Final Report

Waste Air Recapture Study

Team #18085

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1.0 Introduction and Scope

The demand for energy continues to grow as population increases and our environment has a bigger energy demand for its technology. Since our major resources for energy are coal, fossil fuels, and nuclear power, a new type of energy is in demand.

This is where renewable energy comes into play, the only issue is most of these energy sources are dependent upon mother nature to get them functioning. Hence, these energy sources are limited to their location and cannot operate in highly populated areas. Therefore, the solution is the Regenesis system.

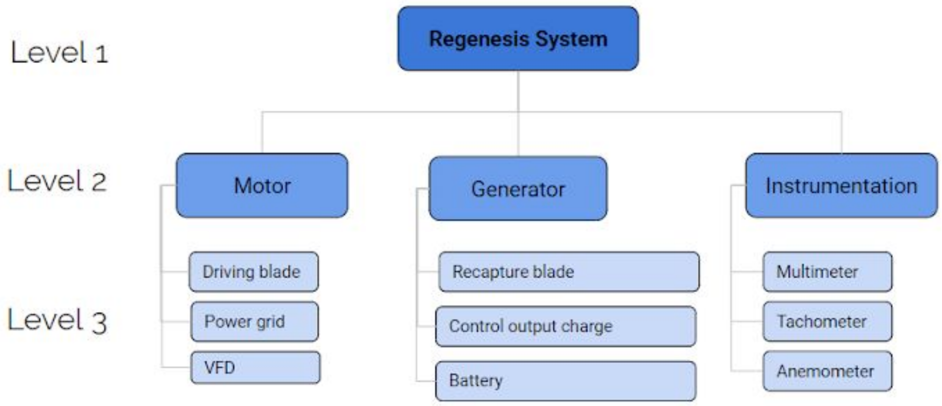
The Regenesis system is a fan system powered by the waste air of HVAC exhaust fans that converts mechanical motion back to useable energy. This energy is either stored in a battery for future use or returned to the grid, thus lowering the cost of operating the unit over its useful lifetime. A ⅓ HP EcoSaver motor powers a retrofitted, clockwise rotating driving fan (blue fan) which creates a strong airflow. In turn, the driving fan airflow powers a counter-clockwise rotating recapture fan (green fan). Mating a 24-volt generator along with a charge controller which harnesses the wasted energy producing an output wattage.

The main testing part is shown in Figure 1.0 below and setup for test is in 4.0.1.0.

2.0 System Block Diagram

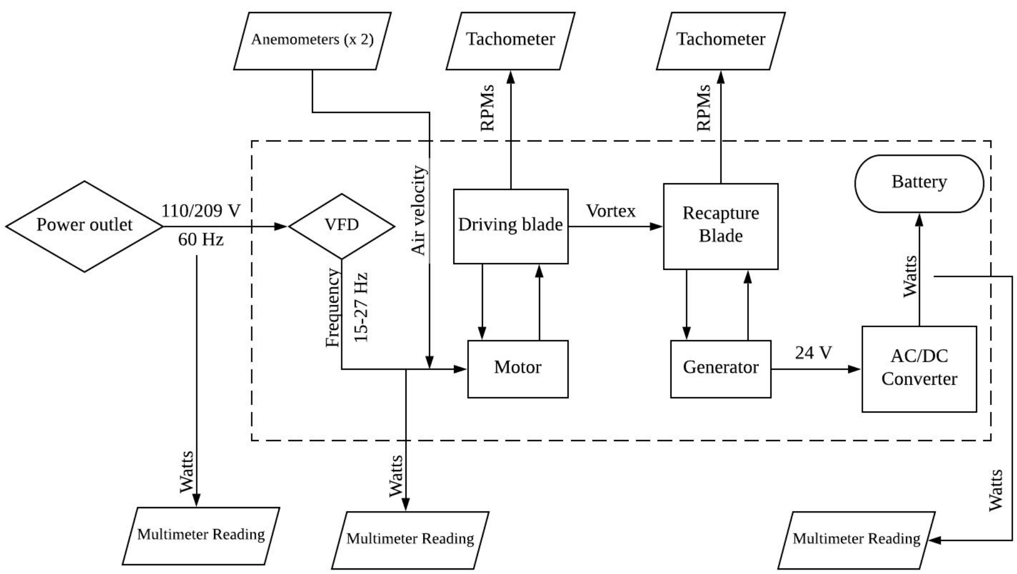
2.1.0 System Architecture

The system's architecture is composed of three different levels. The first level is the one that describes the system as a whole. Then, the second level is composed by the subsystems. Finally, the third level contains the instrumentation within each subsystem.



2.2.0 System Block Diagram

The system block diagram helps visualize how each subsystem and sub-assembly is connected and their interfaces. In our block diagram, our system essentially starts at the power outlet. Everything enclosed by the dotted line is the main and fixed components of our system. Everything else shown is for data collection, which will be crucial for the results and analysis of the system.



3.0 Technical Data Package

3.1.0.0 System Requirements

3.1.1.0 Interface Requirements

3.1.1.1 Mechanical Interface: The system shall have a recapture fan that converts mechanical energy into electrical energy.

3.1.1.2 Electrical Interface Input: The driving fan shall be powered by the Variable Frequency Drive.

3.1.1.3 Electrical Interface Output: The system shall have a 24-volt generator attached to the recapture fan.

3.1.1.4 Power Interface: The system shall be powered using a 3-phase 209 voltage outlet.

3.1.2.0 Performance Requirements

3.1.2.1 Frequency Regulation: The system's input frequency shall be regulated by a Variable Frequency Drive ranging between 15-27 Hz.

3.1.2.2 Output: The system shall output energy into a Battery connected to an AC to DC converter.

3.1.2.3 Data Collection: The system shall record RPM, air velocity, frequency, amperage and voltage data using instrumentation.

3.1.3.0 Customer Constraints

3.1.3.1 Cost: The system's experimental setup and procedure shall not cost more than $4,000.

3.1.3.2 Operation: The system's driving fan shall rotate clockwise while the recapture fan rotates counter-clockwise as viewed in between the two fans.

3.1.3.3 Position: The system's fans shall be placed at a predetermined optimal distance.

3.2 Airflow Test

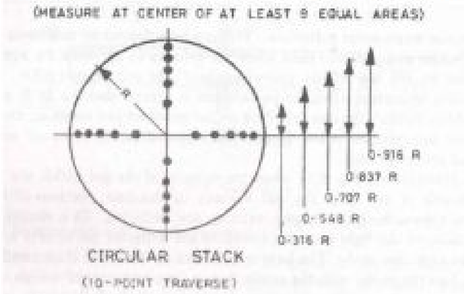
The Airflow test is the most important of the three tests, as any data will have to be compared via Cubic Feet per Minute (CFM) to existing systems. Anemometers are used to test airflow across the two intake ducts, vs respective area, to estimate the total airflow for each fan configuration.

Procedure

An anemometer will measure the intake air velocity from below the fan and another anemometer will be above the fan. We will test with and without the recapture blade. The plastic vane anemometer will measure air velocity at specific points. To provide a more precise reading, points will be chosen at different radii.

Expected Output

Shown below are theoretical relations between RPMs, HP, static pressure, and airflow.



$$\frac{RPM_2}{RPM_1} = \left(\frac{Airflow_2}{Airflow_1}\right)$$

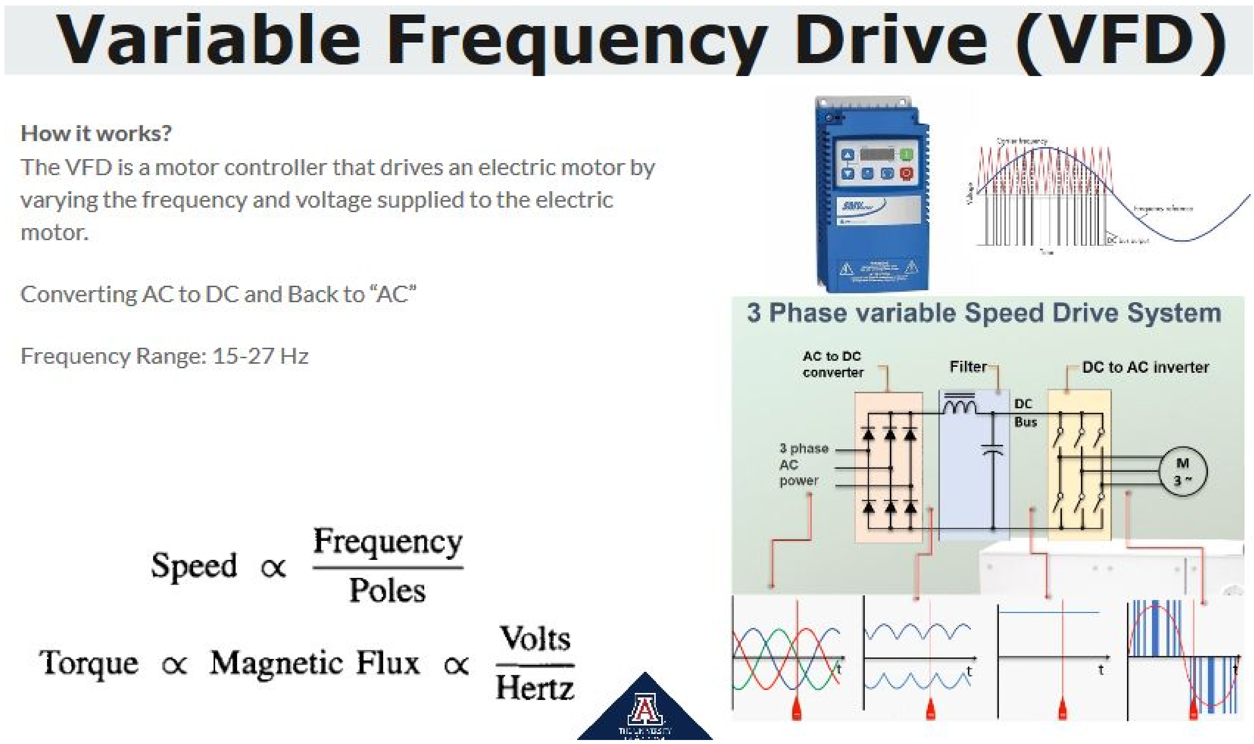
$$\frac{Static\ Pressure_2}{Static\ Pressure_1} = \left(\frac{Airflow_2}{Airflow_1}\right)^2$$

$$\frac{Horsepower_2}{Horsepower_1} = \left(\frac{Airflow_2}{Airflow_1}\right)^3$$

To balance time constraints, and accuracy of data produced, it was decided to test from three points, three times each. After testing the flow speed through the upper, lower, and central speeds, a CFM can be estimated.

3.3 Variable Frequency Drive

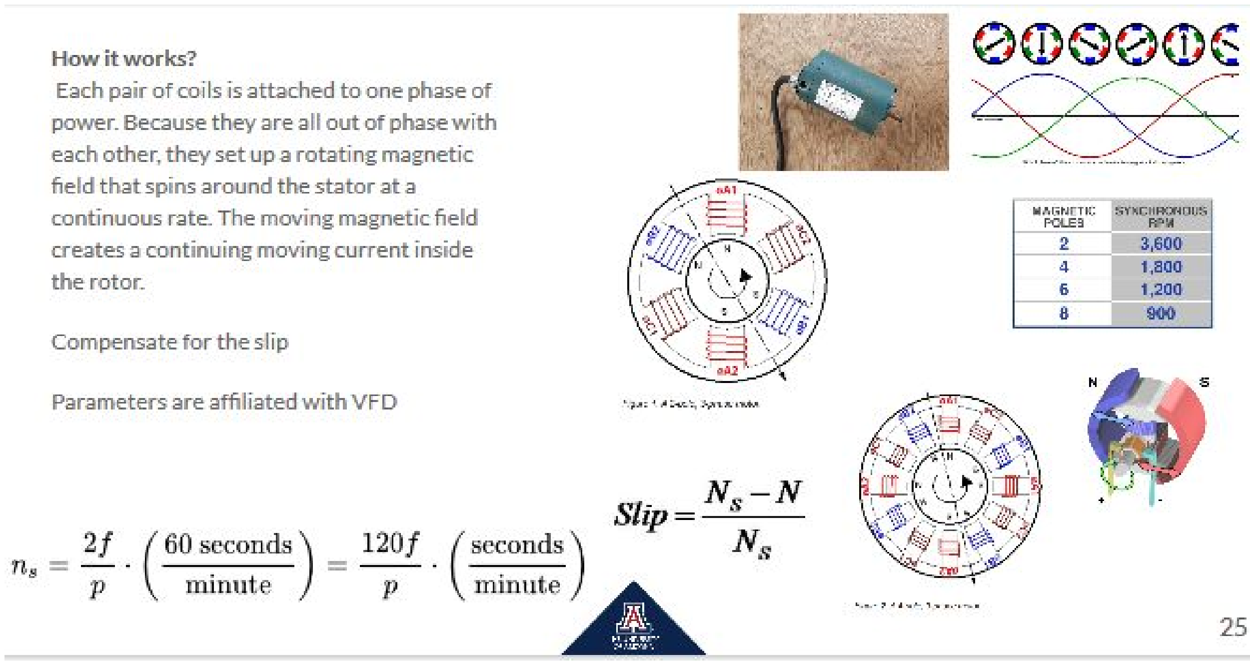
The Variable Frequency Drive (VFD) gave team Regenesis the flexibility to test at different frequencies while not having to worry about the change in current and voltage. This means that the VFD regulated its output in accordance to the 3 phase motor’s needs. Since the VFD manages to regulate frequency, amperage and voltage synchronously then this means it manages to put the 3 phase motor in less stress.



The usage of the Variable Frequency Drive made it a big contributor to our overall capstone project. It is because of the VFD that our prototype is able to perform better than a standard HVAC system.

3.4 Phase Inductance Motor

The 3 phase motor used is ideal for the purpose intended. The fact it's a 2 pole motor allowed it to output high RPMs at low frequencies. Even though it sacrificed torque in the process this still had little effect on the efficiency considering the 3 phase motor is equipped with a lighter and a more propellant fan than the ones found on standard systems. The retrofitted driving fan creates a more direct, powerful airflow to the recapture fan, which is exactly what is needed to propel the recapture fan. Since the 3 phase motor only needs to move air from A to B it allows for a consistent airflow, hence making the VFD output to the 3 phase motor more uniform and accurate.



The performance output by the 3 phase motor showed to be flexible, responsive, and rugged it is very well orchestrated to the VFD hence it outputted great results while not even reaching ½ of its potential in power output and not even a ⅓ of its potential in RPM.

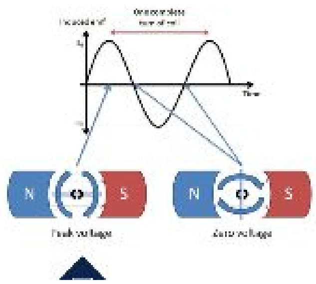
3.5 Generator

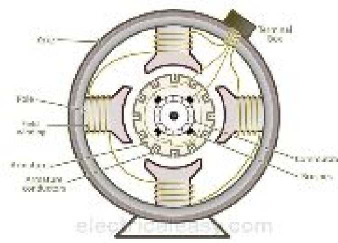
The Generator attached to the recapture fan is a 24 Volt, 12 Pole AC output generator. The fact that the generator is concealed and connected directly to the recapture fan gives less friction and more stability to handle the high RPMs.

How it works?
The Electric Generator converts mechanical energy obtained from an external source into electrical energy as the output. It uses the mechanical energy supplied to it to force the movement of electric charges present in the wire of its windings through an external electric circuit.

Voltage: 12 pole 24V AC Generator

Parameters are affiliated with Charge Controller





The domino effect initiated from the driving fan to the airflow and on to propel the recapture fan gave the generator its RPMs. Since it is a 12 pole generator this allowed it to output high frequencies because $f = \frac{RPM * \# \, of \, Poles}{2 * 60 \, min}$. Hence, the output from the generator gave a higher Root Mean Square (RMS) current output into the charge controller. It is important to note, the 24V generator used will not be the official generator for Regenesis, as this is a prototype. During the engineering phase, the generator will be optimized to best fit the Regenesis system.

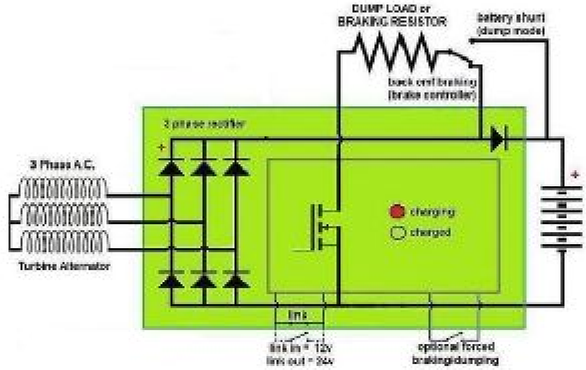
3.6 Charge Controller and Battery

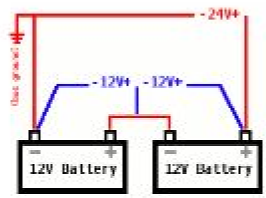
Since our storage requires a Direct Current it is necessary to not only to use a charge controller but also an AC to DC converter. This is where we bundled both the charge controller and battery in order to take in the power output of the generator and regulate the charge going into the battery. Similar to the VFD, the charge controller uses the diode bridge rectifier to take the currents RMS and output the wattage on its display.

How it works?

AC Current is supplied into the main intake which is first taken through a bridge rectifier which converts the 3 phase voltage to to a DC voltage. Now the charge controller can use it to charge the load at the output.

Compensate for the slip





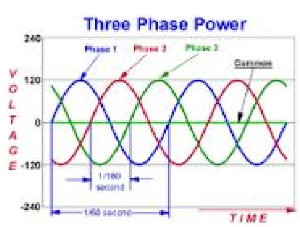
On multiple occasions the charge controller stopped the surge to charge the battery then moved back to charging status once the current was good to go on to the battery. Therefore the charge controller showed it compelled to safeguarding the battery and displaying the output efficiency.

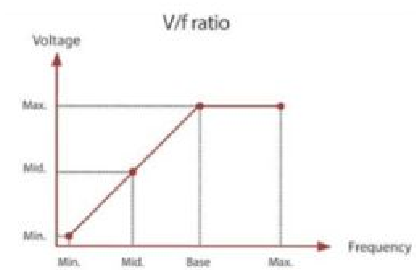
3.7 VFD and Motor Test Method

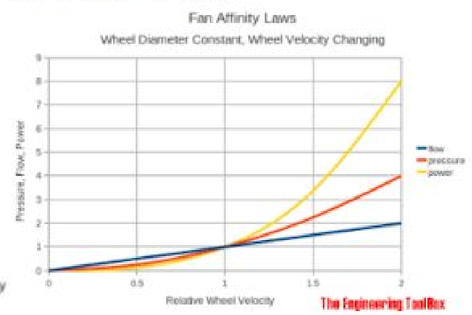
In order to get more accurate data team Regenesis not only decided to split the multiple test procedures, but also to take into consideration multiple components as a unit. Hence, the VFD and motor were tested in unison because of their well ability to work together. This meant that this unit alone took into consideration power consumption from the VFD to the Motor, RPM readings and airflow of the driving fan.

Procedure
A Multimeter will be collecting the data coming out of the 3-phase 250v outlet and into the VFD. Another multimeter will be collecting data coming out of the VFD and into our 3 phase induction motor. The Delta of the VFD will be obtained and compared with the airflow efficiency.

Expected Output
The VFD will put the motor more at ease hence resulting in less power intake from the grid.







At the end this allowed team Regenesis to take one reading for power rpm and airflow all while allowing to make the bridge between the propellant airflow to the recapture fan.

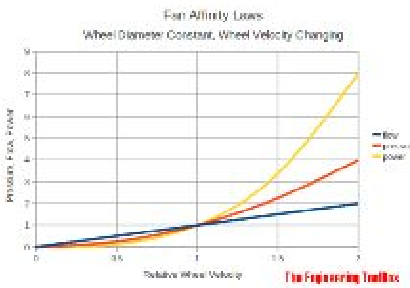
3.8 Generator and Charge Controller Test Method

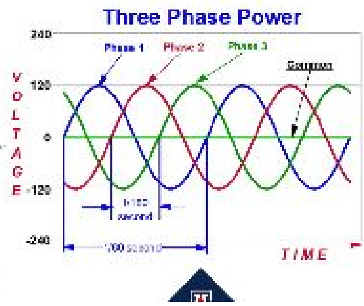
Taking into consideration the 4th test configuration is where Team Regenesis saw the contribution of both the Generator and Charge Controller made to the prototype. Similar to the VFD and Motor Team Regenesis only had to take one reading for power while charging the power storage device. This was due to the precision that the charge controller has. The charge controller's internal components calculate the output current and voltage drop off the 2 nodes, hence giving us our power output in watts.

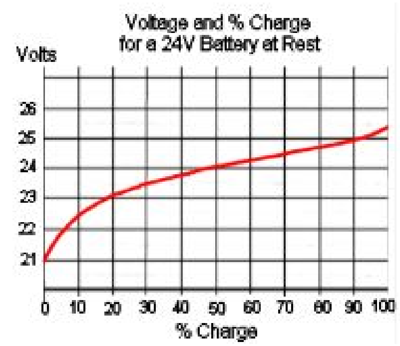
Procedure

An RPM reading of the recapture blade is made in order to calculate and compare the generators output power. This is now the input that is taken in by the charge controller. A similar procedure will be conducted to that of the VFD, although now we are going to end up with a DC Voltage output. The difference off the input and output of the charge controller will be taken into account and will be considered as that being dissipated into the dump load resistor.

Expected Output



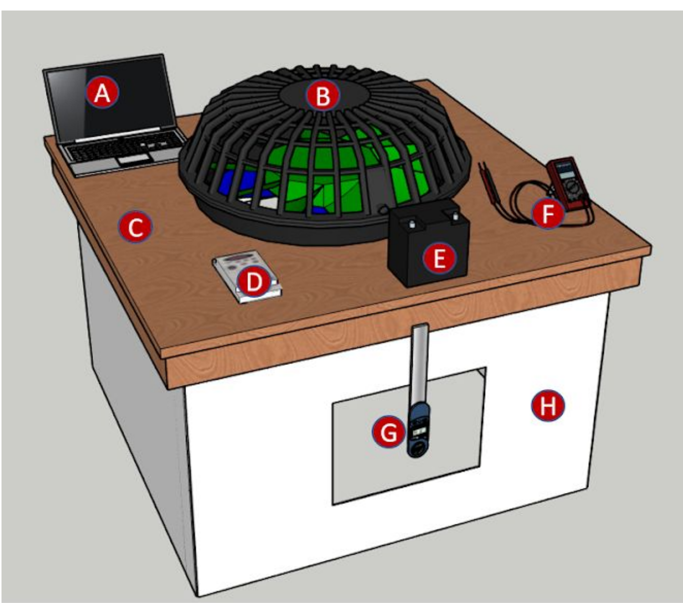




Regardless of the change of resistance from the battery as it was charged the charge controller gave promising results and regulated its power output in accordance to what the battery was able to handle.

4.0 Acceptance Test Procedure

4.0.1: General experimental test setup



A) Laptop

B) Regenesis System

C) 4ft x 4ft wooden table

D) VFD

E) Battery

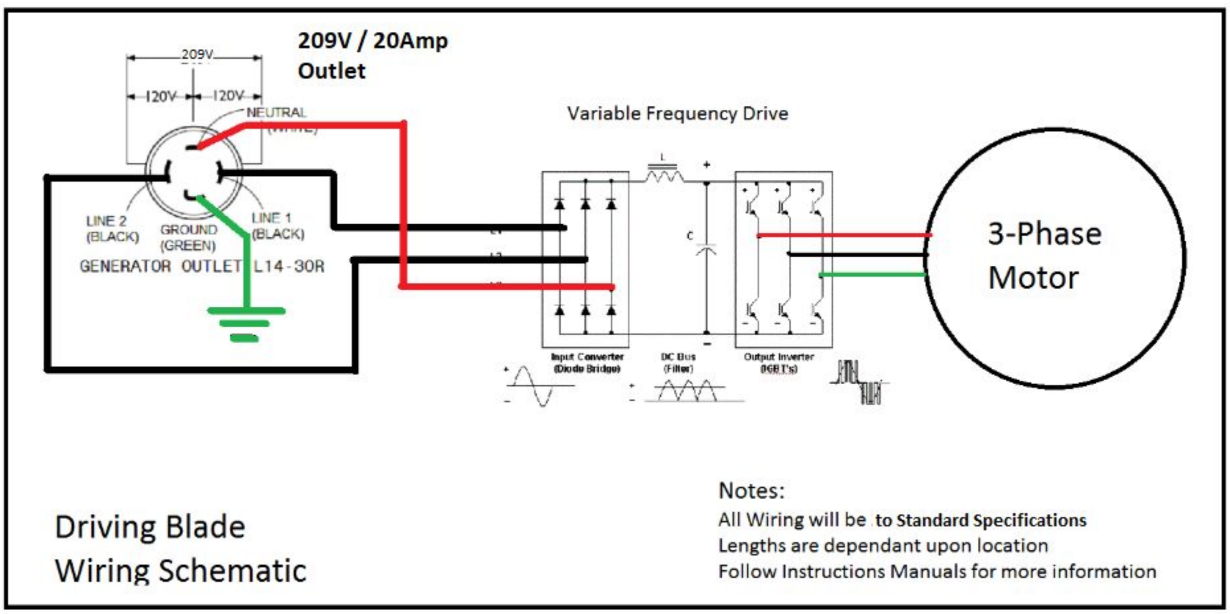
F) Multimeter

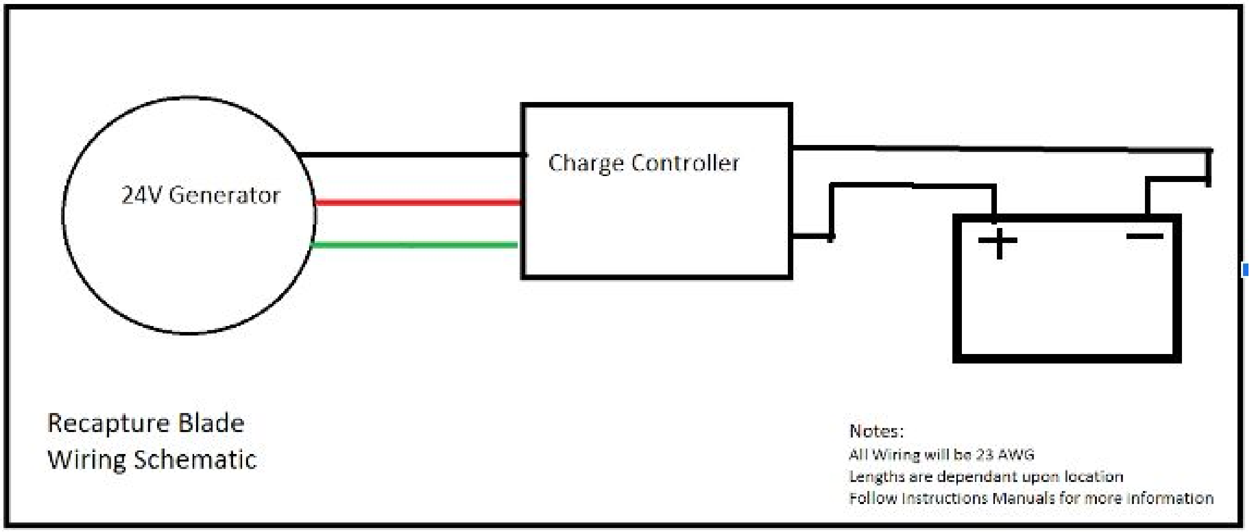
G) Anemometer

H) White cardboard

I) Tachometer

4.0.2 Wiring Schematics





4.0.3 Factors

For each acceptance test procedure listed below, there are a few factors or variables we changed. The two factors are the frequencies regulated by the VFD and fan configuration. The VFD frequency changes the speed of the driving fan. Since the frequency correlates to the speed of the driving fan, we were able to select the frequency range based off our desired RPM range. To obtain a RPM range of 750-1200 RPMs, we selected a VFD frequency range of 15-27 Hz. The fan configuration factor is split up into four cases. The fan configurations are; driving fan only, stationary recapture fan, freespin recapture fan, and with load configuration. Each acceptance test procedure is completed with the two above mentioned factors.

4.1.0 Acceptance Test Procedure for RPM Relationship

4.1.1 RPM Relationship Acceptance Test 4.1.2 Introduction: This procedure outlines the acceptance test to be performed on the mechanical interface which consists of the RPM relationship. This test verifies the RPM

relationship between the driving and the recapture fan. Finding this relationship will help us show the effect the recapture fan has on the driving fan.

4.1.3 Referenced Documents: RS System Requirement Document, 10/02/18

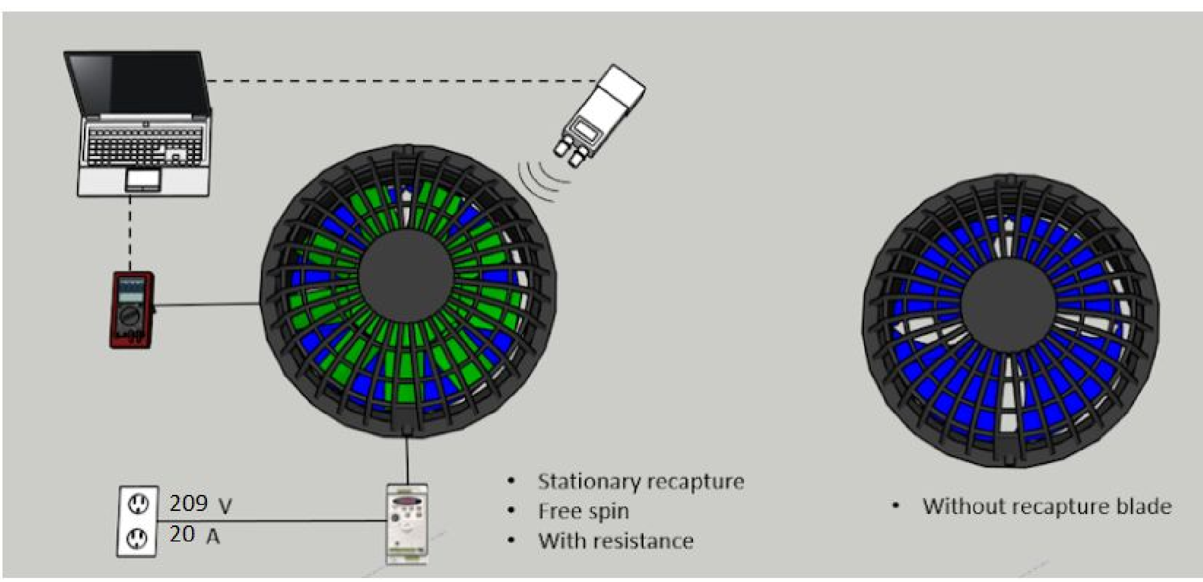
4.1.4 Required test equipment: The list of required test equipment includes:

Description	Model Number	Accuracy
Tachometer	6206-010	±0.002%
Regenesis System	N/A	N/A
VFD	ESV251N01SXB	N/A

4.1.5 Table of Tests:

Test#	Test	Requirement
4.1.1	RPM’s	RPM ratio of the driving and recapture fan

4.1.6 Step-by-step Procedure:



a.) Turn on VFD to begin driving fan.

b.) Measure the humidity, dry-bulb, and wet-bulb of the room.

c.) Adjust fan configuration, and set frequency with lower levels to begin.

d.) Use the laser tachometer to measure the RPM of the driving fan and the recapture fan.

e.) Record RPMs onto spreadsheet.

f.) Adjust the frequency level while keeping the fan the same configuration.

g.) Measure and record the RPMs of the driving and recapture fan. Repeat at the next frequency levels.

h.) Repeat steps f.) and g.) for each frequency (15, 17, 19, 21, 23, 25, and 27 Hz).

4.1.7 Support Requirements

The test shall be conducted in a controlled environment (which is the AME machine shop) and the stationary distance between two fans.

4.2.0 Acceptance Test Procedure for Air Flow Efficiency

4.2.1 Air Flow Efficiency Acceptance Test

4.2.2 Introduction: This procedure is to test the efficiency of airflow as the fan and motor configurations change. This test will verify the loss of airflow at different frequencies and fan configurations. The comparison of those results will let us know the efficiency of airflow of this system.

4.2.3 Referenced Documents: RS System Requirement Document, 10/02/18

4.2.4 Required test equipment: The list of required test equipment includes:

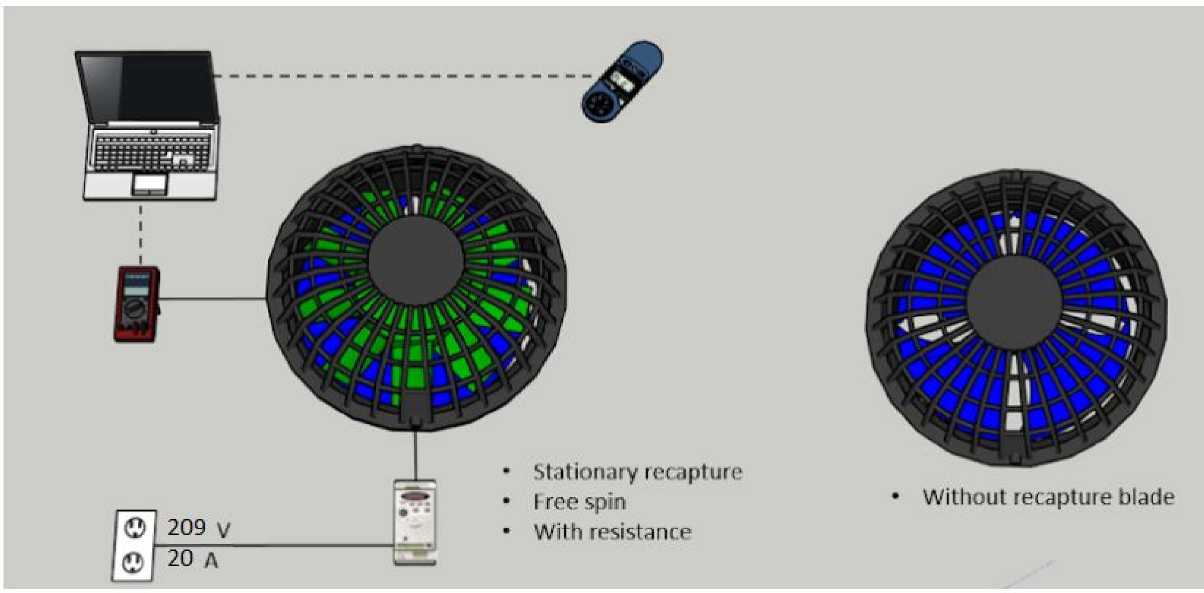
Description	Model Number	Accuracy
Anemometer	DAFM3B	±5%
Regenesis System	N/A	N/A

VFD	ESV251N01SXB	N/A
Table and Plastic setup	N/A	N/A

4.2.5 Table of Tests:

Test #	Test	Requirement
4.2.1	Airflow efficiency	Minimum loss of airflow

4.2.6 Step-by-step Procedure:



a.) Turn on VFD to begin driving fan.

b.) Measure the humidity, dry-bulb, and wet-bulb of the room.

c.) Adjust fan configuration, and frequency to lower levels to begin.

d.) Use two anemometers to measure the air velocity at top, middle, and bottom of square intake-duct of two sides. Record this using a spreadsheet.

e.) Adjust the frequency level while keeping the same fan configuration. Wait 60 seconds before recording new airflow.

f.) Repeat steps d.) and e.) for each frequency (15, 17, 19, 21, 23, 25, and 27 Hz).

g.) Reset to 15Hz, wait 90 seconds for motor to cool down, and record a second/third set of data.
h.) Repeat steps f.) and g.) for each configuration.

4.2.7 Support Requirements
The test shall be conducted in a controlled environment (which is the AME machine shop) and the stationary distance between two fans.

4.3.0 Acceptance Test Procedure for Overall Efficiency

4.3.1 Overall Efficiency Acceptance Test

4.3.2 Introduction: The purpose of this procedure is to find the overall efficiency of the recapture system by comparing the input and output power. By doing so, we can find out the total power loss and total power captured during the operation so that future test can work on higher efficiency based on our data of efficiency.

4.3.3 Referenced Documents: RS System Requirement Document, 10/02/18

4.3.4 Required test equipment: The list of required test equipment includes:

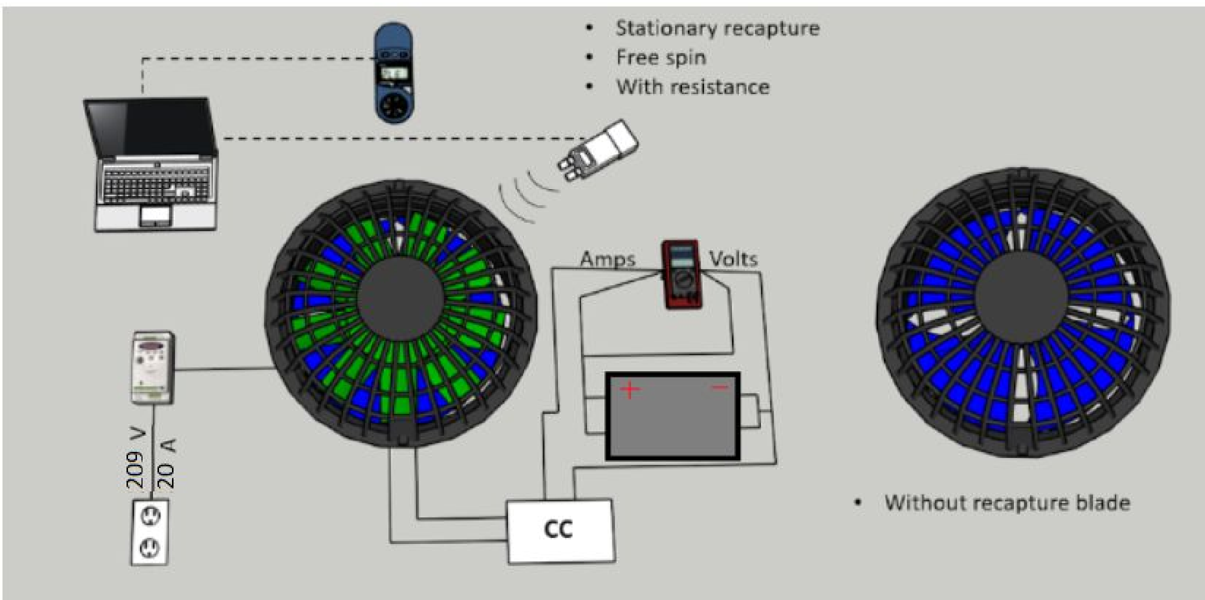
Description	Model Number	Accuracy
Anemometer	DAFM3B	±5%
Tachometer	6206-010	±0.002%
Regenesis System	N/A	N/A
VFD	ESV251N01SXB	N/A
Table and Plastic setup	N/A	N/A
Charge controller	N/A	±0.005%

Battery	JIANXIN-09-13-310-25-02	N/A
Multimeter	2737460	±0.005%

4.3.5 Table of Tests:

Test #	Test	Requirement
4.3.1	Overall efficiency	Minimum loss of power

4.3.6 Step-by-step Procedure:



a.) Turn on VFD to begin driving fan. Adjust frequency to lower settings to begin.

b.) Adjust frequency into setting values and keep it constant for the same fan configuration.

c.) Maintain voltage this is required to maintain current RPM and keep the voltage regulated by the VFD in the following step g.)

d.) Allow driving motor to warm up, and set up in one level of fan figuration.

e.) Connect the generator to the charge controller

f.) Connect the charge controller to a Battery.

g.) Run the system while putting one multimeter for measuring the voltage and the other multimeter measuring current input between power input and VFD. Then, put the rest multimeters between charge controller and Battery.

h.) Read the multimeters and calculate the energy efficiency. i.) Record data in datasheet. j.) Drain Battery if needed for next test run k.) Run the system with the regulated voltage level and repeat steps c.) through j.) 4.3.7 Support Requirements The test shall be conducted in a controlled environment (which is the AME machine shop) and the stationary distance between two fans.

5.0 Models / Analyses

5.1.0: Analyses

The Three experiments we ran as a team are RPM relationship test, Airflow efficiency and the overall efficiency of the Regenesis system. The data collected from these experiments includes RPMs, air velocity, input current, input voltage and output power. All other data shown is calculated using the measured values.

5.1.1: RPM Relationship Test Analysis

The RPM relationship test measures the relationship between the driving fan and recapture fan in the freespin and load configurations. RPMs of the driving fan were collected for each configuration, however RPMs of the recapture fan were only collected during the freespin and with load configurations. The range for RPMs shown in Figure 5.1 is 735-1190 RPMs. Throughout the four configurations, the RPMs of the driving fan stayed fairly consistent at each frequency. This tells us, the driving fans speed is affected very little when the recapture fan is in place. The RPMs of the recapture fan span from 127-401 RPMs throughout the two configurations shown in Figure 5.2. The RPMs are not consistent throughout the two configurations for the recapture fan.

RPMS of Driving Fan				
Frequency [Hz]	Driving Fan Only	Stationary Recapture	Freespin Recapture	With Load
15	752	754	759.9	735
17	835.75	857	838.4	798
19	913.75	956	925	875
21	992	1024	971	940
23	1061	1113	1037	1025
25	1122.5	1155	1074	1102
27	1127.1	1190	1115	1181

Figure 5.1-Driving Fan RPMs

RPMS of Recapture Fan		
Frequency [Hz]	Freespin Recapture	With Load
15	255.3	127
17	290	132
19	323	134
21	355	135
23	380	139
25	390	140
27	401	143

Figure 5.2-Driving Fan RPMs

After compiling all the RPM data, the RPM relationship between the driving and recapture fan was found using a ratio.

RPM ratio:

$$RPM\ Ratio = \frac{Recapture\ Fan\ RPM}{Driving\ Fan\ RPM} \quad (1)$$

5.1.2 Airflow Efficiency Test Analysis

The airflow efficiency test measures the loss or gain of airflow during the four fan configurations at different motor frequencies. Air velocity was measured directly on the top, middle and bottom of the square duct for both ducts. This process was done three times. For example, there were three takes for the high, then another three takes for the middle and then another three takes for the bottom. To get an approximate airflow reading in cubic feet per minute (CFM), the air velocity was multiplied by the area of the duct. This is not an exact airflow measurement but an approximation. As shown in Figure 5.3, the team measured air velocity three times at the top of the duct, middle and low for each frequency. West denotes the side that the duct is on. The sample template shows air velocities only from the West duct.

Free Spin									
Air Velocity [ft/min]	West								
Hz	High			Mid			Low		
15	885	866.1	826.8	629.9	669.3	649.6	728.3	787	807
17	905.5	925	866.1	728.3	787	767	807.1	787	807
19	984	1003.9	866	787	807	826	885	866	885.8
21	1003.9	1082.7	1003.9	846.5	905.5	846.5	946.5	905.5	866.1
23	1102.4	1043.3	1023.6	885.8	866.1	885.8	925.2	944.9	964.6
25	1102.4	1200.8	1141.7	964.6	984.3	905.5	925.2	944.9	1043.3
27	1102.4	1200.8	1220.5	984.3	1003.9	984.3	1063	1003.9	1023.6

Figure 5.3-Sample Air Velocity Template

West				East					West	East	Total
Avg High	Avg Mid	Avg Low	Total Avg	Avg High	Avg Mid	Avg Low	Total Avg	**Total Velocity Avg**	Airflow	Airflow	**Airflow**
859.3	649.6	774.1	761	787.533333	734.866667	734.9	752.4333333	**756.7166667**	1693.225	1669.53971	**3362.76471**
898.866667	760.766667	800.366667	820	966.133333	793.966667	833.366667	864.4888889	**842.2444444**	1824.5	1918.17463	**3742.67463**
951.3	806.666667	878.933333	878.966667	958	839.933333	885.8	894.5777778	**886.7722222**	1955.70083	1984.93748	**3940.63831**
1030.16667	866.166667	906.033333	934.122222	1049.86667	872.666667	925.2	949.2444444	**941.6833333**	2078.42194	2106.23483	**4184.65678**
1056.43333	879.233333	944.9	960.188889	1082.66667	866.166667	977.7	975.5111111	**967.85**	2136.42028	2164.51673	**4300.93701**
1148.3	951.466667	971.133333	1023.63333	1174.56667	944.9	1036.73333	1052.066667	**1037.85**	2277.58417	2334.38233	**4611.9665**
1174.56667	990.833333	1030.16667	1065.18889	1135.16667	984.266667	1017.03333	1045.488889	**1055.338889**	2370.04528	2319.7872	**4689.83248**

Figure 5.4-Sample AirFlow Template for Freespin Configuration

To obtain higher accuracy, a total average is calculated. We averaged each high, mid, and low air velocities for each duct at each frequency. The process to obtain an approximate air flow was more tedious. First, an average high, mid, and low for each duct were found. Second, we summed the aforementioned averages and multiplied them by a third of the area. After obtaining an airflow calculation for each duct, we summed the airflows together to obtain a total approximate airflow measurement at each frequency.

Airflow Equation:

$$West\ Duct\ Area = 2.225\ ft^2$$

$$East\ Duct\ Area = 2.2188\ ft^2$$

$$Total\ Airflow\ (CFM) = \frac{1}{3}A * V_{high,\,avg} + \frac{1}{3}A * V_{mid,\,avg} + \frac{1}{3}A * V_{low,\,avg}$$

$$= \frac{1}{3}A * (V_{high,\,avg} + V_{mid,\,avg} + V_{low,\,avg}) \quad (2)$$

Where,

$V_{high, avg}$, $V_{mid, avg}$, and $V_{low, avg}$ denote air velocities at top, middle and bottom of duct. A represents the duct area.

5.1.3 Overall Efficiency Test Analysis

The overall efficiency test represents the total power recaptured and efficiency of the Regenesis system. The parameters measured directly for this experiment are the input current, input voltage of VFD and output power. The input current was measured using a clamp multimeter which measured current by inductance, and the input voltage was measured off the VFD using a separate multimeter. The output power was measured straight from the charge controller in Watts. Shown below in Figure 5.5 is a sample template of the input power measured. Figure 5.6, shows the output power. The output power was only computed during the load configuration.

Driving Blade Only			
Frequency [Hz]	Current [Amps]	Volts	Power [Watts]
15	0.2	101.2	20.24
16	0.3	104.7	31.41
17	0.4	108.5	43.4
18	0.5	112.2	56.1
19	0.9	115.2	103.68
20	1	120.1	120.1
21	1.3	123.7	160.81
22	1.7	126.5	215.05
23	2	130.4	260.8
24	2.2	134	294.8
25	2.7	137.9	372.33
26	2.9	141.2	409.48
27	3	145	435

Figure 5.5-Sample Input Power Template for Driving Fan Only Configuration

Output Power [Watts]	
15 Hz	8.2
17 Hz	9.3
19 Hz	9.7
21 Hz	11.1
23 Hz	11.75
25 Hz	12.4
27 Hz	13.1

Figure 5.6-Output Power for Load Configuration

Efficiency Equation:

$$Power\ Recaptured\ efficiency = \eta = \frac{Output\ Power}{Input\ Power} \quad (3)$$

Note, we did not include the input power saved (which is a significant input power drop of VFD) due to loaded recapture fan on the system into our calculation. The input power saved is the difference in input power from the driving fan alone configuration and with load configuration. Including the input power saved, the equation would be.

$$Power\ Recaptured\ efficiency = \eta = \frac{Output\ Power + Input\ Power\ Saved}{Input\ Power} \quad (4)$$

The system has higher efficiency of power usage once considering power saved situation.

5.2.0 Data Sheets

5.2.1 RPM Relationship Acceptance Test Data Sheet

Refer to the Appendix for the RPM Relationship raw data.

Regenesis System Acceptance Test Data Sheet	
Reference ATP paragraph number: 5.2.1.1	
Analysis Reference (for verification by T/A): ---	
Name of Test: RPM Relationship Acceptance Test (four configurations with 15, 17, 19, 21, 23, 25, and 27 hz)	
Unit Under Test: Rotation of blades per minute (RPM) Name: Regenesis System Part Number: N/A Serial Number: N/A	
The result (Pass/Fail): Pass	Date of Test:4/1/2019 - 4/23/2019

Recording of Test Measurement:	Requirement (SRD with tolerances):	Test Equipment Error:	Adjusted Test Limit:
Minimum RPMs of Driving fan =	>800 RPMs	+/- 5% RPMs	>760 RPMs
Maximum RPMs of Driving fan =	<1200 RPMs	+/- 5% RPMs	<1260 RPMs
Minimum RPMs of Recapture fan =	>300 RPMs	+/- 5% RPMs	>285 RPMs
Maximum RPMs of Recapture fan =	<600 RPMs	+/- 5% RPMs	<630 RPMs

Analysis results and computation:

The minimum RPM of driving fan appears in load configuration at 15 hz with 735 rpms which is 3.29% lower than adjusted test limit.

The maximum RPM of driving fan appears at the stationary recapture fan configuration at 27 hz with 1190 rpms which is 5.56% lower than adjusted test limit.

The minimum RPM of recapture fan appears in load configuration at 15 hz with 127 rpms which is 55% lower than adjusted test limit. The error is large due to the load put on the recapture fan while the test limit is not considering this condition, and therefore, this error is under acceptable range.

The maximum RPM of recapture fan appears in free spin configuration at 27 hz with 401 rpms which is inside the test limit.

Signatures:

Tester ____________________

Customer__________________

5.2.2 Airflow Efficiency Acceptance Test Data Sheet

Refer to the Appendix for the Airflow Efficiency Test raw data.

Regenesis System Acceptance Test Data Sheet			
Reference ATP paragraph number: 5.2.2.0			
Analysis Reference (for verification by T/A): ---			
Name of Test: Airflow Efficiency Acceptance Test			
Unit Under Test: Name: Regenesis System Part Number: N/A Serial Number: N/A			
The result (Pass/Fail): Pass		Date of Test: 3/11/2019 - 4/21/2019	
Recording of Test Measurement:	Requirement (SRD with tolerances):	Test Equipment Error plus error due to environment:	Adjusted Test Limit:
Air Flow of driving fan =	-Dependent upon RPMs and humidity	+/- 5% error	N/A
Air Flow of recapture fan=	- Dependent upon RPMs and humidity	+/- 5% error	N/A

Analysis results and computation:
Signatures: Tester ____________________ Customer__________________

5.2.3 Overall Efficiency Acceptance Test Data Sheet

Refer to the Appendix for the Power Efficiency raw data.

Regenesis System Acceptance Test Data Sheet			
Reference ATP paragraph number: 5.2.3.0			
Analysis Reference (for verification by T/A): ---			
Name of Test: Overall Efficiency Acceptance Test			
Unit Under Test: Name: Regenesis System Part Number: N/A Serial Number: N/A			
The result (Pass/Fail): N/A		Date of Test: 3/15/2019	
Recording of Test	Requirement (SRD	Test Equipment	Adjusted Test Limit:

Measurement:	with tolerances):	Error:	
Input max amperage=	<1.77 A	±2.0% A	<1.80 A
Input Voltage=	~105 V	±1.1%	> 90.7 V; < 209V
Output wattage =	N/A		
Analysis results and computation: The maximum overall efficiency is from frequency 19 to 21 hz around 12%.			
Signatures: Tester ____________________ Customer__________________			

6.0 Acceptance Test Results

6.1.0 RPM Relationship Test Results

As mentioned before, RPM relationship test was only conducted during the freespin recapture fan and with load configurations. This is because these are the only two configurations that the recapture fan is in motion. The following results show the two separate ratios on the same plot. The plot is recapture fan rotations by driving fan rotations. Since the trend is linear it is clear the recapture and driving fans have a linear relationship. As the driving fan speed increases, so does the recapture fan.

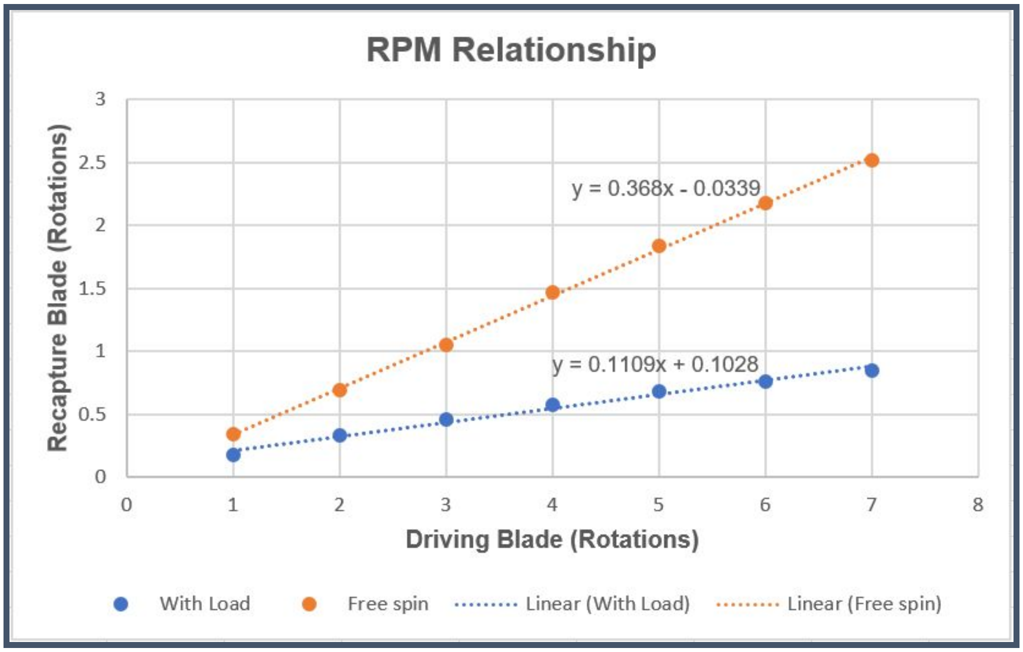


Figure 6.1-RPM Relationship Results

Free Spin RPM Ratio:

$$\frac{Recapture\ Blade\ RPM}{Driving\ Blade\ RPM} \approx 0.37$$

With Load RPM Ratio:

$$\frac{Recapture\ Blade\ RPM}{Driving\ Blade\ RPM} \approx 0.11$$

The ratios are shown by the slope. For example, the ratio for the freespin configuration is 0.368 and 0.1109 for the with load configuration. This means when the Regenesis system is in the freespin configuration, everytime the driving fan rotates once the recapture fan rotates 0.368 times. As you can see, once a load is attached the recapture fan speed is significantly changed. The load does seem to slow the recapture fan down. However, the recapture fans speed does not affect the driving fans speed, nor does the load. The speed of the driving fan stay consistent throughout the four configurations.

6.2.0 Airflow Efficiency Test Results

The idea of the airflow efficiency test was to determine a change in airflow at each of the four fan configurations. We also looked to determine how much airflow is produced in relation to the power it took to generate it. The first plot shown in Figure 6.2 is Airflow vs. RPMs. Each fan configuration is denoted by a different colored line. From this plot, we observed the driving fan only configuration generates the most airflow at each RPM with freespin next, then with load and lastly stationary. However, all four configurations are within a 1,000 CFM range of each other. The expected result from this test was that with the load configurations airflow would be very similar to the driving fan only configurations airflow. Although this is not the case, the airflow does not have a significant drop. After plotting this graph we wanted to compare the airflow and input power at each RPM. This is shown in Figure 6.3.

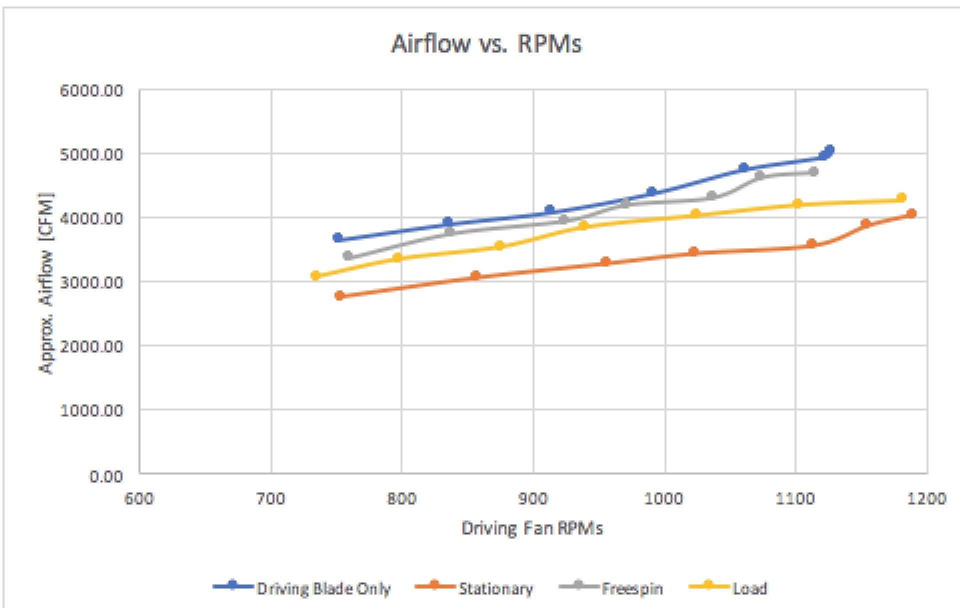


Figure 6.2-Airflow vs. RPMs

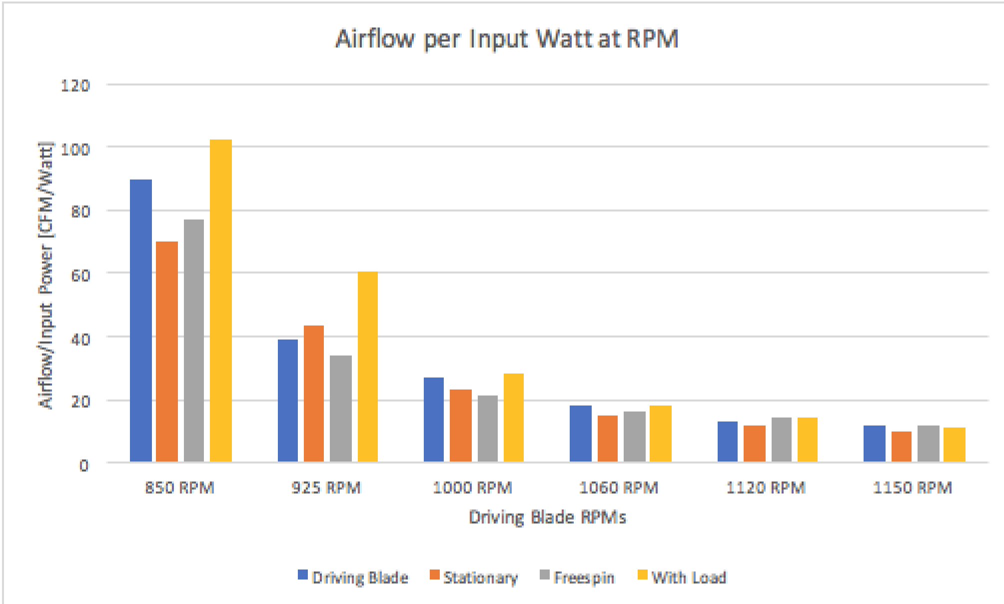


Figure 6.3-Airflow Efficiency

Figure 6.3 shows the amount of CFM/(Unit Input Watt) at specific RPMs. This plot is important because it tells us when there is a load attached, the system creates the most airflow per unit watt than the other three configurations. In Figure 6.2, we saw there is a drop in airflow between the driving fan only configuration and the with load configuration. However, this bar graph accounts for the input power that is used to produce the airflow. Having more airflow generated while using less input power to produce it is significant. It is significant because input watts is what you pay for. As you can see, as RPMs increase further than 1000 RPM, CFM/(Unit Watt) starts to stabilize off between the four configurations. However, during the RPMs of 850-1000 RPMs, with load configuration is where there is the most airflow efficient. Typical HVAC exhaust fans run around these speeds and that is when the Regenesis system is most efficient. The Regenesis system produces more airflow with less power Hence with less money.

6.3.0 Overall Efficiency Test Results

The overall efficiency test results includes the input current and voltage relationship hence the input power and also the output power relationship. The input current and voltage relationship, shown in Figure 6.4, is important because it shows us the amperage draw drop from the four different fan configurations. In the graph, the driving fan only configuration draws the most current at any given voltage. When the recapture fan is placed on the system stationary, the amperage drops. When the recapture fan is allowed to freespin, the amperage rises up again to a similar value of the driving fan. Lastly, when a load is attached the amperage draws drops lower than the stationary configuration. The difference in amperage at a specific voltage between the driving fan only configuration and the with load configuration is the savings in power. The savings in power is key because it takes less input power when the Regenesis system is in place attached to a load. We observed on average, the amperage drops about a third of an amp from the driving fan alone configuration to the load configuration. This observation was particularly interesting to us, as a third of an amp can significantly change the input power thus, saving power and money.

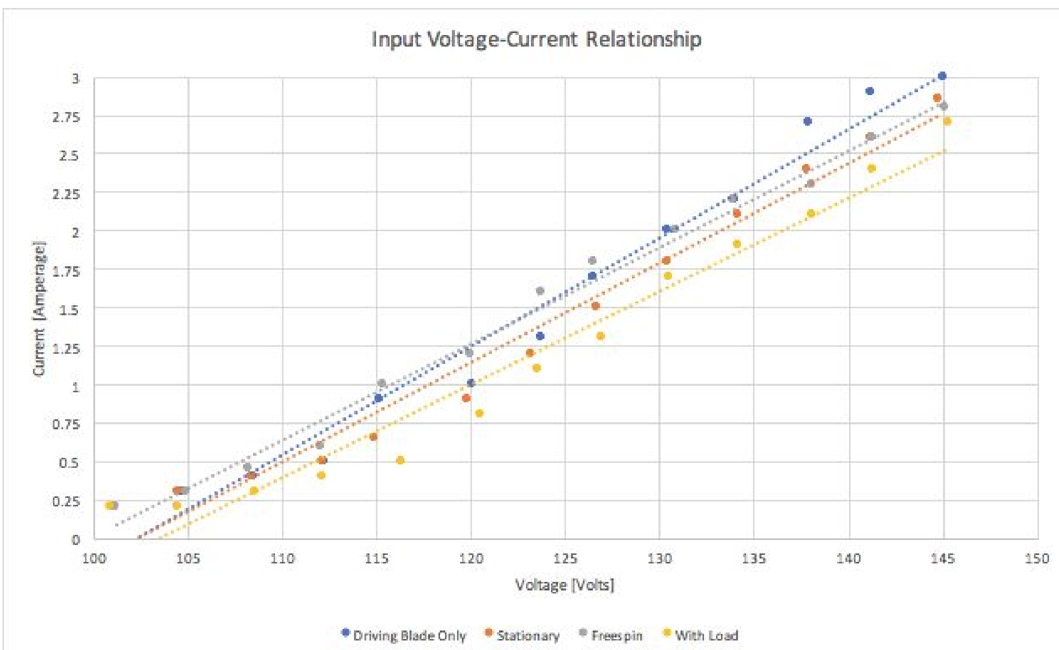


Figure 6.4-Input Voltage-Current Relationship

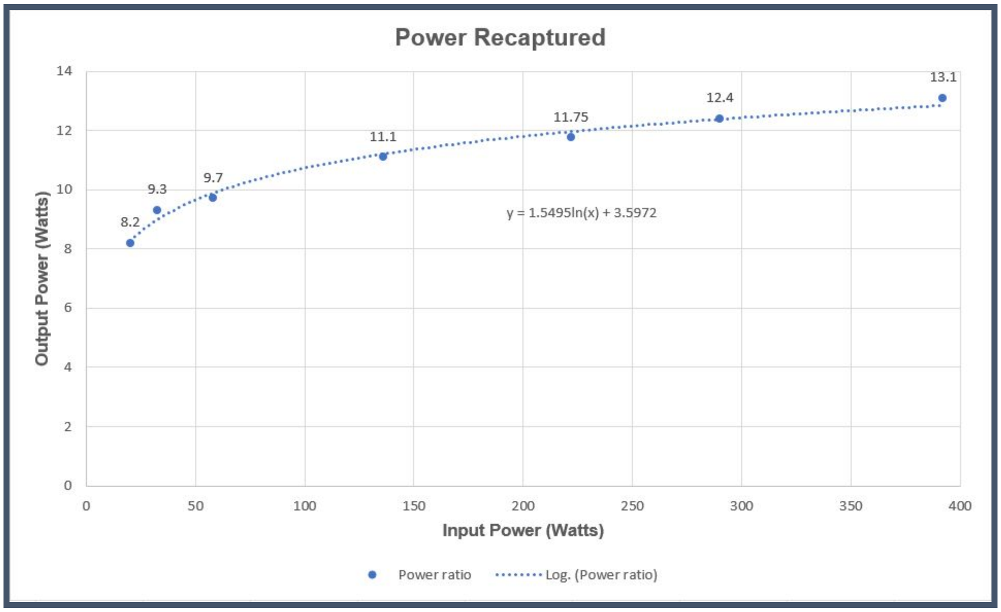


Figure 6.5-Power Recaptured

When calculating the percentage of power recaptured, the power savings was not included in our calculation. We only included input power and output power into our calculations. Figure 6.5 shows the relationship between the output power and input power. Lower input power does correspond to lower RPMs. The system is most efficient at lower RPMs and decreases logarithmically until plateauing at higher RPMs. The values we are interested in are the input powers that correspond to the 800-1000 RPM range because these are the speeds of a typical HVAC exhaust fan. The system recaptures 29% of the power at 800 RPMs, 17% at 875 RPMs, 12% at 900 RPMs, and 5% at 1025 RPMs. Although the power recaptured ranges from 5% to 29% within this RPM range, there is a point for optimization. It is also important to note, the power saved was not included into the calculation. Including the power saved would increase these percentages. Overall, the ideal configurations to optimize the Regenesis system with the data we collected would be to run the system at 900 RPMs. At 900 RPMs, the Regenesis system is the most airflow efficient, power efficient and recollects 12% of the input power.

6.4.0 Additional Testing with Stock Fan

6.4.1 Introduction

The purpose of testing with the stock fan is to obtain a performance comparison between the stock fan and the blue retrofit fan. The same tests were conducted as before; airflow, RPMs, input and output power. A few modifications were made to account for the stock fan. We ranged the VFD frequency from 13-21 Hz to achieve a RPM range of 750-1200 RPM, Whereas we ranged the VFD frequency from 15-27 Hz to achieve the same RPM range when the blue driving fan was in place. Also the recapture fan was lowered in order to compensate the height difference between fans. Here the same four fan configurations were tested; driving fan only, stationary recapture fan, freespin recapture fan, and with load, were used. From testing, we observed the stock fan did not produce as much airflow as the blue driving fan. We also observed there to be less power recapture and no savings in input power when the stock fan is in place.

6.4.2 Results

The first test conducted was the airflow test. Along with measuring approximate airflow we also measured RPMs. In figure 6.6, the airflow and RPMs of the stock fan relationship is shown. It follows the same trend as the blue driving fan. The driving fan only configuration produces the most airflow and stationary produces the least amount of airflow. The one key and important difference however, is the stock fan produces on average of 1,000 CFM less than the blue driving fan. This shows the blue driving fan is more efficient than the stock fan when looking at production of airflow in CFM. It is in fact beneficial to retrofit the HVAC exhaust fans using the blue driving fan. It produces more airflow and also works in unison with the green recapture fan.

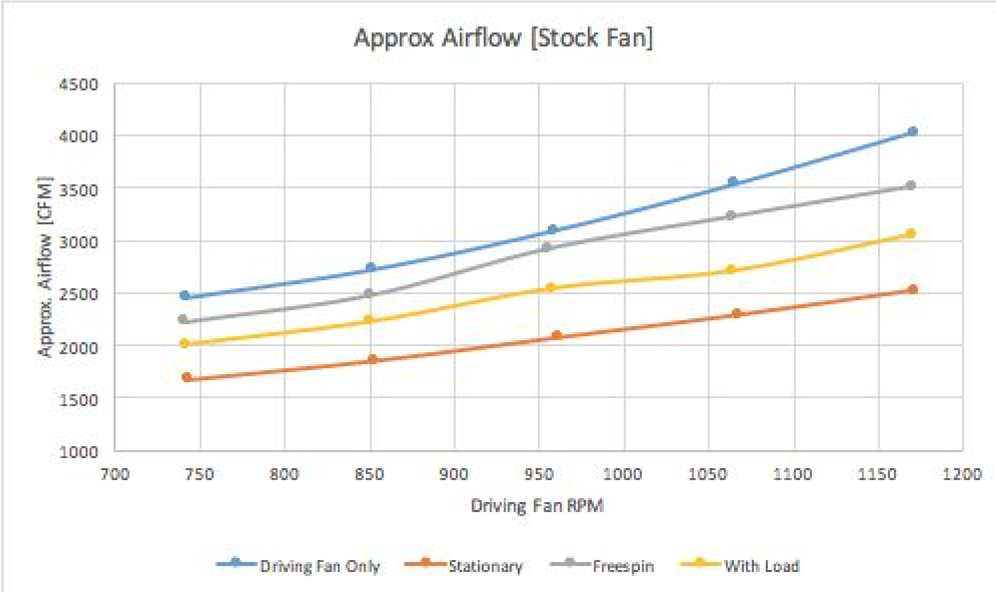


Figure 6.6-Approx. Airflow for Stock Fan

Another way we looked at airflow efficiency is comparing how much airflow is produced to the input power, this is shown as a bar graph in figure 6.7.

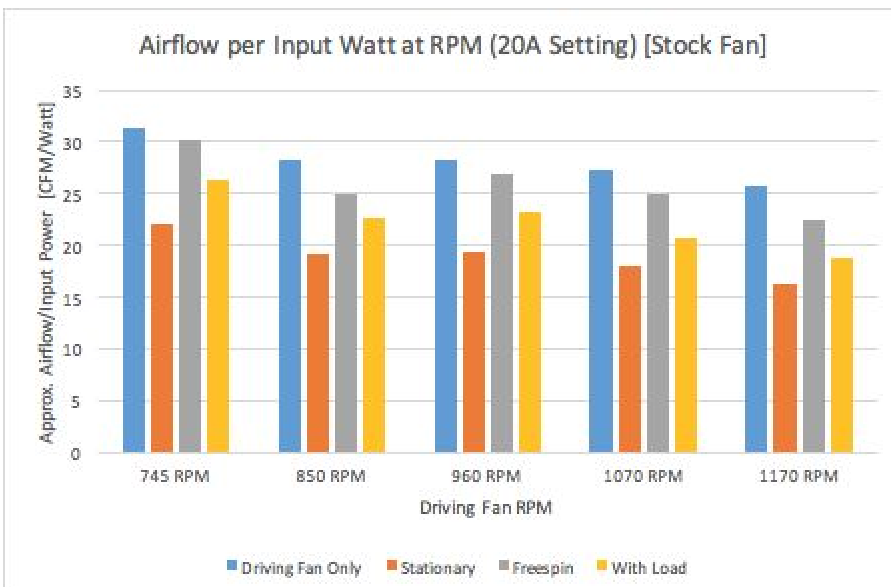


Figure 6.7-Airflow per Input Watt for Stock Fan

Looking at the bar graph, the stock fan only configuration produces the most airflow per unit input Watt than the other three fan configurations. For the blue driving fan, with the load configuration it created the most CFM/(Unit Watt). As RPMs increase, the CFM/(Unit Watt) decreases but not as much as it did for the blue driving fan. The key difference we observed is the blue driving fan produces much more airflow per unit input Watt than the stock fan does. For example, at 850 RPM, the driving fan produces 90 CFM/(Unit Watt) while the stock fan produces 27.5 CFM/(Unit Watt). This again shows the efficiency and benefits of the blue driving fan.

The last test we ran was measuring the input and output power. The input current and input voltage relationship is shown in figure 6.8.

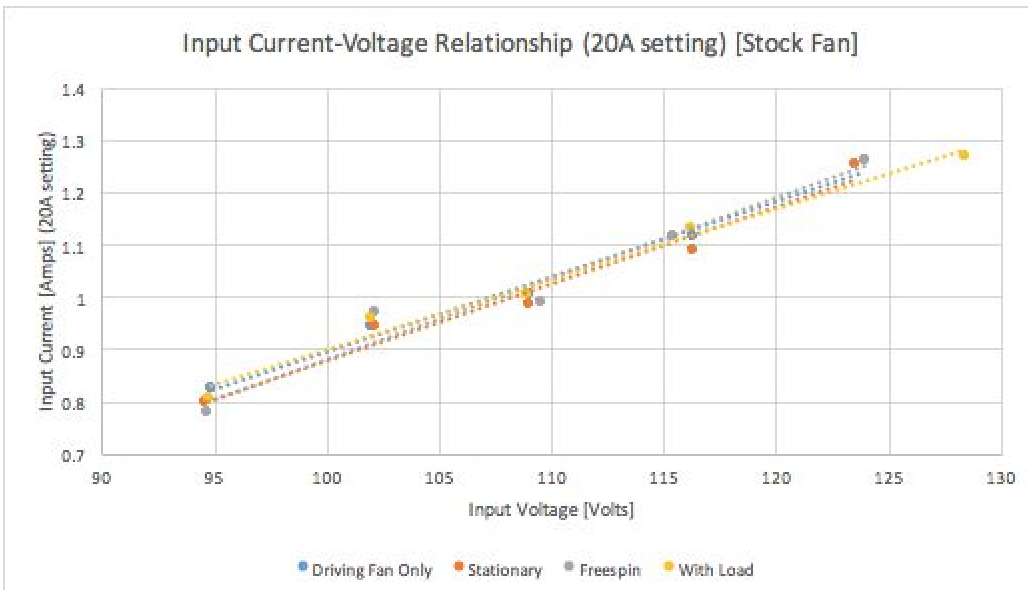


Figure 6.8-Input Current and Voltage for Stock Fan

Figure 6.8 shows the stock fan input power stays fairly consistent throughout the four fan configurations. Also the Airflow was so low at 13 Hz that the recapture blade was not able to rotate quick enough to output a reading on the charge controller this is not to mention that the RPM's were similar. Hence the blueblade outperformed the stock blade in the overall efficiency on the test. This concludes there is very little to none savings in power when the stock fan is in place.

7.0 Final Budget

Like most projects the intent to accomplish the task a certain way backfires once the hands on tasks initiate. This is has been the case team Regenesis since the start of this project. As shown a few of the components and parts purchased were not used because they turned out inadequate for the task, yet the team remained under 20% of the allowable budget.

#	Item Name	ID	Web Link	Expected USD	Quantity	Date proposed	Final Cost	Date purchased	Received
1	Digital Anemometer	DAFM3B	https://www.amazon.com/U	$197.95	1	12/1/2018	$209.04	1/18/2019	1/25/2019
2	25Ohm Resistor (x2)	JIANXIN-09-13-310-25-02	https://www.amazon.com/Cı	$6.99	2	12/1/2018	$7.38	1/18/2019	1/26/2019
3	Plastic Drop Cloth	P1250R	https://www.amazon.com/Fr	$10.98	1	11/17/2018	$11.59	1/18/2019	1/27/2019
4	L Brace pack (x4)	43398-26452	https://www.amazon.com/Bı	$11.99	1	12/1/2018	$12.66	1/18/2019	1/28/2019
5	Velcro	90277B	https://www.amazon.com/VI	$29.75	1	11/17/2018	$31.42	2/14/2019	2/21/2019
6	8" Ziptie (x100)	4332799364	https://www.amazon.com/M	$5.49	1	11/20/2018	$5.80	1/18/2019	1/25/2019
7	3/4 in. x 4 ft. x 8 ft. Sanded Plywood	100478798	https://www.homedepot.cor	$36.88	1	12/1/2018	$38.95	1/22/2019	1/29/2019
8	4'x4'x8' Lumber	54699255197	https://www.homedepot.cor	$9.57	2	12/1/2018	$10.11	1/22/2019	1/29/2019
9	2 in. x 4 in. x 8 ft. Lumber	202094172	https://www.homedepot.cor	$2.98	7	12/1/2018	$3.15	1/22/2019	1/29/2019
10	2-1/2 in. Construction Screw	207200494	https://www.homedepot.cor	$8.47	1	12/1/2018	$8.94	1/22/2019	1/29/2019
11	4 fl. oz. Wood Glue	306912991	https://www.homedepot.cor	$2.97	1	12/1/2018	$3.14	1/22/2019	1/29/2019
12	AmazonBasics USB 2.0 Cable	N/A	https://www.amazon.com/Aı	$5.49	1	1/20/2018	$5.80	1/24/2019	1/31/2019
13	Miscellaneous	N/A	https://www.amazon.com/Yı	$30.00	N/A	N/A	$31.68	1/24/2019	1/24/2019
14	Non-Contact Digital Tachometer	DT2234A	https://www.amazon.com/D	$26.83	1	2/26/2018	$28.33	2/26/2019	3/25/2019
15	Digital Anemometer	DAFM3B	https://www.amazon.com/U	$197.95	1	2/26/2018	$209.04	2/26/2019	3/5/2019
16	Range Hall Current Sensor For Arduino	ACS712	https://www.amazon.com/Yı	$12.35	1	3/9/2019	$13.04	3/10/2019	3/14/2019
17	Analog Current Meter Sensor Module	3-01-0056	https://www.amazon.com/Hi	$6.99	1	3/9/2019	$7.38	3/10/2019	3/14/2019
18	Premium Bristle Paint Brushes	N/A	https://www.amazon.com/Pa	$7.99	2	4/11/2019	$8.44	4/12/2019	4/22/2019
19	Heavy Body Acrylic Paint Mars Black	N/A	https://www.amazon.com/Sa	$9.46	1	4/11/2019	$9.99	4/12/2019	4/22/2019
20	Poster Printing (FedEx)	N/A	https://www.fedex.com/en-u	$129.99	1	8/21/2018	$137.27	4/28/2019	4/28/2019
						Shipping=	=		
			Expected Total=	$751.07					
						Adjusted total=	$793.13		

At the end, Team Regenesis managed to obtain all purchases within budget and within the expected time frame.

8.0 Lessons Learned

8.1.0 Communication

Efficient communication is a vital tool to complete any project. Throughout the year, team Regenesis has improved and has taken corrective actions to better the way the team handles new challenges along the way. The first step was creating a group chat in order to keep everyone informed in real time about pertinent aspects of the project and also, agreeing on meeting times, assignments due dates, important documents etc. When the team's individuals' schedules were too demanding, sometimes we had to rely upon having brief Google meetings to check in with every team member. We believe that the amount and quality of communication that there is within a team will determine the success of the project.

8.2.0 Identifying and Understanding the Problem

A big part of problem solving is troubleshooting and with that comes finding the problem. First step is to brainstorm what is the system not doing or what is it doing wrong; hence, figuring what components are affiliated to this issue that may be causing the problem.

Unfortunately, our experience was different for one scenario. Team Regenesis was certain that a device was going to be ideal for our data output since it had been used last year. The scenario is regarding our data logger which seemed like it was giving off too much information based off its graph. Team Regenesis attempted to cope with this issue and regulate its sampling rate. It turned out the data logger outputted at most 8 samples per second hence team regenesis needed a substitution to this device. Identifying this issue turned out to be deceiving because what seemed to be the issue turned out to be the complete opposite.

8.3.0 Redesigning Test Methods

The major part of our project is data collection; therefore, we had to make sure the numbers being collected out of the different devices and test procedures were accurate. After conducting a few test rundowns with all the different configurations, we noticed that the airflow and power output were not quite accurate. The original airflow test procedure involved taking only one reading on the center of the duct. We identified that the air velocity varies greatly across the duct; hence, the airflow is also different. To get a more precise reading, we decided to take three readings off of three sections of the duct, top, middle and bottom. The three readings per section were averaged and further on multiplied by the following equation to calculate approximate airflow.

$$Total\ Airflow\ (CFM)\ = \frac{1}{3}A * V_{high,\ avg} + \frac{1}{3}A * V_{mid,\ avg} + \frac{1}{3}A * V_{low,\ avg}$$

$$= \frac{1}{3} * A(V_{high, avg} + V_{mid, avg} + V_{low, avg}) \quad (2)$$

8.4.0 Potential Factors that Yield Biased results

Even though we created a controlled environment to conduct the testing, we determined that there are some factors that may alter the data, so we took the task of identifying and avoiding them. One of the mentioned factors was having any sort of undesired obstruction in front of the air intake ducts. Whenever we would carry out any testing, we made sure this factor was never in place to ensure accurate results. A second example of this issue was the tachometers' readings being altered by light. Since the tachometer measures the revolutions per minute in a reflective manner, any other light sources that were reflecting a glare towards the tachometer would influence the results.

9.0 Summary

This project is meant to provide useful data to our sponsor for further study. Therefore, the team will conduct three acceptance tests in an controlled environment to determine the RPM relationship between two fans, airflow efficiency, and overall efficiency. The RPM relationship test shall show the relationship of the two fans and the effect the recapture fan has on the driving fan. The airflow efficiency test shall show the minimum airflow loss, air velocity at different frequencies, voltage inputs and fan configurations. The final test shall show the overall efficiency of the recapture system by recording the power input and power output. After conducting these experiments, we observed many interesting results. We observed the Regenesis system being very efficient at typical HVAC exhaust fan parameters. When the Regenesis system is intact, input power is saved while creating more airflow and recapturing a percentage of the input power.

10.0 Appendix

10.1 Drawings

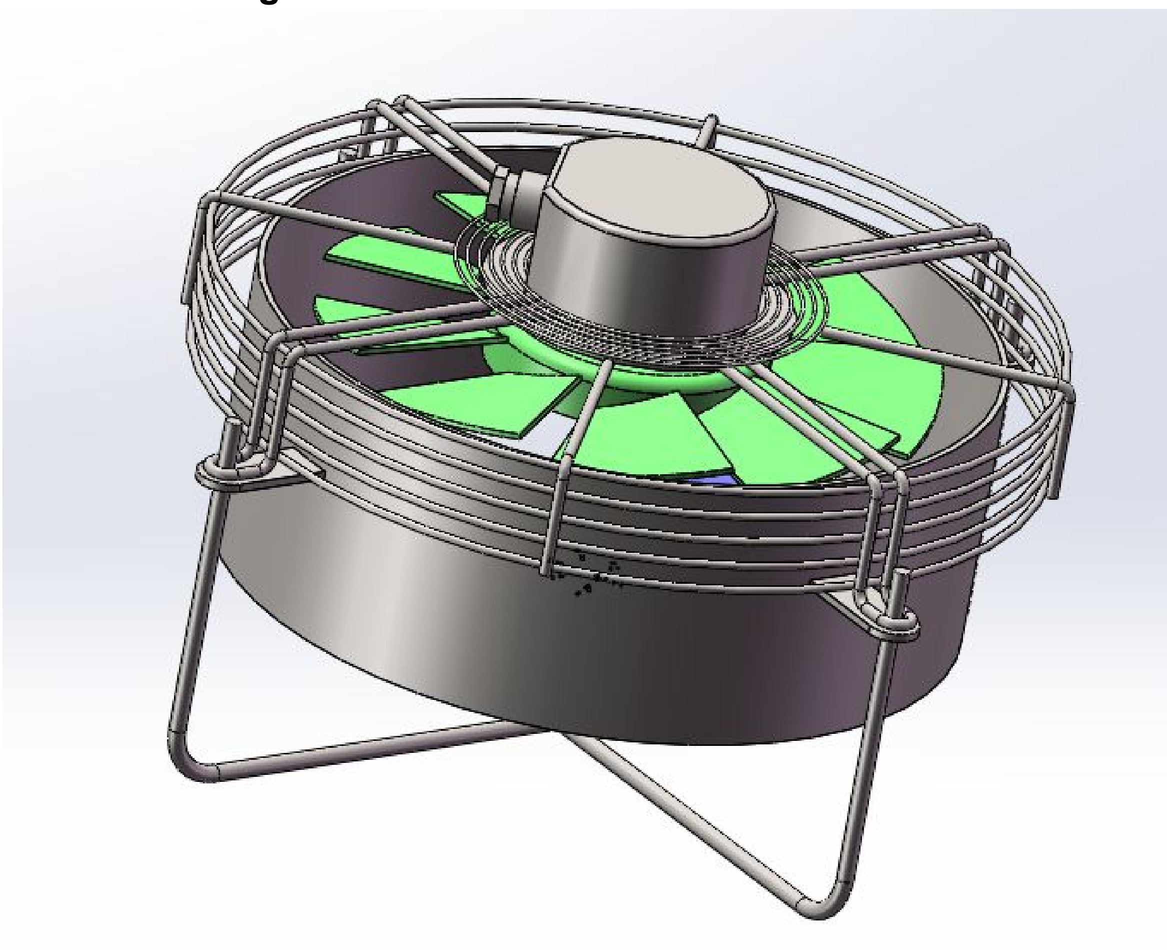


Figure 10.1-Regenesis Fan system

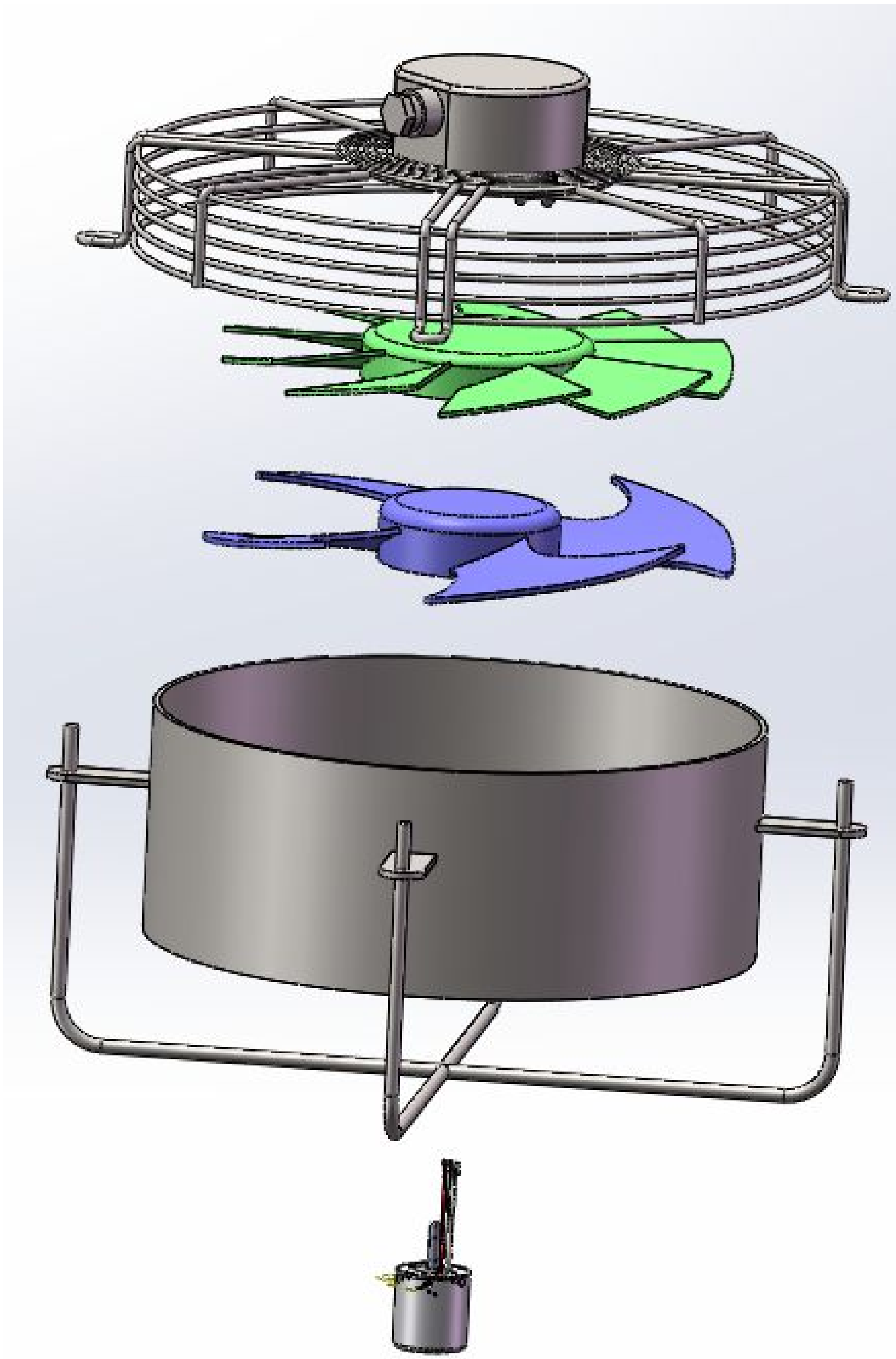


Figure 10.2-Exploded view of Regenesis Fan System

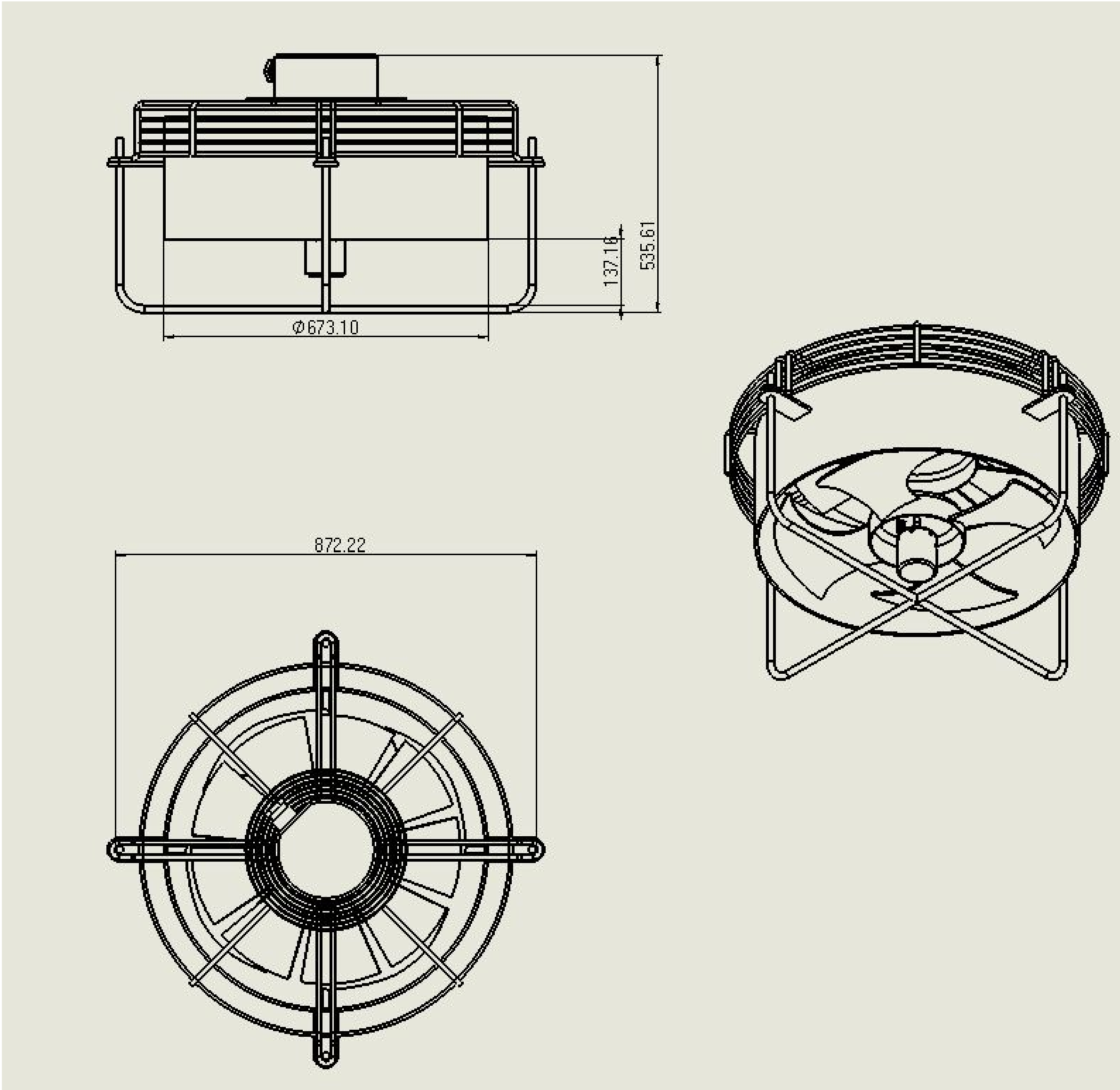


Figure 10.3-Drawing of Regenesis Fan System

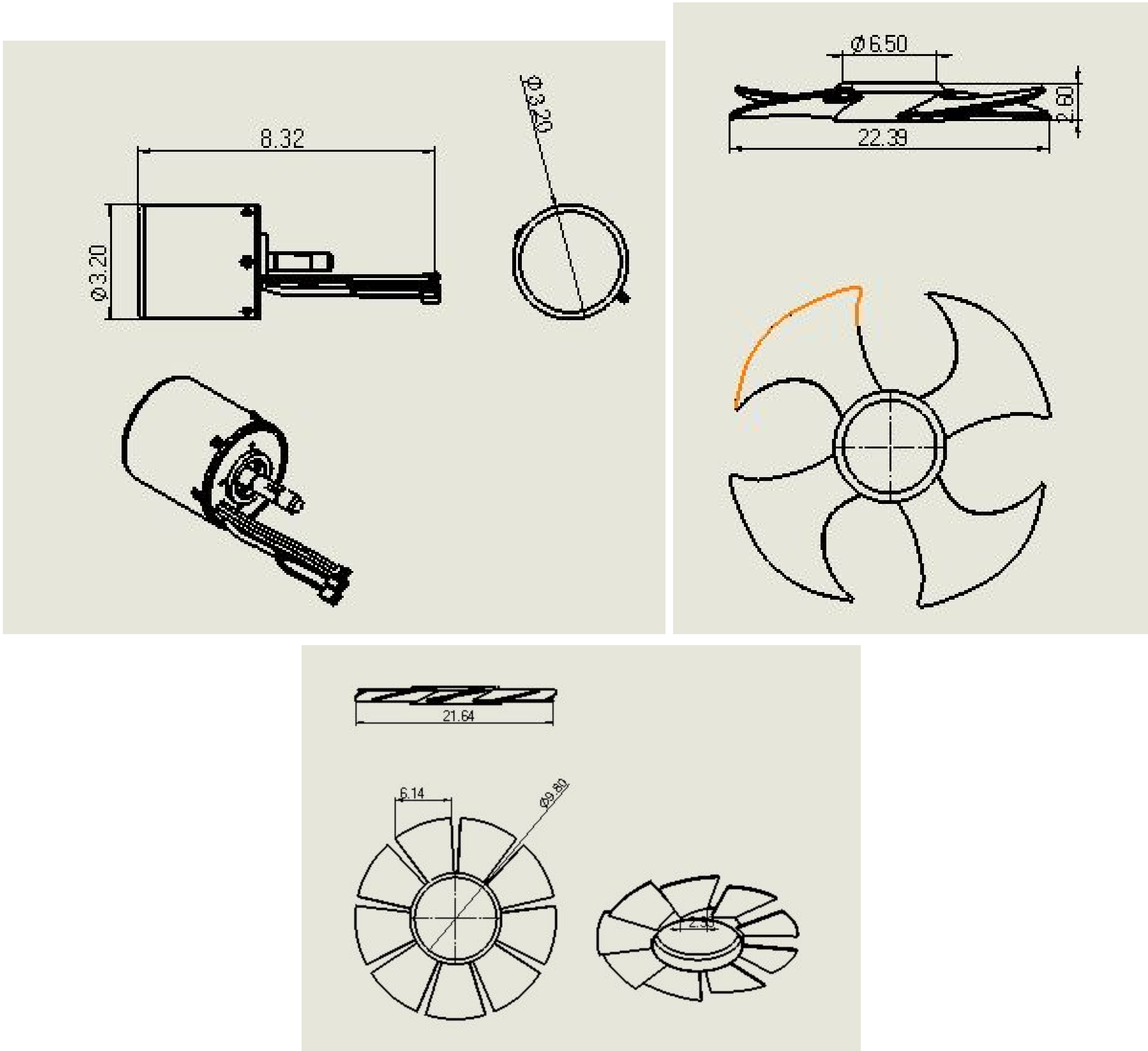
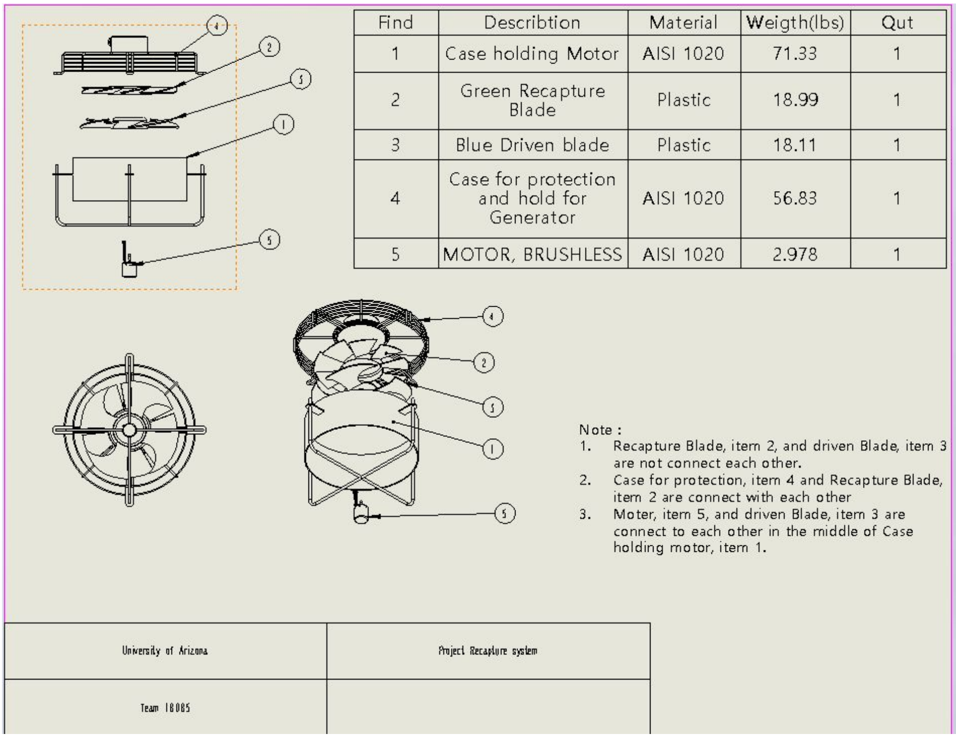


Figure 10.4-Drawings of individual components of Regenesis Fan System



Find	Describtion	Material	Weigth(lbs)	Qut
1	Case holding Motor	AISI 1020	71.33	1
2	Green Recapture Blade	Plastic	18.99	1
3	Blue Driven blade	Plastic	18.11	1
4	Case for protection and hold for Generator	AISI 1020	56.83	1
5	MOTOR, BRUSHLESS	AISI 1020	2.978	1

Figure 10.5-Drawing of Regnesis Fan System

10.2 Devices used in this project

10.2.1: Tachometer

Brand	CyberTech
Model	FBA_tach-mtr-01
Item Weight	3.04 ounces
Product Dimensions	6 x 4 x 1 inches
Item model number	FBA_tach-mtr-01
Manufacturer Part Number	FBA_tach-mtr-01

10.2.2: 3-Phase Motor

Technical Specifications			
Electrical Type :	Squirrel Cage	Starting Method :	Line Or Inverter
Poles :	2	Rotation :	Reversible

Nameplate Specifications			
Output HP :	0.33 Hp	Output KW :	0.25 kW
Frequency :	60 Hz	Voltage :	230/460 V
Current :	1.4/0.70 A	Speed :	3450 rpm
Service Factor :	1.35	Phase :	3
Efficiency :	69.50%	Duty :	Continuous
Insulation Class :	B	Design Code :	B
KVA Code :	S	Frame :	48

General Specifications			
Model :	C4T34DB7A	Catalog No :	E101447.00
Part Description :	..1/3 HP..3600RPM	Category :	Open Drip Proof (ODP)

10.2.3: Anemometer

Airflow meter:

- Measures: Air velocity, temperature, RH%.
- Calculates: Wet bulb, dew point, and air volume (CFM, CMM).
- Operating temperature: 32˚ to 122˚F (0˚ to 50˚C).

10.2.4 Multimeter

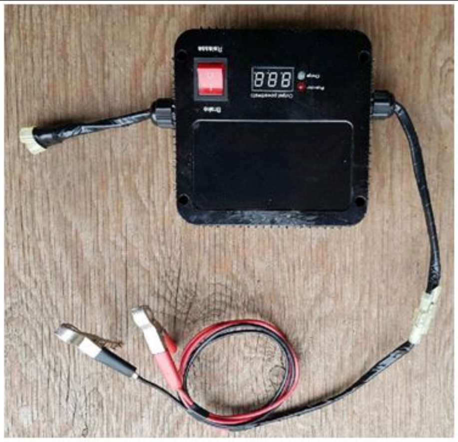
Brand	Innova
Model	3340
Item Weight	8 ounces
Product Dimensions	12.5 x 4.5 x 6.5 inches

10.2.5: Variable Frequency Drive (VFD)

2.00 HP Lenze SMVector Variable Frequency Drive with Water Drip Rating - ESV152N02YXB
by Lenze / AC Tech

- 2.0 HP, 7.0 Amps, Lenze / AC Tech, SMVector Series
- 208 - 240 VAC Input, 240 VAC Output
- Single Phase Input, Three Phase Output

10.2.6: Charge controller



Item Weight	3 pounds
Product dimension	6 x 6 x 2 inches
Output	Wattage

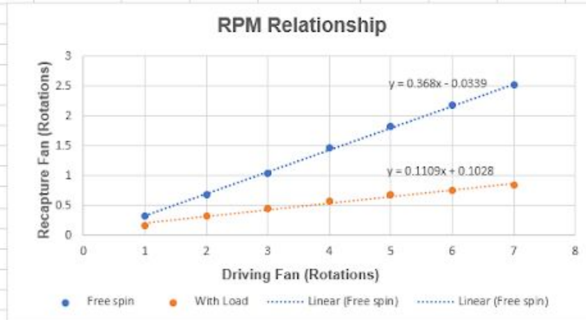
RPM Relationship raw data

RPM Relationship Test

	Frequency [Hz]	Drive Fan Only	Stationary	Freespin	With Load
RPMS of Driving Fan	15	752	754	759.9	735
	17	835.75	857	838.4	798
	19	913.75	956	925	875
	21	992	1024	971	940
	23	1061	1113	1037	1025
	25	1122.5	1155	1074	1102
	27	1127.1	1190	1115	1181

	Frequency [Hz]	Drive Fan Only	Stationary	Freespin	With Load
RPMS of Recapture Fan	15	N/A	N/A	255.3	127
	17	N/A	N/A	290	132
	19	N/A	N/A	323	134
	21	N/A	N/A	355	135
	23	N/A	N/A	380	139
	25	N/A	N/A	390	140
	27	N/A	N/A	401	143

	Frequency [Hz]	Drive Fan Only	Stationary	Freespin	With Load
RPM Ratio	15	N/A	N/A	0.3359653	0.17278912
	17	N/A	N/A	0.3458969	0.16541353
	19	N/A	N/A	0.3491892	0.15314286
	21	N/A	N/A	0.3656025	0.14361702
	23	N/A	N/A	0.3664417	0.13560976
	25	N/A	N/A	0.3631285	0.12704174
	27	N/A	N/A	0.3596413	0.12108383
			Average Ratio	0.3551236	0.14552826



Freespin (X)	Y
1	0.335965
2	0.691794
3	1.047568
4	1.46241
5	1.832208
6	2.178771
7	2.517489

With Load (X)	Y
1	0.172789
2	0.330827
3	0.459429
4	0.574468
5	0.678049
6	0.76225
7	0.847587

Airflow Efficiency Test raw data

Note: For a clearer view, see Excel file attached.

Air Velocity [ft/min]

	West							East								
		Mid			Low			High			Mid			Low		
Drive Fan only	905.5	787.4	767.7	748.0	748.0	807.1	767.7	846.5	925.2	1063.0	728.3	728.3	708.7	787.4	826.8	748.0
	1023.6	826.8	767.7	787.4	807.1	905.5	866.1	964.6	964.6	1003.9	767.7	767.7	787.4	866.1	885.8	866.4
	1102.4	826.8	885.8	846.5	807.1	846.5	807.1	925.2	1082.7	1063.0	826.8	826.8	885.8	944.9	885.8	944.9
	1200.8	846.5	925.2	964.6	925.2	846.5	866.1	984.3	1102.4	1122.0	905.5	866.1	905.5	984.3	984.3	1023.6
	1220.5	984.3	1003.9	1063.0	1003.9	1023.9	1003.9	1181.1	1141.7	1259.8	905.5	925.2	964.6	1003.9	1023.6	1023.6
	1299.2	1043.3	1023.6	1063.0	984.3	1023.6	1063.0	1102.4	1161.4	1279.4	984.3	984.3	984.3	1122.0	1141.7	1141.7
	1242.2	1102.4	1082.5	925.2	1043.3	1063.0	1161.4	1358.3	1338.6	1141.7	#####	#####	984.3	1043.3	1003.9	1082.7

Air Velocity [ft/min] / **Airflow [ft3/min]**

	West				East				Both sides	West	East	Total
	Avg High	Avg Mid	Avg Low	Total Avg	Avg High	Avg Mid	Avg Low	Total Avg	Average	Airflow	Airflow	Airflow
Drive Fan only	925.2	767.7	774.3	822.4	944.9	721.8	787.4	818.0	**820.2**	1829.8	1815.1	3644.9
	971.1	794.0	859.6	874.9	977.7	774.3	872.8	874.9	**874.9**	1946.6	1941.3	3887.9
	1030.2	853.0	820.2	901.2	1023.6	846.5	925.2	931.8	**916.5**	2005.1	2067.5	4072.5
	1148.3	912.1	879.3	979.9	1069.6	892.4	997.4	986.4	**983.2**	2180.3	2188.8	4369.0
	1220.5	1017.1	1010.6	1082.7	1194.2	931.8	1017.0	1047.7	**1065.2**	2409.0	2324.6	4733.7
	1286.1	1043.3	1023.6	1117.7	1181.1	984.3	1135.1	1100.2	**1108.9**	2486.8	2441.1	4927.9
	1313.0	1036.7	1089.2	1146.3	1279.5	1030.2	1043.3	1117.7	**1132.0**	2550.6	2480.0	5030.5

	West							East								
		Mid			Low			High			Mid			Low		
Statio-nary	669.3	531.5	590.6	531.5	649.6	669.3	649.0	669.3	610.2	629.9	531.5	570.9	610.2	669.3	649.6	649.6
	767.7	610.2	610.2	649.9	629.9	669.3	669.3	767.7	767.7	767.7	649.9	669.3	629.9	649.6	689.0	669.3
	826.8	669.0	689.0	669.3	708.7	728.0	748.0	748.0	767.7	787.4	708.6	689.0	669.3	728.3	748.0	708.7
	846.5	708.1	748.0	708.7	728.0	767.0	807.0	787.4	807.1	826.8	689.0	748.0	728.3	787.4	748.0	787.4
	944.9	728.3	728.3	748.0	826.0	728.3	807.0	826.8	826.8	826.8	669.0	728.3	748.0	728.3	826.8	826.8
	944.9	748.0	767.7	807.1	885.8	885.8	866.1	944.7	944.9	964.6	787.4	787.4	787.4	826.8	866.1	826.8
	1082.0	846.0	826.8	846.5	807.1	846.5	885.8	1023.6	1003.9	984.3	866.1	787.4	807.1	846.5	885.8	905.5

	West				East				Both sides	West	East	Total
	Avg High	Avg Mid	Avg Low	Total Avg	Avg High	Avg Mid	Avg Low	Total Avg	Average	Airflow	Airflow	Airflow
Statio-nary	649.6	551.2	656.0	618.9	636.5	570.9	656.2	621.2	**620.0**	1377.1	1378.3	2755.4
	748.0	623.4	656.2	675.9	767.7	649.7	669.3	695.6	**685.7**	1503.8	1543.4	3047.2
	820.2	675.8	728.2	741.4	767.7	689.0	728.3	728.3	**734.9**	1649.6	1616.1	3265.7
	825.7	721.6	767.3	771.5	807.1	721.8	774.3	767.7	**769.6**	1716.7	1703.4	3420.1
	925.2	734.9	787.1	815.7	826.8	715.1	794.0	778.6	**797.2**	1815.0	1727.6	3542.6
	971.2	774.3	879.2	874.9	951.4	787.4	839.9	859.6	**867.2**	1946.6	1907.3	3853.9
	1042.8	839.8	846.5	909.7	1003.9	820.2	879.3	901.1	**905.4**	2024.0	1999.5	4023.5

		West							East								
32			Mid			Low			High			Mid			Low		
33	Free Spin	826.8	629.9	669.3	649.6	728.3	787.0	807.0	787.8	767.7	807.1	728.3	748.0	728.3	728.3	708.7	767.7
34		866.1	728.3	787.0	767.0	807.1	787.0	807.0	925.2	988.9	984.3	807.1	787.4	787.4	807.1	846.5	846.5
35		866.0	787.0	807.0	826.0	885.0	866.0	885.8	1003.9	964.6	905.5	846.5	846.5	826.8	885.8	885.8	885.8
36		1003.9	846.5	905.5	846.5	946.5	905.5	866.1	1063.0	1023.6	1063.0	866.1	885.8	866.1	925.2	925.2	925.2
37		1023.6	885.8	866.1	885.8	925.2	944.9	964.6	1023.6	1102.4	1122.0	846.5	846.5	905.5	964.6	1003.9	964.6
38		1141.7	964.6	984.3	905.5	925.2	944.9	1043.3	1240.2	1200.8	1082.7	944.9	964.6	925.2	1023.6	1082.7	1003.9
39		1220.5	984.3	1003.9	984.3	1063.0	1003.9	1023.6	1161.4	1141.7	1102.4	964.6	964.6	1023.6	1003.9	1003.9	1043.3

	West				East				Both sides	West	East	Total
32	Avg High	Avg Mid	Avg Low	Total Avg	Avg High	Avg Mid	Avg Low	Total Avg	Average	Airflow	Airflow	Airflow
33	859.3	649.6	774.1	761.0	787.5	734.9	734.9	752.4	**756.7**	1693.2	1669.5	3362.8
34	898.9	760.8	800.4	820.0	966.1	794.0	833.4	864.5	**842.2**	1824.5	1918.2	3742.7
35	951.3	806.7	878.9	879.0	958.0	839.9	885.8	894.6	**886.8**	1955.7	1984.9	3940.6
36	1030.2	866.2	906.0	934.1	1049.9	872.7	925.2	949.2	**941.7**	2078.4	2106.2	4184.7
37	1056.4	879.2	944.9	960.2	1082.7	866.2	977.7	975.5	**967.9**	2136.4	2164.5	4300.9
38	1148.3	951.5	971.1	1023.6	1174.6	944.9	1036.7	1052.1	**1037.9**	2277.6	2334.4	4612.0
39	1174.6	990.8	1030.2	1065.2	1135.2	984.3	1017.0	1045.5	**1055.3**	2370.0	2319.8	4689.8

		West							East								
43			Mid			Low			High			Mid			Low		
44	With Load	708.7	689.0	669.3	629.9	649.6	610.2	649.6	787.4	728.3	728.3	649.6	629.9	649.6	689.0	708.7	689.0
45		846.5	689.0	708.7	728.3	708.7	748.0	767.0	826.8	826.8	807.0	708.7	669.3	689.0	767.7	689.0	728.3
46		846.5	767.7	728.3	748.0	748.7	767.7	748.0	826.8	885.8	866.1	767.7	767.7	748.0	767.7	787.4	787.4
47		925.2	787.4	846.5	748.0	885.4	846.5	885.8	984.3	1023.5	944.9	767.7	787.4	807.1	807.1	846.5	807.1
48		1023.6	826.8	846.5	826.8	905.5	885.8	896.0	984.3	1043.3	1003.9	885.8	846.5	846.5	866.1	807.1	885.8
49		1003.9	925.2	944.9	964.6	826.8	885.5	905.5	1003.9	1023.6	1003.9	905.5	885.8	925.2	925.2	905.5	866.0
50		1043.3	1003.9	964.6	984.3	826.8	866.1	826.8	1023.6	1063.0	1043.3	905.5	905.5	925.2	885.8	866.1	944.9

	West				East				Both sides	West	East	Total
43	Avg High	Avg Mid	Avg Low	Total Avg	Avg High	Avg Mid	Avg Low	Total Avg	Average	Airflow	Airflow	Airflow
44	754.6	662.7	636.5	684.6	748.0	643.0	695.6	695.5	**690.1**	1523.2	1543.3	3066.5
45	826.8	708.7	741.2	758.9	820.2	689.0	728.3	745.8	**752.4**	1688.5	1654.9	3343.4
46	866.1	748.0	754.8	789.6	859.6	761.1	780.8	800.5	**795.1**	1757.0	1776.2	3533.2
47	931.7	794.0	872.6	866.1	984.2	787.4	820.2	864.0	**865.0**	1927.0	1917.0	3844.0
48	984.3	833.4	895.8	904.5	1010.5	859.6	853.0	907.7	**906.1**	2012.4	2014.1	4026.5
49	1023.6	944.9	872.6	947.0	1010.5	905.5	898.9	938.3	**942.7**	2107.1	2081.9	4189.1
50	1076.2	984.3	839.9	966.8	1043.3	912.1	898.9	951.4	**959.1**	2151.1	2111.1	4262.2

Power Efficiency raw data

		Driving Fan	Stationary	Freespin	With load	
	Frequency	Input Power	Input Power	Input Power	Input Power	Output Power
Watts	15	20.24	20.22	20.24	20.18	8.2
	17	43.4	43.36	48.69	32.58	9.3
	19	103.68	74.685	115.3	58.15	9.7
	21	160.81	147.84	197.92	135.85	11.1
	23	260.8	234.72	261.8	221.85	11.75
	25	372.33	330.72	317.63	290.01	12.4
	27	435	412.68	406.28	392.31	13.1

		Driving Blade	Stationary	Freespin	With Load
	RPMS	Input Power/ Airflow	Input Power/ Airflow	Input Power/ Airflow	Input Power/ Airflow
CFM/Watt	850	89.58	70.28	76.87	102.62
	925	39.28	43.73	34.18	60.76
	1000	27.17	23.13	21.14	28.30
	1060	18.15	15.09	16.43	18.15
	1120	13.24	11.65	14.52	14.44
	1150	11.56	9.75	11.54	10.86