Portable Clean Room & Hood

Final Proposal Report

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DISCLAIMER

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EXECUTIVE SUMMARY

The objective of the clean room project, proposed by Aneuvas Technology, Inc, is to design and build a portable clean room and hood. The project is overseen by the client/faculty advisor Dr. Timothy Becker who leads the Bioengineering Devices Lab, affiliated with Mechanical Engineering and the Center for Bioengineering Innovation (CBI). The client needs a 6’x8’x8’ clean room to perform training and testing with microcatheters and is also in need of a 2’x4’x4’ clean hood to run small equipment under, specifically the client’s rheometer. The primary requirements given by the client are that both units maintain a positive pressure, be portable, easily transportable, and produces a foreign particle clean environment.

The portable hood will be constructed of three separate pieces consisting of a hollow aluminum frame, a polycarbonate viewing case, and a Fan Filter Unit (FFU). The aluminum frame will support the total weight of the FFU, this will be to prevent the polycarbonate from fracturing or cracking. The aluminum frame will fit over the polycarbonate viewing window and seal the FFU to the viewing window. There will be a rubber seal that will prevent pressure loss between the three components. The polycarbonate viewing window will have a double hinged door that creates access to the client’s product being tested, and to adjust the rheometer that will primarily be operated within the hood.

The portable room will be compiled of four main parts, this includes the framing, the plastic lining and the two FFUs. The aluminum framing for the room will be collapsible, it will fold down into its self, this is to simplify set up and to keep as many parts together, so none are lost. The Framing for the room will also be adjustable, it will be able to be raised and lowered roughly one to two feet depending on the ceiling height the clean room is in. Attached to the framing will be a detachable plastic lining, this creates visibility into the room and maintains the positive pressure. The plastic lining will be attached to the aluminum framing with 3M Dual Lock, it acts like Velcro, but is much stronger and can hold more weight. It was determined that two fans would be required to maintain a clean environment in the room. The room will primarily be used to preform tests utilizing a microcatheter in a semi-sterile environment. The clean room and hood will both create a clean environment on the FFUs lowest setting, allowing for additional cleanliness by turning up the speed of air flow.

Analytically calculations show the clean room and hood will maintain positive pressure with two fan units for the room and one for the hood. The structural analysis performed sows that the framing for the room will not fail under the load of both the FFUs resting on top. The fan filter analysis showed the maximum cleanliness classification the room and hood can sustain, along with indication for when the filters need to be changed. Calculations having been completed, the team moves to building and testing the clean room and hood.

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1 BACKGROUND

1.1 Introduction

The clean room project was created by Aneuvas Technology, Inc and is overseen by Dr. Timothy Becker. The project objective is to design and build a portable clean room and hood. The clean room and hood are to produce and maintain a positive pressure, which will reduce the number of foreign particles in the structures. This makes a clean environment for which the sponsor can conduct sterile experiments and test in. The company manufactures and analyzes minimal invasive microcatheter medical devices, used to treat aneurisms and other vascular defects in the brain. This project will benefit the client's research and development of their products by producing a clean low particle count environment.

1.2 Project Description

Following the original project description provided by Aneuvas Technology, Inc.,

> "The scope of this project is to design, build, and test a fan-filter unit (FFU), a curtain clean room area, and a laminar flow hood to help establish sterile manufacture capabilities. The flow hood (2'x 4') and clean room (4'x 6') must have the ability to be disassembled and reassembled, clean and sterilized, and portable."

The flow hood is to be 2'x 4'x 4' so it can fit over small equipment within the client's lab, along with an FFU placed on top of the frame to induce a positive pressure of clean air. The clean room has been changed to be 6'x 8'x 8' per clients request. It must have the ability to be assembled, disassembled, and carried by 3-4 people; it will have two FFUs placed on top of the frame to cause the positive pressure of clean air within.

1.3 Original System

This project involved the design of a completely new portable clean room and clean hood. There was no original system when this project began."

2 REQUIREMENTS

The requirements of this project include the customer requirements and the engineering requirements. The customer requirements were provided directly from the client/sponsor. The engineering requirements are derived from the customer requirements and are given a unit for measurement and/or a targeted value.

2.1 Customer Requirements (CRs)

The customer requirements were obtained during the first client meeting and from the project description they are listed below.

- Positive pressure – maintained a controlled clean environment
- Inexpensive – low cost and remain within budget
- Clean – meet FDA classification requirements of number of particles in the air per cubic meter
- Portable – ability to be assembled, disassembled, and be carried by 3-4 people
- Visibility – ability to see inside the structures
- Reliability – reassurance that the structure will not fail
- Durability – last for an extended amount of time
- Noise – low emission of noise from FFUs

From the quality function deployment (QFD) chart, as seen in Table 2, the positive pressure and inexpensiveness were weighted the heaviest because they were emphasized the most by the client. While visibility was weighted the lowest because the given material is already transparent. Each customer requirement was obtained by the project description as well as the client.

2.2 Engineering Requirements (ERs)

From the customer requirements, engineering requirements were compiled to meet the CRs and are listed below. The different parameters used for the technical terms are given by table 1. Measuring the area of both the hood and the room is in terms on m^2. The second parameter would be the pressure for each room and is measured in pascals. Also identifying the total potential cost for the room and the hood which is denoted, this is in dollars. An important factor for the ability to transport both the hood and the room is the assembly time which is in minutes. The power generated for both systems is denoted by watts. The velocity for each fan unit will be measured in m/s which will be used to understand positive pressure through the system. The overall sounds coming from each system will also be taken into consideration, this will be measured in decibels and the stress factors within the frame while holding the fans will be measured in pascals.

Table 1. Engineering Requirements

	Area (m^2)	Pressure (Pa)	Cost ($)	Weight (kg)	Assembly Time (min)	Power FFU (W)	Particle count (per m^3)	Velocity FFU (m/s)	Material	Sound FFU (dBa)
Hood	0.557	> 78000	1000	45.36	5	520	< 102,000	0.58	N/A	50
Room	3.26	> 78000	1000	54.43	30	1040	< 102,000	0.58	N/A	50

From the quality function deployment (QFD) chart, as seen in Table 2, the pressure and number of particles had the highest score of 13. While the lowest scored ER was sound with a score of 1.4.

2.3 Testing Procedures (TPs)

This section discusses the testing procedures considered to verify each of customer requirement has been met.

2.3.1 Area

To test the area of both units is to measure each side 2-3 times for accuracy and then calculate the area with the dimensions measured with a tape measure. The tape measure is previously owned by a team member.

2.3.2 Pressure

To measure the pressure the pressure within each unit is to obtain a pressure DAC and a couple of pressure transducers which connect to a computer that has LabVIEW set up. The pressures to be measured is the pressure within each unit and the atmospheric pressure outside both units. The measurements from the transducers is carried to a DAC which takes the data and transfers it to a computer. The computer has a program LabVIEW which interprets and records the data collect by the transducers and DAC. Then LabVIEW takes the data and converts it to a readable pressure measurement. Three readings will be conducted at three different locations within the hood. One measurement 6" below the FFU, one measurement above the door, and final measurement at the bottom of the door. By measuring each location 3 times ensures accuracy. The testing equipment will be obtained through the client, Dr. Becker.

2.3.3 Cost

To verify that the cost is met is to update and evaluate the given budget and bill of materials together. This will verify is the budget is met, below, or exceeded.

2.3.4 Weight

The weight of both units is to be estimated with Solidworks program because they are too large to fit onto any scale. Northern Arizona University has access to Solidworks for students.

2.3.5 Assembly Time

Is to take a timer off our mobile devices and time how long it takes to assemble each unit separately and then time the disassembly of each unit.

2.3.6 Power FFU

To test to see if the FFU has power by plugging in the unit and turning it on. The power of the fan filter unit at its lowest setting is 393 Watts [2].

2.3.7 Particle Count

Due to budget constraints a particle counter could not be obtained to count the particles within each unit. To obtain an estimation of particles within each unit, the information is based from the manufacturer.

2.3.8 Velocity

From the pressures measured and tested with the pressure transducer the velocity can be calculated by using the pipe flow energy equation.

2.3.9 Material

To test the material is to place the FFUs on both units to see if the structures can withstand the weight and location of the fan units. The FFUs are purchased through the manufacturer Terra Universal [2].

2.3.10 Sound FFU

The equipment to test the sound of the FFU is out of the project's budget limit. The fan filter unit does create a sound which is comparable to the sound of a ridge which is roughly 50 dBa [2].

2.4 House of Quality (HoQ)

The House of Quality, as seen in Appendix A, relates and compares the customer requirements to engineering requirements, to meet the client's expectations and desires for the project. The HoQ gives a visual of ERs that have greater importance or higher scores in relation to the ranked CRs. Each ER is given a specific target value that will allow for the design to meet the client's needs. The results from HoQ were that the number of particles, the pressure, and the material were the top 3 ranking ERs. These results show which ERs to focus on to succeed in meeting the client's requests.

3 EXISTING DESIGNS

This section covers the design research, system level, functional decomposition and the subsystem level. Research was conducted to obtain a better understanding of portable clean rooms, their classification, the FFUs, and the type of material used for them. There are a variety of different designs for clean rooms, most clean rooms have similar features but key differences in where they are being used. Most clean rooms have clear walls for manufacturing visibility purposes, as well as a fan that provides the positive pressure in the room. Another difference is in the functionality of the room, for a portable clean room the legs will have wheels, for large equipment use the room will have an accommodating entry.

3.1 Design Research

There are many designs and concepts of portable clean rooms and hoods. Various companies were found through detailed online research, these companies manufacture portable clean rooms and hoods. There are two types of clean hoods, vertical laminar flow and horizontal laminar flow. Clean Air Products and Terra Universal are the top two manufacturers out of many that were researched and analyzed. The vertical and horizontal hood designs were reviewed and analyzed to meet the CR criteria. The vertical flow hood has a FFU place at the top which then produces a vertical flow of air downward. The horizontal flow hood has a FFU placed at the back of the hood blowing a horizontal flow of air towards the front of the hood. For portable clean rooms there are also two types, a soft-walled and a hard-walled clean room. The hard wall clean room can be both permanent and portable room with hard walls all around. The soft wall clean room is primarily a portable based room with soft walls all around. All designs can be seen in the sections below of existing designs. These designs were evaluated to justify which concept best suited the client's conception.

3.2 System Level

There are a few existing designs that are like the design needed for this project. The clean rooms available with similar design requirements pertaining to this project are sold by various companies around the US. The requirements for most clean rooms are similar, they involve creating a laminar air flow and producing positive pressure to prevent particles from accumulating. Clean rooms vary by how clean the room needs to be for customer needs. Each clean room has different standards given the fan utilized, and these standards vary from 10,000 particles per cubic area to 100,000 particles per cubic area. Existing designs like a vertical laminar flow would be useful to create a clean room over a work area. Where a horizontal laminar flow hood is practical for some applications, pushing the flow towards the user, but would not be for this project's client needs.

3.2.1 Existing Design #1: Vertical Laminar Flow Hood

This hood produces a vertical laminar flow of clean air over the work space. This design is an ideal concept to analyze because it meets most of the CRs needed to satisfy the customer. It produces positive pressure, clean air, durable, reliable, and portable. It does not meet the cost or visibility requirement as seen in Figure 1 below.

Figure 1. Vertical Laminar Flow Hood [4]

3.2.2 Existing Design #2: Horizontal Laminar Flow Hood

The horizontal laminar flow hood produces a horizontal laminar flow. This design meets some of the requirements but is not the best design to analyze because the FFU is located on the back side of the hood. This design does not follow the client's specifications, which was having the FFU on the top of the hood due to limited surrounding space. Overall, a great perspective but does not meet the CRs entirely.

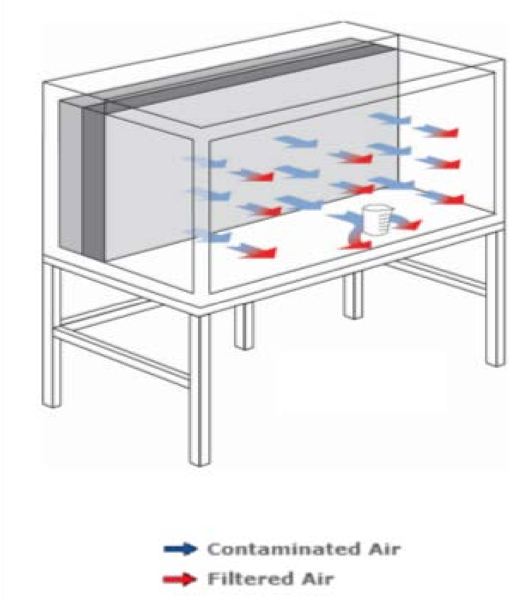

Figure 2. Horizontal Laminar Flow Hood [4]

3.2.3 Existing Design #3: NCI 8'x8'x8' Portable Clean Room

NCI created a clean room that very similar to the customer requirements needed for the clean room project. This portable clean room exceeds the size needed for the project but is portable. The main concern for this portable clean room would be if it could be carried out by three people or less, as specified in the CR's. Due to the size of this clean room created by NCI this may not meet the requirements of portability for the clean room project. Nevertheless, the design can be used for creative idea generation for the clean room project.

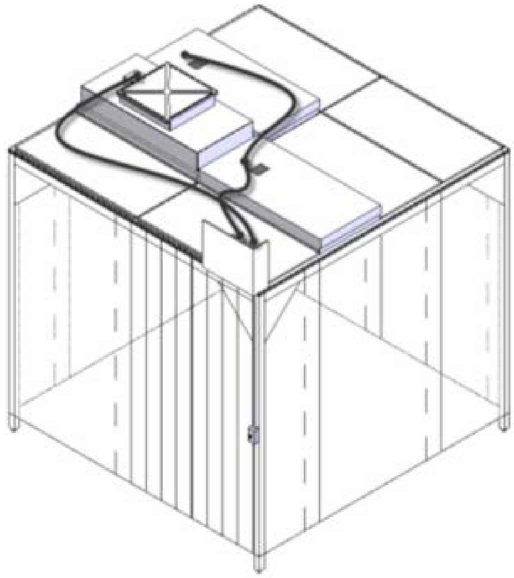

Figure 3. 8'x8'x8' Portable Clean Room [3]

3.2.4 Existing Design #4: Clean Air Products 6'x8'x8' Portable Clean Room

Clean Air Products created a portable clean room related to the requirements our client needs. The dimensions exceed the size needed for our customer needs, but it does meet the engineering requirement of being portable. This requirement is important since the room required by our client will be used in different areas. The concept of this clean room could be used as reference, since it meets some of the customer requirements needed for the clean room project.

Figure 4. 6'x8'x8' Portable clean room [1]

3.3 Functional Decomposition

The functional decomposition breaks down the entire system into smaller components. For this system a black box model and a functional model were created to obtain a better understanding and to simplify the project into smaller sections. These sections incorporate the basic principles of the black box and expand on it. Tracking the different flows like material, energy, and signal to create a logical flow rate of the processes going within the system. The functional model takes the black box model and applies it to each unit and elaborates in detail.

3.3.1 Black Box Model

The black box model Figure 5 portrays a simple overview of the inputs and output of out of positive pressure structures. The three flows through the hood and the room are a material flow, energy flow, and signal flow. For material flow the operations of cleaning the room and utilization of using the hands are expanded upon and create a flow of what materials go in and out of the system. Energy flow is particularly a section of interest since this creates the main functionality of the clean room. The fans capture the kinetic energy coming from the clean room then releases it as laminar air flow which creates the positive air pressure. The electrical energy is used to power the fan which then engages the fans functionality. Human energy is introduced in the system when system under operation and humans are operating within the system. Signal flow is used to indicate whether the system is under operation and this allows the user to understand whether the clean room is on or off.

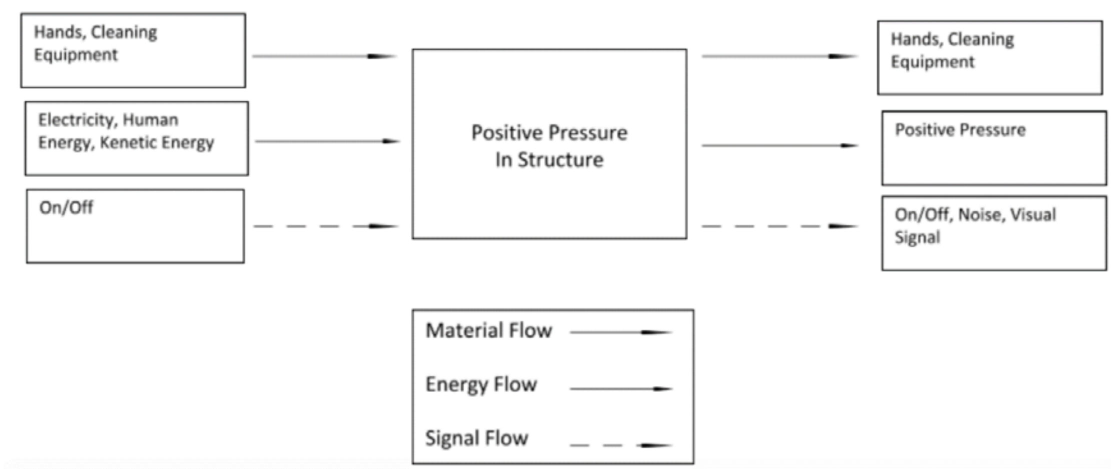

Figure 5. Black Box Model

3.3.2 Work Process Diagram

The work process diagram shows the hierarchal type work needed to create the clean room project. This figure illustrates the work needed to create the clean room proposed by the customer. It starts with the project description and then created ideas for the described project. Research is conducted using journals, the internet, and companies also implementing similar task. Proposed designs are compared and created by the team and resented to the client and iterated until the design takes shape. Once approved, possible prototypes of the design can be created. A final cost analysis with a list of different designs is created and presented to the client for final decision making. This creates the clean room that has been outlined by the work process diagram.

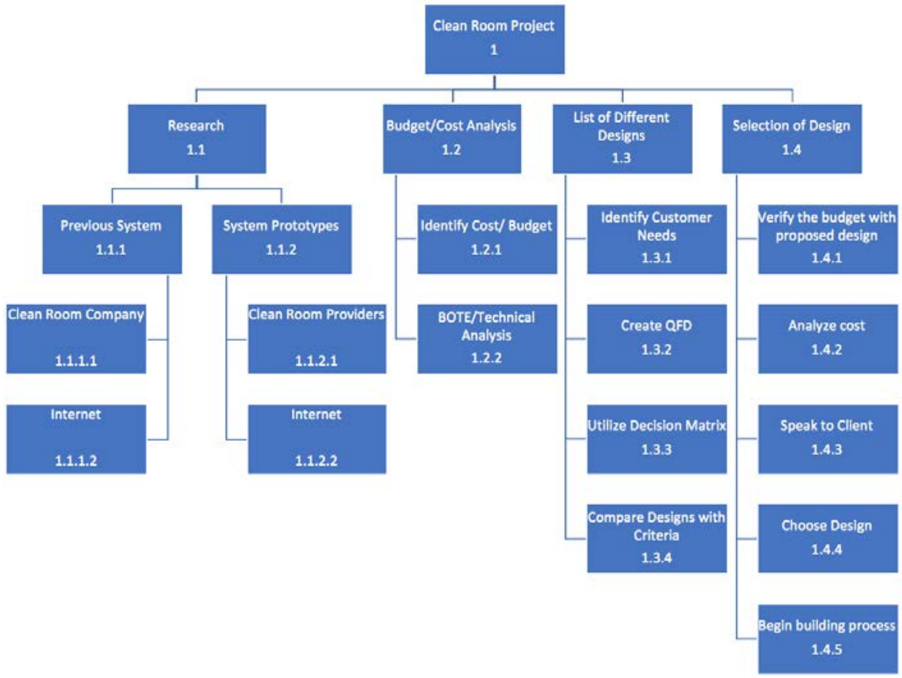

Figure 6. Work Process Diagram

3.3.3 Functional Model

The functional model is a breakdown of the process taken to achieve a successful clean room and hood. As seen in Figure 7 there are various broken-down steps that give a layout of what needs to be completed to obtain a successful finished project.

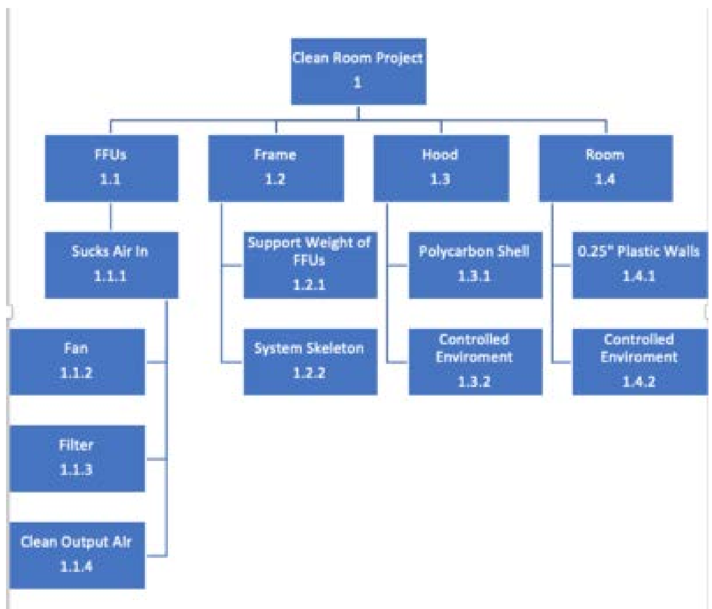

Figure 7. Functional Model

3.4 Subsystem Level

The subsystem shows the pre-existing designs that are currently being used by different clean room providers. The clean rooms that are relevant to this project will follow a set of customer requirements. The first requirement is portability. For the portable hood, it must be carried by a maximum of 2 people and for the portable clean room it must be carried for a maximin of three people. The other requirement is that each room must create positive air pressure within the system. For the clean hood one of the requirements is a specific plastic that is to be incorporated within, which is polycarbonate.

3.4.1 Subsystem #1: Fan Filter Unit (FFU)

An FFU is the most important component to the project. Fan filter units are what induce positive pressure and produce a clean environment for a given room, hood, and portable room. These designs are pre-existing and have been used through industry for all aspect of rooms and hoods.

3.4.1.1 Existing Design #1: WhisperFlow, 2' x 4', HEPA, 120, Powder-Coated Steel

This FFU is manufactured by Terra Universal [2]. This unit is a 2’x4’ powdered-coated steel, with a HEPA certified filter at the bottom and weighs about 71lbs. This unit is design to inhibit a positive air pressure and filtered clean air for both units. The level of cleanliness is also based on the size of the room and how many FFUs are needed to meet the rooms requirements. This FFU is design for an ISO classification down to a class 10.

3.4.1.2 Existing Design #2: Motorized Ceiling Fan Filter Unit CAP118

This FFU is manufactured by Clean Air Products [5]. The unit is a 2’x4’ galvanized steel, with a HEPA certified filter at the bottom, and weighs about 80lbs. This FFU is design for an ISO classification of class 10. The FFU is designed to obtain positive pressure and produce filtered clean air.

3.4.1.3 Existing Design #3: FFU – Fan Filter Unit Price Industries

The fan filter unit is manufactured by Price Industries [3]. The FFU is a 2’x4’ the material is aluminum and steel, with a HEPA filter, and weight ranges from 66-76 lbs. The ISO classification is for class 10. The fan filter unit is designed to produce filtered clean are and positive pressure within the units.

3.4.2 Subsystem #2: Portable Clean Room

There are many portable clean rooms, client requirements specific and narrow the team’s choices. For this clean room it required for the room to be lightweight and the ability to be transported with a max of 3 people. The clean room must meet a specific dimension based on the size of room described by the client, and the ability for 3 people to work within the clean room. There were 3 subsystems that were evaluated and analyzed.

3.4.2.1 Existing Design #1: Clean Air Product’s Softwall Clean Room

An existing design researched and analyzed manufactured by Clean Air Products [1]. A soft wall design has also been used by different clean room providers. The softwall designs are transparent walls that allow easy visibility to the atmosphere inside the room. A soft wall implemented within the project would help meet the requirement of being lightweight.

3.4.2.2 Existing Design #2: Clean Air Products Hardwall

This subsystem provides a better support than the other walls, but visibility will not be as good as the other walls considered. The hardwalls will improve the overall safety of the clean room by providing a more robust and durable material to withstand the different forces that the room is being subjected to. The hardwall room analyzed was manufactured by Clean Air Products [13].

3.4.3 Subsystem #3: Portable Clean Hood

This subsystem shows a room that can be easily transported within rooms. Clean room providers have created a clean room that is both portable, but also having walls that are see through. This room is important since this subsystem could implement for the clean room project.

3.4.3.1 Existing Design #1: Vertical Flow Hood

This hood produces a vertical laminar flow of clean air over the work space. This design is an ideal concept to analyze because it meets most of the CRs needed to satisfy the customer. It produces positive pressure, clean air, durable, reliable, and portable. This design was manufactured by Terra Univeral [4].

3.4.3.2 Existing Design #2: Horizontal Flow Hood

The horizontal laminar flow hood produces a horizontal laminar flow analyzed from the manufactuer Terra Universal [4]. This design meets some of the requirements but is not the best design to analyze because the FFU is located on the back side of the hood. This design does not follow the client's specifications, which was having the FFU on the top of the hood due to limited surrounding space. Overall, a great perspective but does not meet the CRs entirely.

4 DESIGNS CONSIDERED

This section describes the designs the team considered for selection of the final design. The section is broken up in to designs for the portable hood and designs for the portable clean room. Overall, it was difficult in considering designs because of the many restrictions through the client, FDA, and HEPA which limited our designs.

4.1 Portable Hood Designs

Below are concept designs for portable clean hoods.

4.1.1 Design #1: Portable Hood with Exterior Frame

Using an outer skeleton as a frame which reduces the strain on the polycarbonate walls of the room. The frame is used to hold the FFU and is sealed with the help of an adhesive which can be removed easily. The frame is made from aluminum which reduces the weight of the overall clean room. This helps with the ease of transportation which is a requirement by the customer. The polycarbonate walls have an entrance point that is 6inx12in which is required for working within the station. The bad thing about this device is the opening which is a hinge style opening which may reduce the visibility of the user when working. Another con may be the outer frame can also decrease the visibility when looking through the sides of portable hood.

Table 2. Pros and Cons of Portable Hood with Exterior Frame

Cons	Pros
Bad visibility due to frame	Lightweight
Bad visibility due to hinge opening	Clear Panels
Expensive material	Ease of work within clean room

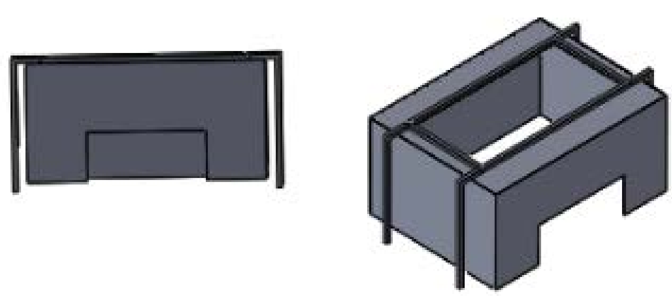

Figure 8. Design for Portable Hood with Exterior Frame

4.1.2 Design #2: Slide on External Frame Clean Hood

The design shown in figure 9 contains two parts, plus the FFU. The design is made so that the rubber feet on the bottom of the polycarbonate hood, can sit on the feet of the metal structure, this creates less movement of parts. The doors hinged on the polycarbonate structure open to the sides, rather than above, this removes the need for magnets or a latch to keep the door open while working. The metal frame has tabs that help to hold the FFU in place, rather than having the weight of the FFU sitting on the polycarbonate directly, this reduces the thickness of the polycarbonate and therefore reduces the price of the polycarbonate.

Table 3. Pros and Cons of Slide on External Frame Clean Hood

Cons	**Pros**
Expensive materials	Lightweight
Thin polycarbonate	Low number of parts
Large components	Durable design
Hard to move	Simple construction

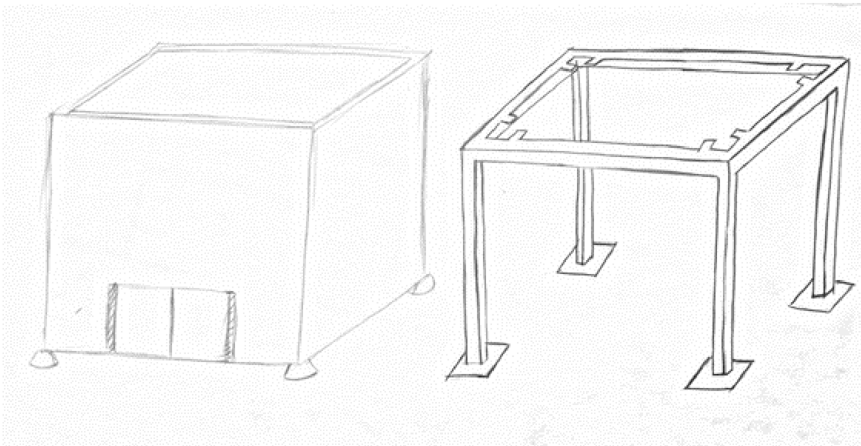

Figure 9. Design for Slide on External Frame Clean Hood

4.1.3 Design #3: Vertical Laminar Flow Hood with Solid Frame

The vertical laminar flow hood design in figure 10 has a separate aluminum frame with an inner polycarbonate shell and the FFU on top. The small door on the front has hinges on the top that attach to magnets to hold in place. This hood is designed as a solid combined piece which increases the weight but is a single system.

Table 4. Pros and Cons of Vertical Laminar Flow Hood

Cons	**Pros**
Expensive materials	Single system
Thick polycarbonate	Low number of parts
Large component	Durable design
Heavy	Simple construction

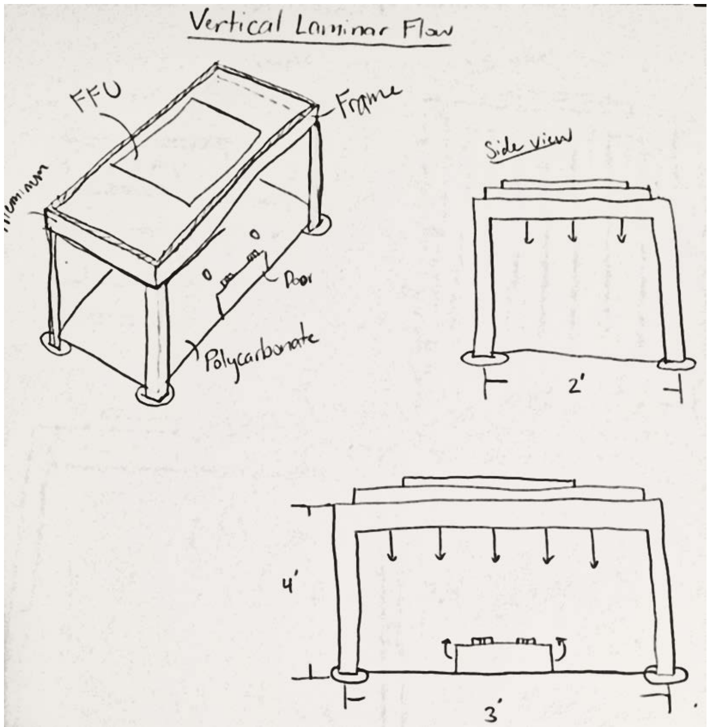

Figure 10: Vertical Laminar Flow Hood

4.1.4 Design #4: Horizontal Laminar Flow Hood with no Frame

The horizontal laminar flow hood design has the FFU unit on the back half of the system as seen in Figure 11. The front of the hood is open which will affect the positive pressure and with the FFU on the back will interfere with the equipment inside. With the FFU in the equipment will not be properly in the path of the clean filtered air. The polycarbonate walls may not have the ability to withstand the weight of the FFU.

Table 5. Design of Horizontal Laminar Flow Hood

Cons	**Pros**
Expensive material	Single system
Thick polycarbonate	Low number of parts
Large component	Durable design
Heavy	Simple construction

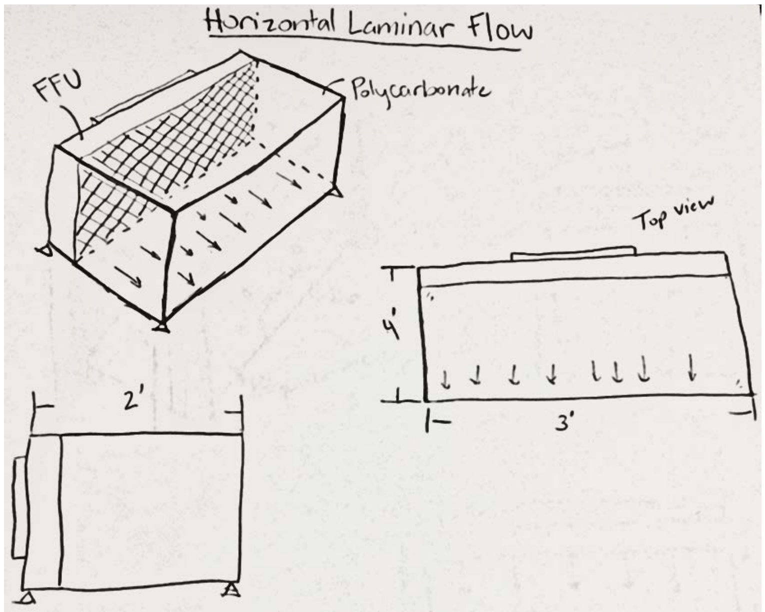

Figure 11. Design of Horizontal Laminar Flow Hood

4.2 Portable Clean Room Designs

Below are various concept designs for portable clean rooms.

4.2.1 Design #5: Clean Room with Detachable Frame

This design shows a clean room that has a frame which is adjustable based on the framing type being utilized. This concept tries to solve the issue of transportation through various locations. Using this type of framing will make it assembly and disassembly easier for the customer. The drawback is the use of the pricing on this type of material will raise the cost of the overall clean room.

Table 6. Pros and cons of Clean Room with detachable Frame

Cons	**Pros**
Cost of Frame	Lightweight
No wheels on room	Clear Panels
Assembly time	Durable Frame

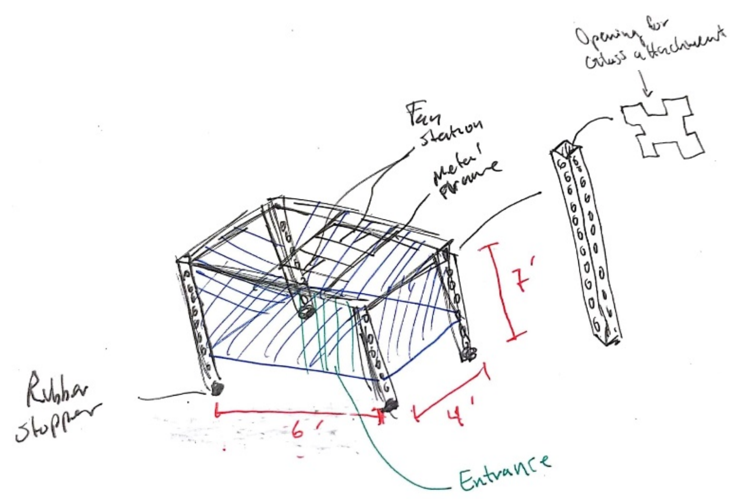

Figure 12. Design for Clean Room with detachable Frame

4.2.2 Design #6: Double Flap Clean room

The portable clean room in figure 11 shows the top view and front view. In the top view it can be seen the there are two fans and the fans are spaced on the top for better air distribution. The fans are mounted in place and are supposed to be in the optimal position. In the front view the flaps on the entrance side are to have a double layer of plastic slats that are off set from each other to reduce the amount of air escaping, while the other three sides are solid vinyl sheeting, ensuring there is positive pressure in the structure. The bottom of the frame is to have castor wheels, so it can be easily moved, but also be locked in place.

Table 7. Pros and cons of Double Flap Clean room

Cons	**Pros**
Cost of Frame	Small pieces to carry
Fans don’t slide/adjust	Clear panels
Assembly time	Durable structure
Fixed floor plan	Double layer of plastic sheeting at door
More material	Roll able/ moveable

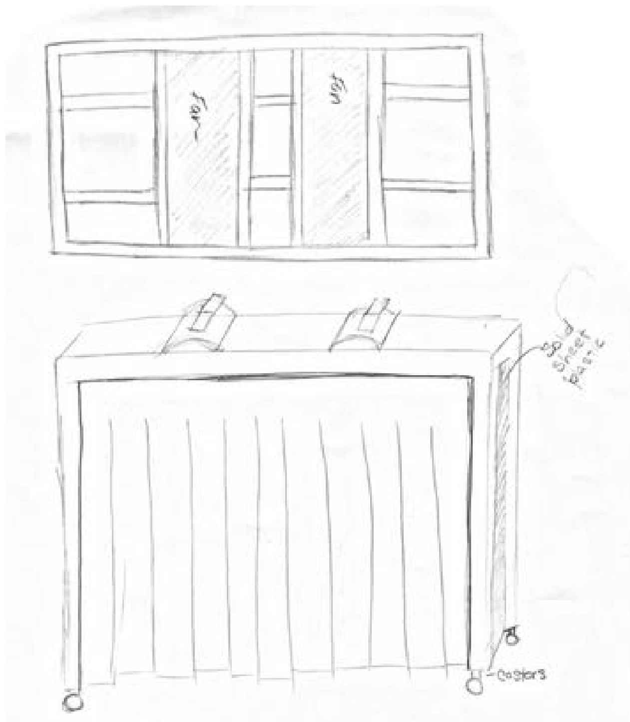

Figure 13. Design for Double Flap Clean room

4.2.3 Design #7: Portable Clean Room Single Flaps

The portable clean room as seen in Figure 14 below has two FFU units at the top, steel framing, clear plastic walls, with wheels as the feet, and single flap entrance unit. This system has steel framing with multiple pinned units this may create potential leaks of air but will be very heavy.

Cons	**Pros**
Heavy	Moveable
Fans don’t slide/adjust	Clear panels
Multiple part	Durable structure
Potential small leaks	Easy to assemble

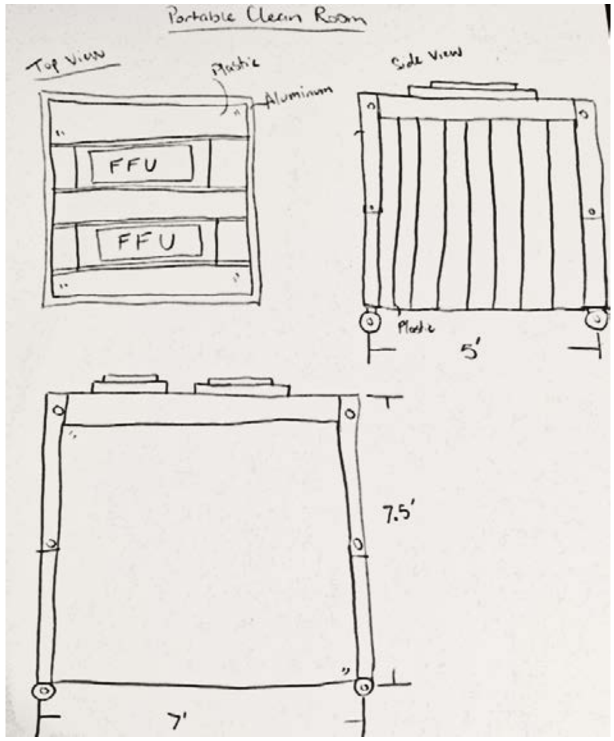

Figure 14. Design for Portable Clean Room Single Flaps

5 DESIGN SELECTED – First Semester

Various design concepts were considered but due to the constraints of the CRs and needing to meet FDA criteria, the overall design selected was an aluminum framed polycarbonate clean hood and an aluminum frame clear walled plastic clean room. The selection of two possible design were made by comparing all the designs that we created with customer requirements. Using a Pugh chart, which used all of customer requirements and compared them to seven different designs described above and two in the Appendix. Each design was given a ranking according to the relevance to the CR's.

5.1 Rationale for Design Selection

The hood design and room design chosen met the all of the customer requirements while remaining under budget. The aluminum framing was decided because of how extremely lighter and durable the material is compared to steel, even though the cost is greater. The polycarbonate hood was specifically chosen by the client. The clear walled plastic was chosen for the visibility aspect, cost, and light weight. Rubber lining was chosen because of its elasticity and relative cost. The Pugh chart in table 9 is designed to show how each concept correlates with each CR. As seen in the Pugh chart, the hood design 2 and 4 ranked the highest because steel is cheaper than aluminum but is also heavy but are equivalent in all other aspects. The room designs all had a relative equal ranking but number 6 was the better option. The chosen designs for the hood and room can be seen in Figure 9 and Figure 13, respectively.

Table 8. Pugh Chart

Customer Requirements	Datum	1	2	3	4	5	6	7	8	9
Inexpensive	(+)	(-)	(+)	(-)	(+)	(-)	(-)	(+)	(-)	(+)
Portable	(+)	(+)	(+)(-)	(+)	(+)(-)	(+)	(+)	(+)(-)	(+)	(+)(-)
Positive Pressure	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Visibility	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
Clean	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)
Reliability	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Durability	(+)	(+)	(+)	(+)	(+)	(+)(-)	(+)	(+)(-)	(+)(-)	(+)
Classification	(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Noise	(+)	(0)	(0)	(0)	(0)	(0)	(0)	(-)	(-)	(-)
Safety	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(+)
Total (+)	10	7	8	6	8	7	7	7	6	7
Total (0)	0	2	2	2	2	2	2	1	1	1
Total (-)	0	1	1	2	1	2	1	4	3	3

1. Design 1 hood - Aluminum frame, polycarbonate hood, foam top lining
2. Design 2 hood - Steel frame, polycarbonate hood, rubber top lining
3. Design 3 hood - Aluminum frame, polycarbonate hood, rubber top lining
4. Design 4 hood - Steel frame, polycarbonate hood, foam top lining
5. Design 5 hood - Aluminum frame, acrylic hood, foam top lining
6. Design 1 room - Aluminum frame, 0.25" plastic wrap, duralock, lock pins
7. Desgin 2 room - Steel frame, 0.25" plastic wrap, velcro, latch locks
8. Design 3 room - Aluminum frame, 0.25" plastic wrap, velcro, latch locks
9. Design 4 room - Steel frame, 0.25" plastic wrap, duralock, lock pins

(+) - Positive Corrolation
(0) - Neutral Corrolation
(-) - Negative Corrolation

5.2 *Design Description*

The final design will be produced next semester and is detailed within this section. Initially the designs were iterated and worked on multiple times to see which design worked best for the client. After multiple design concepts and approvals by the client the team was able to create two separate design concepts these two concepts will be detailed in section 6, and this section shows the final design and dimensions for the portable clean room.

5.2.1 Engineering Calculations

Using the proposed engineering requirements from table from section 2.2 there were a series of calculations used to determine if the clean room would operate within those parameters. Each team member took on a different task to work on the analysis required for the clean room. The following the three main analysis on the clean room was frame, pressure, and fan filter analysis. Each different analysis goes into detailing explaining the results for the calculations and can be found in Appendix D.

For this project, it was decided that a fluid analysis is to be done on the portable hood and room to determine if a positive pressure will result with the chosen dimensions and fan filter units (FFU). The analysis is crucial because it is one of the client's requirements that both the hood and the room have positive pressure continuously while in use ensuring a clean atmosphere within. Aneuvas Technology Inc. manufactures and researches minimal invasive microcatheter medical devices, used to treat aneurisms and other vascular defects in the brain. This project will benefit the client's research and development of their products by producing a clean low particle count work environment. There must be positive pressure in both units to be considered a clean atmosphere, meaning that the particle count is low and HEPA certified.

5.2.2 Model Drawings

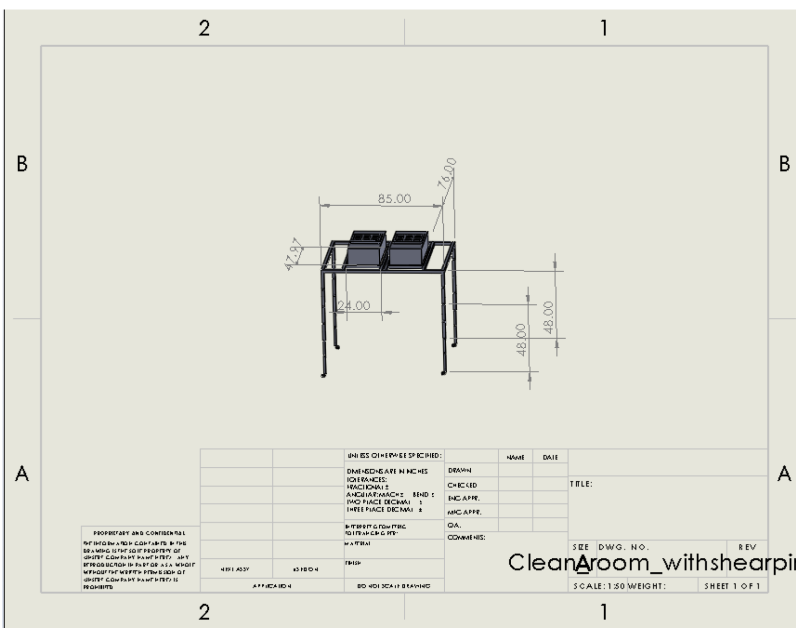

Figure 15. Portable Clean Room CAD Drawing

The portable clean room chosen for the final design is shown in figure 15 above. The model shows the dimensions it will have and how the fans will sit once it is built. The shear pins will hold the collapsible legs in place giving the portable clean room a height of 84 inches in total. The wheels will be able to lock and unlock for easy mobility and the fans can be detached in order to reduce weight when transporting.

Figure 16. Portable Room CAD Assembly

In figure 16 above is a 3D CAD model of the clean room for our final design. This design shows a clear image of the shear pins used to hold the legs of the clean room at different heights. It also shows the position of the fans located at the top being held together by their individual frame for maximum strength. The wheels are also important to note since they will be used for ease of mobility when transporting from one location to the next.

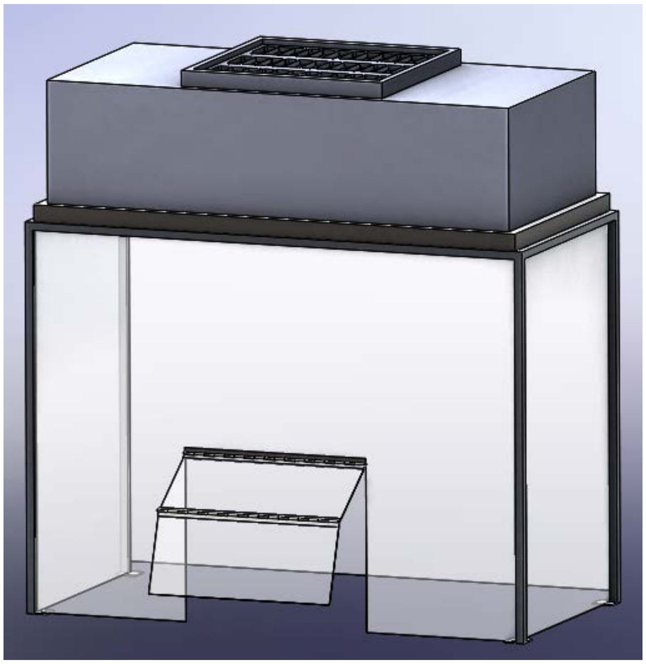

Figure 17. Portable Hood CAD Assembly

In figure 17 above is the final CAD design model for the portable clean hood. This design has an aluminum framing to help support the weight of the FFU. A Polycarbonate hood is within the aluminum framing where the testing equipment is to be placed and used. The double hinged door allows for two different openings, opened fully allows the user access to the top of the equipment and half opened allows access to the midsection of the equipment.

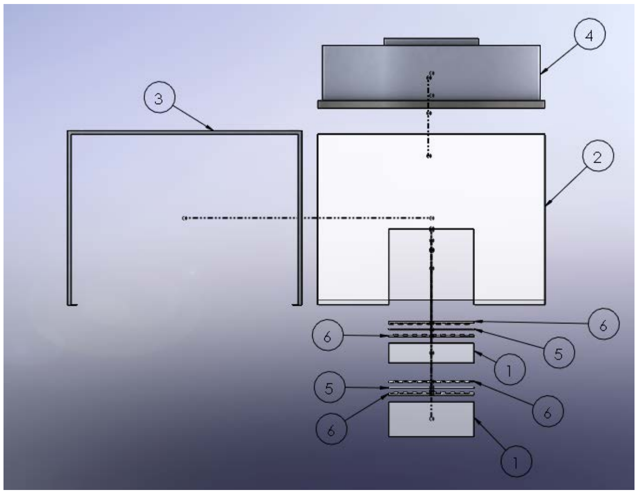

Figure 18. Portable Hood Exploded View

Figure 18 shows the exploded view of the portable hood, where balloon 1 is the polycarbonate door, 2 is the polycarbonate viewing window, 3 is the aluminum frame, 4 is the FFU, 5 is the pin to the hinges, and 6 are the wings for the hinges.

6 PROPOSED DESIGN – First Semester

The next process of design is to fabricate a prototype model of the hood and order the chosen fan filter units from Terra Universal due to the length of time that it takes to ship [5]. Then start purchasing the list of material from the Bill of Materials (BOM), in order to build the final design. To fabricate the frames for both the hood and the room NAU's machine shop in building 98C has all the required equipment to successfully build the design. Once the final design is fabricated measurements will be taken to verify that the customer's dimensions are met, a pressure test will be done to verify that positive pressure is obtained and sustained. As stated in the testing procedure section above, the pressure will be measured using pressure transducers, DAQ system, and LabVIEW program.

6.1 Implementation of Design

In order to implement the design, the team will work together with several resources that are available to us. The frame will be made and through the help of the machine shop, one of our teammates is recently certified for machining. This will prove to very helpful in the spring semester. In order to get more precise measurements for pressure distribution along the portable clean room, a group member has taken the task of learning CFD. Using the software ANSIS and creating a mesh out of the CAD file the team can create a more precise pressure distribution based on the geometry of the clean room.

6.2 Bill of Material

The bill of materials (Appendix E) will be a comprised of the total amount of material needed to create both the clean room and the portable hood. Starting with the FFU which will have to be ordered online through a source that specializes in fan filter units. The framing will come partially from the machine shop and the rest of the frame will be ordered through home depot. The steel shear pins will also be bought through home depot along with the wheels for the portable room. Welding for this project will be covered through the help of the machine shop. The other materials like epoxy and polycarbonate cutting tools will be bought through the home depot.

6.3 Final Design Assembly View and Exploded View

Figure 19. Portable Room CAD Assembly

The figure 19 above provides a detail assembly image of the proposed final design project. Showing the different components for the clean room like the adjustable legs and the shear stress pins, as well as the fan filter units.

Figure 20. Portable Room CAD Exploded View

Figure 20 displays an exploded view of the portable clean room for the final design project. The lines show the way the different are attached based on the starting point and ending points of the lines.

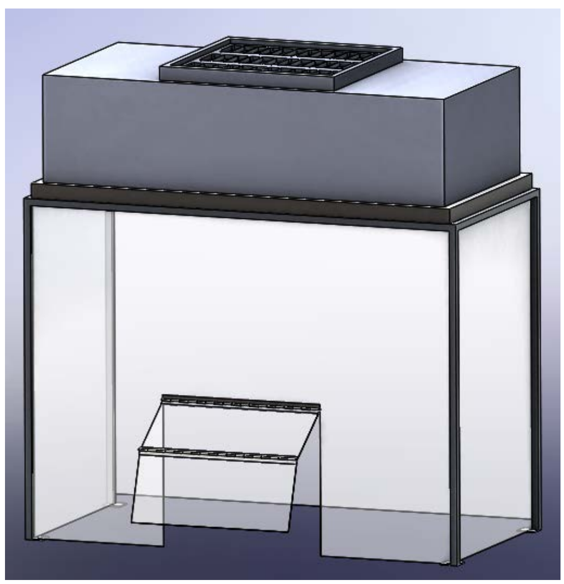

Figure 21. Portable Hood CAD Assembly

This figure 21 shows the portable hood design assembly for the final design project. This assembly shows the different components like the double hinge door, polycarbonate cover, as well as the fan filter unit.

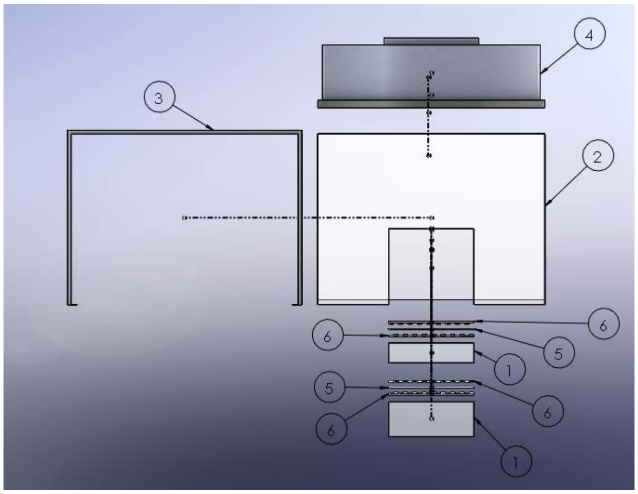

Figure 22. Portable Hood Exploded View

This figure 22 shows the exploded view for the portable hood for our final design project. The image showcases the different components by assigning a different to each part. Also implementing the line diagrams to show how the portable is assembled back together.

7 CONCLUSION

This report contained background, customer and engineering requirements, existing designs, designs created, design selected, design description, and the proposed design for the portable clean room and clean hood. The main design parameter is for the flow hood and clean room to have the ability to be disassembled and reassembled, have clean and sterilized air, maintain a positive pressure, and be portable. The team will be developing a prototype to present to the class and will be meeting with the client to get final approvals to order the fan filter units to prepare for the spring semester.

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9 APPENDICES

9.1 Appendix A: House of Quality

Table 2. House of Quality

System QFD

Project: Aneuvas Technologies Inc. Clean Room and Hood
Date: September 20, 2018
Input areas are in tan

Technical Requirement	Unit	Dimensions -Area	Pressure	Weight	Cost	Assembly Time	Power	Number of Particles	Velocity	Hood Material	Room Material	Stress	Sound
Dimensions -Area	m^2												
Pressure	Pa												
Weight	kg	(++)											
Cost	$$	(++)		(++)									
Assembly Time	min			(++)	(+)								
Power	W		(+-)		(+/-)								
Number of Particles	m^3		(++)		(+/-)		(++)						
Velocity	m/s		(++)				(++)	(++)					
Hood Material	n/a	(++)		(++)	(++)	(++)		(+)					
Room Material	n/a	(++)		(++)	(++)	(++)		(+)					
Stress	Pa		(++)						(+)	(++)	(++)		
Frequency	dBa				(+)			(+/-)					

Technical Requirements

Customer Needs	Customer Weights	Dimensions -Area	Pressure	Weight	Cost	Assembly Time	Power	Number of Particles	Velocity	Hood Material	Room Material	Stress	Sound
Inexpensive	5	3		3	9	3	1	1		9	9		1
Portable	3	9	1	3	3	9	3			1	1		
Positive Pressure	5		9		1		3	9	9			1	3
Visibility	2					3				9	9		
Clean	4	1	9		3		3	9	3	9	9		9
Reliability	3	3		1		1						9	
Durability	3	3				1				3	3	9	
Classification	5		9		9		3	9	1				9
Noise	4												9
Technical Requirement Units		m^2	Pa	kg	$$	min	W	m^3	m/s	n/a	n/a	Pa	dBa
Technical Requirement Raw Score		64	129	27	116	54	56	131	62	111	111	59	12
Relative Wieght %		6.9565	14.02	2.935	12.61	5.87	6.087	14.23913	6.73913043	12.07	12.07	6.413043	1.382
Target ER Values Hood		0.7432		45.36	1000	2	576	102,000	0.58	-	-		54
Target ER Values Room		2.23		54.43	1000	15	576	102,000	0.58	-	-		54
Rank Order		6	2	11	5	9	10	1	7	3	4	8	12

9.2 Appendix B: Portable Hood with Adjustable Frame

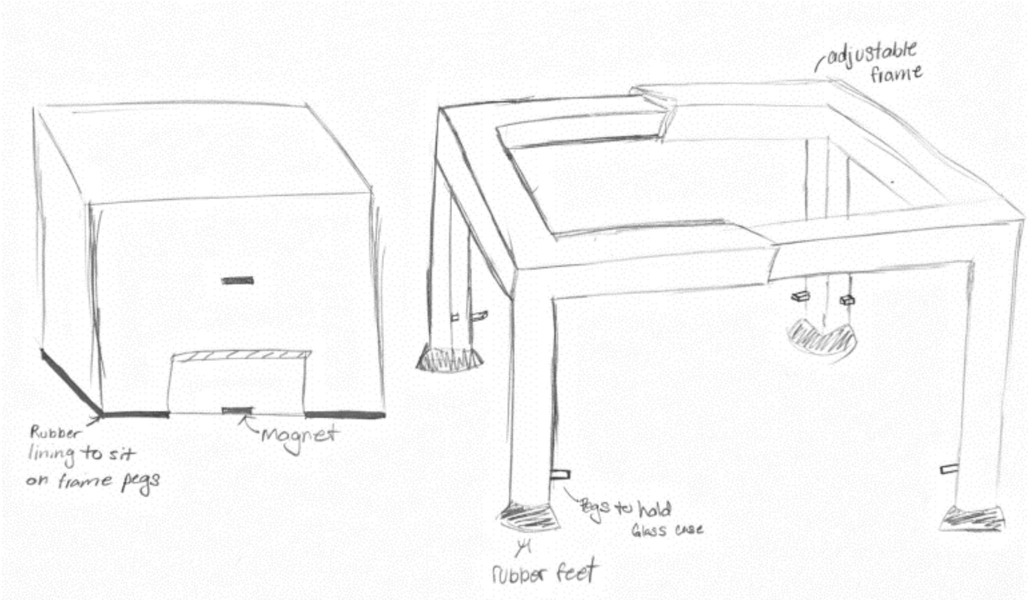


Figure 23. Portable Hood with Adjustable Frame

9.3 Appendix C: Portable Hood with Tabbed Framing

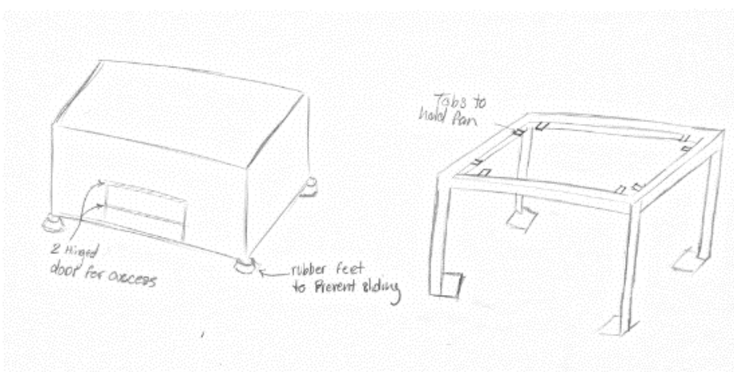


Figure 24. Portable Hood with Tabbed Framing

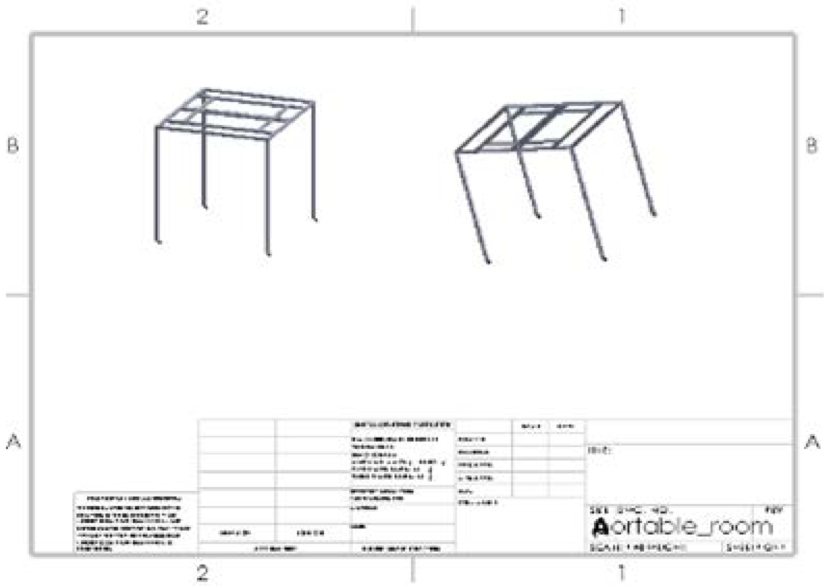
9.4 Appendix D: Technical Analysis

Frame Analysis

These assumptions were taken based on the customer requirements of the size of the clean room and portable hood. This will also account for the material used, based on several meetings with our client the preferred material for frame is aluminum. This is due to the fact of the overall strength durability and lightweight nature of aluminum. The other assumption was the aluminum framing for the hood is 1in x 1in cross sectional area and hollow, and for the portable room it is 2in x 2in cross sectional area hollow. Both frames will have a load of 35 pound given that the fan is 70 pounds. This is since the fan will be held by two parallel frames which will distribute the weigh evenly therefore just having a load of 35 pound in one side of the frame.

9.4.1.1.1 Details of Physical Model

Using an outer skeleton as a frame which reduces the strain on the polycarbonate walls of the room. The frame is used to hold the FFU and is sealed with the help of an adhesive which can be removed easily. The frame is made from aluminum which reduces the weight of the overall clean room. This helps with the ease of transportation which is a requirement by the customer. The polycarbonate walls have an entrance point that is 6inx12in which is required for working within the station. The bad thing about this device is the opening which is a hinge style opening which may reduce the visibility of the user when working. Another con may be the outer frame can also decrease the visibility when looking through the sides of portable hood



The portable clean room in figure shows the top view and front view. In the top view it can be seen the there are two fans and the fans are spaced on the top for better air distribution. The fans are mounted in place and are supposed to be in the optimal position. In the front view the flaps on the entrance side are to have a double layer of plastic slats that are off set from each other to reduce the amount of air escaping, while the other three sides are solid vinyl sheeting, ensuring there is positive pressure in the structure. The bottom of the frame is to have castor wheels, so it can be easily moved, but also be locked in place.

9.4.1.1.2 Equations

These equations were used to understand the mechanism going on within the frame. Using the stated assumptions, the frame was under a distributed load across the frame in the y-axis direction. Illustrating the shear and bending moment equations and the reaction forces within the system. The calculations were used to understand the maximum bending a shear moment acting on the frame for both the portable hood and room.

$$\sum F_{xyz} = 0 \tag{1}$$

This equation shows the sum of the forces acting on x, y, and z direction. This is a very important factor since the distributed load on the frame will have reactions forces that are on the frame.

$$\tau = \pm \frac{v}{A} \tag{2}$$

$$\sum v = 0 \tag{3}$$

This equation is the sum of the shear moments along with how the shear moment equation is derived using tow. This will help understand the shear force being applied due to the initial distributed load of the fan.

$$\sum M = 0 \tag{4}$$

$$dM = \delta v \, dx \tag{5}$$

These equations were used to understand the bending moments happening within the frame. This is important since bending moments can be accumulated based on the load being applied.

$$S_{m_a x} = \frac{p}{A_{net}} \tag{6}$$

This equation is used to get the maximum tensile stress for acting on the frame based on the distributed load being added.

9.4.1.1.3 2.4 Software Used

GS-USA is a software that is used to analyses different types of frames. This software can be used by setting specific parameters specific to what you need. I set the material property to aluminum and a hollow cross-sectional area of 1x1 in and 2x2 in for the hood and the portable room. The next step was to set nodes which are the x and y coordinates for the hood and the portable room. This will allow you to have a 2d look at where the coordinates of the frame will be. The next step is to assign elements to each of the nodes, this is the actual straight line or the frame of the design. For both frame analysis conducted the frame was the same given that they are going to be sitting with the same dimensions. The only difference between the room and hood is the cross-sectional area which was mentioned earlier. Given these inputs the software then can calculate the min and max bending moments as well as shear diagrams. Another interesting data given for this analysis is the maximum tensile strengths.

This analysis shows the how the distributed load acts on the frame. Based on the assumptions made initially a technical analysis was able to be done. Using the software and following the governing equations structural analysis was done. The maximum bending moment and shear diagram showed that both the room and hood frame would be able to withstand the distributed being applied based on the weight of the fan. The other important aspect was the maximum tensile stress that occurs within the frame this too also showed to be able to have met the requirements for the framing being used for this demand. Ultimately the framing can be reasonably said to withstand the weight of the fans which will hold safely based on the technical analysis illustrated. The future work will be to apply this analysis if there are any future changes to the design which can be easily done following this technical analysis.

9.4.1.2 Pressure Analysis

For this project, it was decided that a fluid analysis is to be done on the portable hood and room to determine if a positive pressure will result with the chosen dimensions and fan filter units (FFU). The analysis is crucial because it is one of the client's requirements that both the hood and the room have positive pressure continuously while in use. The company manufactures and analyzes minimal invasive microcatheter medical devices, used to treat aneurisms and other vascular defects in the brain. This project will benefit the client's research and development of their products by producing a clean low particle count work environment. There must be positive pressure in both units to be considered a clean atmosphere, meaning that the particle count is low and HEPA certified.

9.4.1.2.1 Assumptions, Equations, and Variables

For this project, it was decided that a fluid analysis is to be done on the portable hood and room to determine if a positive pressure will result with the chosen dimensions and fan filter units (FFU). The analysis is crucial because it is one of the client's requirements that both the hood and the room have positive pressure continuously while in use. The company manufactures and analyzes minimal invasive microcatheter medical devices, used to treat aneurisms and other vascular defects in the brain. This project will benefit the client's research and development of their products by producing a clean low particle count work environment. There has to be positive pressure in both units to be considered a clean atmosphere, meaning that the particle count is low and HEPA certified.

9.4.1.2.2 Assumptions

This section of the report contains assumptions, equations, and variables used in analyzing the fluid flow and the pressure within the room and the hood.

Assumptions

1. Incompressible flow, ρ = constant
2. Steady state, $\frac{\partial}{\partial t} = 0$
3. Mass flow rate in equals mass flow rate out, $\dot{m}_{in} = \dot{m}_{out}$
4. The FFU is treated as a pump, as one whole unit
5. The relative roughness is smooth
6. The polycarbonate case is to be treated as a duct

Equations

Equation 1: Mass flow rate

$$\dot{m} = \dot{\forall} * \rho$$

Equation 1 calculates the mass flow rate by multiplying the volumetric flow rate given which then allows the ability to obtain the velocity at various points.

Equation 2: Velocity

$$V = \frac{\dot{m}}{\rho * A}$$

The equation above can calculate the velocity by taking the calculated flow rate and dividing it by the density of air and the area with which the velocity is flowing through.

Equation 3: Hydraulic diameter

$$D_h = \frac{4Lw}{2(L + w)}$$

The equation above calculates the hydraulic diameter by using the 2 times the area divided by the perimeter of the unit which then will be applied to equation 4 below.

Equation 4: Head supply of pump

$$h_{SP} = \frac{P}{\dot{m}}$$

This equation calculates the head supply of the unit, by taking the power of the FFU and dividing it by the mass flow rate.

Equation 5: Reynold's number

$$Re = \frac{\rho V L}{\mu}$$

The Reynolds number is a dimensionless number, the calculation determines the type of flow that the FFU produces through the hood and room. If less than 2300 the flow is laminar and if the value is greater than 4000 the flow is turbulent.

Equation 6: Head loss major of unit

$$h_{lM} = f * \left(\frac{L}{D_h}\right)\left(\frac{V^2}{2}\right)$$

Equation 6 above calculates the major head loss that occurs through the hood and room.

Equation 7: Pipe flow energy equation

$$h_{lM} - h_{SP} = \left(\frac{P_1}{\rho} + \frac{V_1^2}{2} + gz_1\right) - \left(\frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2\right)$$

$$h_{lM2} + h_{lM3} = \left(\frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2\right) - \left(\frac{P_3}{\rho} + \frac{V_3^2}{2} + gz_3\right)$$

This equation is used to obtain the value of pressure 2 located 6” below the FFU and pressure 3 located at the bottom of the entire unit. This equation will show whether or not that either unit maintains a positive pressure throughout.

Nomenclature

$P_{low} -$ *Power at low setting* $[W][\frac{kg * m^2}{s^3}]$

$h_{lM2} -$ *Head loss Major of pump unit for* 6" *below FFU* $[\frac{m^2}{s^2}]$

$h_{lM3} -$ *Head loss Major of pump for bottom of unit* $[\frac{m^2}{s^2}]$

$h_{SP} -$ *Head supply of pump unit* $[\frac{m^2}{s^2}]$

$D_{h2} -$ *Hydraulic Diameter for* 6" *below FFU* $[m]$

$D_{h3} -$ *Hydraulic Diameter for bottom of unit* $[m]$

$\dot{\forall}_{low} -$ *Volumetric flow rate at low setting* $[\frac{m^3}{s}]$

$\dot{m}_{low} -$ *Mass flow rate at low setting* $[\frac{kg}{s}]$

$h_{fan} -$ *Height of fan unit* $[m]$

$h_{hood} -$ *Height of hood* $[m]$

$h_{door} -$ *Height of door* $[m]$

$L -$ *Length* $[m]$

$w -$ *width* $[m]$

$A -$ *Area of unit* $[m^2]$

$A_{pf} -$ *Area of pre* $-$ *filter* $[m^2]$

$V_1 - Velocity\ at\ top\ of\ hood\ [\frac{m}{s}]$
$V_2 - Velocity\ located\ 6"\ below\ FFU\ [\frac{m}{s}]$
$V_3 - Velocity\ at\ bottom\ of\ unit\ [\frac{m}{s}]$
$z_1 - Hight\ at\ point\ 1(top\ of\ fan)\ [\ m\ ]$
$z_2 - Hight\ at\ point\ 2(6"\ below\ fan)\ [\ m\ ]$
$z_3 - Hight\ at\ point\ 3(bottom\ of\ unit)\ [\ m\ ]$
$g\ - Earth's\ gravity\ [\frac{m}{s^2}]$
$p_1 - Atmospheric\ pressure\ in\ Flagstaff\ [\frac{kg}{ms^2}]$
$p_2 - Pressure\ 6"\ below\ FFU\ [\frac{kg}{ms^2}]$
$p_3 - Pressure\ at\ bottom\ of\ unit\ [\frac{kg}{ms^2}]$
$Re - Reynolds\ number$
$f_2 - Friction\ factor\ for\ 6"\ below\ FFU$
$f_3 - Friction\ factor\ for\ bottom\ of\ unit$
$\rho - Density\ of\ air\ in\ Flagstaff\ [\frac{kg}{m^3}]$
$\mu - viscosity\ of\ air\ [\frac{kg}{ms}]$

9.4.1.2.3 Schematic of the Hood and Room

This section of the report a schematic of the clean hood and the clean room.

9.4.1.2.3.1 Clean Hood

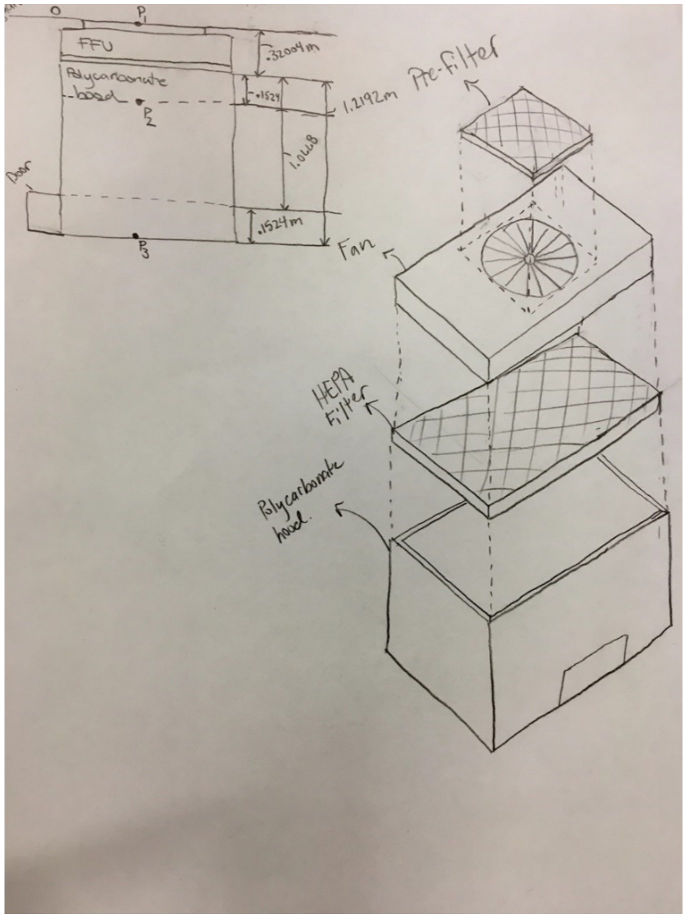


Figure 25: 2'x4' Clean Hood

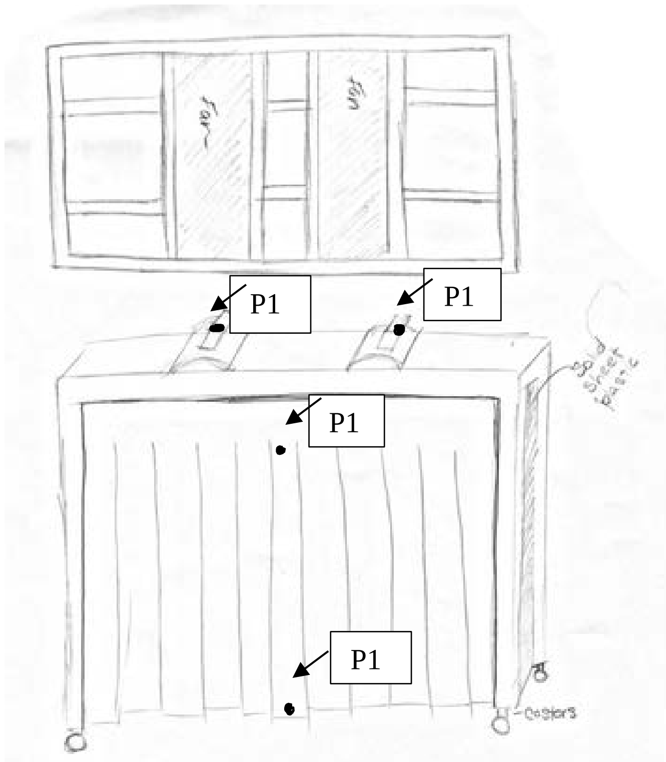


Figure 26: 6'x8'x8' Portable Room

9.4.1.2.4 Equation Flow Chart

This section of the report contains the details of how the equations in the section above are calculated and applied in the analysis.

9.4.1.2.5 Calculations

9.4.1.2.5.1 2'x4' Clean Hood

In this section is the calculations for the 2'x4' clean hood at the low speed setting. Listed below are the known variables.

$P = 393\ W\ \left[\frac{kgm^2}{s^3}\right]$
$\dot{\forall} = 0.3087\ \frac{m^3}{s}$
$h_{hood} = 1.219\ m$
$h_{fan} = 0.332m$
$h_{door} = 0.1524\ m$
$h_{6"\ below\ fan} = 0.1524\ m$
$L_2 = 0.1524\ m$
$L_3 = 1.067\ m$
$w = \ 0.6096\ m$
$A_{pre-filter} = 0.2581\ m^2$
$z_1 = 0\ m$
$z_2 = 0.15837\ m$

$z_3 = 1.067\ m$

$\rho_{flagstaff} = 1.20\ \frac{kg}{m^3}$

$p_{flagstaff} = 797156\ \frac{kg}{ms^2}$

$V_2 = V_3 = 0.4724\ \frac{kg}{m^3}$

$\mu = 1.8x10^{-6}\ \frac{Ns}{m^2}$

Listed below is the calculation process taken to prove that there is a positive pressure at the bottom of the unit.

$$\dot{m} = \dot{\forall}\rho = 0.3087 * 1.20 = 0.37044\ \frac{kg}{s}$$

$$V_1 = \frac{\dot{m}}{\rho A_{pf}} = \frac{0.37044}{1.20 * 0.2581} = 1.1961\ \frac{m}{s}$$

$$h_{SP} = \frac{P}{\dot{m}} = \frac{393}{0.37044} = 1060.9 \frac{m^2}{s^2}$$

$$Re = \frac{\rho VL}{\mu} = \frac{1.20 * 0.4724 * 0.15837}{1.8x10^{-6}} = 49876 > 2300 - Turbulent\ Flow$$

Reynold’s number and assumption 5 are applied to the Moody’s Diagram to estimate the friction factor. [2]

$$f_2 \approx 0.037$$

$$D_{h2} = \frac{2L_2 w}{L + w} = \frac{2 * 0.15837 * 0.6096}{0.15837 + 0.6096} = 0.25142\ m$$

$$h_{lM2} = f_2 * \left(\frac{L}{D_{h2}}\right)\left(\frac{V_2^2}{2}\right) = 0.037 * \left(\frac{0.15837}{0.25142}\right)\left(\frac{0.4724^2}{2}\right) = 0.002601 \frac{m^2}{s^2}$$

$$\mathrm{h_{lM}} - \mathrm{h_{SP}} = \left(\frac{P_1}{\rho} + \frac{V_1^2}{2} + gz_1\right) - \left(\frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2\right)$$

$$\rightarrow 0.002601 - 1060.9 = \left(\frac{79715.6}{1.20} + \frac{1.196^2}{2} + 0\right) - \left(\frac{P_2}{1.20} + \frac{0.4724^2}{2} + (9.81)(0.15837)\right)$$

$$\rightarrow -1060.9 = (66429.7 + 0.71521) - \left(\frac{P_2}{1.20} + 0.11158 - 1.5536\right)$$

$$\rightarrow -1060.9 = 66430.4 - \frac{P_2}{1.20} + 1.44202$$

$$\rightarrow -1060.9 = 66429 - \frac{P_2}{1.20}$$

$$\rightarrow -67489.9 = -\frac{\mathrm{P}_2}{1.20}$$

$$\rightarrow \mathrm{P}_2 = 80988\ Pa$$

With the pressure known at point 2, use same equations to find the pressure at point 3 which is the bottom of the unit.

$$Re = \frac{\rho VL}{\mu} = \frac{1.20 * 0.4724 * 1.067}{1.8x10^{-6}} = 336034 > 2300 - Turbulent\ Flow$$

Reynold's number and assumption 5 are applied to the Moody's Diagram to estimate the friction factor. [2]

$$f_3 \approx 0.0235$$

$$D_{h3} = \frac{2L_3 w}{L + w} = \frac{2 * 1.067 * 0.6096}{1.067 + 0.6096} = 0.77591\ m$$

$$h_{lM3} = f_3 * \left(\frac{L}{D_{h3}}\right)\left(\frac{V_2^2}{2}\right) = 0.0235 * \left(\frac{1.067}{0.77591}\right)\left(\frac{0.4724^2}{2}\right) = 0.005431\frac{m^2}{s^2}$$

$$h_{lM2} + h_{lM3} = \left(\frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2\right) - \left(\frac{P_3}{\rho} + \frac{V_3^2}{2} + gz_3\right)$$

$$\rightarrow 0.002601 + 0.005431 = \left(\frac{80988}{1.20} + \frac{0.4724^2}{2} + (9.81)(0.15837)\right) - \left(\frac{P_3}{1.20} + \frac{0.4724^2}{2} - (9.81)(1.076)\right)$$

$$\rightarrow 0.008031 = (67490 + 0.11158 + 1.5536) - \left(\frac{P_3}{1.20} + 0.11158 - 10.556\right)$$

$$\rightarrow 0.008031 = 67488.6 - \frac{P_3}{1.20} + 10.444$$

$$\rightarrow 0.008031 = 67499 - \frac{P_3}{1.20}$$

$$\rightarrow -67499 = -\frac{P_3}{1.20}$$

$$P_3 = 80999\ \mathrm{Pa}$$

9.4.1.2.6 6'x8'x8' Clean Room

In this section is the calculations for the 6'x8'x8' clean room with 2 FFUs at the low speed setting. Listed below are the known variables for one 2'x4' FFU.

$P = 393\ W\ \left[\frac{kgm^2}{s^3}\right]$
$\dot{\forall} = 0.3087\ \frac{m^3}{s}$
$h_{room} = 2.438\ m$
$h_{fan} = 0.332m$
$h_{spacing} = 0.305\ m$
$h_{6"\ below\ fan} = 0.1524\ m$
$L_2 = 0.1524\ m$
$L_3 = 1.9801\ m$
$w = \ 1.8288\ m$
$A_{pre-filter} = 0.2581\ m^2$
$z_1 = 0\ m$
$z_2 = 0.15837\ m$
$z_3 = 1.9801\ m$
$\rho_{flagstaff} = 1.20\ \frac{kg}{m^3}$
$p_{flagstaff} = 797156\ \frac{kg}{ms^2}$
$V_2 = V_3 = 0.4724\ \frac{kg}{m^3}$
$\mu = 1.8x10^{-6}\ \frac{Ns}{m^2}$

Listed below is the calculation process taken to prove that there is a positive pressure at the bottom of the unit.

$$\dot{m} = 2\dot{\forall}\rho = \ 2 * 0.3087 * 1.20 = 0.74088\ \frac{kg}{s} \rightarrow 2\ FFUs$$

$$V_1 = \frac{\dot{m}}{\rho A_{pf}} = \ \frac{0.74088}{1.20 * 0.2581} = 2.3921\ \frac{m}{s} \rightarrow 2\ FFUs$$

$$h_{SP} = \frac{2P}{\dot{m}} = \ \frac{2 * 393}{0.74088} = 1060.9\frac{m^2}{s^2}$$

$$Re = \frac{\rho VL}{\mu} = \ \frac{1.20 * 0.4724 * 0.15837}{1.8x10^{-6}} = \ 49876 > 2300 - Turbulent\ Flow$$

Reynold’s number and assumption 5 are applied to the Moody’s Diagram to estimate the friction factor. [2]

$$f_2 \approx 0.037$$

$$D_{h2} = \frac{2L_2 w}{L + w} = \ \frac{2 * 0.15837 * 1.8288}{0.15837 + 1.8288} = 0.291497\ m$$

$$h_{lM2} = f_2 * \left(\frac{L}{D_{h2}}\right)\left(\frac{V_2^2}{2}\right) = 0.037 * \left(\frac{0.15837}{0.291497}\right)\left(\frac{0.4724^2}{2}\right) = 0.002243\frac{m^2}{s^2}$$

$$\mathrm{h_{lM} - h_{SP}} = \left(\frac{\mathrm{P_1}}{\rho} + \frac{\mathrm{V_1^2}}{2} + \mathrm{gz_1}\right) - \left(\frac{\mathrm{P_2}}{\rho} + \frac{\mathrm{V_2^2}}{2} + \mathrm{gz_2}\right)$$

$$\rightarrow 0.002243 - 1060.9 = \left(\frac{79715.6}{1.20} + \frac{2.3921^2}{2} + 0\right) - \left(\frac{\mathrm{P_2}}{1.20} + \frac{0.4724^2}{2} + (9.81)(0.15837)\right)$$

$$\rightarrow -1060.9 = (66429.7 + 2.8611) - \left(\frac{\mathrm{P_2}}{1.20} + 0.11158 - 1.5536\right)$$

$$\rightarrow -1060.9 = 66432.6 - \frac{\mathrm{P_2}}{1.20} + 1.44202$$

$$\rightarrow -1060.9 = 66434 - \frac{\mathrm{P_2}}{0.813}$$

$$\rightarrow -67494.9 = -\frac{\mathrm{P_2}}{1.20}$$

$$\rightarrow \mathrm{P_2} = 80994\ Pa$$

With the pressure known at point 2, use same equations to find the pressure at point 3 which is the bottom of the unit.

$$Re = \frac{\rho V L}{\mu} = \frac{1.20 * 0.4724 * 1.9801}{1.8x10^{-6}} = 623599 > 2300 - Turbulent\ Flow$$

Reynold’s number and assumption 5 are applied to the Moody’s Diagram to estimate the friction factor. [2]

$$f_3 \approx 0.0198$$

$$D_{h3} = \frac{2L_3 w}{L + w} = \frac{2 * 1.9801 * 1.8288}{1.9801 + 1.8288} = 1.9014\ m$$

$$h_{lM3} = f_3 * \left(\frac{L}{D_{h3}}\right)\left(\frac{V_2^2}{2}\right) = 0.0198 * \left(\frac{1.9801}{1.9014}\right)\left(\frac{0.4724^2}{2}\right) = 0.002301\,\frac{m^2}{s^2}$$

$$h_{lM2} + h_{lM3} = \left(\frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2\right) - \left(\frac{P_3}{\rho} + \frac{V_3^2}{2} + gz_3\right)$$

$$\rightarrow 0.002243 + 0.002301 = \left(\frac{80994}{1.20} + \frac{0.4724^2}{2} + (9.81)(0.15837)\right) - \left(\frac{P_3}{1.20} + \frac{0.4724^2}{2} - (9.81)(1.9801)\right)$$

$$\rightarrow 0.004544 = (67495 + 0.11158 - 1.5536) - \left(\frac{P_3}{1.20} + 0.11158 - 19.4248\right)$$

$$\rightarrow 0.008031 = 67493.6 - \frac{P_3}{1.20} + 19.3132$$

$$\rightarrow 0.008031 = 67512.9 - \frac{P_3}{1.20}$$

$$\rightarrow -67512.9 = -\frac{P_3}{1.20}$$

$$P_3 = 81015.5 \text{ Pa}$$

9.4.1.2.7 Results

As seen in section 3 above the calculations for both the clean hood and clean room at P_3 ,the bottom of the units, result in a positive pressure above atmospheric pressure. Since the pressure is positive at the FFU's lowest speed settings this means that the medium speed and high speed settings will be sufficient enough to sustain the positive pressure. This analysis supports the client's requirement of the units producing and maintaining a positive pressure throughout use.

9.4.1.3 Fan Filter Unit Analysis

The purpose of the fan filter analytical report is to determine the capabilities of a High Efficiency Particulate Air (HEPA) fan filter. The client has requested a clean room for medical device testing, and a clean hood for operating their rheometer under, and they need to pass a clean room classification certification. This project will create a class certified clean room using at most two fan units, with a known cleanliness of the room, air velocity, air change rate (ARC), along with when to replace the filter. These are all factors that will play in the clean room
classification.

9.4.1.3.1 Background

HEPA fan filters are used to filter out particles in the air, they are specially designed for use in cleanrooms and precision assembly areas [8]. These filters have an efficiency rating of 99.99% with particles 0.3 microns and larger in diameter [8]. They can be categorized into classes of cleanliness for a given number of particles in a given sized room. The classifications have two different ways of being rated, the International Standards Organization (ISO) and the U.S. General Service Administration's standards (known as FS209E) [9]. The FS209E contains six classes, while the ISO classification system has two cleaner standards and one dirtier standard. The "cleanest" cleanroom in FS209E is referred to as Class 1; the "dirtiest" cleanroom is a class 100,000. ISO cleanroom classifications are rated according to how much particulate of specific sizes exist per cubic meter. The "cleanest" cleanroom is a class 1 and the "dirtiest" is a class 9 [9]. The ISO class 3 is approximately equal to FS209E class 1, while ISO class 8 approximately equals FS209E class 100,000. Classifications will be done in the ISO format because it supersedes the FS209E standard as of 2014 [9].

9.4.1.3.2 Classification Effects

The client has specified they want a room that is 6'x8'x8', and a hood that is 2'x4'x4' and must maintain positive pressure. The classification plays a key role in the cleanliness of the room, air velocity, and the air change rate. Table 1 shows the effect of classification on these factors. The client mentioned the cleanliness should be around an ISO class of 6-8. The difference between the ISO ratings is drastic in the number of foreign particles in the room as the rating number goes up.

Table 9. Classification Ranges for All Three Factors [9]

Class ISO 146144-1 (Federal Standard 209E)	Average Airflow Velocity m/s (ft/min)	Air Changes Per Hour
ISO 8 (Class 100,000)	0.005 – 0.041 (1 – 8)	5 – 48
ISO 7 (Class 10,000)	0.051 – 0.076 (10 -15)	60 – 90
ISO 6 (Class 1,000)	0.127 – 0.203 (25 – 40)	150 – 240
ISO 5 (Class 100)	0.203 – 0.406 (40 – 80)	240 – 480
ISO 4 (Class 10)	0.254 – 0.457 (50 – 90)	300 – 540
ISO 3 (Class 1)	0.305 – 0.457 (60 – 90)	360 – 540
ISO 1 – 2	0.305 – 0.508 (60 – 100)	360 – 600

The main factor is the velocity, for it directly affects the number of air changes per hour. The air change rate is the number of times per hour that "new" air is introduced into the system. The velocity affects the air flow in whether it is laminar for a longer time or becomes turbulent sooner. This directly affects the cleanliness, the sooner the flow turns turbulent the "dirtier" the air, with a laminar flow the speed and direction provide a uniform environment that prevents air pockets where foreign particles might collect [9].

9.4.1.3.3 Fan Filter Unit Calculation

The calculations for determining the total number of fan filter units (FFUs) was used to further define the classification of the project, respecting the clients need for a maximum of two FFUs. Equation 1 [9] and table 1 were used to calculate the number of fan units.

$$No.of\ FFUs = \left(\frac{Air\ Changes\ per\ Hour}{60}\right) * \left(\frac{ft^3\ of\ Room}{650^*}\right) \quad (1)$$

*CFM output of a loaded FFU

The cleanest ISO rating allowing for the full range of the listed air changes per hour in table 1, was an ISO rating of 7. This was calculated with the maximum ARC per hour of 90 and the room size of 6'x8'x8' which is 384 ft³, the total number of FFUs calculated was 0.886, which can be rounded up to 1.00, as FFUs are sold as a single unit. With only numerically needing one FFU the client will potentially save money for the total cost of the project, having budgeted for the price of two units. For the ISO rating of 6 equation 1 was rearranged to calculate the maximum ARC per hour, which was 203, in which more than 2 FFUs would be required to produce the full range of ARC in an ISO class 6 environment.

$$Air\ Changes\ per\ Hour = \left(\frac{2}{\left(\frac{ft^3\ of\ Room}{650^*}\right)}\right) * 60 \quad (2)$$

The calculations for the hood were also produced using equation 1. An ISO rating of 1 was calculated with the maximum ARC of 540 per hour and the hood size of 2'x4'x4' which is 32 ft³, the total number of FFUs calculated was 0.443, which can be rounded up to 1.00, creating an extremely clean work environment under the clean hood. The client plans to inter change the FFU between the clean room and hood, so this means the total required FFUs is still one.

9.4.1.3.4 Filter Replacement

Other than the need to know how many fan units can be used for the given dimensions of the room and the hood, the client also needs a way of knowing when to replace the filters in the FFUs. Fan filter units have a total of three filters inside of them, a pre-filter, a bag filter, and the HEPA filter. The general agreement is that prefilters are to be changed roughly six times a year, bag filters are roughly changed every year, and HEPA filters are generally about three to eight years [10,11]. There are many different aspects that effect a HEPA filter and when it is changed, such as geographic or physical location of the building, nearby construction, proximity to freeways and commuter railroad tracks, as well as fog or other climate-related conditions [11]. They first year of changing filters is a trial period of observing when to change the filters [10,11].

Figure 1. 2'x4' FFU [12]

Figure 1 shows a 2’x4’ FFU in which the blue pre-filter can be seen on top. Similar FFUs are to be purchased for this project’s clear room/hood, and they will have the pre-filter, bag/box filter and the HEPA filter inside. The filters will be used in a laboratory on campus surrounded with lots of traffic, a train station close by, and a dry dusty climate. With these factors the client can do a trial year and observe the filters over time or they can try the other approach.

The other approach is to record the back pressure in the clean room/hood the first time it is used. Then when the back pressure in the clean room/hood has dropped by half the back pressure of the once new HEPA filter the filter is to be changed. This is because as the HEPA filter accumulates particles over its lifetime, pressure builds in the space between the blower and the HEPA filter [12]. If a HEPA filter accumulates too many particles and becomes clogged, it can result in a loss of efficiency that can compromise the cleanroom's ISO rating. If they are not replaced in a timely manner, severely clogged filters can destroy the motors in the Fan/Filter Units and potentially pose a fire hazard in the event of catastrophic electrical failure [12].

The purpose of this analytical report was to determine the capabilities of a High Efficiency Particulate Air fan filter. This was accomplished with the use of tabulated data displaying the ISO cleanliness classification, air velocity, and the air change rate, along with an equation for the number of fan filter units required for the size of the projects clean room and hood. The last method used to further determine the capabilities of a HEPA fan filter was to have an analytical method for when the HEPA filter was to be replaced. From the results found it was determined that the client will only need one FFU for his needs, and the initial back pressure will need to be recorded and checked for loss in back pressure to safely operate the system.

9.5 Appendix E: Bill of Materials

Bill of Materials									
Team				Clean Dream Team					
Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost	Total Cost	Link to Cost estimate
1	Aluminum Frame	12	Room Frame	Supports Fan	AL	97"x1'	$ 27.50	$ 330.00	https://www.grainger.com/category/aluminum-extrusions/structural-framing-systems/material-handling/ecatalog/N-c3q#nav=%2Fcategory%2Faluminum-extrusions%2Fstructural-framing-systems%2Fmaterial-handling%2Fecatalog%2FN-
2	Plastic Sheeting Roll	1	Plastic to Wrap Room	Creates covering for room	Plastic	8'x100'	$ 78.00	$ 78.00	https://www.homedepot.com/?cm_mmc=SEM%7CG%7CBase%7CNA%7CNA%7CNA%7CBT1%7c71700000002449093%7c58700000047538642%7c43700003817116349&ds_rl=5041&gclid=Cj0KCQiA3IPgBRCAARIsABb-iGKe4e_BM97hMySr3rp6pmb7vCHlI8vxipQNdmKFoflbK8idHENquRQaAt6pEALw_wcB&gclsrc=aw.d
3	Polycarbonate	1	Material For Hood	Creates convering for hood	Polycarbonate	48"x96"x.125	$ 140.25	$ 140.25	https://www.eplastics.com/sheets/polycarbonate/clear?page=2
4	Aluminum Frame	8	Hood Frame	Supports Fan	Aluminum	36"x.5"x1/16	$ 11.53	$ 92.24	https://www.grainger.com/category/aluminum-extrusions/structural-framing-systems/material-handling/ecatalog/N-c3q#nav=%2Fcategory%2Faluminum-extrusions%2Fstructural-framing-systems%2Fmaterial-handling%2Fecatalog%2FN-
5	Velcro Duralock	2	Adhesion for plastic Wra	Holds plastic wrao in place	Velcro	1"x75'	$ 52.00	$ 104.00	https://www.homedepot.com/p/Liquid-Nails-Fuze-It-9-oz-All-Surface-Construction-Adhesive-LN-2000/206736831
6	Aluminum Joints	16	Joints to support Frame	Supports frame	Aluminum	n/a	$ 8.50	$ 136.00	https://www.homedepot.com/?cm_mmc=SEM%7CG%7CBase%7CNA%7CNA%7CNA%7CBT1%7c71700000002449093%7c58700000047538642%7c43700003817116349&ds_rl=5041&gclid=Cj0KCQiA3IPgBRCAARIsABb-iGKe4e_BM97hMySr3rp6pmb7vCHlI8vxipQNdmKFoflbK8idHENquRQaAt6pEALw_wcB&gclsrc=aw.d
7	Polycarbonate Cutting	1	material to cut plastic	helps with sizing poly	Polycarbonate	n/a	$ 20.00	$ 20.00	https://www.homedepot.com/?cm_mmc=SEM%7CG%7CBase%7CNA%7CNA%7CNA%7CBT1%7c71700000002449093%7c58700000047538642%7c43700003817116349&ds_rl=5041&gclid=Cj0KCQiA3IPgBRCAARIsABb-iGKe4e_BM97hMySr3rp6pmb7vCHlI8vxipQNdmKFoflbK8idHENquRQaAt6pEALw_wcB&gclsrc=aw.d
8	Shear Pins	4	Holds legs in place	Help adjusting size of room	steel	2.75"x6"	$ 1.76	$ 7.04	https://www.homedepot.com/p/Ariens-Deluxe-Sno-Thro-Shear-Pin-72100500/202274701
9	Epoxy	4	seals the polycarbonate	creates a seal for no air to escape	plastic	n/a	$ 5.47	$ 21.88	https://www.homedepot.com/p/Loctite-0-85-fl-oz-Plastic-Epoxy-1360788/100371824
10	Fan Filter Unit - Whisp	2	Fan Filter Unit	Induce positive pressure and produce filtered clean	Powdered-coated stee	2'x4'x1.5'	$780.00	$ 1,560.00	https://www.terrauniversal.com/product/6601-24-H
				Total Cost Estimate:			$ 2,489.41		