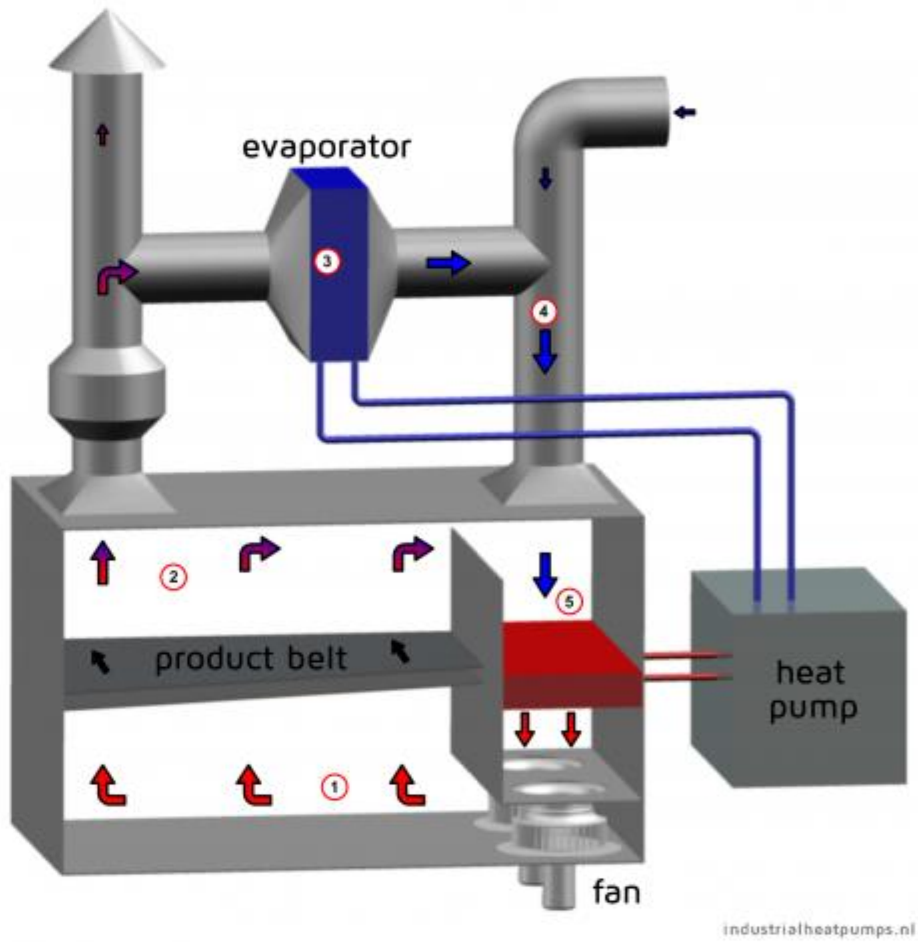


Figure 4: Heat Pump Dryer (Industrial Heat Pumps, 2017)

Hot air (1) is circulated over a product belt inside the actual dryer. Temperature of the air will decrease as its humidity increases during this cycle in the drying process. About one-third of the cool, humid air (2) is then circulated over the evaporator. The air is further cooled inside the evaporator even further below the condensation temperature (3). Below this temperature, the air will be dehumidified. The cool, dry air (4) is then mixed with the circulated air from the dryer. The mixture of air (5) is heated to the desired drying process temperature for that industry (or company) within the condenser. This air can then be reused in the drying process (1). This is a fully-closed, functional drying process that can be translated to help Pacific Can with their own drying process.

2.5.3 Convection Heat Transfer

Convection heat transfer can be defined as the flow of energy through the mass movement of matter from a hot region to a cooler region (Convection, 1999). It is the macroscopic movement of matter. The way it works is thus: the heating of a local region of air spreads out those air molecules in the cooler region, thus making it less dense than the unheated, surrounding air.

An example of convective heat transfer can be seen in the heating up of a pot of water on a stove. The initial transfer of heat from the stove to the pot of water is conductive heat transfer, but becomes convective once the water begins to bubble (or boil). Those bubbles of hot, localized water reach the surface of the water pot, transferring their heat to the cooler water at the top of the pot via convection. The cooler, denser water at the top of the pot is then forced to the bottom of the pot, where it is heated, and then rises to the surface of the water yet again. The path that the bubbles follow is called a convective heat current, and many are formed this way.

The equation for convection is as follows:

$$q = h_c A \Delta T$$

where

q = heat transfered per second in Joules

A = area of the surface in meters squared

h_c = convection coefficient $(W/(m^2K)$ or $W/(m^{2o}C))$

ΔT = temperature difference

Figure 5: Convection Heat Transfer Equation (Convective Heat Transfer, 2017)

Heat exchangers utilize convective heat transfer, which is one part of the solution that our team is willing to propose to Pacific Can to replace their older and less efficient hot-air dryer/blower.

2.5.4 Heat Exchangers as a Viable Drying Option

As stated previously, heat exchangers are used in industrial drying processes, and they are very efficient at completing this task. Heat exchangers can also be used in these drying processes to save energy, and therefore money, by being used as a heat recovery system to reduce drying times (Dryer Heat Recovery Systems, 2000). An example of a viable heat recovery system can be seen in a typical clothes dryer. A typical clothes dryer draws in heat from the outdoor air, heats the air, and distributes it throughout the clothes. After the circulation of the air throughout the clothes, the air is exhausted, taking with it moisture and heat from the wet clothes in the dryer. In order to recover the exhausted heat, and air-to-air heat exchanger can be installed so that the incoming air is preheated by the hot exhaust air. The gas burner, or whichever heat source is used, therefore is able to operate less, saving money, all because the incoming air is preheated.

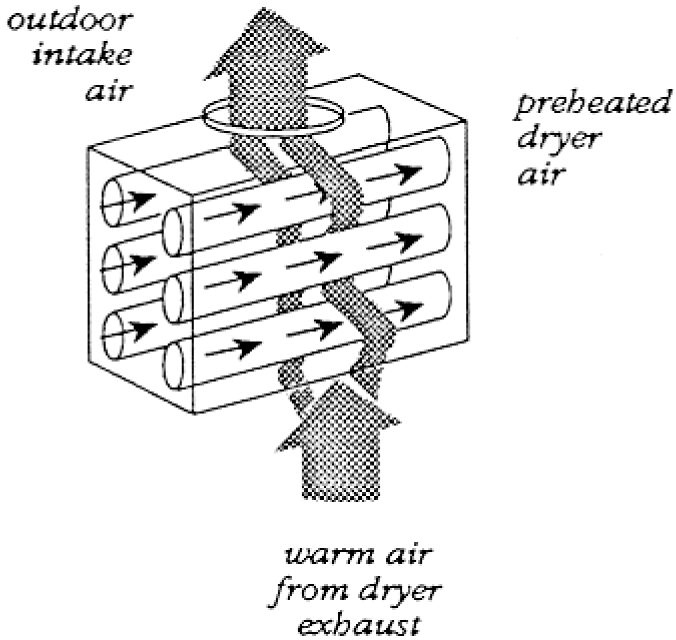


Figure 6: Dryer Heat Recovery System (Dryer Heat Recovery Systems, 2000)

Although this type of dryer heat recovery system is applied to typical laundry dryers, the concept and process can be applied to larger, more industrial drying processes. Such applications can be copied and morphed to fit a new design for Pacific Can's old drying oven.

2.6 Ceramics

Ceramics are used in a wide variety of industries, being used as the lining for many different types of ovens, such as furnaces, ovens, kilns, and other high-temperature devices (About Ceramics, 2008). In addition to making up certain types of ovens, ceramics can also make up refractory materials that are used to line high-temperature furnaces found in certain production lines and facilities. Ceramics are excellent insulators, being used in high-tension insulators because of that property, which means that they can hold heat very well without giving it off. They can be up to 40% lighter than comparative metals, and unlike most metals, ceramics are much more resistant to oxidation and corrosion. Ceramics are also resistant to high temperatures, which allows them to be used in place of cooling equipment and in the place of metals that could not withstand such high temperatures.

2.6.1 Ceramic Ovens

As stated previously, ceramics can make up a wide-range of ovens used in varying industries. Some examples are large baking ovens because they have the ability to hold heat in very well, kilns to fire pottery, high-temperature furnaces to forge metal, and etc.

The properties of ceramics that make them so well-suited for use as and in ovens are their low thermal conductivities and their high specific heat capacities. Using these two very important facts about ceramics, our team is going to move ahead with our idea of replacing the metal oven that Pacific Can currently uses to dry their aluminum cans with a ceramic oven (either fully or lined on the inside with ceramic refractory materials) that will be able to hold the heat from a heat exchanger so well that it would not have to run continuously throughout the day. Not having to run the heat exchanger all day would cut back on energy consumption and costs, which would fall right in line with what Pacific Can wants from this project.

3 Methodology

The goal of this project was to assist Pacific Can with their drying process by designing and recommending a more efficient and cost-effective drying system that could be implemented into their manufacturing line. There have been previous teams of WPI students who have tackled this same project for Pacific Can, and our job this year was to analyze previous teams' recommendations, and also to incorporate some ideas of our own. We have completed our project goal through the following objectives:

- The analysis of Pacific Can's current drying process;
- The analysis of the results and recommendations of previous MQP teams;
- Experimentation with a larger amount of cans than previous MQP teams;
- Design of a workable and sustainable model that can be implemented by Pacific Can;
- Scaling up to the industrial level.

3.1 Analysis of Pacific Can's Current Drying Process

To get a better understanding on how to improve upon the current drying process taking place at Pacific Can, our team took a trip to the facility to take a more complete look at the drying process of Pacific Can's older and less productive drying process. We were given information about both the new and the old drying processes in place on both of the production lines. The newer drying oven that they have in place on one of the production lines can dry 3,000 cans per minute, while the washing process can wash 1,500 cans per minute, thus no problem exists there. The older production line uses a far smaller, far less efficient drying oven that can only dry 1,200 cans per minute, while the washing process can still wash 1,500 cans per minute. Therein is where the problem lies: our team must find a solution to make the older drying oven more productive than the current 1,200 cans per minute it can only dry now. While making the new drying oven more efficient, cost-effectiveness and sustainability will be possible added bonuses to our proposed drying process.

3.2 Analysis of Previous MQP's Results & Recommendations

Once our team was able to determine the current productivity (or lack thereof) of Pacific Can's older drying oven, we then focused on the previous results and recommendations of previous MQP teams that have worked on this project.

We have determined that the use of infrared heaters by previous MQP teams was a step in the right direction, when the project's goal was focused more on cost-effectiveness and sustainability. However, our team believes that there still is an upside to using infrared heaters for reasons other than cost-effectiveness and sustainability. Not only could the use of infrared technology save the company money and cut down on energy consumption, it can also heat up and cool down very quickly, thus a viable option to increase Pacific Can's productivity from 1,200 cans a minute to somewhere closer to 1,500 cans a minute, or possibly even more than that.

We have also determined that the previous design that MQP teams have come up with can be a good starting point for our team's own design, being added on to in order to create a drying oven that is even more feasible and productive than it was previously. We will go into the details of our CAD/SolidWorks design(s) in a later section.

3.3 Design & Prototype

As stated previously, our team will also use CAD/SolidWorks to design the drying oven that we will eventually be proposing to Pacific Can to replace the older drying oven that is currently in use in one of their production lines.

Our design of the drying oven will copy some elements straight from the designs of previous MQP teams because their designs are good starting points for our eventual final design. We also adopted the basic, overall design of Pacific Can's current drying oven, making modifications where necessary to make it more productive. We constructed the entire design using CAD/SolidWorks, and then translated that design to a physical prototype using the materials described by previous MQP teams, along with our own modifications that we believe will make the drying oven operate more efficiently.

We built the prototype based on our CAD/SolidWorks design, and tested it through experiments described in the next section.

3.4 Experimentation with Cans

Our experiments measured how well the prototype dried the cans from calculating the percentage of dried water based on original, wet, and dried masses of cans. The cans were wet and dried in six different trials described after the following procedure.

3.4.1 Experiment Procedure

1. Number 20 random cans directly from the factory's production line from 1-20.
2. Weigh the cans to obtain the original mass (in grams) of each.
3. Collect the amount of cans according to each trial and wet them as described (see 3.4.2)
4. Weigh the cans to obtain the wet mass (in grams) of each.

5. Place the cans on the conveyor belt in rows of 5 according to each trial and dry them at varying speeds (see 3.4.2).
6. Record the time it takes for the cans to make it from the oven's entry to exit.
7. Weigh the cans to obtain the dried mass (in grams) of each.
8. Determine the percentage dried in each trial (or sub-trial, if running trials #1 and #2) by averaging each mass category and applying the following formula:

$$\frac{\textbf{(Wet Mass - Original Mass) - (Dried Mass - Original Mass)}}{\textbf{(Wet Mass – Original Mass)}}$$

9. Repeat steps 3-8 for the remaining 5 trials.

3.4.2 Explanation of Trials

<u>Trial #1) 5 cans at a time:</u> Spray water on 5 cans on all sides (top, bottom, left, right, front, and back sides) with an industrial spray pump and dry them on the conveyor belt at varying speeds. Repeat three more times to get data on all 20 cans. Consider each of the four sets an individual sub-trial.

<u>Trial #2) 5, then 15 cans:</u> Spray water on 5 cans on all sides and dry them. Repeat with 15

cans organized in rows of 5. Consider the two sets of 5 and 15 individual sub-trials.

<u>Trial #3) 20 cans at once:</u> Spray water on all 20 cans on all sides and dry them on the conveyor belt organized in rows of 5.

<u>Trial #4) 20 cans, additional inside spray:</u> Spray water on all 20 cans on all sides, and

spray each can's inside once more. Dry them on the conveyor belt in rows of 5.

Trial #5: 20 cans, dipped in water: Instead of spraying the 20 cans, submerge them in a tank of water. Dry them on the conveyor belt in rows of 5.

Trial #6: 20 cans, underside IR tubes: Spray water on all 20 cans on all sides. Activate the prototype's angled infrared tubes as well from the previous team's project.

3.5 Scaling up to the Industrial Level

After obtaining the result from the prototype, our team performed energy calculation to scale up the process. Then, analysis of material helped us to decide the recommendation of building material. Finally, the cost-effectiveness would determine the feasibility of scaling up the prototype.

3.5.1 Energy Calculation

The reason to perform an energy analysis was to obtain the number of IR tube needed. This section focused in calculation involving convection and conduction in heat transfer calculation. Following step-by-step calculations through Mathcad led to the final number of lights:

1. Energy needed to heat up the cans
2. Energy needed to heat up water
3. Energy needed to heat up conveyor belt
4. Energy loss from the oven due to heat conduction
5. Energy loss from the vent due to heat conduction
6. Energy loss from the vent due to heat convection and the initial temperature of air entering the vent

7. Energy loss from the heating room due to heat conduction
8. Energy needed to heat up the air
9. Total energy needed including energy efficiency of the light
10. Number of the light with given energy produced by each light.

3.5.2 Material Analysis

After finishing energy calculation, our team noticed the IR tubes would produce really high temperature. The chosen material's characteristic then needed to not only withstand high temperature, but also have high temperature resistance. Finally, the cost of material played would be another consideration. Our team decided to used CES Edu pack 2016 to perform the analysis.

3.5.3 Cost-Effectiveness in our Design

After making final decision about building materials, the cost-effectiveness would determine the feasibility of the scaling. Firstly, our team estimated the capital cost. Then, the profit of an addition of 300 cans/min was calculated. Finally, the payback time determined the practicality of the design.

3.6 Sustainability in our Design

Along with cost-effectiveness, sustainability is not the main focus of our goal to make the older drying process for one of Pacific Can's production lines more productive, but through the materials that we used, it can be a byproduct of it. Instead of using natural gas as the heating source for our drying oven, we will be using infrared heaters, thus reducing the amount of energy that the company has to expend on that production line, and therefore, a more sustainable form of energy production. Also, many infrared tubes, heaters, and lights can be recycled, thereby making them a sustainable energy/heat source on their own.

3.7 Research Methods Overview

We have provided a table below to describe, in detail, each of the methods that our team used in order to fulfill our objectives and goal:

Method	How It Was Used	Outcome
Engineering Design	Followed the process from start to finish as many times as we needed in order to design the best possible drying oven for Pacific Can.	After analyzing the design of Pacific Can's current drying oven and designs by previous MQP teams, a final iteration was chosen.
Design of Experiments	We designed experiments where one variable at a time was tested. Can sample analyses involved both blocking and randomization.	Through our experiments we have determined that with our addition to the previous MQP drying oven prototype, more cans will be dried than the current 1,200 per minute.
Systems Thinking	Externalities present that could affect our alternative designs/processes and alternatives that could affect externalities in the production line were taken into account.	The changes that we proposed to Pacific Can's current drying process did not affect any other part of the system.
Cost-Benefit Analysis	Compared the costs of the current drying process with alternatives that we proposed ourselves to find the most cost-effective design and process possible.	We were able to determine the most cost-effective design/process and ROI (return on investment).
Sustainability Assessment	Researched and analyzed potential solutions that could be applied to our designs and	China, as a country, is moving towards more renewable and sustainable energy sources to combat its energy

	processes in order to make them more sustainable than the current design and process.	consumption and pollution due to its dependence on fossil fuels. Infrared tubes fit the bill, not consuming as much energy as natural gas and being recyclable.

3.8 Project Timeline

In order to keep our team organized and on track to complete the project within the specified seven-week period, we put together a Gantt Chart that outlines what our plans were for each week of the project. Obviously the final chart does not resemble the first chart we had put together, because we needed to change some things around as problems or conflicts arose, as stated in our Conclusions and Recommendations chapter.

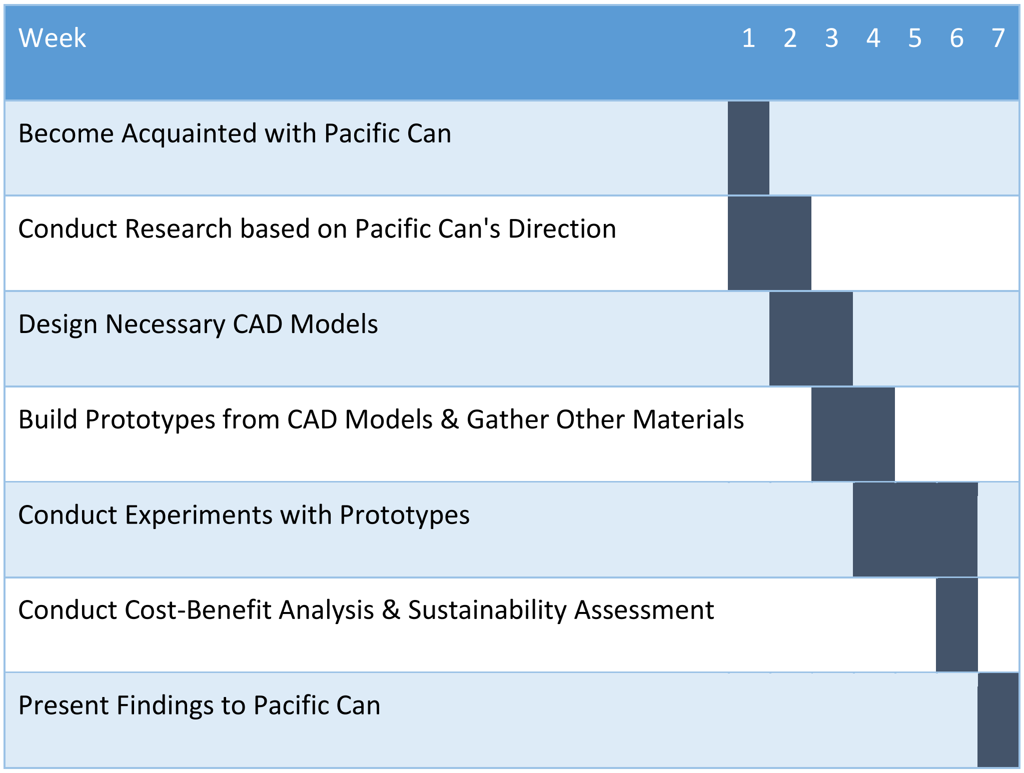


Figure 7: Gantt Chart of Project Timeline

4 Results & Analysis

We analyzed the data collected with each method discussed in the previous chapter to attain our goal of designing and building a prototype of a more productive drying oven for use by Pacific Can, using previous MQP and older drying oven designs as a base for own design. We achieved our goal through the completion of our four objectives.

This chapter reports our data collection and analyses. The bill of materials for our prototype drying oven is provided in Appendix A. The SolidWorks design models are provided in Appendix B.

4.1 Pacific Can's Current Drying Process

After reviewing the concept of current oven, the flow of air is circulating in the oven as shown in the diagram below.

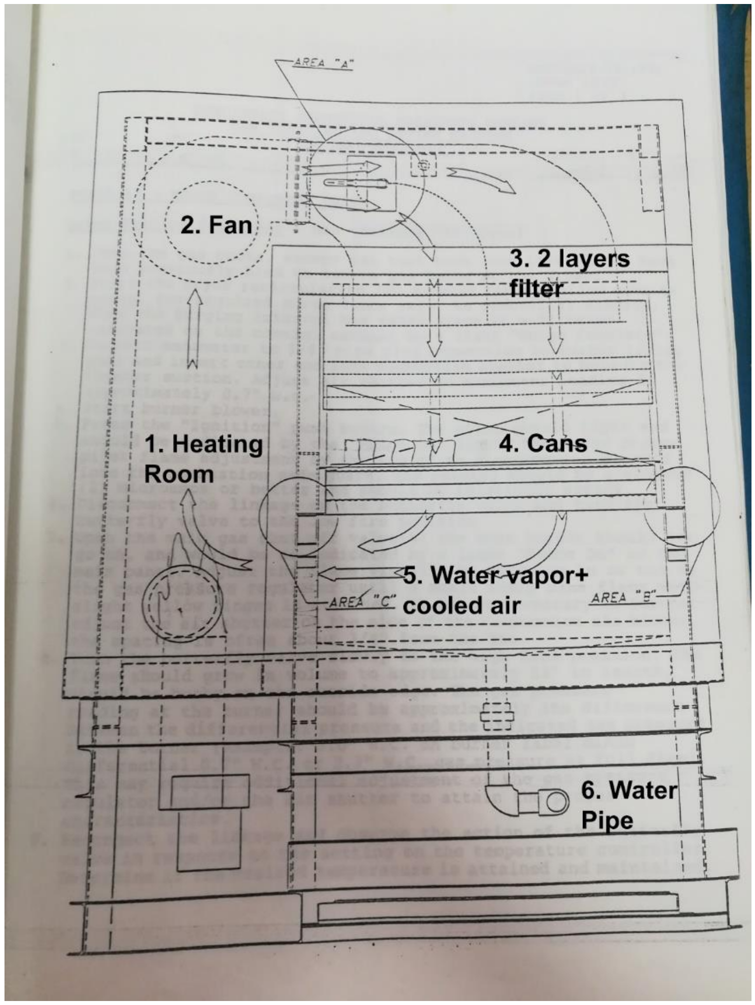


Figure 8: Pacific Can's Drying Oven Design

First, the air is heated at the heating room (1) by burning natural gas. Then, the fan (2) will suck the hot air and blow it through two layers of air filter to slow the air velocity to 1.83 m/s. The hot air will remain the oven (4) temperature at 240◦C and dry the cans. Finally, the cooled air flow will carry the evaporated water and get heating up again at below the conveyor belt. The excess water vapor will be removed through a pipe (6). The remaining hot air will once again have sucked into the heating room (1) and start another circulation of air flow.

4.2 Experimental Design & Prototype

The experimental design for our drying oven was designed using SolidWorks, and through many iterations, our team was able to decide on one that worked the best for Pacific Can and the previous MQP prototype oven. At Pacific Can, with the help of Pacific Can workers, we were able to put together a prototype drying oven based on our own iterations.

4.2.1 New Concept

Based on the current design of the drying process in the factory, the team decided to innovate the design in a more sustainable and economically way. A new simplified drawing of the new concept is shown below.

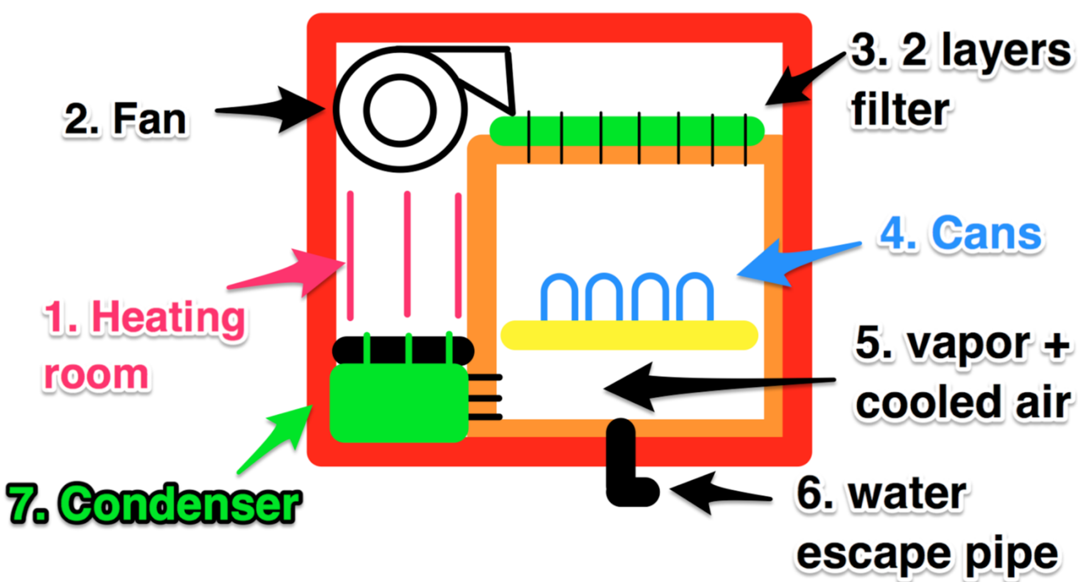


Figure 9: Color-Coded Drying Oven Design

At first, the air is heated at the heating room (1) by heating the infrared tubes. Then, the fan (2) will suck the hot air and blow it through two layers of air filter to slow the air velocity to 1.83 m/s. The hot air will keep the oven (4) temperature at 240°C and dry the can. Finally, the cooled air flow will carry the evaporated water and get heating up again at below the conveyor belt. The excess water vapor will be condensed with condenser (7) and removed through a pipe (6). The remain hot air will once again have sucked into the heating room (1) and start another circulation of air flow.

Heating room is the focus of the new design. Infrared tubes are installed in the heating room instead of the traditional heating method using natural gas based on their advantages in background section.

The new concept is also integrated with a condenser and a heat pump. The condenser will completely condense the water vapor from the air back to water. This process will increase the efficiency of the drying process as well as eliminate the influence of humidity. The extra heat from the infrared tubes will also be optimal as it is connected to the heat pump.

4.2.2 New Design

The SolidWorks assembly used to model our experimentation underwent several iterations as an accessory built upon the previous team's prototype. Thus, our assembly is intended to fit adjacent to its top and side. As reference, the square-shaped insulation box is modeled from their drawings as the only piece that existed before we built our original components.

Our model serves to house both the heating tubes and the fan that circulate hot air to dry the cans. The first iteration (Figure 10) was modeled as a rough draft before any materials were ordered and optimization was taken into account. The model consists of a frame made of stainless steel 3cm x 3cm stock (Figure 11) and an exterior shell (Figure 12) to contain the air. The frame is supported by four legs that support five long rods parallel to the insulation box and two large horizontal bars that are also supported directly above and perpendicular to the insulation box. The parallel bars come in an upper set of 3 and lower set of 2. The upper 3 serve to support the exterior shell as well as the fan while the lower 2 just support the shell before it bends downwards to the insulation box.

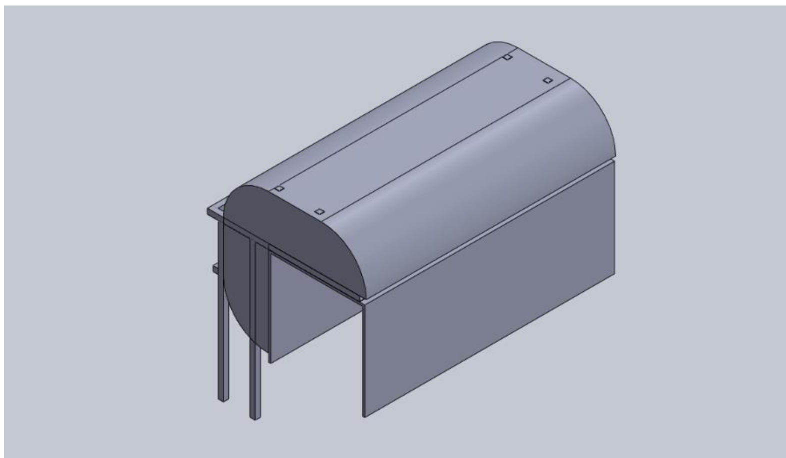
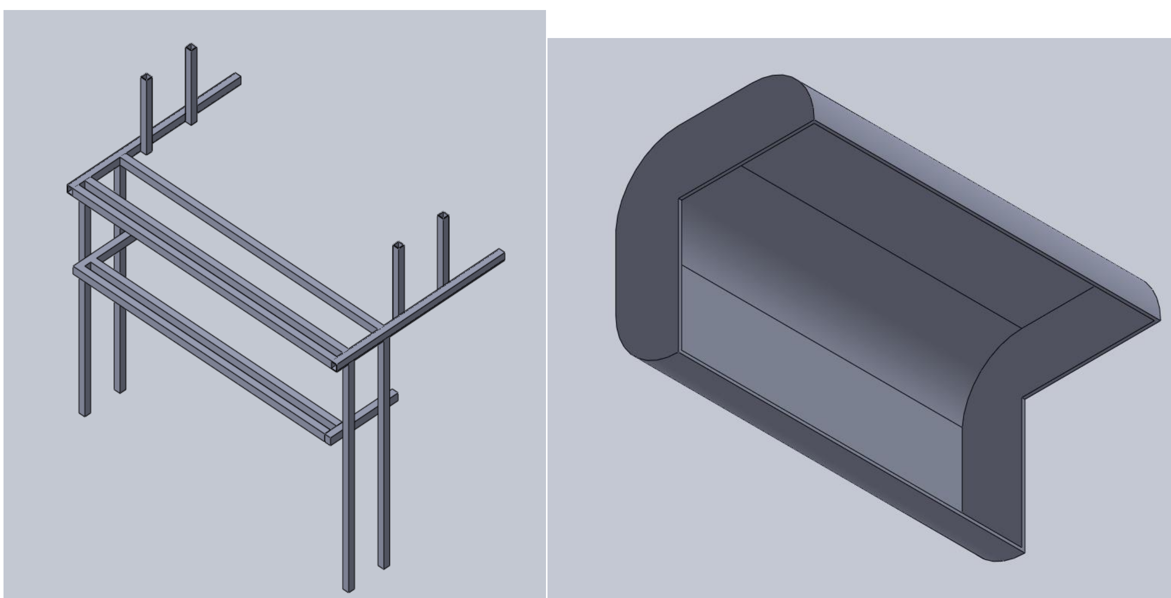
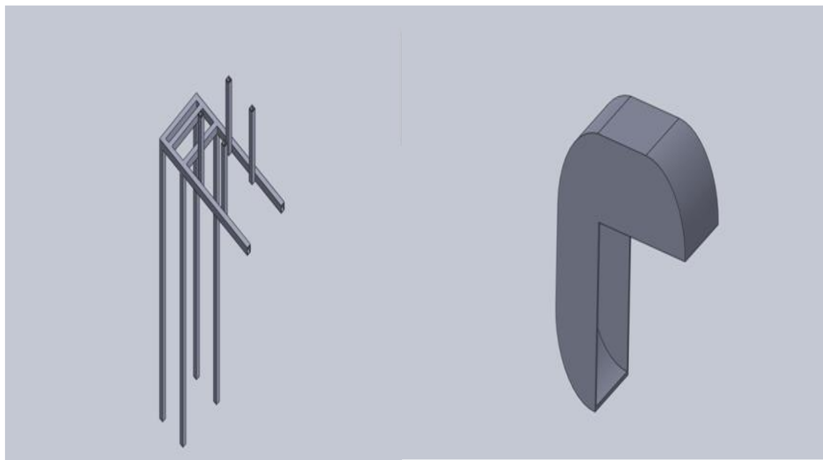


Figure 10: 1st Iteration: Drying Oven



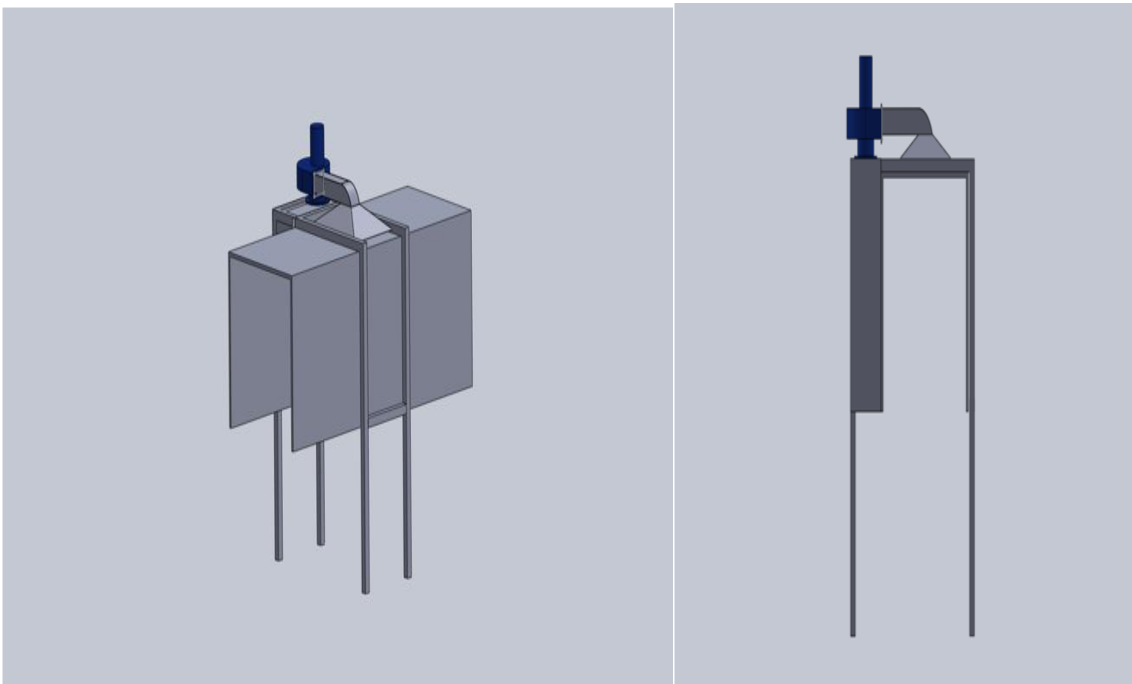
Figures 11 & 12: 1st Iteration: Drying Oven Frame & Exterior Shell

The model’s second iteration focused on achieving the same purpose while using less materials. Its most significant change reduced the width of the model by over half. The smaller width concentrates the heat from the ceramic infrared rods more and more efficiently channels the air to the center of the oven. Additionally, this model uses less materials than the previous iteration, which saves material cost.



Figures 13 & 14: 2nd Iteration: Drying Oven Frame & Exterior Shell

The third iteration saw the most changes from any of the project’s models. The frame’s inner legs have been moved to the opposite side of the insulation box for greater stability (Figure 15). The rounded air chamber that originally covered the side and top of the insulation box is now changed to a smaller, rectangular box bolted to the side of the insulation box (Figure 16). Since the fan simply transfers the hot air, the third iteration saves more materials by exposing the fan (modeled here as a reference part) and building a custom-made steel vent on the fan’s exit (Figure 16). The frame also changed to include another parallel bar to hold more ceramic infrared tubes (Figure 17). This iteration was the first to be manufactured before a few necessary adjustments needed to be made.



Figures 15 & 16: 3rd Iteration: Drying Oven & Frontal View Showing Updated Air Box and Vent

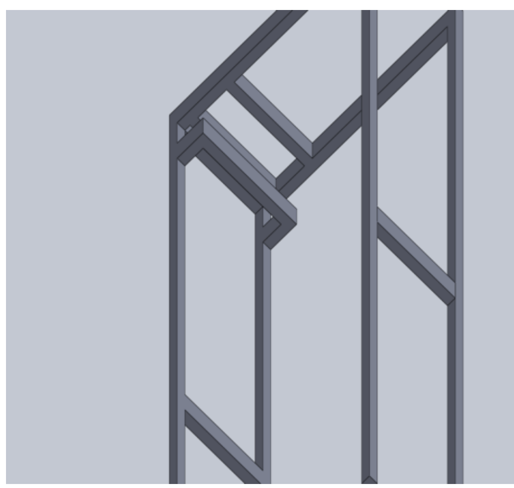


Figure 17: 3rd Iteration: Close-up View on New Parallel Bar

After building the third iteration, a ~1 cm separation appeared between the vent and the roof of the insulation box. The separation came from assuming the top of the box to be perfectly flat, though in reality the box was curved in the middle. To fix the problem, the large horizontal and far legs of the frame were removed in order to install a 1 cm thick rectangular perimeter to the bottom of the vent. The perimeter was then welded to the roof to provide and regain the stability that was lost to the removed legs.

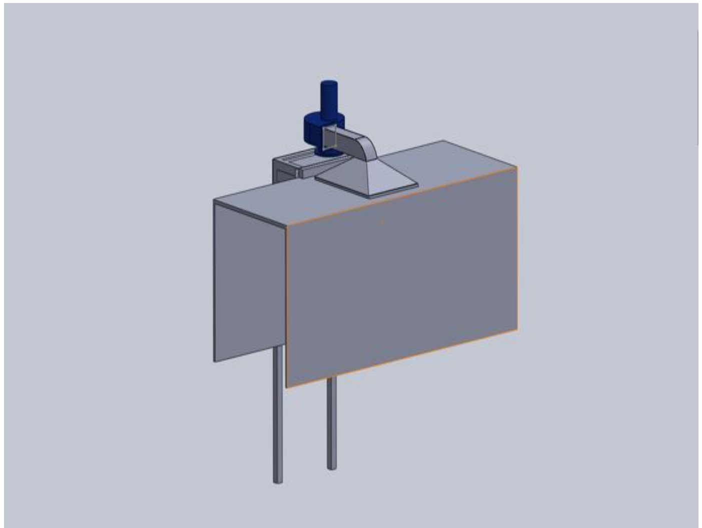


Figure 18: Fourth Iteration: Drying Oven

4.3 Experimental Data

Though the drying time for the trials mostly increased from last year's project of 46 seconds, our drying percentage significantly improved upon their ~44%. Each trial revealed information regarding how the speed and method of trial affects each situation's drying percentage.

Trial 1's four sub-trials give very different values to their drying percentages with the wide range of 36.89%-99.1% when drying 5 cans at a time. These drastically different values come from the having a wide time variance of 0:32 and 1:57 respectively. Though sub-trials 1-1 and 1-2 run at identical times, the latter is dryer likely because of the infrared tubes being heated longer than the first ever sub-trial.

Trial 2's two sub-trials of 5 and 15 cans also show a wide breadth of difference despite not having too large of a time difference. Trial 2-2 demonstrates that can amount is not a large obstacle as 96.59% of the water became dry as opposed to the 5 cans' 71.88%. Another case of pre-heating rods may have led to this effect.

When drying 20 cans at once, Trial 3 confirms from sub-trial 2 that a roughly 2:00 minute drying time is enough to get over 90% of the cans' water evaporated. Specifically, it took 1:55 for the cans to dry at 94.09%

However, if the cans have more water in their insides than their outsides, the percentage decreases as seen in Trial 4: 76.89% in 1:55. This is likely because all the heat is coming from heat coming from above as opposed to below.

Trial 5 saw the cans being submerged in water and we expected a similar lesser percentage as Trial 4 due to the cans being wet on the inside. However, the experiment revealed a drying percentage of 93.7% in 3:40. The additional drying time likely contributed to this significant increase.

Trial 6's change of including an additional heating source from the underside led to a high drying percentage of 97.78% in 3:20. The infrared tubes left from the previous year's team were angled at what they considered the optimal position from their experiments. Both the surrounding heat and longer drying time likely led to this high percentage.

Drying Percentage Calculations			
	Avg. masses (g)	Percentage Dried (%)	Time
Original Mass	10.12		
Trial 1-1 Wet	10.43		
Trial 1-1 Dry	10.18	80.25	1:57
Trial 1-2 Wet	10.57		
Trial 1-2 Dry	10.12	99.10	1:57
Trial 1-3 Wet	10.61		
Trial 1-3 Dry	10.43	36.89	0:32
Trial 1-4 Wet	10.79		
Trial 1-4 Dry	10.34	67.36	1:26
Trial 2-1 Wet	10.82		
Trial 2-1 Dry	10.32	71.88	1:30
Trial 2-2 Wet	10.53		
Trial 2-2 Dry	10.13	96.59	1:55
Trial 3 Wet	10.75		
Trial 3 Dry	10.16	94.09	1:55
Trial 4 Wet	10.76		
Trial 4 Dry	10.27	76.89	1:55
Trial 5 Wet	11.36		
Trial 5 Dry	10.20	93.70	3:40
Trial 6 Wet	11.40		
Trial 6 Dry	10.15	97.78	3:20

Table 1: Drying Percentages and Times per Trial

4.4 Scaling up to the Industrial Level

4.4.1 Energy Calculation

According to the energy calculation and Mathcad (Appendix E), the total energy that is needed to dry 300 cans per minute was $5.133*10^7$ J per min (assuming the efficiency of the IR tube was 90%). From that, total IR tubes needed was 951 tubes. The number of the tubes could be lower as the calculation was a rough estimated without precise measurement and the cans only withstood 240°C.

4.4.2 Material Analysis

Based on data in existing library in CES Edu pack 2016, the software fully graphed price versus thermal conductivity, and melting point versus thermal conductivity (Appendix F). The lower the thermal conductivity the higher the thermal resistance, which helped keep all the heat inside. Also, the design required material that could withstand high temperature with low capital cost. According to the graphs, it clearly shows that bricks and concrete both had wanted characteristic. Bricks had thermal conductivity of .6 and concrete had thermal conductivity of .8, which were lower than most of the other common materials was. They both can stand high temperature up to 2000°C. Despite having higher thermal conductivity, concrete had lower price that bricks. For 1 pound of brick, the cost was around $.5 while it only costed $.02 for 1 pound of concrete. However, brick was more easily shaped than concrete was, our team finally recommended using brick for the design instead of concrete.

4.4.3 Cost-Effectiveness in our Design

Along with a table of capital cost of all needed material (Appendix G), appendix G also contained a table calculating profit of the extra 300 cans per minute. The capital cost was up to 25,608 yuan, while the profit of the increased production is 1,273.91 yuan per hour. From that, the payback time was 20.11 hours, which was even less than a full time operating day.

Saving money is very important to large businesses and factories, which is one of the reasons why our team focused some of our efforts on incorporating money-saving technology into our design and prototype. Ceramic and infrared tubes are both very inexpensive forms of energy and heat, much more cost-effective than natural gas. Also, with the addition of a heat exchanger into the design and prototype, hot air can be recycled back through the oven, thereby saving the factory energy by not wasting any of the hot air.

4.5 Sustainability Assessment

As stated previously, sustainability is an important part of economic and technological development, especially for China. Our team recommends that Pacific Can use either ceramic tubes or infrared tubes as an energy source for their drying oven because it uses less energy than natural gas, which is currently in use at their factory. Ceramic and infrared tubes also do not give off any fumes, thereby contributing less to pollution than the natural gas in use now. The incorporation of a heat exchanger that can reuse the hot air blown onto the cans by the fan can also save energy.

5 Conclusions & Recommendations

We analyzed our results and have assembled the conclusions and recommendations based on those analyses. We developed these recommendations using conclusions drawn from our research, designs, prototypes, and experiments. The purpose of these recommendations is to implement a new, improved and more productive drying oven for one of Pacific Can's production lines, using previous MQP and older drying oven designs as a base in which to build on.

5.1 Innovation & Entrepreneurship Revisited

Our team was able to produce an innovative design for a new and improved drying oven that Pacific Can can use in place of their old drying oven. Our team's drying oven prototype was designed to be both more productive, in order to dry closer to 1,500 cans rather than the current 1,200, and also more environmentally-friendly, using infrared ceramic tubes rather than the current energy source of natural gas.

Our team also incorporated infrared ceramic tubes with a heat exchanger design to recycle unused hot air through the use of a vent and a fan. The innovative drying oven design that our team recommends to Pacific Can can be incorporated into their production line easily and effectively, as it will cost the factory less money by replacing natural gas with infrared ceramic tubes, and will have less of a negative effect on the environment by using less energy and producing no harmful fumes.

5.2 Interpreting the Results

Based on the data acquired by the six trials, the highest drying percentages that occurred in the least amount of time were all over 90% in about 2 minutes, especially as seen in Trials 1-2, 2-2, and 3. These three trials all involved spraying water evenly on the surface of the cans, which is more in-line to the factory's method of washing the cans. The two lowest drying percentages occurred in Trials 1-3, and 1-4 and likely resulted from being in the oven for too short of a time.

These results reflect the efficiency of the prototype. Therefore, if Pacific Can wishes to incorporate our design, then they should find the optimal drying time for their production line to reach similar or better drying percentages according to the speed of the conveyor belt.

5.3 Drying Processes

The two types of drying processes that we implemented in our new drying oven design and prototype are a heat exchanger, namely an evaporator and heat pump, and infrared heating tubes. We recommend that both of these drying technologies be adopted by Pacific Can for reasons explained in the following sections.

5.3.1 Heat Exchanger

One of the biggest problem from last year's design is that moist air would still stay in the oven. Water vapor would make the cans wet again. We added a heat exchanger which included an evaporator and a heat pump to solve this problem. Ceramic tubes provide energy to heat up the air inside the heating room. The heat pump brings hot air from heating the air to dry out the cans. The evaporator will suck out the moist air inside the oven. Another problem is when the infrared light was on the whole the entire oven would become hot and dangerous. To solve this problem, we covered the heating room with an insulation board and glass wool.

5.3.2 Ceramic Infrared Tubes

According to our research we found out that ceramic infrared tubes can save up to 30% of energy compared to standard infrared tubes. Ceramic is one of the best insulators with a high heat resistance, therefore being a better option than regular infrared tubes.

5.3.3 Infrared Tubes

Unfortunately for this part of our prototype and experiment, the infrared tubes that were a part of the previous MQP design were not working, and so our team could not experiment on the use of infrared tubes in addition to our own design prototype. Therefore, our team recommends that infrared tubes be used in the new drying process only as an addition to the heat exchanger and ceramic tubes, and even then not to be used as a constant source of heat, but more of a backup in case of insufficient drying or damage to the ceramic tubes.

5.4 Constraints & Future Research

There will always be obstacles and constraints to overcome during any project done in another country, including the language barrier and access to information. Due to these and other constraints listed in the next section, future research is almost always needed in order to improve upon a design or process that was not brought completely to fruition.

5.4.1 Constraints & Obstacles

There were many constraints and obstacles present to our team during the seven-week span of our project. The most glaring and difficult to overcome was the language barrier. Although one member of our group could speak Chinese fluently to our sponsor, the BUCT students working alongside us, and to buy supplies needed for the building of our prototype, it was still difficult to traverse Beijing with a very limited vocabulary and understanding of the Chinese language.

Second most difficult obstacle to overcome was the access, or lack thereof, to information needed to complete our background research. China blocks access to many websites, including but not limited to, Google, Facebook, and YouTube. Therefore, each of us needed to buy a VPN or access the WPI VPN in order to access reliable information and the SolidWorks software to work on our design of a new drying oven.

The time constraint of seven-weeks was itself a fairly large obstacle to overcome, but getting into contact with our sponsor, Pacific Can, early and often by communicating with our liaison at the factory and visiting whenever possible to work on our prototype and experiments led us on a straightforward path to getting our project completed within the short timeframe allowed to us.

A final obstacle to our completion of the project was the ability to get ahold of materials, tools, and lab space in which to build our prototype and also to test it through our experiments. The BUCT students working alongside us helped us find the necessary materials to build our prototype, albeit timely and the funds coming from our own pockets. In addition to a lack of materials, the BUCT labs available to us were also devoid of the necessary space and tools necessary to the building of our prototype. To solve this problem, our team traveled to the Pacific Can factory (about an hour away from our hotel, another problem restricting number of visits) to use their space, tools, and engineers to help in the building and experimentation periods of our project.

We recommend that any and all future MQP teams that will be traveling to Beijing to work on their project for Pacific Can to follow our advice on the above stated obstacles and how to overcome them in order to complete their project in a timely and organized manner.

5.4.2 Future Research

Our team was able to improve upon the old drying oven in use by Pacific Can in one of their two production lines, but further improvements will be necessary due to time constraints that restricted the amount of possible ideas. Future research may come into play to solve remaining goals.

We recommend that Pacific Can and future MQP teams focus on the following ideas that our own team thought up in order to make improvements upon our own drying oven prototype. First, our air flow is not completely even, and our original design of the vent was not perfect. The air is concentrated more further on the far end of the exhaust. We originally intended to add another layer of steel plating to even out the air. But due to time constraints the vent won't be finished in time, because it requires a lot of skill and we need to ask another company to build the vent. In the original design, we wanted to incorporate an evaporator to suck out the moist air, but we did not have enough time to buy or build one. Right now we only have circulated air to bring out the water vapor, but it is not as efficient as an evaporator. Future MQP groups can use these suggestions to improve the oven.

This year we have worked with a BUCT student team. Their main focus was the control of the drying system. Our BUCT partners could help us control the temperature inside the heating room, which can save Pacific Can more energy and increase their can production. Additionally, the controlled system can prevent the air temperature from becoming too high, which could damage the cans.

References

1. "About Ceramics." *Khyati Ceramics*. N.p., 2008. Web. 14 June 2017. <http://www.khyaticeramics.com/about_ceramics.php>
2. "Aluminum Beverage Can." *How Products Are Made*. N.p., 2017. Web. 14 June 2017. <http://www.madehow.com/Volume-2/Aluminum-Beverage-Can.html>
3. Brubaker, Richard. "Reframing Sustainability for China, and Future Cities." *Forbes*. CEIBS, 2014. Web. 14 June 2017. <https://www.forbes.com/sites/ceibs/2015/06/02/reframing-sustainability-for-china-and-future-cities/#389caa31697a>
4. "Convection." *Convection*. N.p., 29 Sept. 1999. Web. 14 June 2017. <http://theory.uwinnipeg.ca/mod_tech/node76.html>
5. "Convective Heat Transfer." *The Engineering ToolBox*. N.p., n.d. Web. 14 June 2017. <http://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html>
6. "Dryer Heat Recovery Systems." *GreenRiverside*. Enercom, 2000. Web. 26 June 2017. <https://www.energydepot.com/RPUcom/library/MISC002.asp>
7. Kearns, Andre. "Innovation And Entrepreneurship." *LinkedIn SlideShare*. N.p., 17 Nov. 2009. Web. 14 June 2017. <https://www.slideshare.net/andrekearns/innovation-and-entrepreneurship>
8. Frederick, David. "The Six Steps In Cost/Benefit Analysis." *David Frederick's | IAIR BLOG*. N.p., 14 July 2011. Web. 14 June 2017. <https://instituteair.wordpress.com/2011/07/14/the-six-steps-in-costbenefit-analysis/>
9. Gaia. "Environment and Ecology." *Systems Thinking*. N.p., 2017. Web. 14 June 2017. <http://environment-ecology.com/general-systems-theory/379-systems-thinking.html>

10. "Heat of Vaporization of Water." *Heat of Vaporization*. N.p., n.d. Web. 14 June 2017. <http://www.kentchemistry.com/links/Energy/HeatVaporization.htm>

11. "Industrial Heat Pumps." *Drying Processes / Industrial Heat Pumps*. N.p., n.d. Web. 26 June 2017. <http://www.industrialheatpumps.nl/en/applications/drying_processes/>

12. "Infrared Waves." *Redsun*. N.p., n.d. Web. 14 June 2017. <http://www.redsun.bg/en/infraredheating/infrared-heat-waves/>

13. Pacific Can. (2011). *pacificcan.com.* Retrieved May 1, 2017, from pacificcan.com. <http://www.pacificcan.com/en/about.html>

14. "Quartz Tube & T3 Halogen Lamps." *Delta T*. N.p., n.d. Web. 14 June 2017. <https://www.deltat.com/quartz_tube.html>

15. "Radiation Heat Transfer." *The Engineering ToolBox*. N.p., n.d. Web. 14 June 2017. <http://www.engineeringtoolbox.com/radiation-heat-transfer-d_431.html>

16. "Return on Investment - ROI." *Investopedia*. N.p., n.d. Web. 14 June 2017. <http://www.investopedia.com/terms/r/returnoninvestment.asp>

17. STI Group - Industrial, Midstream & Fabrication Services. "Heat Exchangers: How They Work, and Why They Are Needed." *STI Group - Industrial, Midstream & Fabrication Services*. N.p., 22 Sept. 2014. Web. 26 June 2017. <http://setxind.com/downstream/industrial-heat-exchangers-what-they-are-how-they-work-and-why-they-are-needed/>

18. Sundararajan, K. "Design of Experiments - A Primer." *ISixSigma*. N.p., 2000. Web. 14 June 2017. <https://www.isixsigma.com/tools-templates/design-of-experiments-doe/design-experiments-%E2%90%93-primer/>

19. The Aluminum Association. (2016, June). *aluminum.org.* Retrieved May 1, 2017, from aluminum.org. <http://www.aluminum.org/aluminum-can-advantage>

20. "The Engineering Design Process." *Science Buddies*. N.p., 2002. Web. 14 June 2017. <http://www.sciencebuddies.org/engineering-design-process/engineering-design-process-steps.shtml#theengineeringdesignprocess>

21. "The Importance of Sustainability in Engineering Management." *The Importance of Sustainability in Engineering Management*. Kettering University Online, 7 July 2016. Web. 14 June 2017. <https://online.kettering.edu/news/2016/07/07/importance-sustainability-engineering-management>

22. The World Counts. (n.d.). *theworldcounts.com.* Retrieved May 1, 2017, from theworldcounts.com. <http://www.theworldcounts.com/counters/world_food_consumption_statistics/aluminium_cans_facts#more-facts>

23. "What Is Design of Experiments (DOE)?" *ASQ*. N.p., 2017. Web. 20 June 2017. <http://asq.org/learn-about-quality/data-collection-analysis-tools/overview/design-of-experiments.html>

24. "What Is Infrared Drying?" *Bekaert*. N.p., n.d. Web. 14 June 2017. <http://drying.bekaert.com/en/drying-technology/what-is-infrared-drying>

25. "What Is Systems Thinking?" *Waters Foundation*. N.p., 2017. Web. 14 June 2017. <http://watersfoundation.org/systems-thinking/what/>

26. "Why Choose Solaira Infrared Technology." *Solaira Heaters*. N.p., 2015. Web. 14 June 2017. <http://www.solairaheaters.com/why_quartz.html>

Appendix A: Bill of Materials

	Price (yuan, ¥)	Use
Centrifugal Fan	200	Sucks in the hot air from the heat source and circulates it into the drying oven.
Ceramic Tubes	60	Insulators that are placed inside the heating part of the drying oven in order to increase and also maintain the temperature being circulated into the drying oven.
Iron Rods	200	Skeleton (base) of the additions our team is making to the previous MQP drying oven prototype.

Table 2: Bill of Materials

Appendix B: SolidWorks Models & Pictures

Figure 19: Holders for Ceramic Tubes

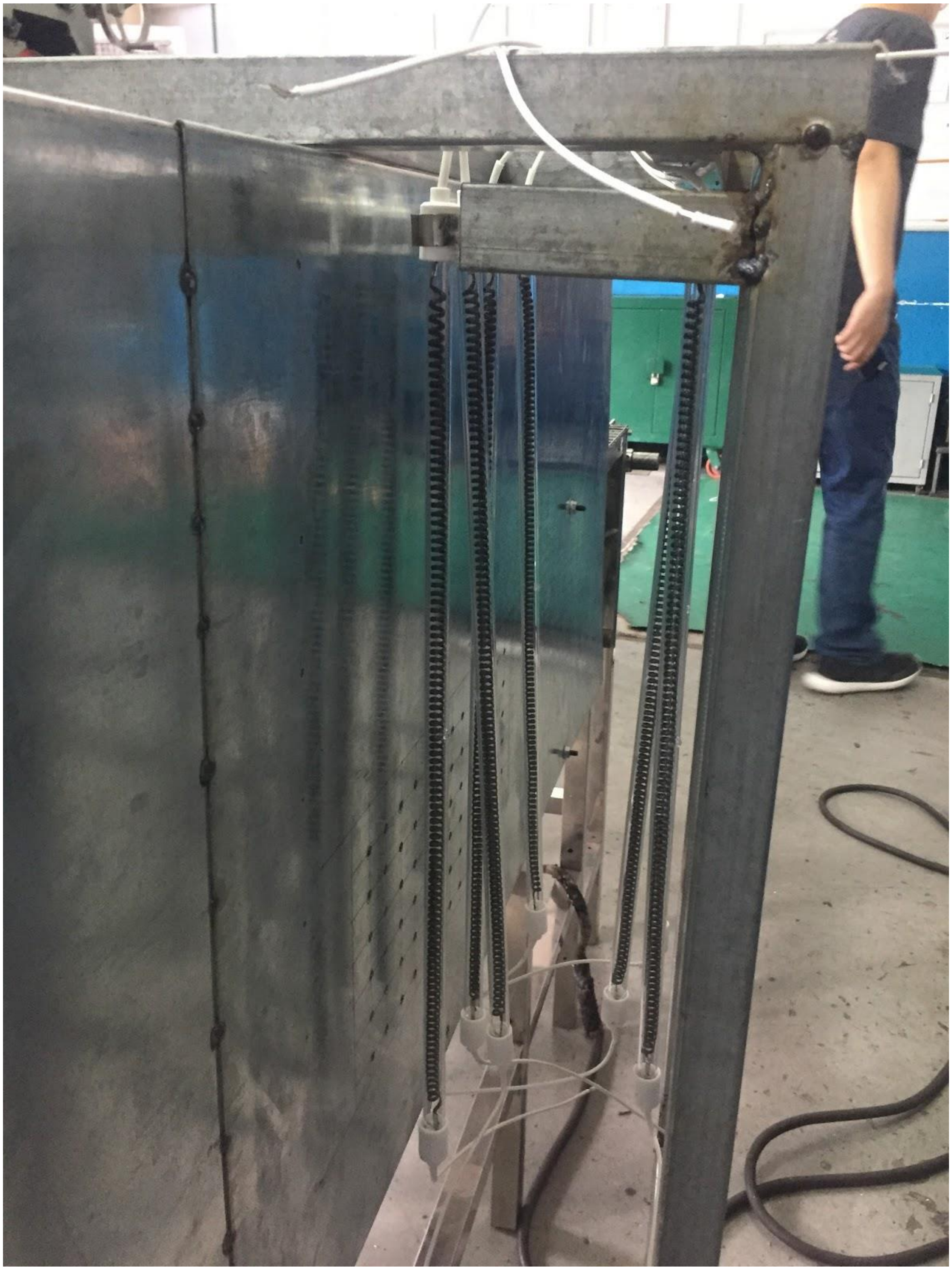


Figure 20: Ceramic Tubes in Place

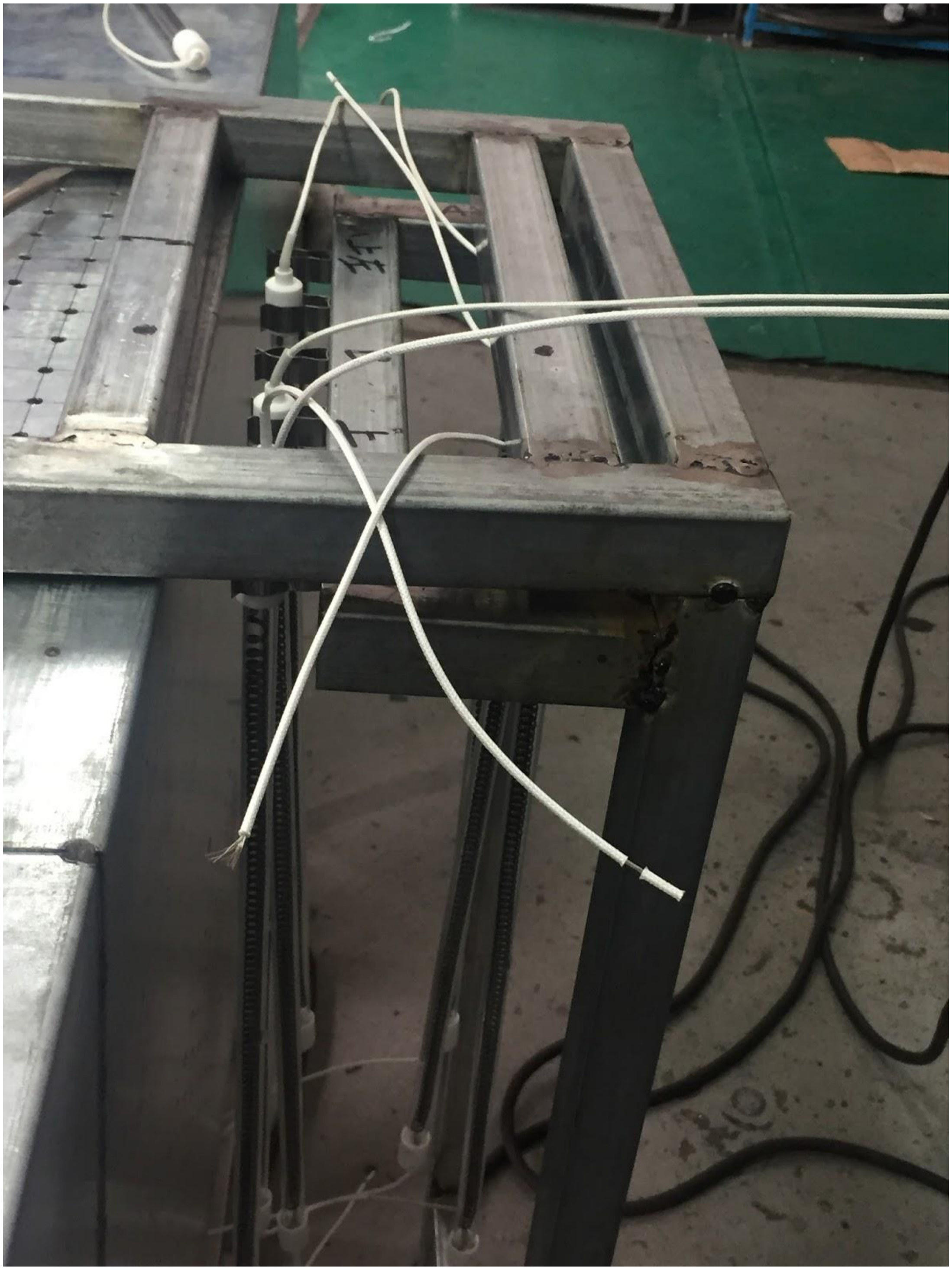


Figure 21: Top View of Ceramic Tubes

Figure 22: Ceramic Tubes Connected via Wires

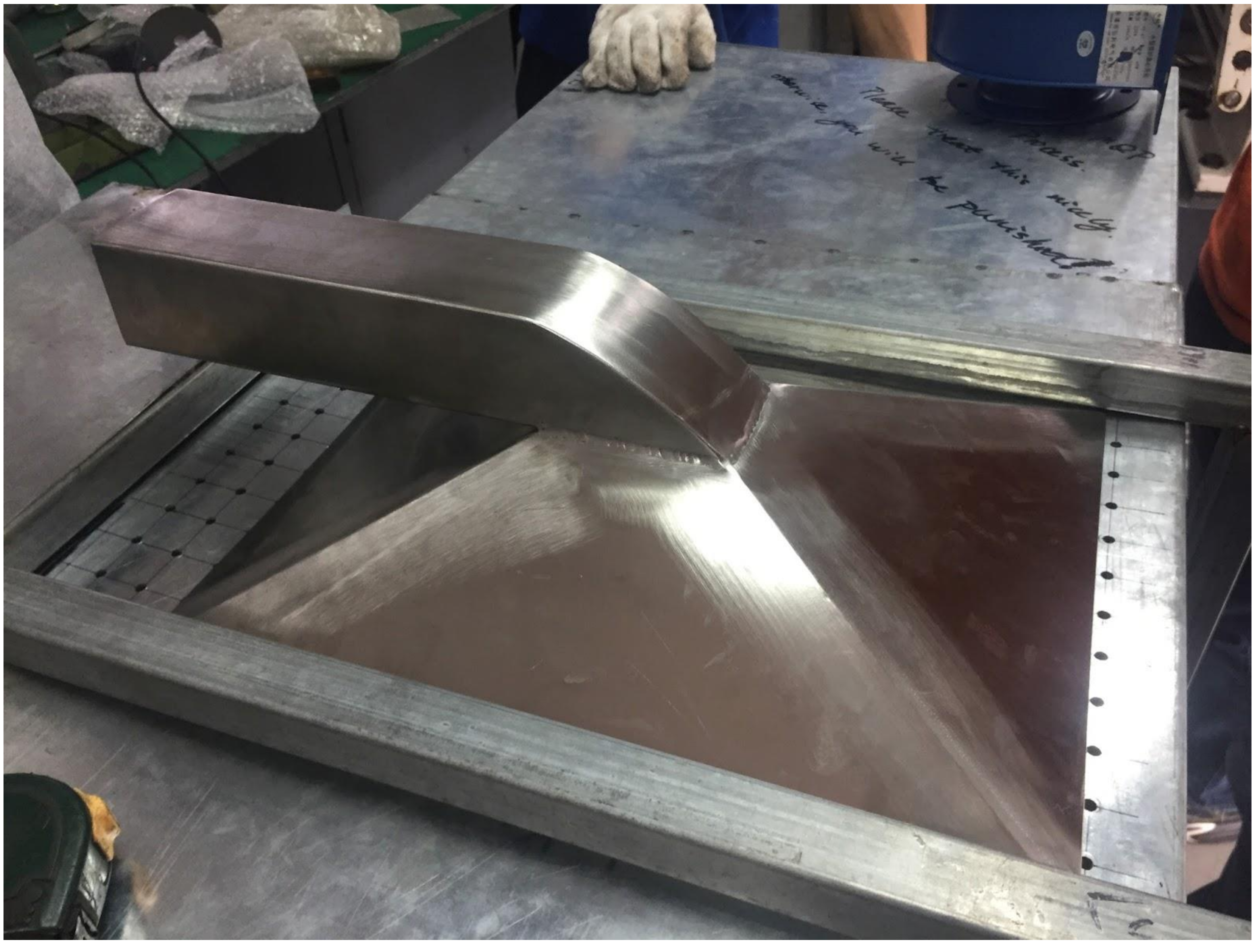


Figure 23: Vent for the Drying Oven Prototype

Figure 24: Drilling the Hole for the Fan

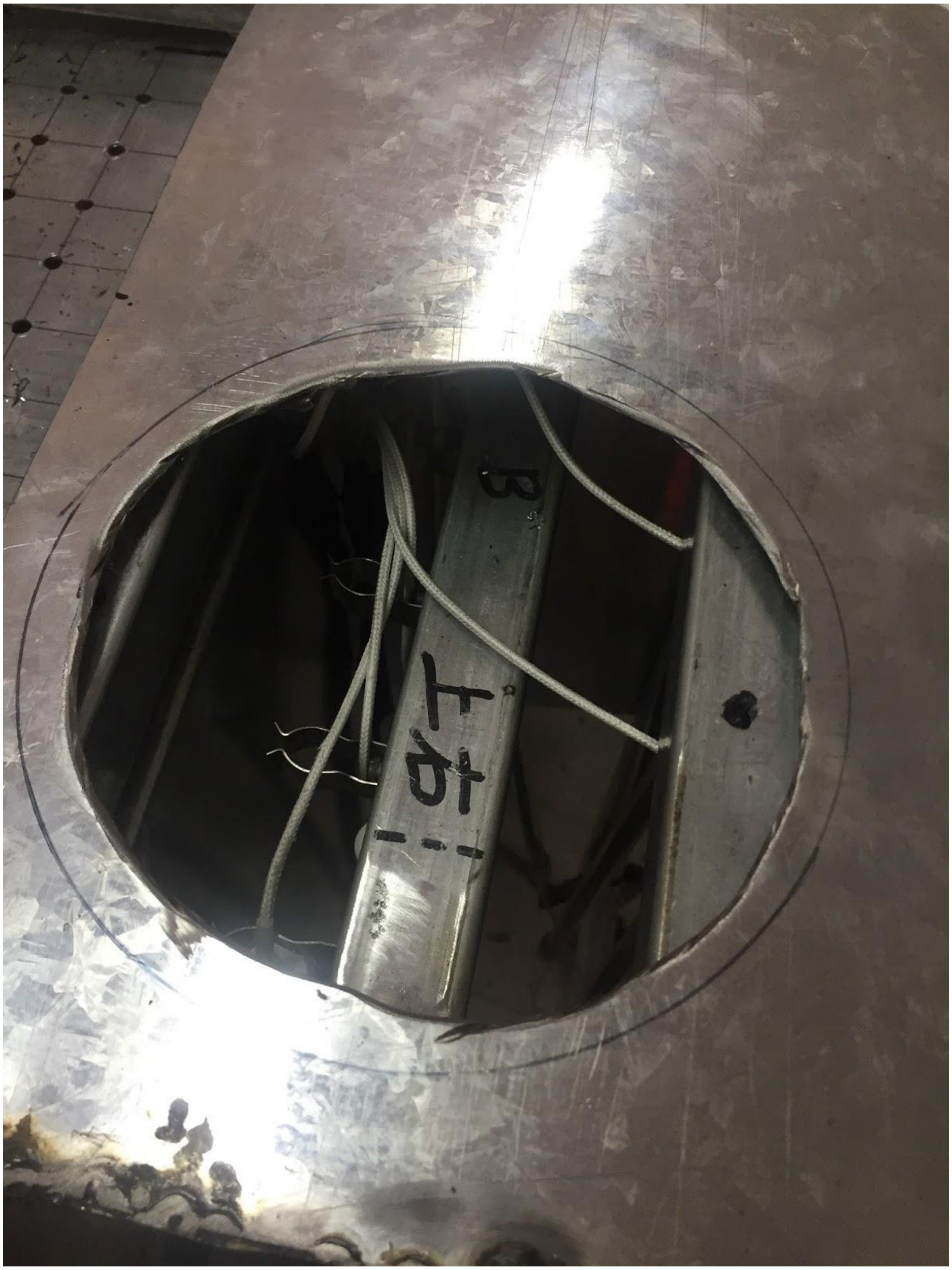


Figure 25: Hole for the Fan

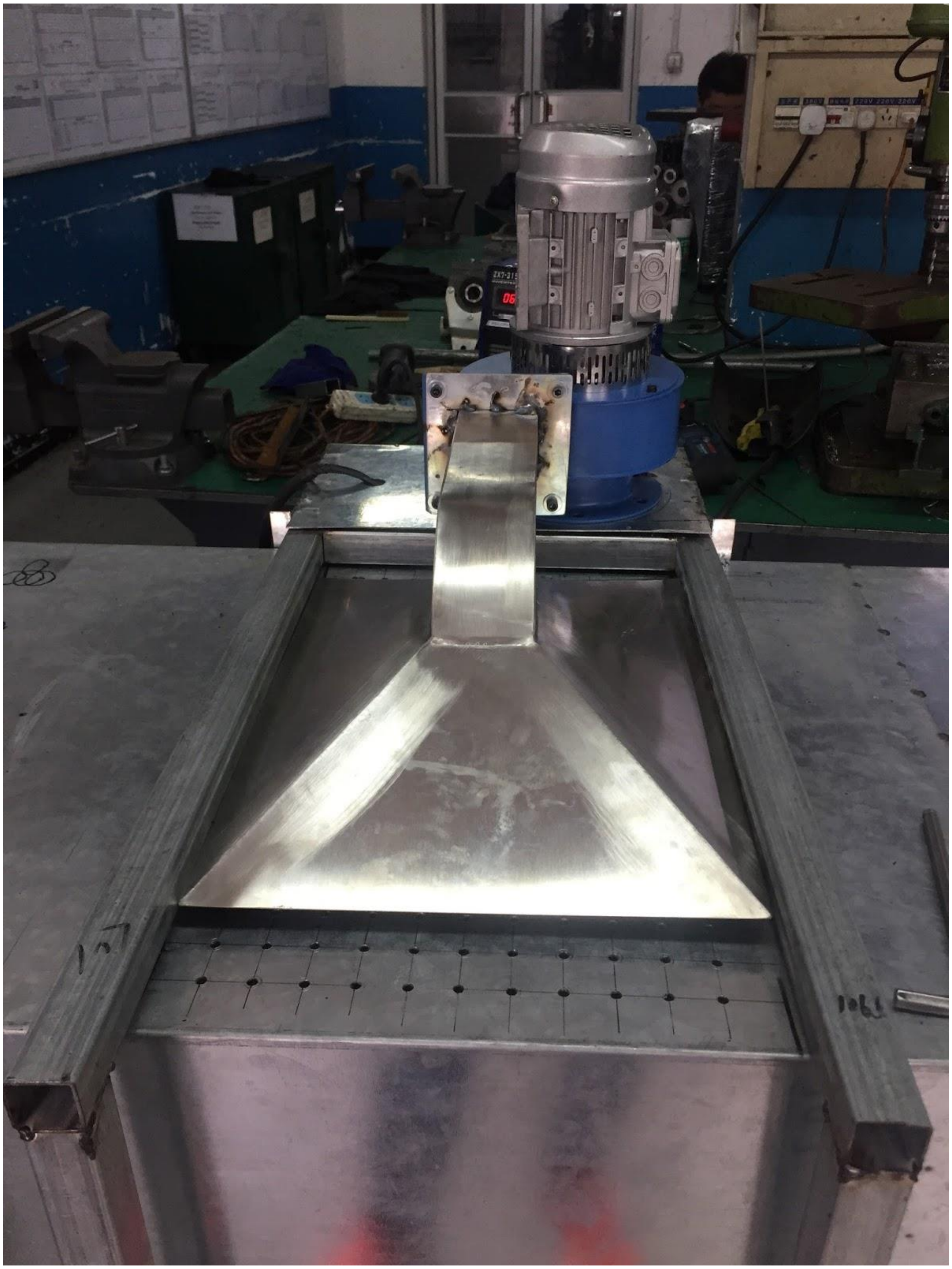


Figure 26: First Iteration of our Drying Oven Prototype

Figure 27: Completed Drying Oven Prototype

Figure 28: Discarded Legs of our Drying Oven Prototype

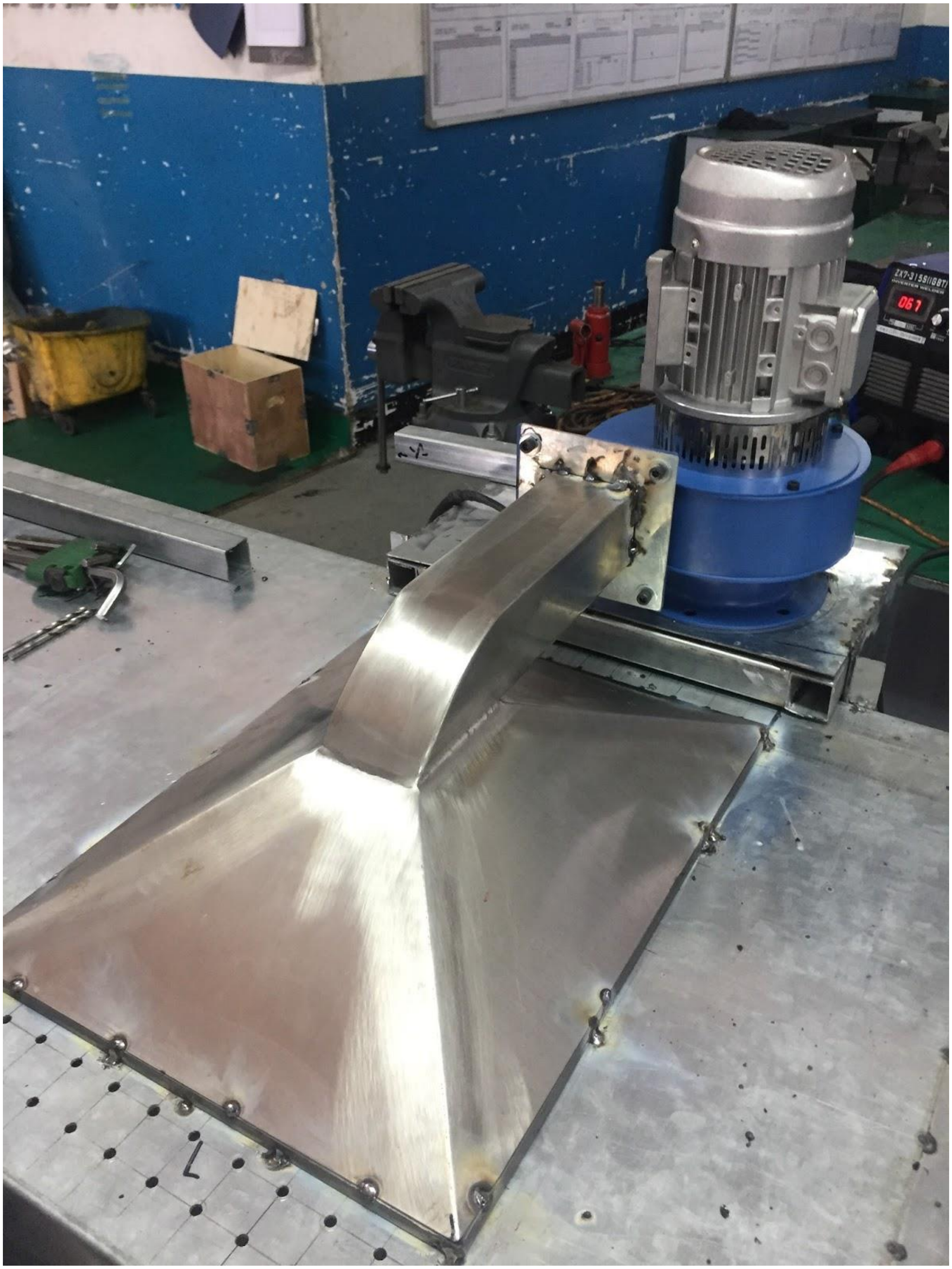


Figure 29: Fan and Vent for our Drying Oven Prototype

Figure 30: Insulation for the Heat Room

Figure 31: Two Sides Insulated

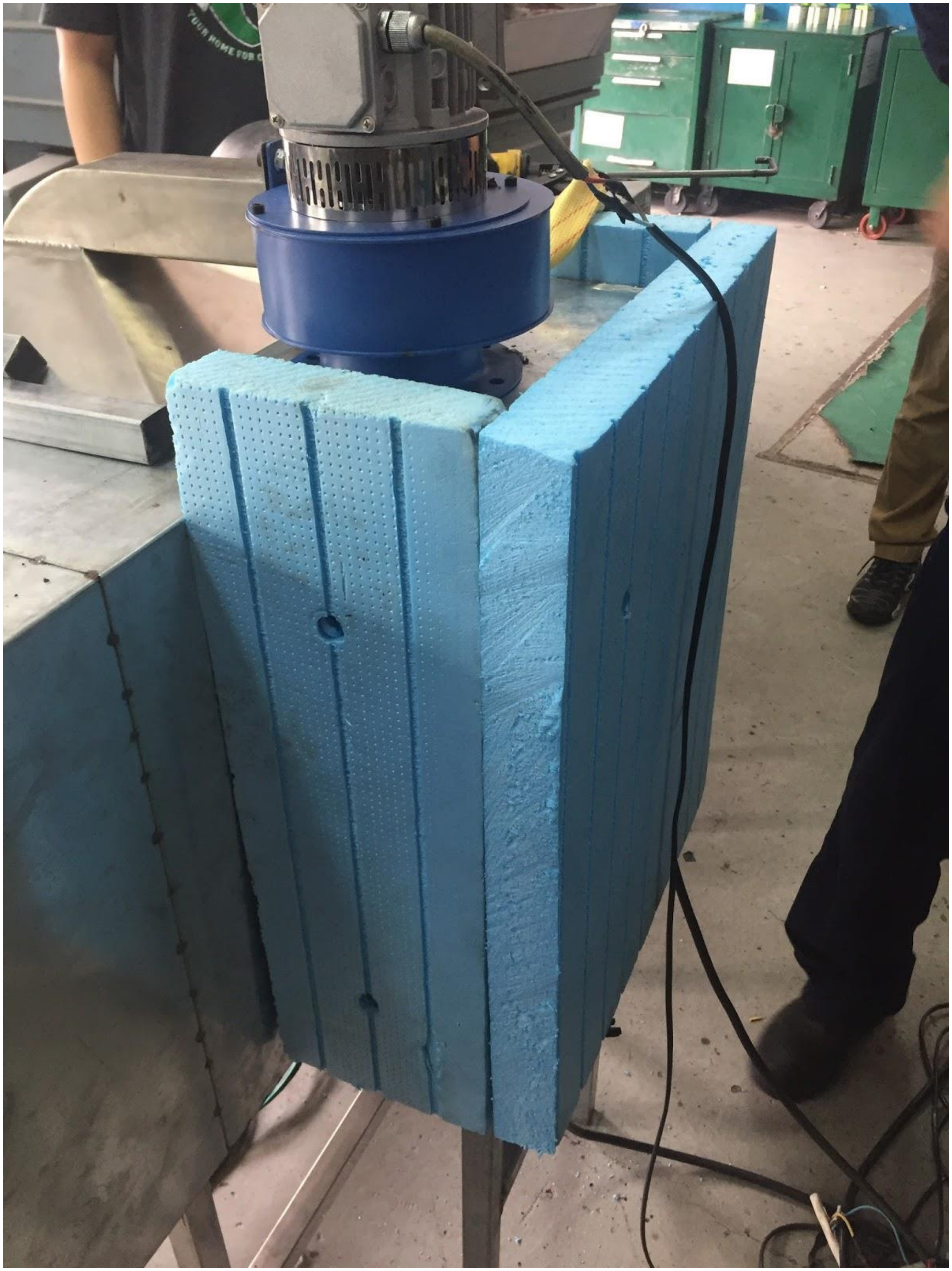


Figure 32: All Three Sides Insulated

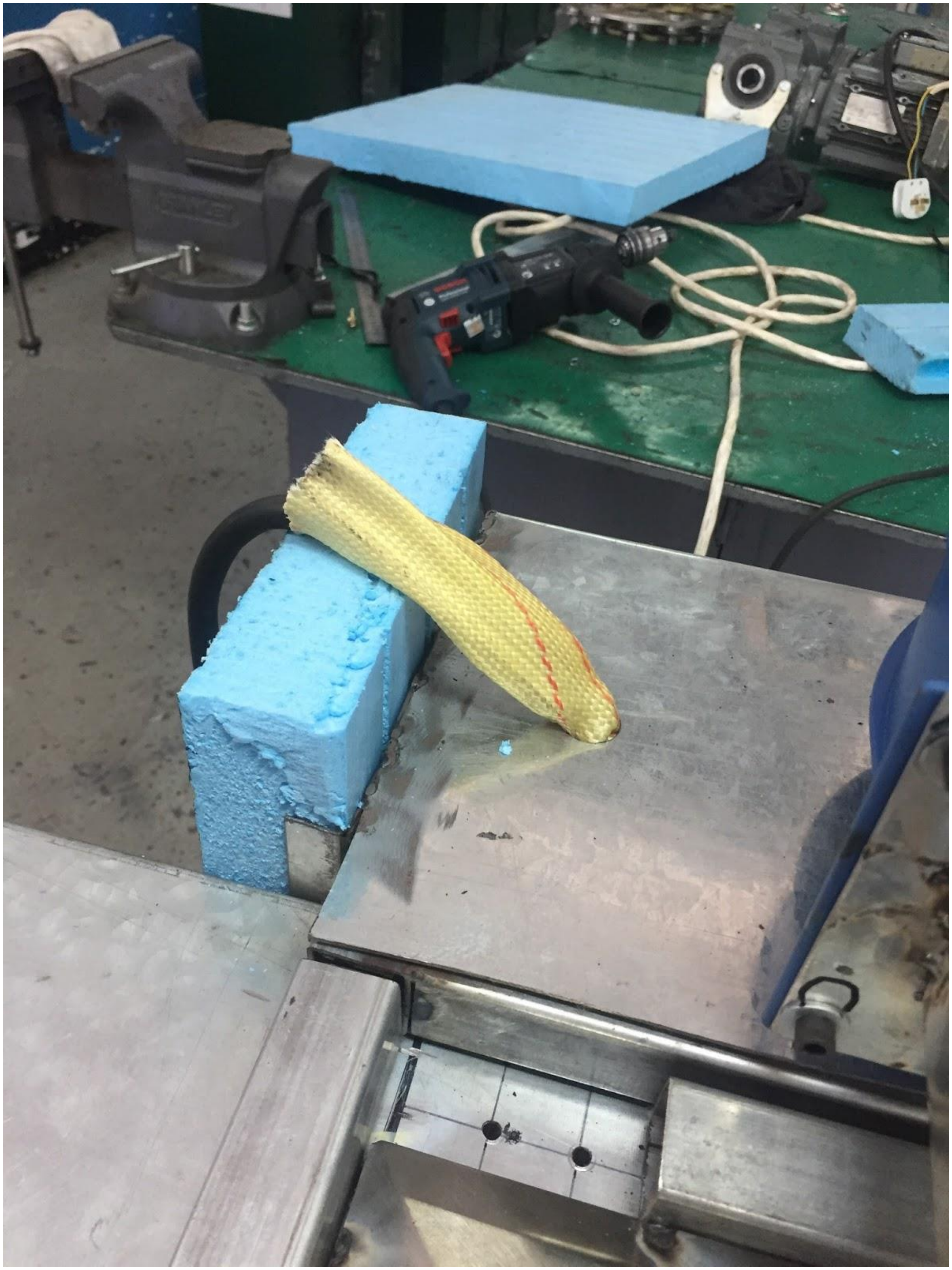


Figure 33: Wire Protection

Figure 34: Heating Room Completely Insulated

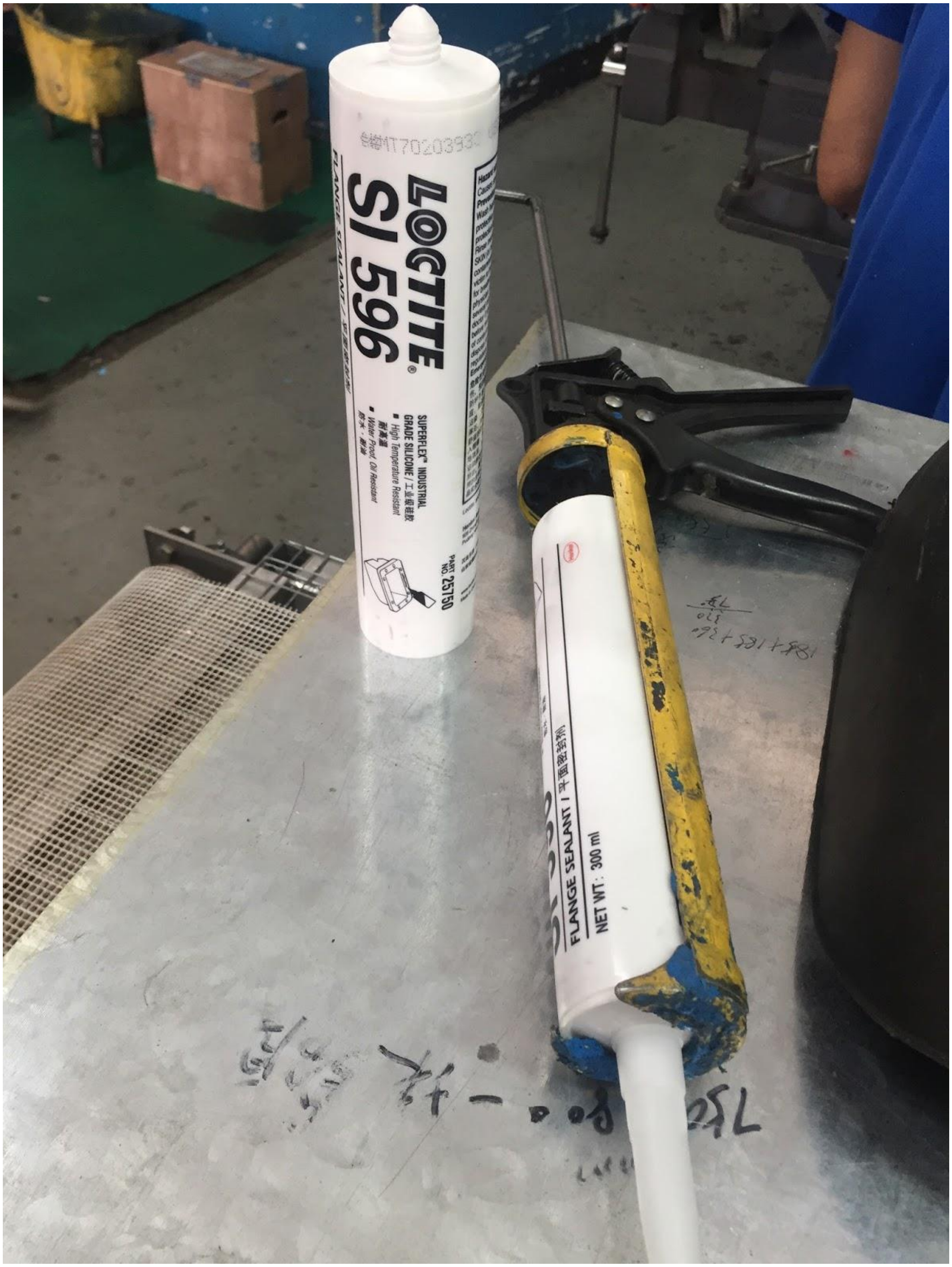


Figure 35: Insulating Silicone

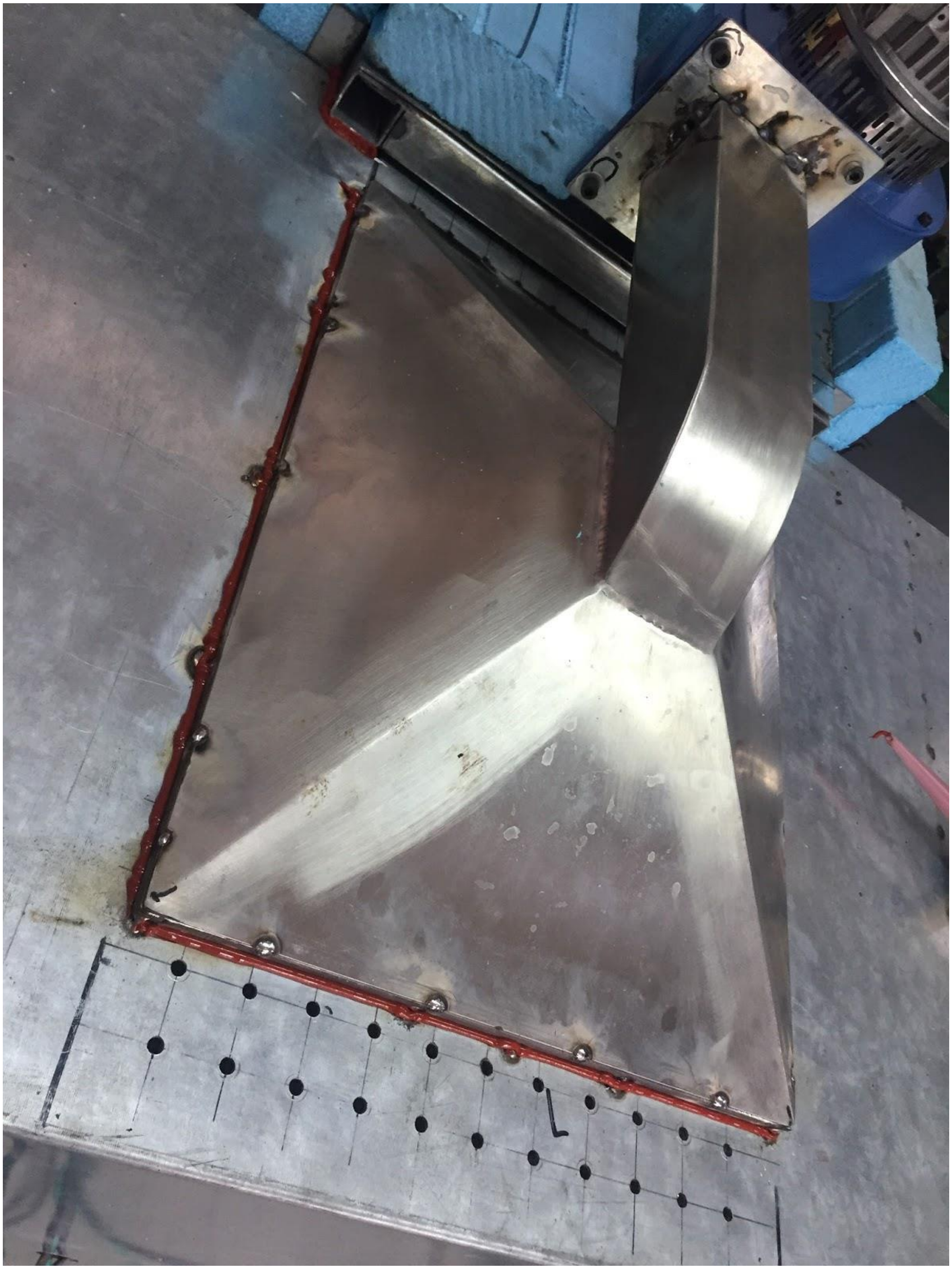


Figure 36: Vent Sealed using Silicone

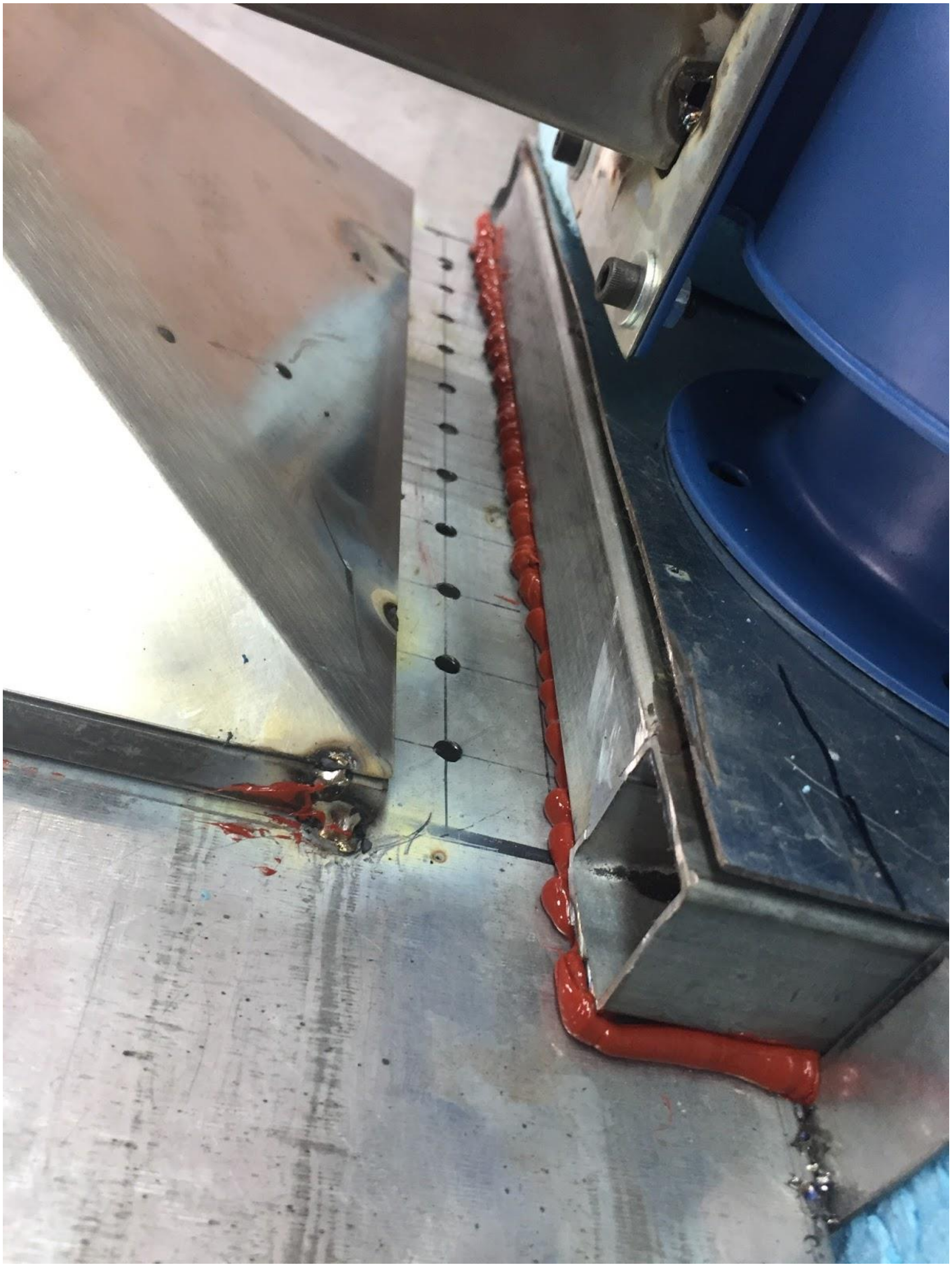


Figure 37: Heating Room Sealed using Silicone

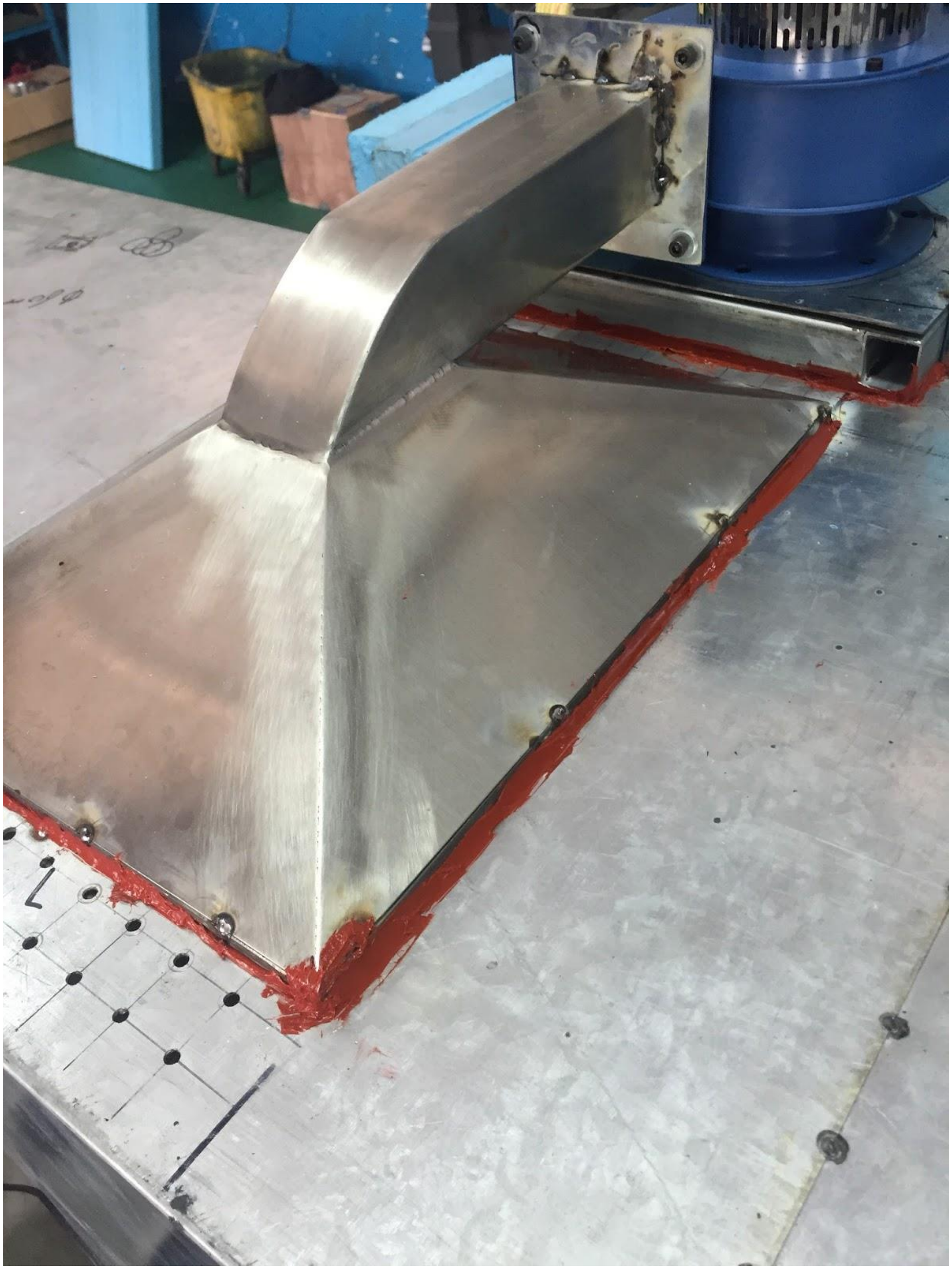


Figure 38: More of the Sealed Vent

Figure 39: Some Extra Holes Sealed with the Silicone

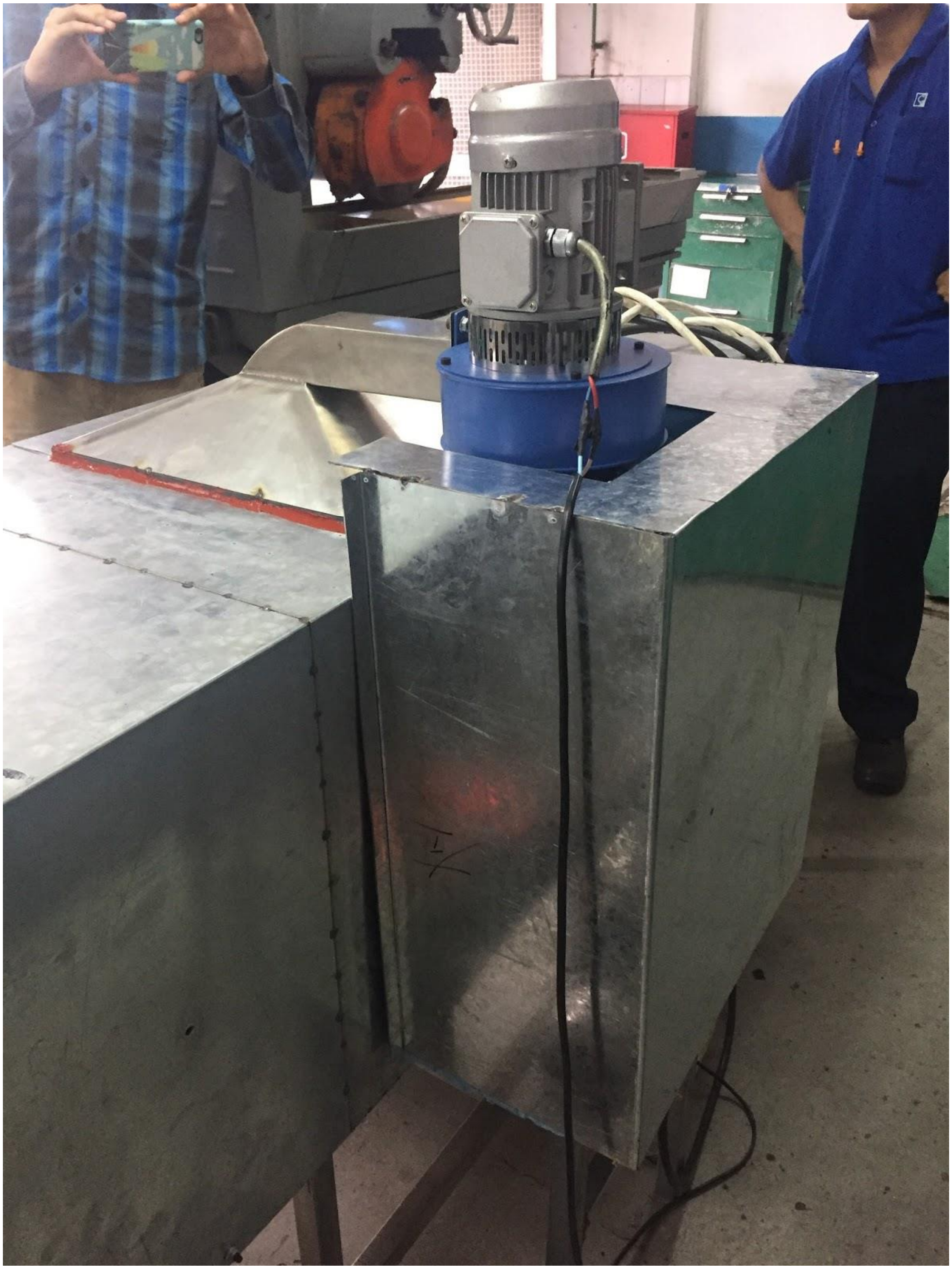


Figure 40: Completed Drying Oven Prototype

Figure 41: Completed Drying Oven Vent and Fan

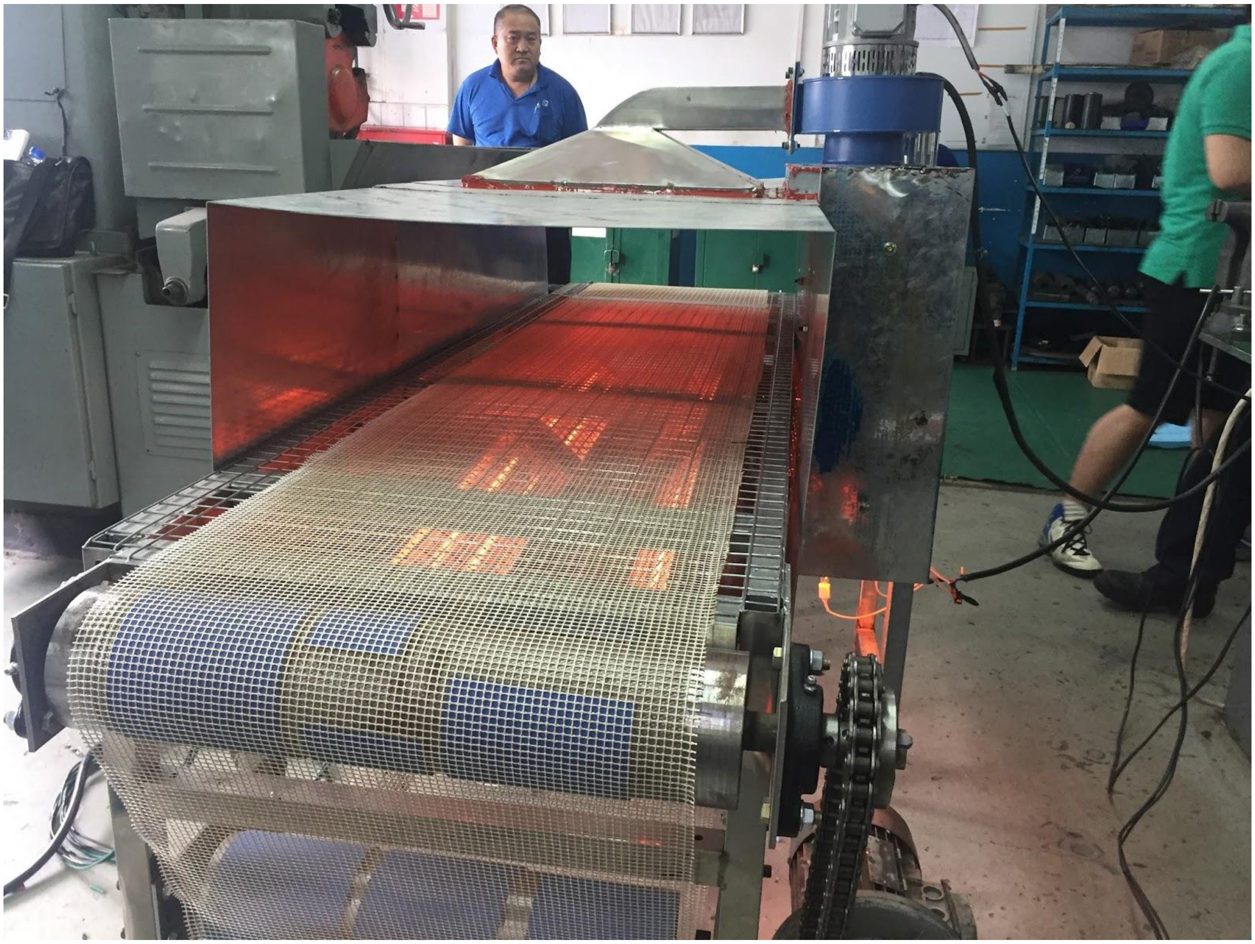
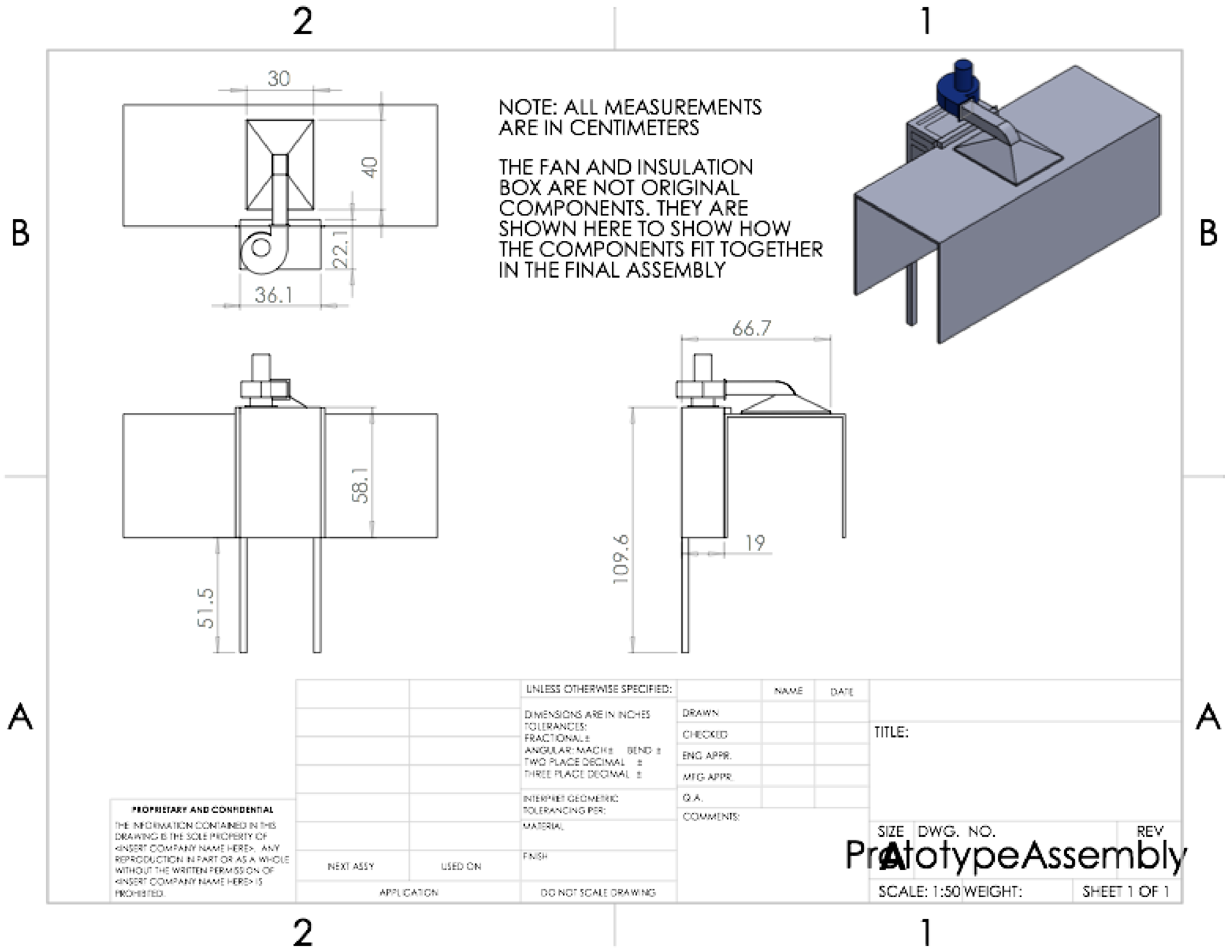


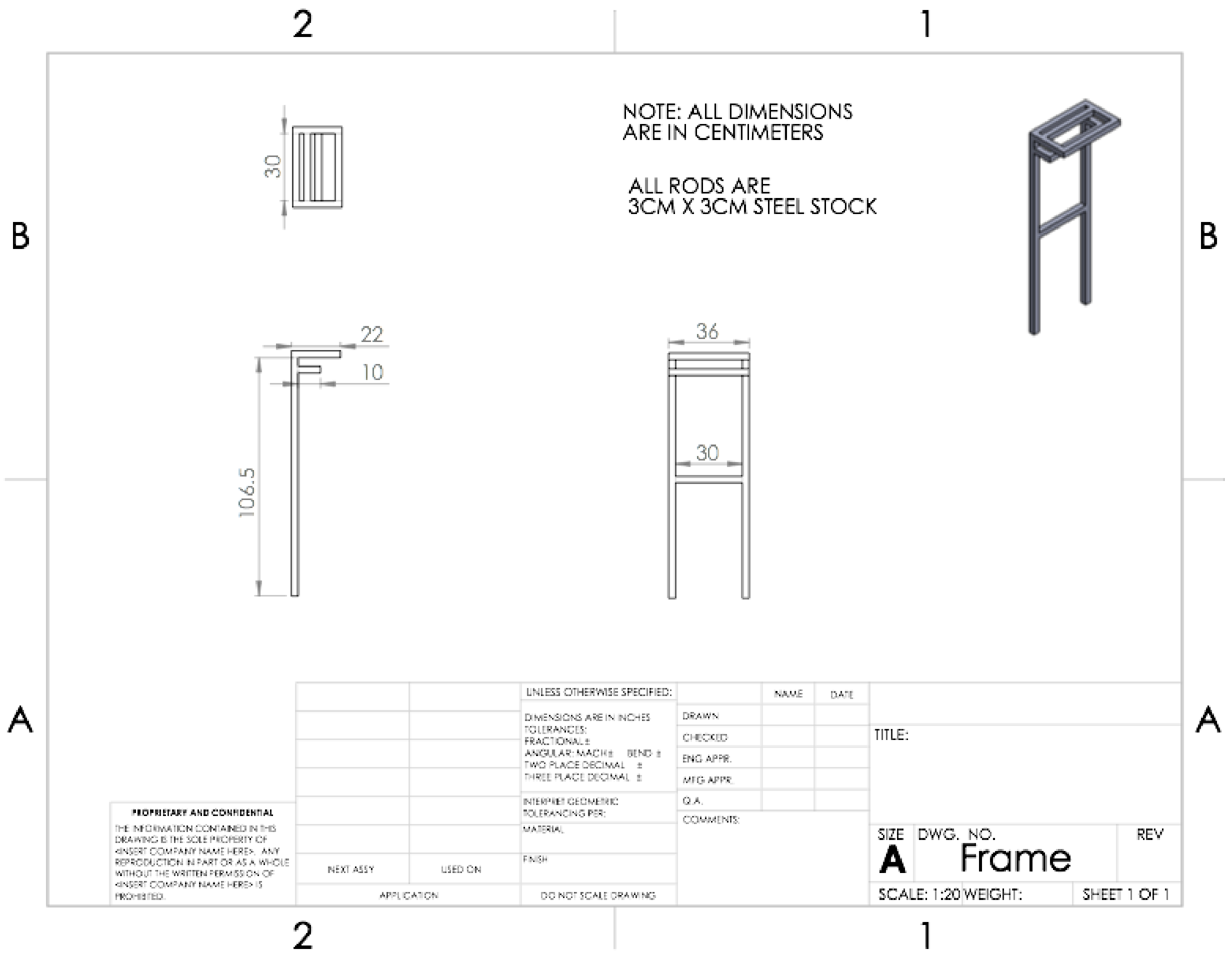
Figure 42: Working Drying Oven Prototype

Appendix C: SolidWorks Drawings

1. Prototype Assembly

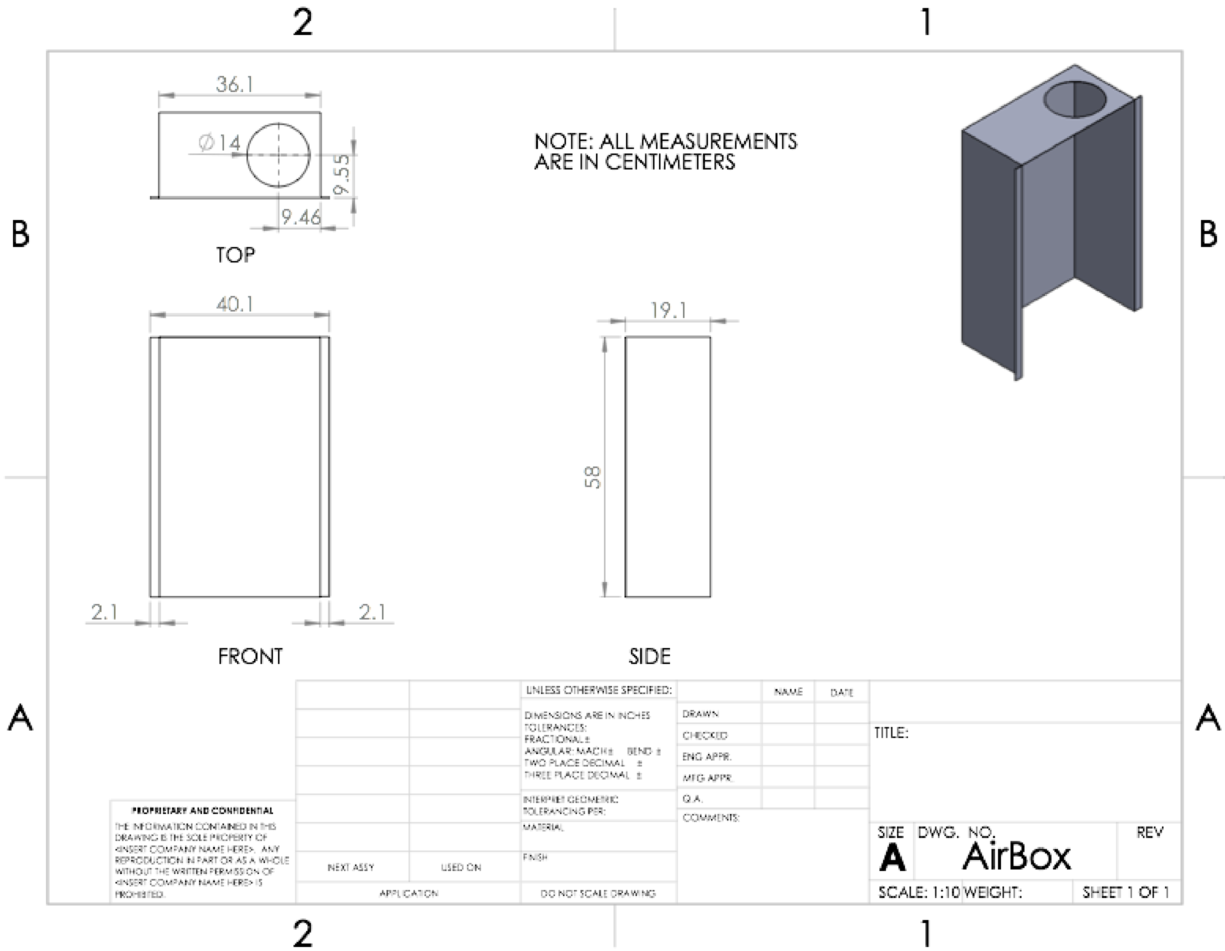


2. Frame



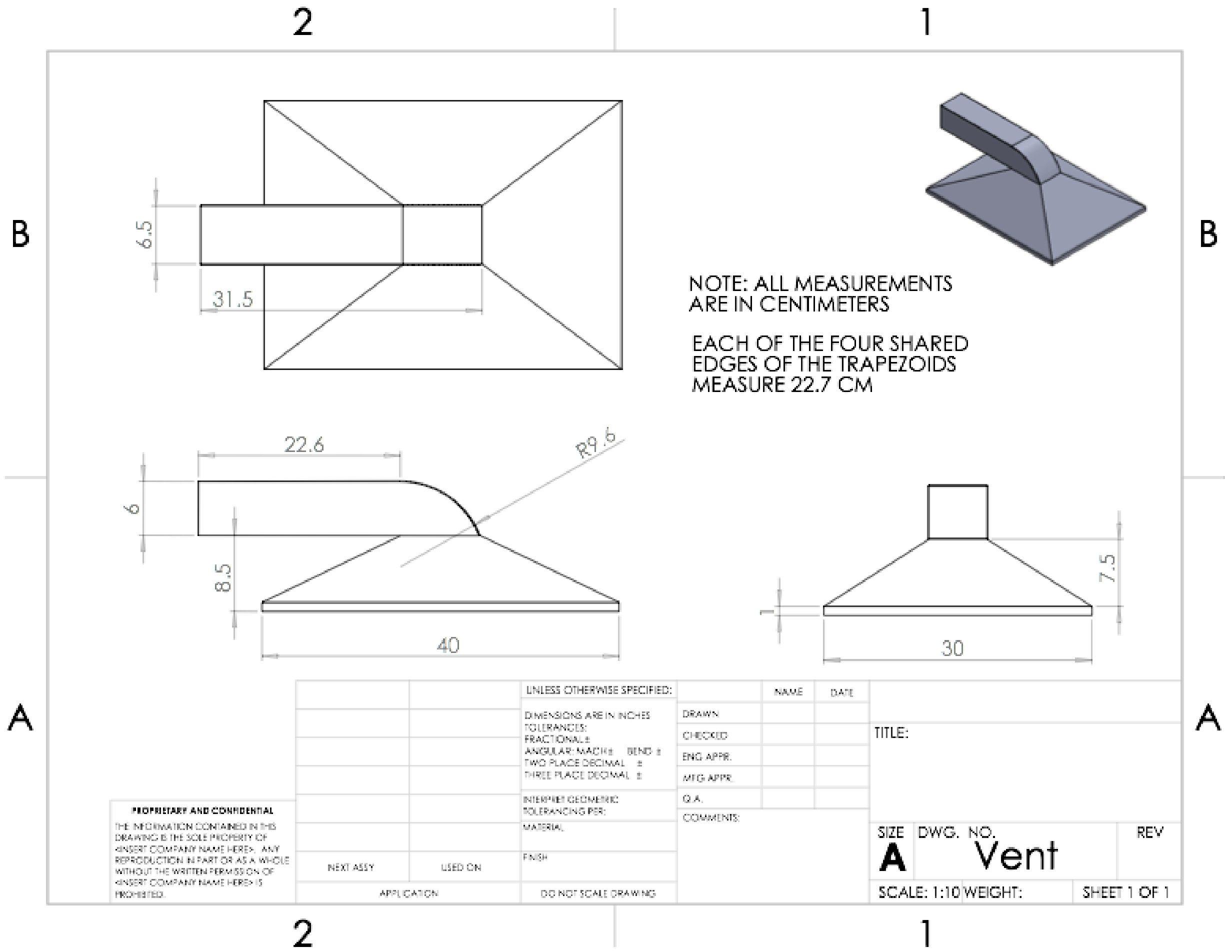
NOTE: ALL DIMENSIONS
ARE IN CENTIMETERS
ALL RODS ARE
3CM X 3CM STEEL STOCK
30
22
10
106.5
36
30
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
DWG. NO.
REV
A
Frame
SCALE: 1:20
WEIGHT:
SHEET 1 OF 1

3. Airbox



NOTE: ALL MEASUREMENTS ARE IN CENTIMETERS
36.1
Ø14
9.55
9.46
TOP
40.1
2.1
2.1
FRONT
19.1
58
SIDE
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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.
TITLE:
SIZE
A
DWG. NO.
AirBox
REV
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1

4. Vent


NOTE: ALL MEASUREMENTS ARE IN CENTIMETERS
EACH OF THE FOUR SHARED EDGES OF THE TRAPEZOIDS MEASURE 22.7 CM
6.5
31.5
22.6
R9.6
6
8.5
40
7.5
1
30
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.
Vent
REV
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION

Appendix D: Experimental Data

1. Data from Trials with Descriptions of Each

Trial 1: 5 cans at a time					Trial 2: 5 then 15 cans at a time					Trial 3: 20 cans at once				
Can #	Original Mass (g)	Wet Mass (g)	Dried Mass (g)	Time	Can #	Original Mass (g)	Wet Mass (g)	Dried Mass (g)	Time	Can #	Original Mass (g)	Wet Mass (g)	Dried Mass (g)	Time
1	10.15	10.52	10.28		1	10.15	10.89	10.42		1	10.15	10.90	10.27	
2	10.10	10.39	10.14		2	10.10	10.67	10.27		2	10.10	10.85	10.18	
3	10.10	10.44	10.18		3	10.10	10.91	10.36		3	10.10	10.73	10.16	
4	10.02	10.41	10.15		4	10.02	10.84	10.25		4	10.02	10.88	10.19	
5	10.07	10.41	10.16	1:57	5	10.07	10.81	10.29	1:30	5	10.07	10.43	10.08	
6	10.10	10.67	10.11		6	10.10	10.53	10.09		6	10.10	10.60	10.13	
7	10.20	10.55	10.21		7	10.20	10.78	10.20		7	10.20	10.99	10.27	
8	10.06	10.55	10.08		8	10.06	10.72	10.08		8	10.06	10.82	10.16	
9	10.22	10.68	10.21		9	10.22	10.60	10.18		9	10.22	10.86	10.12	
10	10.05	10.38	10.01	1:57	10	10.05	10.47	10.04		10	10.05	10.82	10.22	
11	10.22	10.58	10.40		11	10.22	10.62	10.22		11	10.22	10.65	10.16	
12	10.12	10.52	10.37		12	10.12	10.53	10.08		12	10.12	10.50	10.11	
13	10.18	10.79	10.65		13	10.18	10.99	10.37		13	10.18	10.62	10.28	
14	10.11	10.52	10.31		14	10.11	10.56	10.05		14	10.11	10.61	10.02	
15	10.18	10.63	10.41	0:32	15	10.18	10.74	10.16		15	10.18	10.93	10.19	
16	10.08	10.93	10.32		16	10.08	10.60	10.06		16	10.08	10.60	10.01	
17	10.21	10.77	10.39		17	10.21	10.65	10.23		17	10.21	10.90	10.18	
18	10.06	10.84	10.31		18	10.06	10.56	10.11		18	10.06	10.53	10.14	
19	10.10	10.75	10.36		19	10.10	10.53	10.08		19	10.10	10.98	10.13	
20	10.08	10.68	10.32	1:26	20	10.08	10.64	10.06	1:55	20	10.08	10.89	10.15	1:55

Trial 4: 20 Cans at once, Additional Inside Spray					Trial 5: 20 Cans at once, Dipped in Tank of Water					Trial 6: 20 Dipped Cans, Underside IR Tubes				
Can #	Original Mass (g)	Wet Mass (g)	Dried Mass (g)	Time	Can #	Original Mass (g)	Wet Mass (g)	Dried Mass (g)	Time	Can #	Original Mass (g)	Wet Mass (g)	Dried Mass (g)	Time
1	10.15	10.76	10.28		1	10.15	11.43	10.24		1	10.15	11.37	10.18	
2	10.10	11.07	10.14		2	10.10	11.24	10.08		2	10.10	11.44	10.12	
3	10.10	10.60	10.18		3	10.10	11.61	10.15		3	10.10	11.17	10.14	
4	10.02	10.53	10.15		4	10.02	11.10	10.04		4	10.02	11.02	10.1	
5	10.07	10.77	10.16		5	10.07	11.55	10.15		5	10.07	11.60	10.1	
6	10.10	10.89	10.11		6	10.10	11.51	10.24		6	10.10	11.16	10.11	
7	10.20	10.89	10.21		7	10.20	11.36	10.32		7	10.20	11.69	10.21	
8	10.06	10.69	10.08		8	10.06	11.60	10.33		8	10.06	11.06	10.07	
9	10.22	10.81	10.21		9	10.22	11.07	10.23		9	10.22	11.77	10.24	
10	10.05	10.78	10.01		10	10.05	11.26	10.09		10	10.05	11.68	10.04	
11	10.22	10.54	10.40		11	10.22	11.45	10.26		11	10.22	11.59	10.23	
12	10.12	10.87	10.37		12	10.12	11.30	10.24		12	10.12	11.33	10.15	
13	10.18	10.81	10.65		13	10.18	11.73	10.45		13	10.18	11.40	10.24	
14	10.11	10.65	10.31		14	10.11	11.33	10.16		14	10.11	11.36	10.11	
15	10.18	10.84	10.41		15	10.18	11.35	10.21		15	10.18	11.58	10.2	
16	10.08	10.62	10.32		16	10.08	11.24	10.13		16	10.08	11.46	10.19	
17	10.21	10.85	10.39		17	10.21	11.31	10.25		17	10.21	11.14	10.22	
18	10.06	10.62	10.31		18	10.06	11.13	10.16		18	10.06	11.34	10.09	
19	10.10	10.98	10.36		19	10.10	11.25	10.12		19	10.10	11.57	10.12	
20	10.08	10.68	10.32	1:55	20	10.08	11.33	10.11	3:40	20	10.08	11.36	10.11	3:20

2. Drying Percentage Calculations

Drying Percentage Calculations		
	Averages (g)	Percentage Dried (%)
Original Mass	10.12	
Trial 1-1 Wet	10.43	
Trial 1-1 Dry	10.18	80.25
Trial 1-2 Wet	10.57	
Trial 1-2 Dry	10.12	99.10
Trial 1-3 Wet	10.61	
Trial 1-3 Dry	10.43	36.89
Trial 1-4 Wet	10.79	
Trial 1-4 Dry	10.34	67.36
Trial 2-1 Wet	10.82	
Trial 2-1 Dry	10.32	71.88
Trial 2-2 Wet	10.53	
Trial 2-2 Dry	10.13	96.59
Trial 3 Wet	10.75	
Trial 3 Dry	10.16	94.09
Trial 4 Wet	10.76	
Trial 4 Dry	10.27	76.89
Trial 5 Wet	11.36	
Trial 5 Dry	10.20	93.70
Trial 6 Wet	11.40	
Trial 6 Dry	10.15	97.78

Appendix E: Energy Calculation

1.Energy needed to heat up the cans

heat loss to heat up cans assume can is heated up to 100 C with m=14.9 g (aluminium.org)

$T1 := (25 + 273.15) = 298.15 \ K$

$T2 := (100 + 273.15) = 373.15 \ K$

$m := 14.9 \ g \qquad M := 27 \ \frac{g}{mol}$

$n := \frac{m}{M} = 0.552 \ mol$

$A := 28.089$

$B := -5.415 \cdot 10^{-3}$

$C := 8.56 \cdot 10^{-6}$

$D := 3.427 \cdot 10^{-9}$

$E := -.277 \cdot 10^{6}$

(webbook.nist.gov)

$$H1 := n \cdot \int_{T1}^{T2} A + B \cdot T + C \cdot T^2 + D \cdot T^3 + \frac{E}{T^2} \, dT = 1.03 \times 10^3 \quad J$$

heat needed for water

$$Hcans := H1 \cdot 300 = 3.089 \times 10^5 \qquad \frac{J}{min}$$

2.Energy needed to heat up water

heat needed to heat up water to 100C assume 5 ml water = 5 g water

$T1 := (25 + 273.15) = 298.15 \ K$

$T2 := (100 + 273.15) = 373.15 \ K$

$m := 5 \ g \qquad M := 18 \ \frac{g}{mol}$

$n := \frac{m}{M} = 0.278 \ mol$

$A := -203.606$

$B := 1523.29 \cdot 10^{-3}$

$C := -3196.413 \cdot 10^{-6}$

$D := 2474.455 \cdot 10^{-9}$

$E := 3.855 \cdot 10^{6}$

(webbook.nist.gov)

$$H1 := n \cdot \int_{T1}^{T2} A + B \cdot T + C \cdot T^2 + D \cdot T^3 + \frac{E}{T^2} \, dT = 1.572 \times 10^3 \quad J$$

heat needed to evaporate 5ml of water from100 C

$Latentheat := 2257 \ \frac{J}{g}$ (engineeringtoolbox)

$H2 := m \cdot Latentheat = 1.129 \times 10^4 \ J$

Heat needed

$Htotal := H1 + H2 = 1.286 \times 10^4 \ J$

heat needed for water

$Hwater := Htotal \cdot 300 = 3.857 \times 10^6 \ \frac{J}{min}$

3.Energy needed to heat up conveyor belt

heat loss to heat up conveyor belt assuming it is heated up to 100 C with m=255 g/m^2 (tanic-tpd.com) with each can needed a 150% of the square of its radius, which is 2.6 in (cancentral.com) = .066 m assuming it is 100%

$T1 := (25 + 273.15) = 298.15 \ K$

$T2 := (100 + 273.15) = 373.15 \ K$

$A := 18.429$

$B := 24.643 \cdot 10^{-3}$

$C := -8.914 \cdot 10^{-6}$

$D := 9.665 \cdot 10^{-9}$

$E := -.013 \cdot 10^{6}$

(webbook.nist.gov)

$Area := 1.50 \cdot .066^2 \cdot \pi = 0.021 \quad m^2$

$m := Area \cdot 255 = 5.234 \quad g$

$M := 55.85 \quad \frac{g}{mol}$

$n := \frac{m}{M} = 0.094 \quad mol$

$$H1 := n \cdot \int_{T1}^{T2} A + B \cdot T + C \cdot T^2 + D \cdot T^3 + \frac{E}{T^2} \, dT = 182.374 \qquad J$$

heat needed for conveyor belt

$$Hcons := H1 \cdot 300 = 5.471 \times 10^4 \qquad \frac{J}{min}$$

4.Energy loss from the oven due to heat conduction

$L := 1.404 \ \ m \qquad H := .539 \ \ m \qquad W := 1 \ \ m \qquad T := .1 \ \ m$

$Area := 2L \cdot (W + H) = 4.322 \ \ m^2 \qquad k := .6 \ \ \frac{W}{mK}$ (engineeringtoolbox.com) $v1 := 1.83 \ \ \frac{m}{s}$

$Tin := 200 + 273 = 473 \ \ K$

$Tout := 25 + 273 = 298 \ \ K \qquad h1 := 10.45 - v1 + 10 \cdot v1^{\frac{1}{2}} = 22.148 \ \ \frac{W}{m^2 K} \qquad h2 := .5 \ \ \frac{W}{m^2 K}$

(engineeringtoolbox.com)

$R1 := \frac{1}{h1 \cdot Area} = 0.01 \ \ \frac{K}{W}$

$R2 := \frac{T}{k \cdot Area} = 0.039 \ \ \frac{K}{W}$

$R3 := \frac{1}{h2 \cdot Area} = 0.463 \ \ \frac{K}{W}$

$Rtotal := R1 + R2 + R3 = 0.512 \ \ \frac{K}{W}$

$Hoven := 60 \cdot \frac{Tin - Tout}{Rtotal} = 2.052 \times 10^4 \ \ \frac{J}{min}$

5.Energy loss from the vent due to heat conduction

$L := .5 \quad m \qquad H := .5 \quad m \qquad W := .5 \quad m \qquad T := .1 \quad m$

$Area := 2L \cdot (W + H) = 1 \quad m^2 \qquad k := .6 \quad \frac{W}{mK}$ (engineeringtoolbox.com) $v1 := 3.66 \quad \frac{m}{s}$

$Tin := 200.667 + 273 = 473.667 \; K$

$Tout := 25 + 273 = 298 \quad K \qquad h1 := 10.45 - v1 + 10 \cdot v1^{\frac{1}{2}} = 25.921 \quad \frac{W}{m^2 K} \qquad h2 := .5 \quad \frac{W}{m^2 K}$

(engineeringtoolbox.com)

$$R1 := \frac{1}{h1 \cdot Area} = 0.039 \quad \frac{K}{W}$$

$$R2 := \frac{T}{k \cdot Area} = 0.167 \quad \frac{K}{W}$$

$$R3 := \frac{1}{h2 \cdot Area} = 2 \quad \frac{K}{W}$$

$$Rtotal := R1 + R2 + R3 = 2.205 \quad \frac{K}{W}$$

$$Hvent1 := 60 \cdot \frac{Tin - Tout}{Rtotal} = 4.78 \times 10^3 \quad \frac{J}{min}$$

6.Energy loss from the vent due to heat convection and the initial temperature of air entering the vent

$p := .7459 \quad \frac{kg}{m^3}$ $\quad k := .03779 \; \frac{W}{mK}$ $\quad$ surface tem constant $\quad Ts := 25 \quad C$

$Cp := 1023$

$Te := 200 \quad C$

$v := 3.455 \cdot 10^{-5} \quad \frac{m^2}{s}$ $\quad D := .25 \quad m$

$Pr := .6974$

$A := D^2 = 0.063 \quad m^2$

$Vavg := 1.83 \cdot 2 = 3.66 \quad \frac{m}{s}$

$$Re := \frac{Vavg \cdot D}{v} = 2.648 \times 10^4$$

turbulance flow

$Lh := 10 \cdot D = 2.5 \quad m$ $\quad L := .5$

$$Nu := .023 \cdot Re^{.8} \cdot Pr^{.3} = 71.31$$

$$h := \frac{k \cdot Nu}{D} = 10.779 \quad \frac{W}{m^2}$$

$$As := 4 \cdot D \cdot L = 0.5 \quad m^2$$

$$m := p \cdot 1.83 = 1.365 \quad \frac{kg}{s}$$

$$Ti := Ts - \frac{(Ts - Te)}{\exp\left(-h \cdot \frac{As}{m \cdot Cp}\right)} = 200.677 \quad T$$

$$Tlm := \frac{Ti - Te}{\ln\left(\frac{Ts - Te}{Ts - Ti}\right)} = -175.338 \quad T$$

$$Hvent := -h \cdot As \cdot Tlm \cdot 60 = 5.67 \times 10^4 \quad \frac{J}{min}$$

7.Energy loss from the heating room due to heat conduction

$L := 1 \quad m \qquad H := .539 \quad m \qquad W := 1 \quad m \qquad T := .1 \quad m$

$Area := 2L \cdot (W + H) = 3.078 \quad m^2 \qquad k := .6 \quad \frac{W}{mK}$ (engineeringtoolbox.com) $v1 := 3.66 \quad \frac{m}{s}$

$Tin := 200 + 273 = 473 \quad K$

$Tout := 25 + 273 = 298 \quad K \qquad h1 := 10.45 - v1 + 10 \cdot v1^{\frac{1}{2}} = 25.921 \quad \frac{W}{m^2 K} \qquad h2 := .5 \quad \frac{W}{m^2 K}$

(engineeringtoolbox.com)

$$R1 := \frac{1}{h1 \cdot Area} = 0.013 \quad \frac{K}{W}$$

$$R2 := \frac{T}{k \cdot Area} = 0.054 \quad \frac{K}{W}$$

$$R3 := \frac{1}{h2 \cdot Area} = 0.65 \quad \frac{K}{W}$$

$$Rtotal := R1 + R2 + R3 = 0.716 \quad \frac{K}{W}$$

$$Hheatroom := 60 \cdot \frac{Tin - Tout}{Rtotal} = 1.466 \times 10^4 \quad \frac{J}{min}$$

8.Energy needed to heat up the air

$$V := 1.83 \cdot 60 = 109.8 \quad \frac{m^3}{min} \qquad pavg := \frac{(1.2 + .746)}{2} = 0.973 \quad \frac{Kg}{m^3}$$

$$T1 := (25 + 273.15) = 298.15 \ \ K$$

$$T2 := (200.667 + 273.15) = 473.817 \ \ K$$

$$m := V \cdot pavg \quad \frac{Kg}{min}$$

$$T := \frac{(T1 + T2)}{2} = 385.983 \quad K$$

$$Cp := \frac{1026 + 1005}{2} = 1.016 \times 10^3 \quad \frac{J}{KgK}$$

heat needed for air

$$Hair := m \cdot Cp \cdot T = 4.188 \times 10^7 \quad \frac{J}{min}$$

9.Total energy needed including energy efficiency of the light

10.Number of the light with given energy produced by each light.

$$HTOTAL := Hwater + Hcans + Hcons + Hheatroom + Hoven + Hvent + Hvent1 + Hair = 4.619 \times 10^{7} \quad \frac{J}{min}$$

Assume the IR tube has 90% efficiency

$$Hneeded := \frac{HTOTAL}{.9} = 5.133 \times 10^{7} \qquad \frac{J}{min}$$

1 IR tube provides 900 W which is 54000 J/min

$$numberIR := \frac{Hneeded}{54000} = 950.48 \qquad \text{tubes}$$

Appendix F: Material Analysis

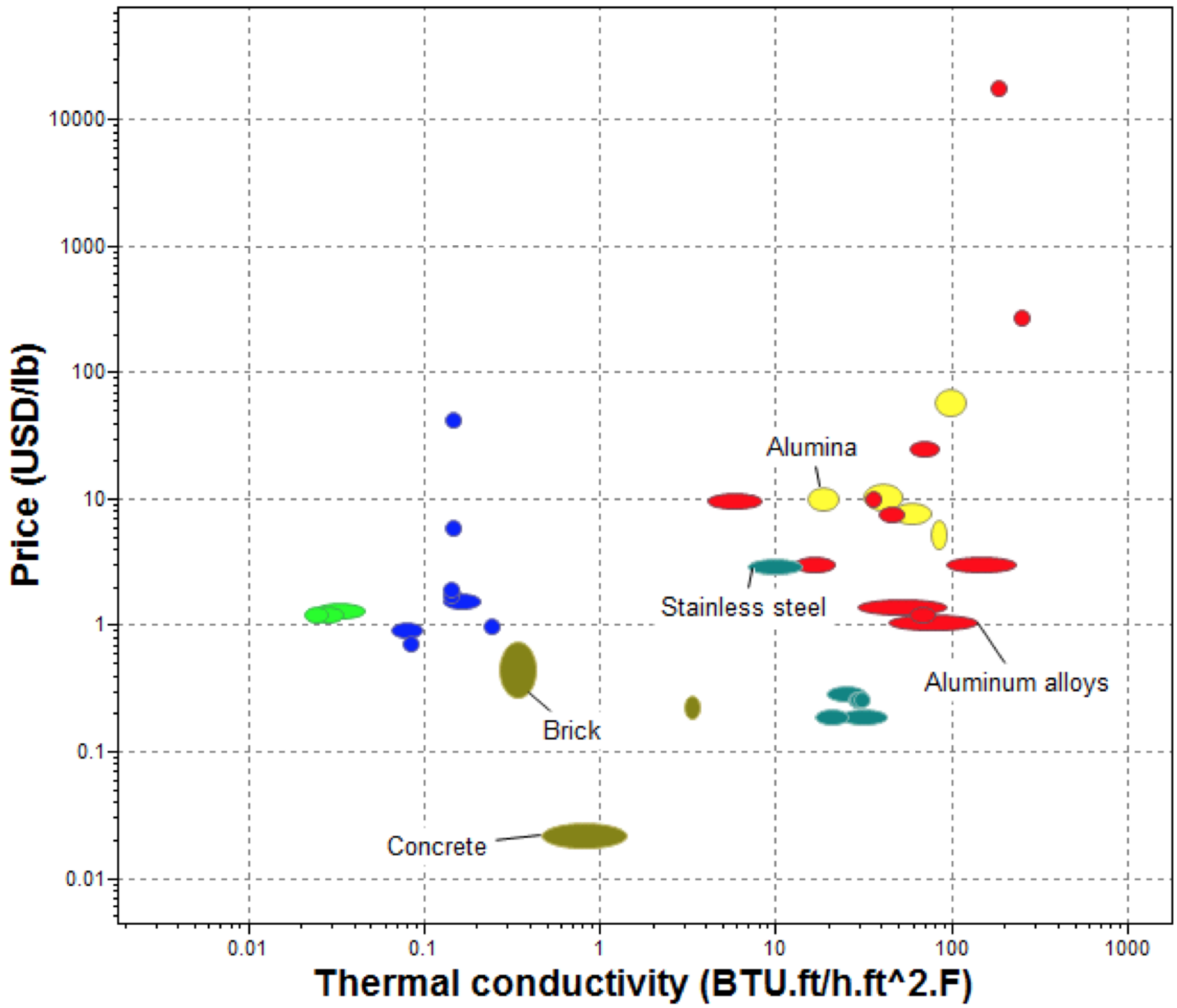


Figure 43: Price Vs Thermal Conductivity Chart

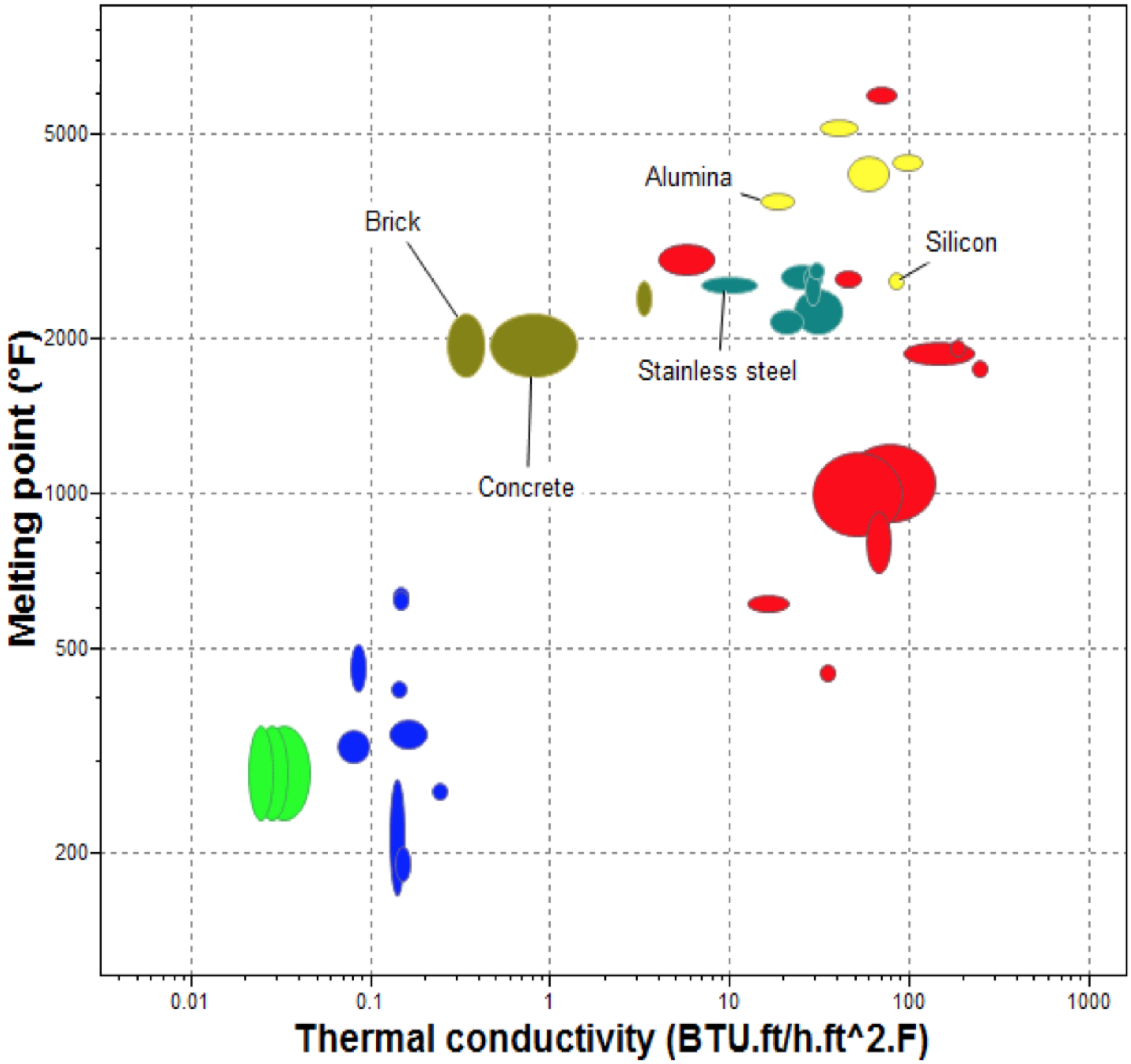


Figure 44: Melting Point Vs Thermal Conductivity Chart

Appendix G: Cost-Effectiveness

Material	Price (yuan)
Brick + cement	5000 (estimated)
IR tubes	7608
Fan (100 kW)	7000 (estimated)
Conveyor belt (5kW)	1000 (estimated)
Other	5000 (estimated)
Total	25,608

Table 3: Capital Cost

Total power used=.9 (IR tube) *951+100 (fan)+5 (conveyor belt) = 960.9 kW

Wholesale Increase	18,000 (cans/h) * .1 (yuan/can) = 1,800 (yuan/h)
Operating cost	.5475 (yuan/kWh) + 960.9 (kW) = 526.09 (yuan/h)
Profit	1,800 - 526.09 = 1,273.91 (yuan/h)

Table 4: Profit Cost

Payback time=25,6081,273.91 = 20.11 hr