To: Dr. Oman and GTA Amy Swartz
From: Team 23 Clean Room
Subject: Final Testing
Date: 4/12/2019

Introduction

This memo outlines the final testing of the clean hood completed as a team Tuesday, April 9, 2019. The scope of the project has been changed to fully finishing the hood, fully designing the room, and manufacturing the frame of the room. The scope changed due to continuously exceeding the budget and time constraints. The final testing exhibits proof of every engineering requirement being met.

Assembled Hood

In Figure 1 below exhibits the final product, the fully assembled clean hood.

Figure 1: Fully Assembled Clean Hood

Area [< 0.743m^2]

The area tested was the bottom surface area of the hood. The original surface area to be under was 0.557m^2, this was because the team had originally designed for a smaller clean hood, this was later revised to be larger per the client's needs. The total work surface area was calculated to be 0.754 m^2. This was calculated using the length values found in figure 2 and 3, and by converting from inches squared to meters squared.

Figure 2. Hood Width, 24.25in

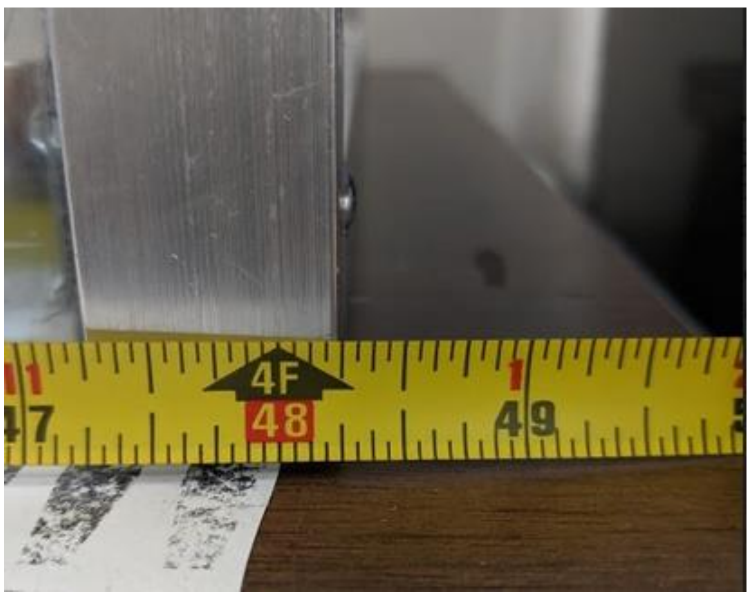


Figure 3. Hood Length, 48.25in

Pressure [>78000 Pa]

Below are the assumptions and calculations made to estimate the output pressure at the bottom of the unit as seen in Figure 4 using fluid mechanics. As seen below, the output pressure is greater than atmospheric which means that positive pressure is induced.

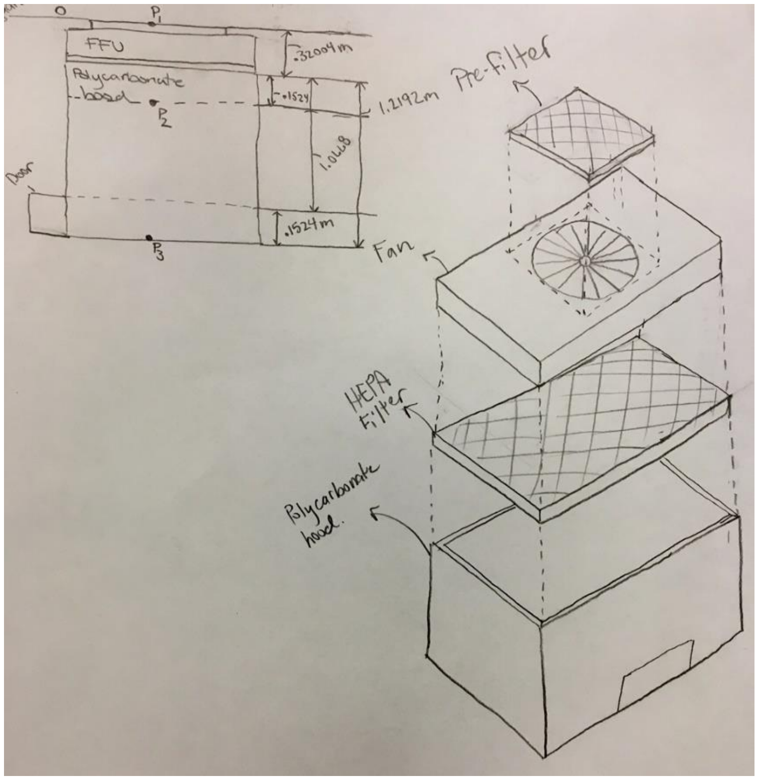


Figure 4: 2'x4' Clean Hood

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.

<u>Assumptions</u>

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

<u>Equations</u>

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

$$h_{SP} = \frac{\dot{W}_{pump}}{\dot{m}\rho}$$

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

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

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

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

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

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

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

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

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

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

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

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

$L - Length\ [\ m\ ]$

$w - width\ [\ m\ ]$

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

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

$V_1 - Velocity\ at\ top\ of\ hood\ [\frac{m}{s}]$

$V_2 - Velocity\ located\ 6"\ below\ FFU\ [\frac{m}{s}]$

$V_3 - Velocity\ at\ bottom\ of\ unit\ [\frac{m}{s}]$

$z_1 - Hight\ at\ point\ 1(top\ of\ fan)\ [\ m\ ]$

$z_2 - Hight\ at\ point\ 2(6"\ below\ fan)\ [\ m\ ]$

$z_3 - Hight\ at\ point\ 3(bottom\ of\ unit)\ [\ m\ ]$

$g\ \ - Earth's\ gravity\ [\frac{m}{s^2}]$

$p_1 - Atmospheric\ pressure\ in\ Flagstaff\ [\frac{kg}{ms^2}]$

$p_2 - Pressure\ 6"\ below\ FFU\ [\frac{kg}{ms^2}]$

$p_3 - Pressure\ at\ bottom\ of\ unit\ [\frac{kg}{ms^2}]$

$Re - Reynolds\ number$
$f_2 - Friction\ factor\ for\ 6"\ below\ FFU$
$f_3 - Friction\ factor\ for\ bottom\ of\ unit$
$\rho - Density\ of\ air\ in\ Flagstaff\ \left[\frac{kg}{m^3}\right]$
$\mu - viscosity\ of\ air\ \left[\frac{kg}{ms}\right]$

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.

$W = 393\ W\ \left[\frac{kgm^2}{s^3}\right]$
$\dot{\forall} = 0.3087\ \frac{m^3}{s}$
$h_{hood} = 1.219\ m$
$h_{fan} = 0.332m$
$h_{door} = 0.1524\ m$
$h_{6"\ below\ fan} = 0.1524\ m$
$L_2 = 0.1524\ m$
$L_3 = 1.067\ m$
$w = 0.6096\ m$
$A_{pre-filter} = 0.2581\ m^2$
$z_1 = 0\ m$
$z_2 = 0.15837\ m$
$z_3 = 1.067\ m$
$\rho_{flagstaff} = 1.20\ \frac{kg}{m^3}$
$p_{flagstaff} = 797156\ \frac{kg}{ms^2}$
$V_2 = V_3 = 0.4724\ \frac{m}{s}$
$\mu = 1.8x10^{-6}\ \frac{Ns}{m^2}$

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

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

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

$$h_{SP} = \frac{W_{pump}}{\dot{m}\rho} = \frac{393}{(0.37044)(1.20)} = 884.08\frac{m^2}{s^2}$$

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

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

$$f_2 \approx 0.037$$

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

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

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

$$\rightarrow 0.002601 - 884.08 = \left(\frac{79715.6}{1.20} + \frac{1.196^2}{2} + 0\right) - \left(\frac{\mathrm{P_2}}{1.20} + \frac{0.4724^2}{2} + (9.81)(0.15837)\right)$$

$$\rightarrow -884.08 = (66429.7 + 0.71521) - \left(\frac{\mathrm{P_2}}{1.20} + 0.11158 - 1.5536\right)$$

$$\rightarrow -884.08 = 66430.4 - \frac{\mathrm{P_2}}{1.20} + 1.44202$$

$$\rightarrow -884.08 = 66429 - \frac{\mathrm{P_2}}{1.20}$$

$$\rightarrow -67313.1 = -\frac{\mathrm{P_2}}{1.20}$$

$$\rightarrow \mathrm{P_2} = 80775.7\ Pa$$

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

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

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

$$f_3 \approx 0.0235$$

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

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

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

$$\rightarrow 0.002601 + 0.005431 = \left(\frac{80775.7}{1.20} + \frac{0.4724^2}{2} + (9.81)(0.15837)\right) - \left(\frac{P_3}{1.20} + \frac{0.4724^2}{2} - (9.81)(1.076)\right)$$

$$\rightarrow 0.008031 = (67313.1 + 0.11158 + 1.5536) - \left(\frac{P_3}{1.20} + 0.11158 - 10.556\right)$$

$$\rightarrow 0.008031 = 67314.7 - \frac{P_3}{1.20} + 10.444$$

$$\rightarrow 0.008031 = 67325.2 - \frac{P_3}{1.20}$$

$$\rightarrow -67325.2 = -\frac{P_3}{1.20}$$

$$P_3 = 80790.2 \text{ Pa}$$

Cost [< $2000]

The cost was exceeded continuously throughout the design and manufacturing process. The budget originally started at $1,000 and then was increased to $2,000. Currently, the budget has no limit per the client's decision. The only remaining purchase is the powder coat for the room's steel frame.

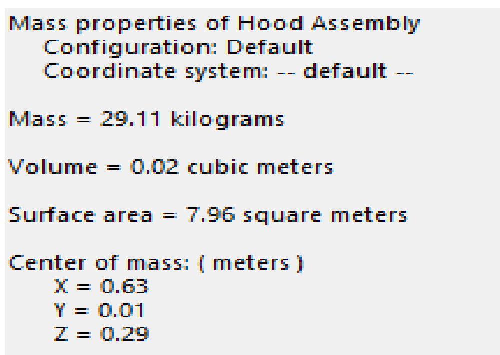
Table 1. B.O.M. Of Hood and Room

Bill of Materials
Clean Dream Team

Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost	Total Cost
			Portable Hood					
Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost	Total Cost
1	Aluminum Frame	6	Hood Frame DONATED -98C	Supports Fan	Aluminum	1"X 1/8" thick - 5 - 6' le	$-	$-
2	Welding Aluminum Frame	1	Welding of the aluminum frame		Aluminum	1"X 1/8" thick - 5 - 6' length and 1 - 7' length	$300	$300
3	Polycarbonate	1	For 3 sheets Material For Hood	Creates convering for hood	Polycarbonate	48"x48"x1/4"	$530.00	$530.00
4	Cut Polycarbonate	1	Cut the polycarbonate	Is the inner shell of the hood	Polycarbonate	48"x48"x1/4"	$240.00	$240.00
5	Epoxy	5	seals the polycarbonate	creates a seal for no air to escape	Plastic	n/a	$6.75	$33.73
6	Rubber lining	1	cushions FFU to frame	to prevent air leakage between frame and FFU	Rubber	19/32" X 10'	$16.74	$16.74
7	Magnets	1	Holds door	Keeps door open for ease of adjustments within hood	Neodymium	1/2 diam.	$4.76	$4.76
8	Machine Screws	1	tightens hinges	secures the hinges	Zinc plated	32x1/2	$3.54	$3.54
9	Ardrino	1	Test Pressure within Unit	To test Pressure within unit	N/A		$36.89	$36.89
10	Power Cord	1	Power the FFUs - 3 wire power tool replacement cord	Power the FFU	N/A		$12.97	$12.97
11	Interior L Brackets	4	Stainless Steel Brackets to support the polycarbonate	support	Stainless steel		$13.08	$52.32
12	Nuts	1	fasten the brackets to polycarbonate	support	Stainless steel		$4.24	$4.24
13	Handle	1	assist in opening door		steel		$4.88	$4.88
14	Hook	1	prop door up		steel		$-	$-
15	Screws	100	fasten the brackets to polycarbonate	support	stainless steel		$5.60	$5.60
16	Hinges	1	hinges for hood	allows the hood door to open	Zinc plated	2-1/2'	$1.97	$1.97
							Total Cost Estimate:	$1,247.63
			Portable Room					
Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost	Total Cost
10	Steel Frame and cutting	120	Steel - 110' - 1.5"x1.5"x1/8"`	Framing for the protable room	steel	1.5"x1.5"x1/8"`	$435.78	$435.78
12	White Powder Coat	120	Powder coat the steel frame	Protect the steel and to reduce particals released by the steel	Powder coat		$750.74	$750.74
17	Power Cord	1	Power the FFUs - 3 wire power tool replacement cord	Power the FFU	N/A		$12.97	$12.97
18	Heavy Duty Swivel Caster Wh	4	600lb capacity swivel caster wheels - DONATED	Allows for the portable room to be stationary and mova	5 x 1-1/4 in nylon poly	Wheels - 5 x 1-1/4, Fran	$-	$-
							Total Cost Estimate:	$1,199.49
							Overall Total Estimate:	$2,447.12
							Total Budget:	$2,000.00
							Remaining Budget:	($447.12)

Weight [< 45.36 kg]

Figure 5 shows the overall estimated weight of the hood that was manufactured. This excludes the weight of the fan unit that will be resting on top. Figure 6 Shows the CAD assembly used to calculate the weight in figure 5.


Mass properties of Hood Assembly
Configuration: Default
Coordinate system: -- default --

Mass = 29.11 kilograms

Volume = 0.02 cubic meters

Surface area = 7.96 square meters

Center of mass: (meters)
X = 0.63
Y = 0.01
Z = 0.29

Figure 5. SOLIDWORKS Generated Mass Properties

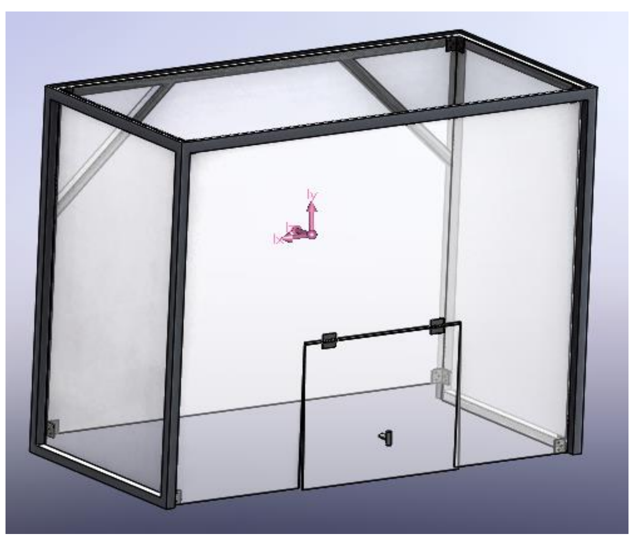


Figure 6. Hood CAD used to Estimate System Weight

Assembly Time [< 10 min]

Figure 7 shows the recorded time for the complete assembly of the Hood along with the fan unit being plugged in and operational. Only 2 people were doing the assembly process and could assemble the hood in less than 2 minutes.

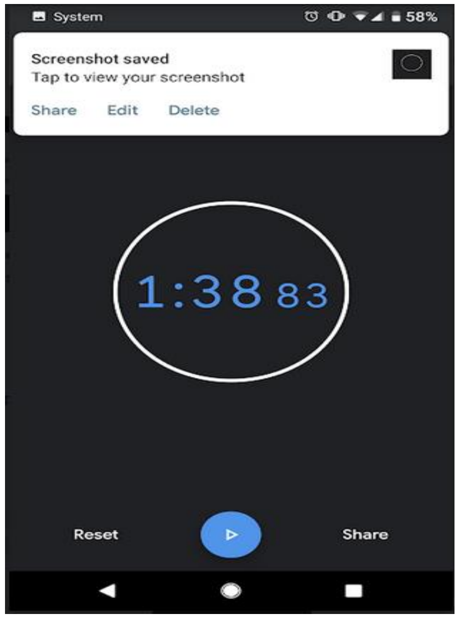


Figure 7. Hood Assembly Time

Power FFU [520 W]

Figure 8 below is from a label on the Fan Filter Unit, the label shows the power the fan outputs is 472 Watts.

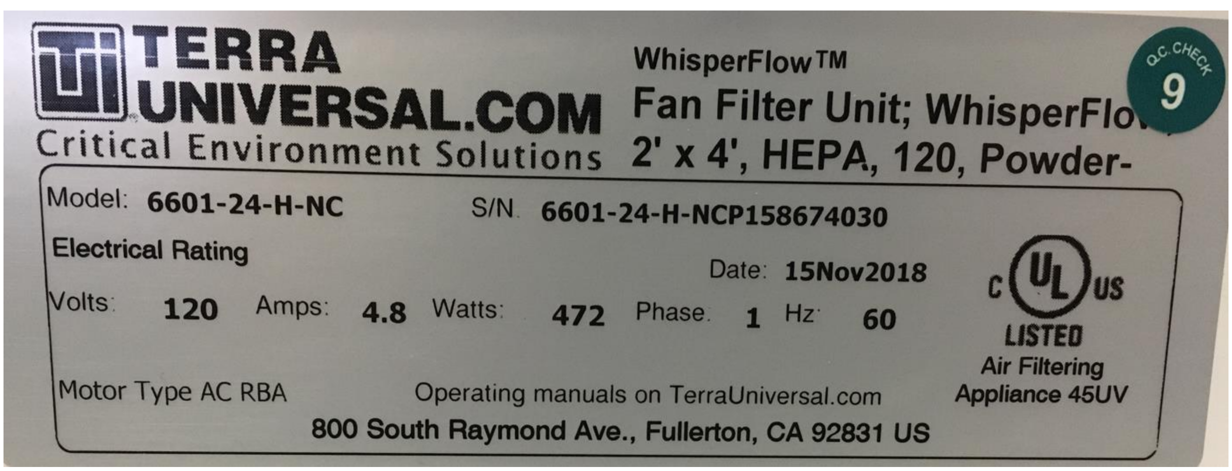
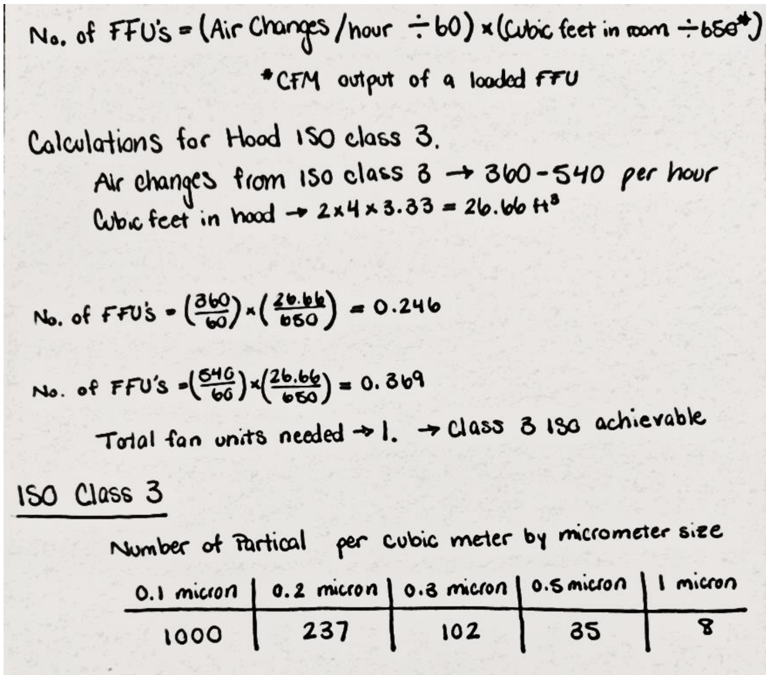


Figure 8. Fan Unit Specifications

Particle Count [< 102,000 $per\ m^3$]

Figure 9 describes the steps taken to find the estimated number of foreign particles for the assumed ISO rating of Class 3. This calculation was done from cleanroom ISO classification charts. Since the clean hood volume is less than one cubic meter it will have less foreign particles than what is listed in figure 9.



No. of FFU's = (Air Changes/hour ÷ 60) × (Cubic feet in room ÷ 650*)

*CFM output of a loaded FFU

Calculations for Hood ISO class 3.

Air changes from ISO class 3 → 360-540 per hour

Cubic feet in hood → 2x4x3.33 = 26.66 ft^3

No. of FFU's = $\left(\frac{360}{60}\right) \times \left(\frac{26.66}{650}\right) = 0.246$

No. of FFU's = $\left(\frac{540}{60}\right) \times \left(\frac{26.66}{650}\right) = 0.369$

Total fan units needed → 1. → Class 3 ISO achievable

ISO Class 3

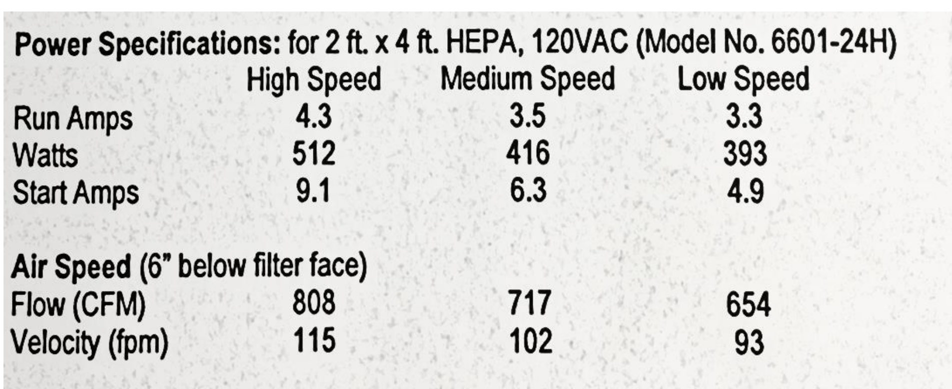
Number of Partical per cubic meter by micrometer size

0.1 micron	0.2 micron	0.3 micron	0.5 micron	1 micron
1000	237	102	35	8

Figure 9. Analytical Solution to find Air Particles

Velocity FFU [> 0.58 $\frac{m}{s}$]

In Figure 10 below is from the Terra Universal's 2'x4' WhisperFlow FFU Manual and states the velocity of the FFU at each setting. On low the velocity is 0.472 $\frac{m}{s}$, on Medium the velocity is 0.518 $\frac{m}{s}$, and on High the velocity is 0.584 $\frac{m}{s}$. Thus, the FFU meets the engineering requirement.



Power Specifications: for 2 ft. x 4 ft. HEPA, 120VAC (Model No. 6601-24H)

	High Speed	Medium Speed	Low Speed
Run Amps	4.3	3.5	3.3
Watts	512	416	393
Start Amps	9.1	6.3	4.9
Air Speed (6" below filter face)			
Flow (CFM)	808	717	654
Velocity (fpm)	115	102	93

Figure 10. Section of FFU Manual

Room Frame Testing:

The weight requirement for the steel frame is to hold up to 70lbs per side for a total of 140lbs. The test done by one of the group members and was to elevate the frame from the ground and add weight to see if there are any noticeable bending happening on the steel frame. The group member weights 200lbs and the complete weight is on just one beam. This test will show that if one beam can withstand 200lbs it can hold 70lbs with no issues.

Figure 11. Weight Bearing Test