Powder Coating Oven

Preliminary Proposal

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DISCLAIMER

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1 Background

1.1 Introduction

This project's purpose is to design a device to operate and complete tasks intended for purposes defined by our client. The stakeholders will be the NAU (Northern Arizona University) Renewable Energy Lab, and the client will be Professor Carson Pete. Expectations for this project are to document our process from the introduction of our selected project, the engineering design methods and processes used, and prototyping and demonstration of our final design selection. The team's goal is to design and fabricate a mobile gas-powered oven that is capable of housing both small and large parts. This oven should be capable of curing parts for the BAJA Car competitions and the renewable energy lab. This team will also work closely with the bumper capstone team to powder coat their finished capstone project.

1.2 Project Description

Below is the following original project description provided by the sponsor.

"Powder Coating is a dry finishing process created by utilizing an electric change that causes a dry powder to fuse to a surface (e.g. metals such as Aluminum or steel, glass, and even plastics) and is then permanently cured to the surface by baking the part in a high temperature curing oven. This creates a hard finish that is typically tougher than conventional paint. For this project, a team of engineering students will design and fabricate a "mobile" gas-powered oven that is capable of housing small to larger parts such as an off-road bumper or even the SAE Baja frame. This system should be able to be easily moved by a single person and would thus be "mobile". The product will be housed in the Renewable Energy lab compound area and will be used for numerous future NAU projects. This design will be optimized to be "mobile", heat generated by a propane heater system, develop a racking system allowing small to large parts to be cured, and have various controls to regulate the curing oven. Professor Pete has new powder coating equipment (~$1k worth of equipment) that will be utilized with this oven. In addition to building this oven, the team will collaborate with the bumper build team to power-coat 3 different bumpers. Additionally, there are other parts required to be powdered coated in the renewable energy lab. Students will need to have skills in the area of fabrication, structural strength analysis, control systems, possible welding or other metal fabrication techniques, computer & heat transfer analysis, and the ability to learn about the powder coating process. Figure 1 shows an example electric powder coating oven."

2 Requirements

To successfully design a powder coating oven, the requirements made by the customer would need to be satisfied. These requirements would ensure that the team creates an oven that fits the clients' needs. The engineering requirements will also need to be satisfied for the oven to meet all the required safety regulations. Below is provided the list of requirements that the client has given along with all the engineering requirements.

2.1 Customer Requirements

After a discussion with the client these were found to be the most important customer needs.

List of Customer Requirements:

1.Propane fueled heater

2.Control system for the heater
3.Retractable rack system
4.Withstand 500 degrees F
5.Dimensions/Size
6.Portability
7.Weather Resistant

The powder coating oven will be housed on the outside of the renewable energy lab. This will require the oven to be fueled by a propane heater. Since the outlets on the outside of the lab average at about 10-15 volts it will not be enough to power the oven. There will need to be a control system for the heater control system which will allow the operator to regulate the temperature inside the oven. The client would also like there to be a retractable rack system. This will allow parts of any size to be powder coated in the oven. Dimension and size are also a cute customer requirement so that Sea Baja competition team will be able to powder coat the frames of their cars. Portability is also a key component so that the oven can be moved from one area to another. It also needs to reach a minimum of 500°F so that any form of powder can be used in the oven. It also must be weather resistant since it will be stored outside the renewable energy lab.

2.2 Engineering Requirements

To create the most optimal powder coating that will meet the client's standards, the team worked together to create engineer requirements. The team created the engineering requirements after analyzing the stakeholder's requirements for the oven to meet safety regulations. Below are listed all the engineering requirements necessary for the oven to meet the specified requirements.

List of Engineering Requirements:

1. PID temperature and time monitor: The PID system was found to be a consistent and safe system for regulating temperature.
2. Corrosion Protected exterior: The exterior of the oven must be weatherproof to withstand being stored outside.
3. Safe to operate: The oven must meet all safety regulations including a carbon monoxide sensor and emergency stop button.
4. Volume: 6.5' x 4' x 5.5' (L x W x H): The oven must fit a standard sized car bumper and Baja car frame.
5. Material Costs: The cost of the oven cannot exceed the $1,500 budget provided by the customer.
6. Heat Circulation and Ventilation: The circulation and ventilation are required to ensure that the oven can reach and maintain a set temperature.
7. Design Assembly/Disassembly: The design must be easily assembled and disassembled for quick movement from one location to another and for maintenance.
8. Heat Output of 500 °F: It needs to reach a minimum of 500°F so that any form of powder can be used in the oven.

2.3 House of Quality (HOQ) (Amber)

The design process of the teams' powder coating oven started with adding the initial customer requirements to the House of Quality in order to organize and develop appropriate engineering requirements. HOQ can be seen in 7.1 Appendix A: House of Quality. In addition to adding the customer and engineering requirements, similar market-available products were added to the HOQ for benchmarking. Implementation of the HOQ allowed the team to identify which needs and requirements to prioritize. To achieve the desired internal oven temperature, the team was able to start selecting materials that maintain integrity while being subjected to large temperatures. For safety purposes, not only is it important to have the correct material, but it is also critical to have a control system to monitor temperatures and fuel levels. Thus, the team was able to select a control system better equipped to monitor these systems and implement an emergency shut-off as needed. It was determined that the most challenging requirement to meet is maintaining a large enough oven size, while also preserving the ovens portability as requested by the customer.

3 Design Research

The team conducted thorough research on powder coating ovens, being able to assign each member an important factor of the oven. The important factors of the oven stated by the client are the control system, structure, heating, and insulation. The team gathered a literature review of each factor of the requirements stated in the next section.

3.1 Literature Review

The team conducted sources for the project to benchmark the design and further research on ovens and powder coating techniques. The literature review conducts an important part each member researched about the project.

3.1.1 Powder Coating Oven and Structure

[1] Lab oven – Blue M

Type-website

This source gives an example of a powder coating oven that is available on the market. The source is beneficial for the team in terms of understanding the different designs that exist for powder coating ovens, and the difference between them.

[2] Innovative powder coating oven airflow from Reliant

Type – Article

This source gives the team a sense of the air circulation of the oven. The source is important for not just understanding the circulation of hot air of the system, but how does this process allow for the regulation of temperature inside the system, so the curing process will be more accurate.

[3] A uniform cure

Type – Article

This source shows a direct illustration of what could be an optimal design for an airflow system for powder coating ovens. This source is most beneficial because it gives the team better ideas for the air circulation for the final design.

[4] Colo-1864 small batch powder coating gas oven

Type – Website

This source gives another example of a powder coating oven. This source will help the team in understanding another powder coating oven design and provide new design ideas.

[5] Colo-0813 LPG gas powder coating oven

Type – Website

The source given above gives a third example of a powder-coating oven that is available on the market. The team will benefit from this source because it gives more opportunity for design ideas and resolves some problems that the ovens industry may have encountered.

3.1.2 Control System and Curing Instructions

[6] Columbia Coating Basic Instructions

Type – Article

This source summarizes and gives the steps of powder coating. This source is useful as the team needs to create a manual on the steps of powder coating and prepping the oven to cure coating. The source is beneficial, and it talks about prepping and pretreatment for the metal before powder coating.

[7] Feedback Controllers - UC Santa Barbara

Type – lecture

The source is a PowerPoint lecture from a university in California that talks about different feedback controllers. This source is useful as it incorporates equations used for the controllers. The team plans to use a Proportional, Integral, Derivative Control (PID) system based on meetings with Professor David Willy.

[8] Model Predictive Control vs. Proportional, Integral, Derivative Control

Type – Article

The source summarizes the differences between a model predictive control and a proportional, integral, derivative control. The source talks about the benefits of an MPC and states that an MPC is more efficient based on cost and energy efficiency. This source helps the team have a variety of control systems to choose from.

[9] The negative consequences of poor PID controller tuning: Process Dynamics and PID controller tuning: Textbook

Type – article

The source summarizes the importance of calibrating the control system, the PID controller. The source states that when the system is not calibrated/tuned errors could occur and lists possible errors. Calibrating data is crucial to being an engineer when designing projects and doing experimental labs.

[10] PID & Process Temperature Controllers

Type – article

The source talks about the overall PID controller system and temperature control. Further research on the PID control system to create an on/off switch for the oven and to be able to control the temperature setting. These are two important factors for the control system.

[11] What is a PID temperature controller?

The source focuses on the type of PID temperature controllers and the history of PID controllers. This source will allow the team to further analyze the control system and choose the final design. The requirement for the control system is to be made from scratch over a kit already made.

3.1.3 Ventilation and Safety

[12] Air flow and ventilation of paint booths: Production systems

Type – Article

The source talks about the different types of ventilation locations and how it affects the airflow of the oven. The source is useful as the team chooses where to place the ventilation system for the powder coating oven. The team plans to place the ventilation system at the bottom of the oven to allow the air to circulate up.

[13] The importance of ventilation for built-in ovens

Type – article

The source summarizes the safety and health of ventilation systems for ovens. The ventilation system ensures no fumes or gas are released into the surrounding environment the person is in. Allowing these fumes to exit into clean air can harm a person's eyes and lungs.

[14] Do ovens need to be vented?

Type – Article

The source talks about the importance of ventilation for a general oven. The source also talks about how to keep a ventilation system clean and what could cause the system to clog. This source is important as the team learns how to stay up to date with maintenance for the oven.

[15] Safety and regulatory overview for powder coating

Type – article

The source states the safety and regulations of the powder coating. The source mentions that the metal needs to be grounded or combustion can occur. The team plans on adding a rack for the metals that are mobile for inside and outside of the oven. A safety requirement for the oven is the air flow movement to reduce the risk of combustion. The team is incorporating these factors into the design to ensure combustion does not occur.

[16] Powder coating oven design, Operation & Maintenance

Type – Article

The source summarizes the important factors to analyze for a powder-coating oven. The source also states the importance of maintenance for the oven with weekly and monthly inspections. These inspections are to ensure that the oven operates correctly, and that no damage occurs. For example, a monthly inspection is Piping, wiring, and connections of all interlocks and shutoff valves. The team plans to gather inspections needed and hand off the information to the client

3.1.4 Insulation and Heating

[17] Heating BTU Calculator: How Many BTUs Per Square Foot?

Type – Article

The source talks about converting the area of the system converted to BTU to heat the area. The source talks about being able to heat a house with a heater. This source gives the team an area of deciding the type of heater to used based on the structural analysis

[18] Thermal properties

Type – Article

The source summarizes the stone wool insulation, the team is deciding to use to encase the heat into the oven. The source states several strengths of using the stone wools, being aesthetics, circularity, robustness, fire resilience, acoustic capabilities, and water properties. The team will do further research into the alternative insulation used for ovens.

[19] BTU Calculator

Type – Article

The source talks about how to calculate the BTU needed for room dimensions. This source is beneficial for when a team member must analyze the size of the heater needed for the oven. The steps of calculating BTU are finding the room dimension, insulation level, and desired rise in temperature.

[20] 125,000 BTU Forced Air Propane Heater

Type – Article

This source shows one of the possible heaters the team will use for the oven based on the dimensions. The heater heats up to 4,000 square feet and uses a 20-pound propane tank. This heater has a range of 75,000-125,000 BTU.

[21] 170,000 BTU Forced Air Propane Heater

Type – Article

This source shows one of the possible heaters the team will use for the oven based on the dimensions. The heater heats up to 4,000 square feet and uses a 20-pound propane tank. This heater has a range of 125,000-170,000 BTU.

3.2 Benchmarking

In the past few years, powder coating has become known as an effective process for finishing parts. Many of the industry and hobbyists were able to design and fabricate their powder coating ovens to achieve the best curing for their parts. To achieve similar if not better results, the team will be using a direct comparison with similar products on the market to see what has worked from their design aspects and what flaws stemmed from these products. The team will be comparing two categories of the overall designs, system level and sub-system level benchmarking. The system benchmarking will be used to compare the overall system designs, while the sub-system benchmarking will compare the parts of the overall design.

3.2.1 System Level Benchmarking

The implementation of this section is to give a few examples of powder coating ovens that are presented on the market and to discuss their relevant designs to the team's project. The selection for this system was based on the customer requirement provided at the beginning of the semester, for the dimensions are like the customer requirements, the heat output and the controlling system, and the oven must be completely mobile.

3.2.1.1 Existing Design #1: Eptex Powder Coating Oven

Figure 1: EPTEX Gas Oven Front view

Figure 2: EPTEX Gas Oven PID and heater

The first benchmark system is a powder coating oven from EPTEX company. The design of their oven was able to meet the criteria of the final design in terms of the overall dimensions (4.7' wide x 6.7' height x 4.7' depth). Their overall design was also able to meet the requirement in terms of the output heat, for it achieves up to 500 degrees Fahrenheit for maximum output. However, the price of this product varies heavily with the requirement of the final design, which exceeds $21,060.00, while the budget for our design is no more than $1000 – 1500.

3.2.1.2 Existing Design #2: Colo Powder Coating Oven (1)

Figure 3: Colo Gas Oven Front view

Figure 4: Colo Gas Oven Rear view

The second benchmark system is a powder coating oven made by Colo Company. Just like the previous company, this design was able to meet the requirements of the project by providing similar dimensions for the overall design (5.25' length x 4.59' width x 5.91' height). The design was also able to achieve a close maximum temperature of 482 degrees Fahrenheit. However, this example lacks in mobility,

3.2.1.3 Existing Design #3: Colo Powder Coating Oven (2)

Figure 5: Colo Gas Oven exterior

Figure 6: Colo Gas Oven interior

The third benchmark system is another Colo Company powder coating oven. The exception to this design is that it contains a separate room for the heater air circulation. This design meets the requirement in terms of exceeding the required maximum temperature (482 degrees Fahrenheit). The design, however, shows a lack of mobility, and a major difference in terms of the required measurements.

3.2.2 Subsystem Level Benchmarking

The relevance of this section is to provide exceptional examples for the subsystems that the powder coating oven is relying on. These three are: heat generation, airflow system (circulation) and airflow system (exit). Each of these subsystems will be described below.

3.2.2.1 Subsystem #1: Heat Generation

The heat generation is the main function of the oven, specifically when it comes to the location of the heat generation source on the oven. In this section, examples will be given to show the relevant locations of heat sources on some ovens that exist on the market, and how these designs meet the criteria for our project.

3.2.2.1.1 Existing Design #1: EPTEX Powder Coating Oven

Figure 7: heating system housing

As shown in the figure above, this design shows the housing of the heat source of the oven. The housing unit that the EPTEX powder coating oven provides a solution for storing the heat source of the oven (the torpedo heater), which will help with most weather conditions. This design is relevant for the team because it shows a way to secure the heat source from weather exposure, as well as provide more design options for concept generation.

3.2.2.1.2 Existing Design #2: Colo Powder Coating Oven (1)

Figure 8:

The second design by Colo Company shows that the heat source is located separately from the oven, which allows for easier access. Also, to achieve better performance, the design includes a back room that allows for less heat generation, thus lowering the power usage for the oven. The benefit of this design stems from its simplicity, and its ability to be compact while producing the same heat rate that is required for the team's design.

3.2.2.1.3 Existing Design #3: Colo Powder Coating Oven (2)

Figure 9:

The third design, also by Colo Company, provides a similar case to their previous oven, apart from a fixed heat source instead of a detachable option. This design will be helpful for the team in generating ideas about the housing of the heat source, and what benefits could arise from such a decision.

3.2.2.2 Subsystem #2: Air Flow System (Circulation)

This section will provide benchmarking examples of products that show different air circulation designs. This section, like the previous, is most important because it allows the team to see different ways of keeping the heat in the system to accomplish an optimal powder coating finish, without the usage of extra electrical or gas power in the process.

3.2.2.2.1 Existing Design #1: EPTEX Powder Coating Oven

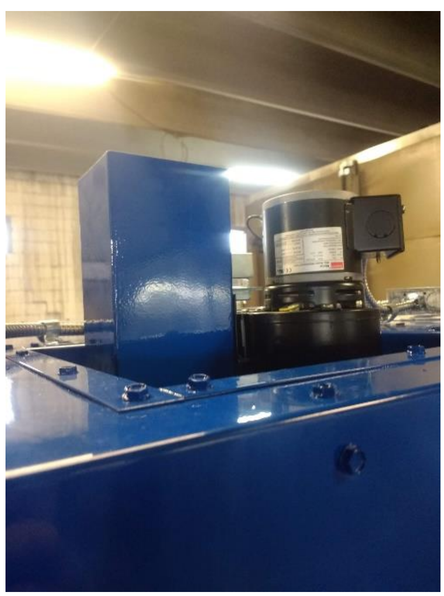


Figure 10:

The first design by EPTEX Company shows that their air circulation is installed at the top of the oven.

For the design, since hot air rises, the fan at the top will circulate the hot air back into the system from the top as well. The design shows the team another idea for installing the heat fan, without the cost of space. The design also shows the team how much accessibility could be implemented into the final design, to provide better maintenance for the airflow system.

Existing Design #2: Colo Powder Coating Oven (2)

Figure 11:

The second design by Colo company shows that the air circulation is housed in a separate compartment. The design shows a different and more efficient way for air circulation, for as the cold air sinks to the bottom of the oven, the heat fan behind the second housing is recycling it back into the system as hot air from the top. This design relates to the requirements because it shows an efficient way of regulating the temperature of the oven, with the cost of extra space.

Subsystem #3: Air Flow System (Exit)

The last step when it comes to regulating the heat inside the oven is through the heat exhaust system. This subsystem is meant to demonstrate the benchmarking of different air flow exit designs from different companies.

3.2.2.2.2 Existing Design #1: Colo Powder Coating Oven (1)

Figure 12:

The first oven from Colo Company shows a simple design for their heat exhaust. Their design consists of a heat exhaust pipe placed in the same housing unit as the airflow system at the back of the oven. The design is helpful for its compatibility, whilst producing an equivalent temperature stabilization for better outcomes.

3.2.2.2.3 Existing Design #2: EPTEX Powder Coating Oven

Figure 13:

The second oven from Eptex shows a different design for heat exhaust, where the cold air leaves the system through an opening at the bottom of the oven. As the cold air accumulates at the bottom of the oven, the opening allows for the cold air to escape from the system, while the rest of the hot air is picked up by the heat fan, so it can be circulated back into the system. The design meets the requirement in terms of achieving similar dimensions to the team's design, with easily accessible systems that allow for instant repairs if needed.

3.3 Functional Decomposition

An important component in the design and development process of creating an oven for powder coating is the application of the functional decomposition method. During this process, the team developed a Black Box model and a Functional model. The Black Box, seen below in Figure 14, models the intended functionality of the oven. Arrows on either side of the box correspond to material, energy, and signal inputs and outputs during the use and operation of the oven. This is a simplistic method used to visualize the core components that will best enable the principal task of the product to be completed. Developing and completing a correct model will ensure a functional model is accurately achieved as well. As seen in Figure 14, the required material inputs are Propane, to fuel the heater; Powder, used to coat the object; Object, of various materials to be placed in the oven. The energy input for the oven is electrical- to power the oven control systems, thermal- heat being added to oven by the selected heater, chemical- reaction between powder and heat, and electrostatic- allows for the powder to cling to object before entering the oven. Signals for the oven will be delivered though on/off and to emergency shut-off switches to control the power supply to the oven.

3.3.1 Black Box Model

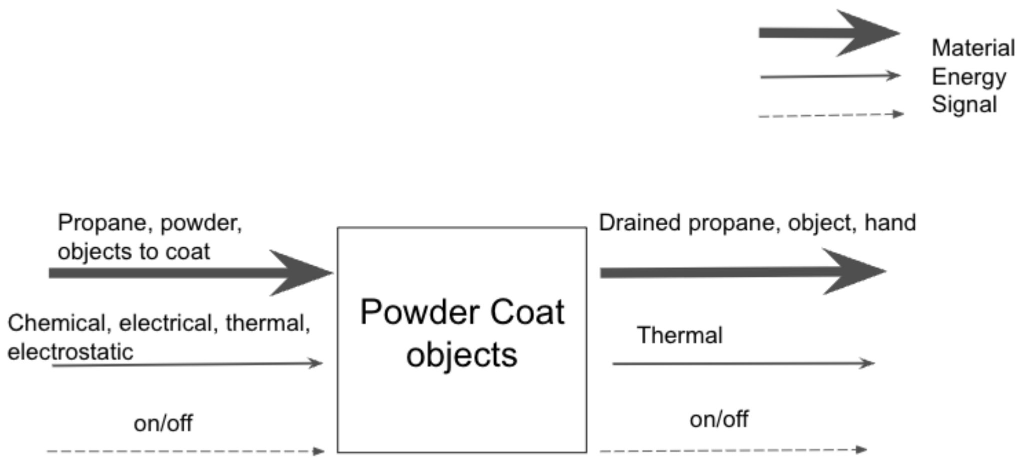


Figure 14: Black Box Model for Powder Coat Oven

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

After compiling the black box, the function model was developed. This model depicts the flow of tasks needed to be performed to meet the needs of the customer. Since providing the best possible product is critical, it is important to verify the task is completed to yield the best possible powder-coated object. The main oven will receive electrical energy to deliver power to the control system and heater. For the heater to heat the oven to the required temperatures, propane will also be added to the system. Before putting the coated object into the oven to cure completely, additional steps should be completed. First, the object being coated needs to have its surface cleaned to ensure the exterior is clear of any particulates or contaminates, followed by a chemical treatment to aid the powder adhering properly. Next, it is recommended that the object is placed in the oven during the preheating process and removed before reaching the powder's instructed curing temperature. Adding the powder coat while the item is hot will aid in attaining a thicker coat with a higher-quality finish. Understanding detailed tasks that need to be completed will enable the team to develop a product that allows each step of the process to be completed by the customer safely and effectively.

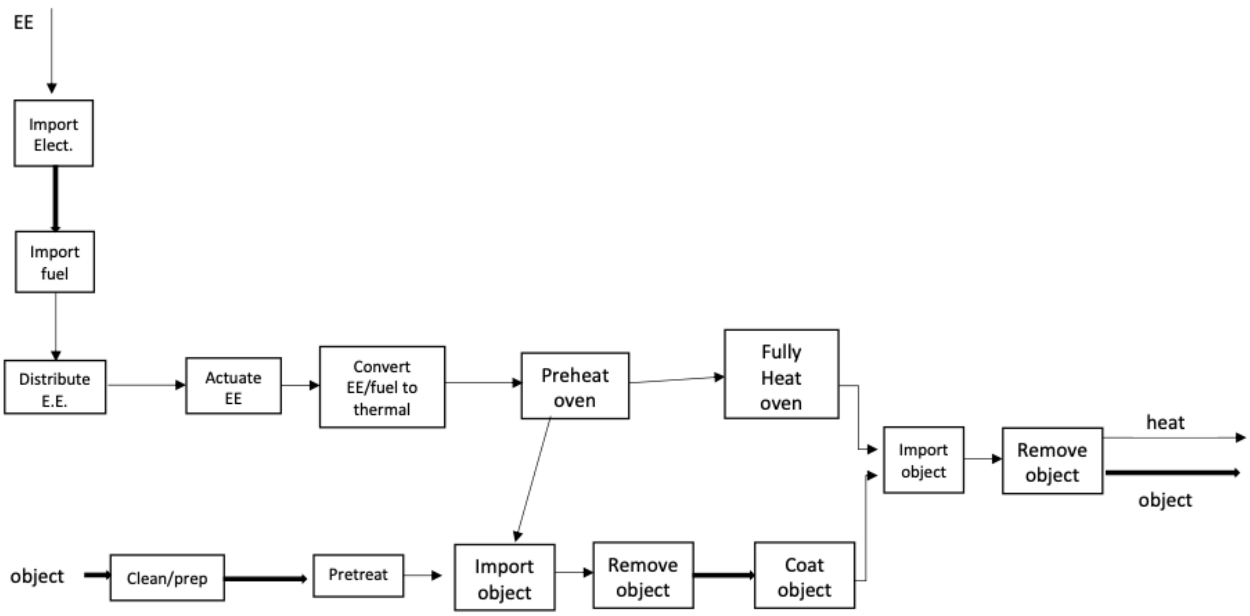


Figure 15: Functional Model for Powder Coat Oven

4 CONCEPT GENERATION

For this section, the team have constructed some concepts for the final design of the powder coating oven. These designs were generated based on the evaluation of the systems and the subsystems of powder coating ovens that are available on the market. From this, the team will evaluate each design based on a few criteria that are provided via the customer requirements, as well as safety requirements overall.

4.1 Full System Concepts

The full concept designs that are provided below will demonstrate the intent of such designs by explaining the pros and cons of each design and whether they meet the design requirements.

4.1.1 Full System Design #1: Prototype 1 (Full System)

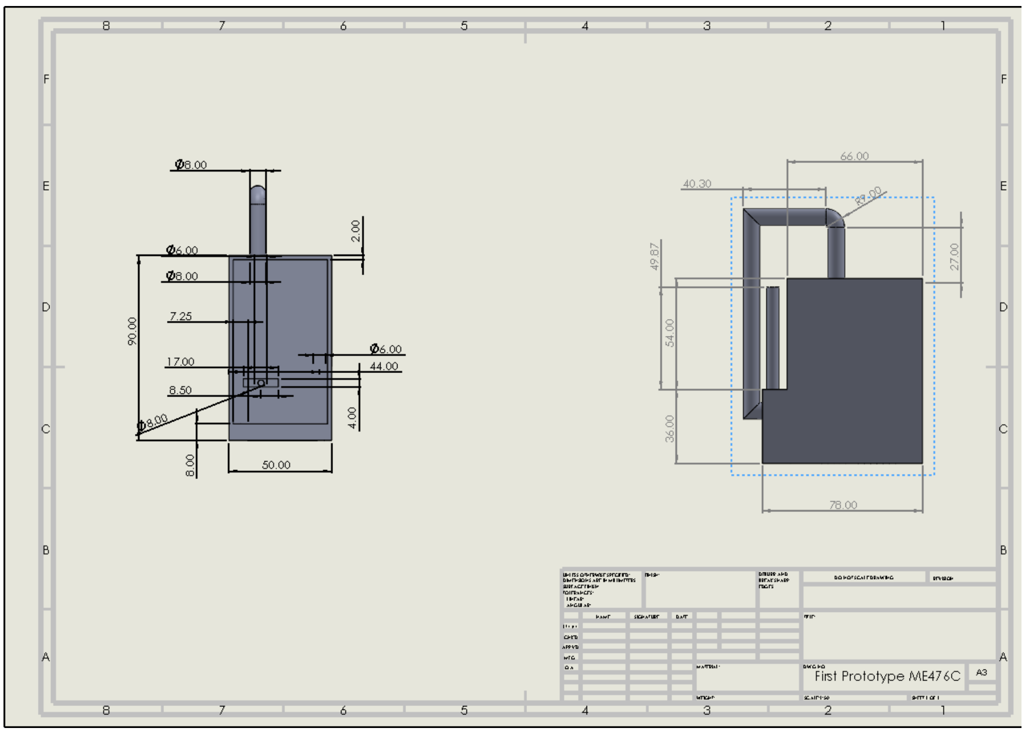


Figure 16: First Prototype – Full System Design

The first system design was designed to meet the requirements in terms of measurements, heat system, and compatibility. As seen on the right, the design offers back housing for the heat generation element (Torpedo heater), the heat fan (air circulation system) and the heat exhaust. One of the pros of this design is that it allows for the most critical parts to be secured from the harsh weather conditions. Another benefit of this design is the efficient air circulation, for the temperature will remain level for the duration of the curing process. The con of this design is the extra material that will be used at the bottom of the oven, which will extend the overall budget of the project.

4.1.2 Full System Design #2: Prototype 2 (Full System)

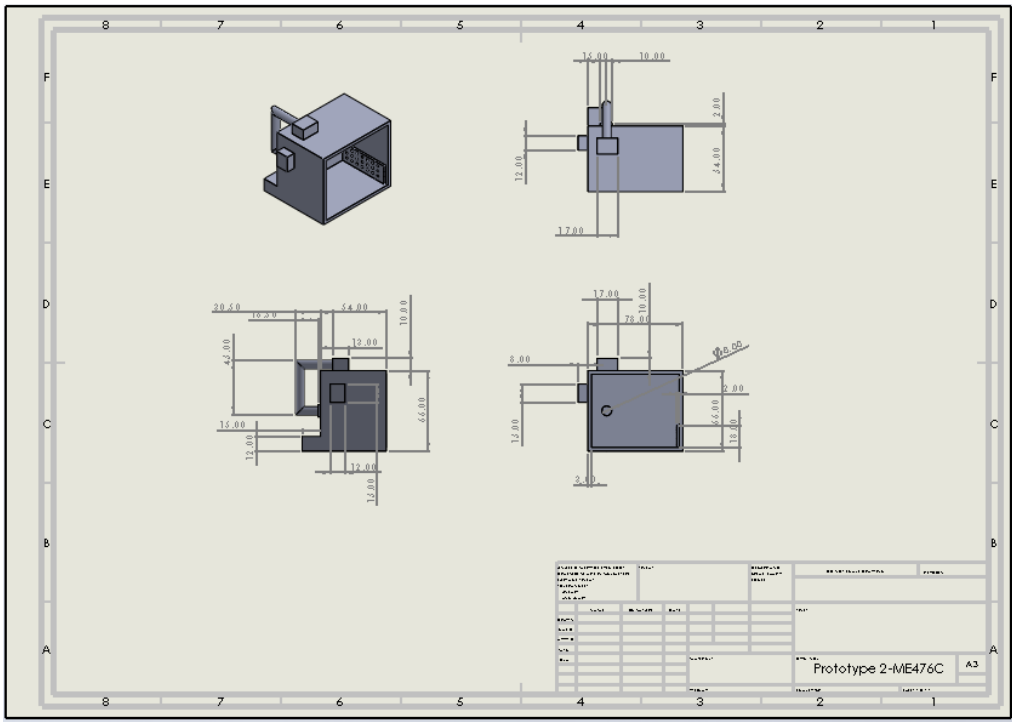


Figure 17: Second Prototype – Full System Design

The second system design was intended to increase the width of the oven, which will allow for easier heat circulation. The decision behind this design was to allow for more space inside the oven, so more parts can be cured at once. Few pros stem from this design. The first was increasing the width of the overall oven. The second was the housing of the heat fan (shown in the top right corner) and the heat generation element (shown in the bottom left corner). These additional adding were considered for the harsh weather conditions and other environmental conditions that might occur, like dust accumulation. The con of this design is mobility, for the design does not allow for the oven to be easily transported.

4.1.3 Full System Design #3: Prototype 3 (Full System)

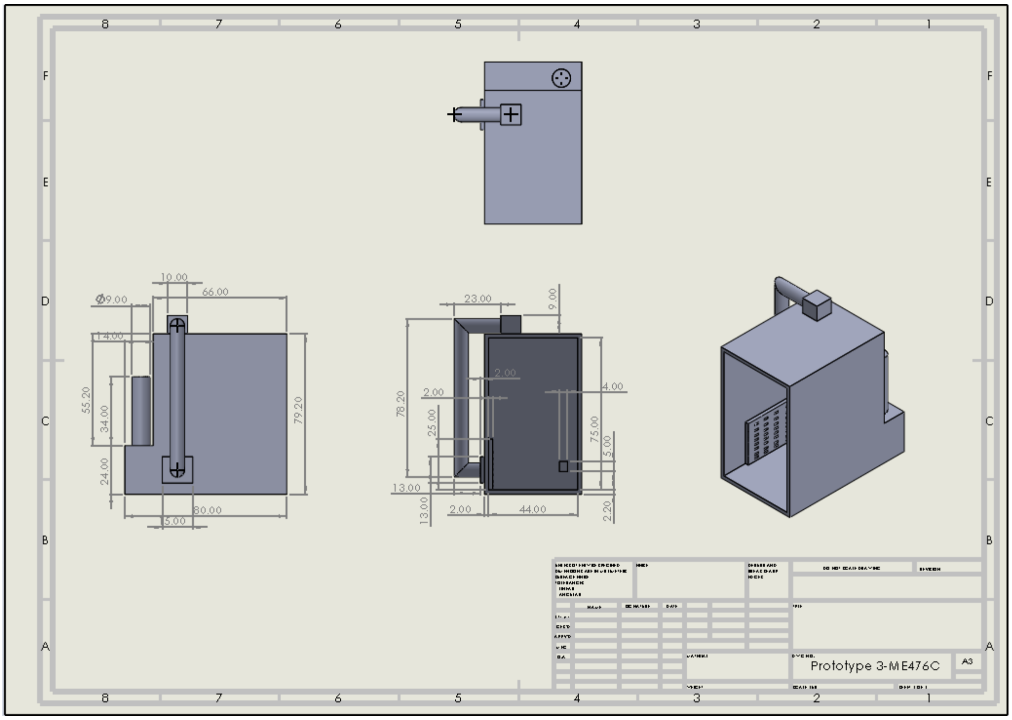


Figure 18: Third Prototype – Full System design

The third design, like the first, was designed to compact the critical elements of the powder coating oven while meeting the requirements of the final design. The difference in this design was the heat circulation system. This system was designed so the hot air would circulate from the side of the oven, through vent opening on the side of the oven (shown in the bottom right corner). One of the pros of this design is the simplicity of the heat circulation system, which allows for much easier repair management if needed. Another benefit of the design is mobility, for the system was designed for more distributed weight, which will allow for a single person to transport the oven. The con of this design is the extra material that will be used to create the vent opening for heat circulation, which will add to the cost of the oven.

4.2 Subsystem Concepts

The subsystems provided below will demonstrate the different designs for the subsystems of the powder coating oven, highlighting the pros and cons of each design.

4.2.1 Subsystem #1: Heat Generation

4.2.1.1 Design #1: Torpedo Heater Housing #1

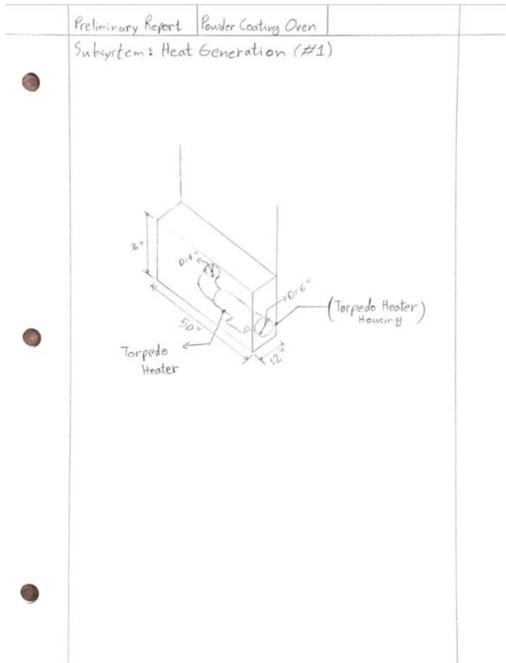


Figure 19: First Prototype – Heat Generation Sub-System Design

The first design was meant to create a housing unit for the heat generation element. The design intended to secure the Torpedo heater for Flagstaff's weather conditions that may cause damage to the heater. As seen in the figure, the heater will be placed inside the housing unit via an opening from the back. The heater will be then connected to the oven via a tube. The pro of this design is that it will allow for the safety of the torpedo heater, which will ensure longer service for the heater, and additional space for the fuel compartment. The con of this design is the extra material that needs to be fabricated for the housing unit.

Design #2: Torpedo Heater Housing #2

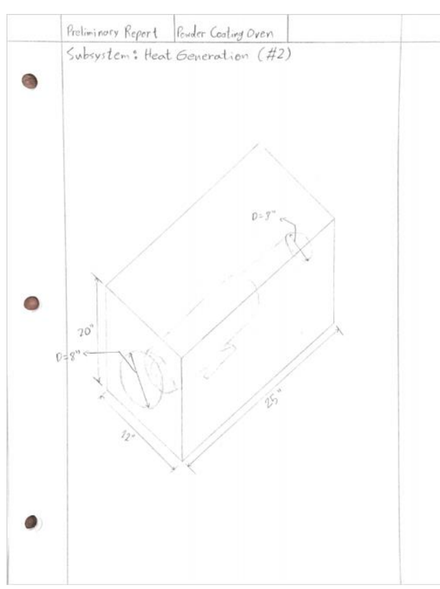


Figure 20: Second Prototype – Heat Generation Sub-System Design

Just like the first, this design was meant to safely secure the Torpedo heater during the usage of the oven. The difference in this design is that the housing unit is connected to the oven from its front end. The benefit of this design is the use of less material to construct the unit. The con of the design is the unbalanced distribution of the overall weight of the oven, with the addition of the housing unit.

4.2.2 Subsystem #2: Air Flow System (Circulation)

4.2.2.1 Design #1: Heating system #1

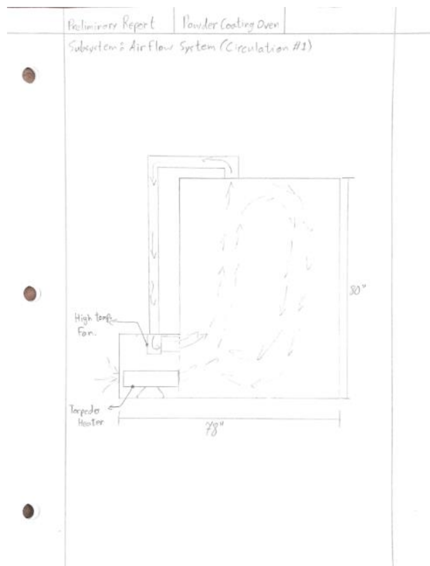
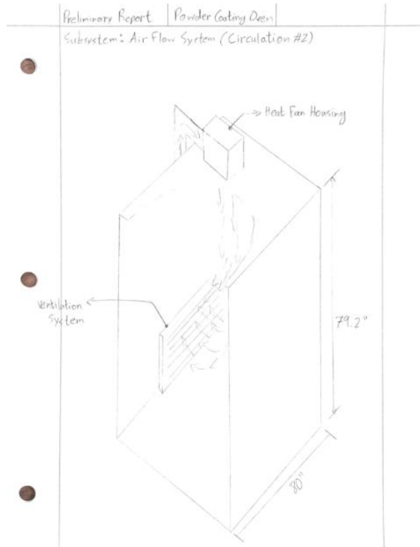


Figure 21: First Prototype – Heating system #1

The idea of this subsystem was to create a more beneficial heat circulation system for the powder coating oven. The first design shown above shows the heat generated from the Torpedo heater into the system, which rises to the top of the oven. At some point, some of the hot air will be collected from the opening at the ceiling of the oven by a heat fan, which will be transported into the tubes and back into the oven. The pro of this design is the lack of complexity and overall efficiency. The con of this is the non-expected increase in heat circulation, which will cause overheating inside the oven, thus resulting in a desired cure of the parts.

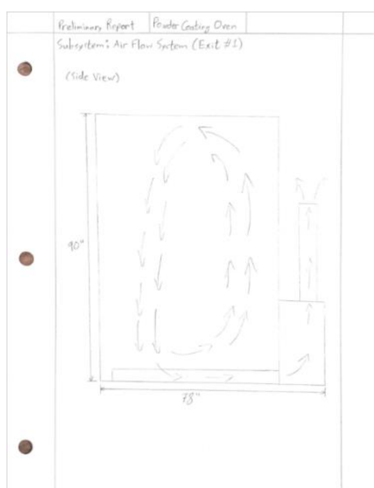
4.2.2.2 Design #2: Heating system #2



The second design for the heating system was built on the third concept generation of the overall system. As shown from the illustration, as the heat comes into the system, the opening on the side of the oven will begin to extract the hot air, transporting it to the top of the oven, which will be released back into the system. The benefit of this design is its simplicity, with easy access for maintenance. The con of the design is the extra material that will be used to make the side vent inside the oven.

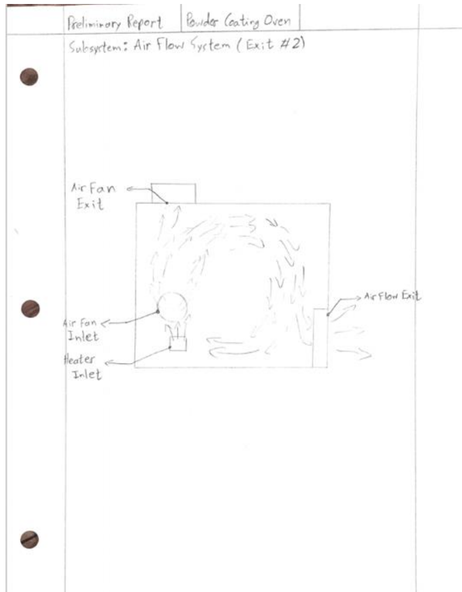
1.1.1 Subsystem #3: Air Flow System (Exit)

4.2.2.3 Design #1: Heat Exhaust #1



For the heat exhaust system, the designs were created to extract as much cold air as possible. The first design shown above demonstrates how the cold air is extracted from the system. When the cold air is lowered to the bottom of the oven, an opening at the bottom of the oven will allow for the air to ventilate. This opening is then connected to the back of the oven (housing unit) which includes the exhaust pipe. The benefit of this design is that it allows for natural circulation of the air without the use of extra power to do so. The con of this design is the use of extra space on the inside of the oven.

4.2.2.4 Design #2: Heat Exhaust #2



The second design was meant for a simpler solution to the air ventilation. As seen above, as the hot air circulates inside the oven, some of it will enter the opening on the right side of the oven, which will allow for an easy exit for the cold air. The benefit of this design is the use of less material to build, and its simplicity during fabrication. The con of this design is the lack of control of the temperature inside this system, which may cause issues during the curing stages of the power coated parts.

5 Design Selected

The team created designs for a powder coating oven from concept generation and benchmarking. The team created a Pugh chart and decision matrix to be able to choose the top two designs the team will analyze and decide for their final design based on further work of technical analysis and prototyping.

5.1 Technical Selection Criteria

For the team to be able to choose the top two designs for the powder coating oven, the design needs to meet the engineering requirements and the customer needs, which are used and scored in the Pugh chart and the decision matrix. The requirements the team input into these two tables is to have a propane-fueled heater, heat output of 500°F, to have a control system, meet safety requirements, be weatherproof, cost-efficient, heat circulation and ventilation, oven volume, retractable rack system, and portability. The team decided to propane-fueled heater because propane is cost-efficient, fuel-efficient, and long lasting compared to other energy sources, and it is not considered a hazardous leak if fuel is lost. The maximum temperature required to cure powder coating on metal is approximately 500°F. One of the requirements the client had for the team is to create a control system that has on/off switch, can control the temperature of the oven, and has a safety feature. The most important requirement for any engineering design is the safety of the oven, the client, Carson Pete, stated that the oven should not overheat and have the metal turn red. The powder oven is being placed outside the renewable energy lab, so the oven needs to handle weather all year round in Flagstaff, Arizona. The team has a budget of $1500 and the team needs to ensure the cost of the oven remains in the cost provided by the client. To ensure that the heater does not explode and to allow the heated air to circulate inside the oven, the team is examining where to place the ventilation system. A customer needs is the oven volume; the team needs to be able to fit the bumper's made by a capstone team and to fit the parts of the SAE Baja team. The oven needs a retractable rack system to be able to hold the material being powder coated and cured and needs to be portable to be able to move around outside the renewable energy lab.

5.2 The Rationale for Design Selection

The team created a Pugh chart and a decision matrix to be able to select the top two designs the team may choose for their final design. The team first created a Pugh chart and selected design number one as the datum because the design meets most of the criteria listed on the left side of the table shown below. The Pugh chart is used to show if the other designs are better (+), worse (-), or similar (S) to the datum. From the Pugh chart, the team decided that one of the propane ovens, an electric oven, and a gas oven and the last few designs in the decision matrix.

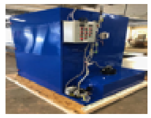
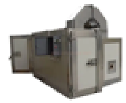
Criteria / Concept	Design 1	Design 2	Design 3	Design 4
	 Epoxy Oven [25]	 Cole Oven [26]	 Propane Oven [22]	 Eptex Oven [27]
1.Propane fueled heater	Datum	+	+	-
2.Control system	Datum	S	+	+
3.Safe to Operate	Datum	S	S	S
4.Weatherproof	Datum	-	S	S
5.Material Cost	Datum	-	S	-
6.Heat Output of 500 F	Datum	+	+	+
7.Heat Circulation and Ventilation	Datum	+	+	+
8.Oven Volume	Datum	-	+	S
9.Retractable Rack System	Datum	-	-	-
10.Portability	Datum	-	+	-
Σ +		3	6	3
Σ -		5	1	4
Σ S		2	3	3

Table 1: Part of Pugh Chart

The team created a decision matrix in order to score the top three designs. These three designs were ranked based on the importance of having a propane fueled heater, a control system, and being safe to operate. The least important criteria was having a retractable rack system and being portable. Although concept two and three were electric and gas fueled, they still met many of the other customer requirements. If a propane fueled heater was not a top criteria concept 3 would have been the selected concept. Concept 1 meets all of the requirements from propane fuel to heat circulation and ventilation. It is also the only concept that met the portability requirement.

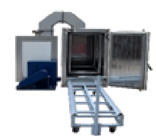
		Concepts								
Weight / Criterion		 Propane Oven [1]			 Electric Oven [2]			 Gas Oven [3]		
1.Propane fueled heater	0.2	100		20	0		0	70		14
2.Control system	0.2	80		16	50		10	50		10
3.Safe to Operate	0.2	74		14.8	70		14	80		16
4.Weatherproof	0.01	81		0.81	75		0.75	90		0.9
5.Material Cost	0.08	70		5.6	40		3.2	30		2.4
6.Heat Output of 500 F	0.07	80		5.6	73		5.11	60		4.2
7.Heat Circulation and Ventilation	0.12	70		8.4	62		7.44	20		2.4
8.Oven Volume	0.06	90		5.4	80		4.8	80		4.8
9.Retractable Rack System	0.03	65		1.95	87		2.61	80		2.4
10.Portability	0.03	100		3	0		0	0		0
Total	1			81.56			47.91			57.1
Relative Rank				1			3			2

Table 2: Decision Matrix

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7 APPENDICES

7.1 Appendix A: House of Quality (HoQ)

Legend		
⊝	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Figure 1: HoQ Legend

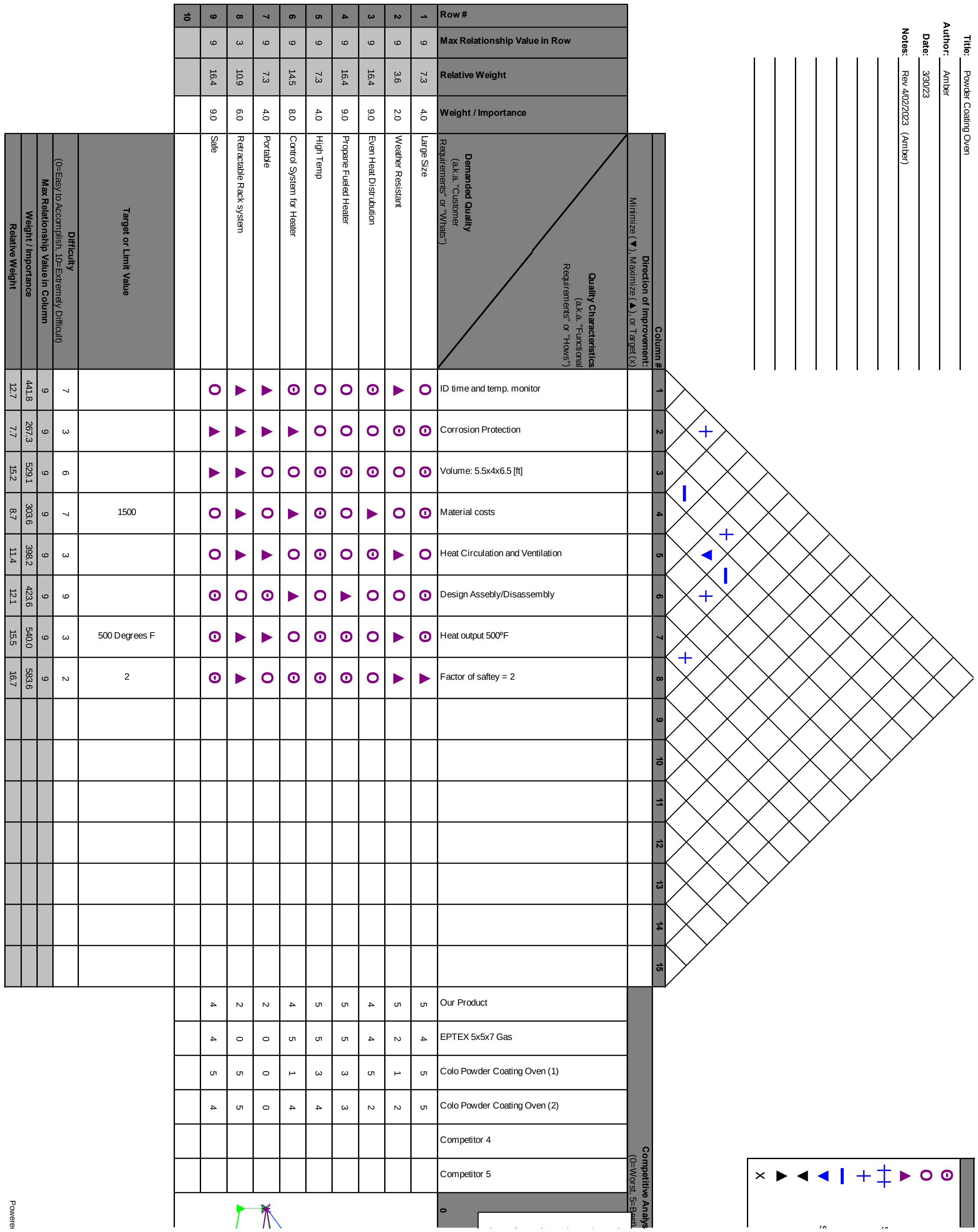


Figure 2: House of Quality

7.2 Appendix B: Budget

7.3 Appendix C: Full Pugh Chart

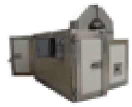
Concept / Criteria	Design 1	Design 2	Design 3
	 Epoxy Oven [25]	 Cole Oven [26]	 Propane Oven [22]
1.Propane fueled heater	Datum	+	+
2.Control system	Datum	S	+
3.Safe to Operate	Datum	S	S
4.Weatherproof	Datum	-	S
5.Material Cost	Datum	-	S
6.Heat Output of 500 F	Datum	+	+
7.Heat Circulation and Ventilatio	Datum	+	+
8.Oven Volume	Datum	-	+
9.Retractable Rack System	Datum	-	-
10.Portability	Datum	-	+
Σ +		3	6
Σ -		5	1
Σ S		2	3

Table C.1.1: Pugh Chart Part 1

Design 5	Design 6	Design 7
 Eptex Oven [28]	 Eptex Oven [29]	 Colo Oven [30]
-	+	S
S	+	+
S	+	+
S	+	+
S	-	-
+	S	S
+	S	S
+	S	S
-	-	-
-	-	-
3	4	3
3	3	3
4	3	4

Table C.1.2: Pugh Chart Part 2

Design 8	Design 9	Design 10
 Electric Oven [23]	 Gas Oven [24]	 Colo Oven [31]
S	+	-
+	+	+
+	+	+
+	+	+
-	-	-
S	S	S
S	S	S
S	S	S
-	+	+
-	-	-
3	5	4
3	3	3
4	3	3

Table C.1.3: Pugh Chart Part 3