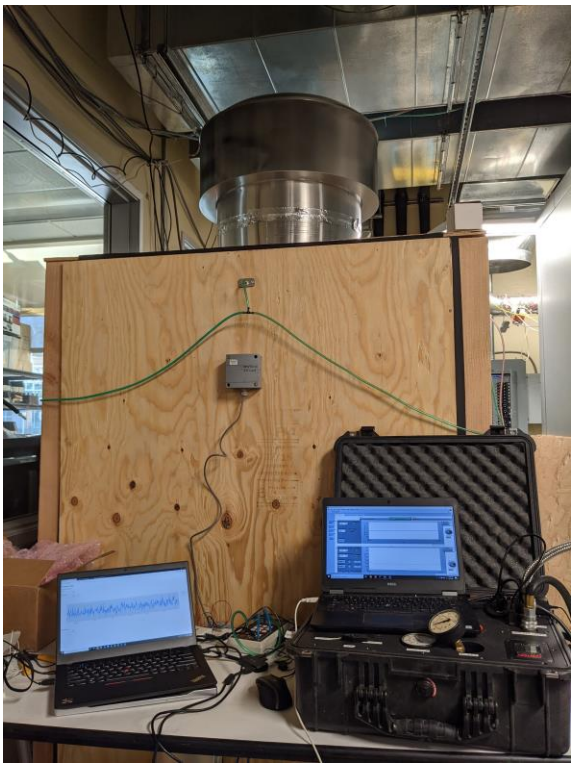
High-Efficiency Hybrid Exhaust Fans

ET18SCE1040



Prepared by:

Western Cooling Efficiency Center
UC Davis

March 2021

SOUTHERN CALIFORNIA EDISON®
Energy for What's Ahead℠

Acknowledgements

Southern California Edison's (SCE) Emerging Products (EP) group is responsible for this project. It was developed as part of SCE's Emerging Technologies Program under internal project number ET18SCE1040. The Western Cooling Efficiency Center (WCEC) – University of California, Davis (UC Davis) and RMS Energy Consulting, LLC conducted this technology evaluation, with overall guidance and management from Daniel Nguyen and Jay Madden. Laboratory testing was conducted at the UC Davis WCEC. For more information on this project, contact daniel.t.nguyen@sce.com.

Disclaimer

EXECUTIVE SUMMARY

This project measured hybrid turbine-style exhaust fan performance compared to typical baseline models found in commercial and industrial buildings. The emerging product line combines high-efficiency, variable-speed, Electrically-Commutated (EC) motors with a turbine-style fan, to harness wind and reduce power usage. This combination of technologies is more generally known as a "hybrid" exhaust system.

Power consumed by two emerging products and four baseline models was characterized at the full range of possible static pressures for each fan. Energy savings from wind was not characterized. We found the emerging product line was significantly more efficient at low static pressures. However, the emerging products were not able to retain airflow rates under higher static pressure loads, which may limit their real-world application.

Statewide potential energy savings are estimated from the California Energy Commission's (CEC) Commercial End Use Survey. The WCEC reports the emerging product's savings in terms of kilowatt-hours (kWh) per year, per Standard Cubic Foot per Minute (SCFM) at different static pressures. This comparison shows the product performs well below 0.25 inches water column (in. H_2O) of static pressure.

We found these hybrid exhaust fans can offer significant energy savings over baseline models. However, there are some factors that could affect market adoption, especially the application's working static pressure. Field measurements of commercial exhaust fans' typical operating static pressures would help identify end users. Additionally, education and outreach could get end users interested in the technology, as it is not known whether a wide audience is aware of this product's availability.

TABLE 1: SUMMARY OF ENERGY SAVINGS FOR ONE FAN IN TERMS OF KWH/YEAR/SCFM AT FIVE STATIC PRESSURES

KWH/YEAR/SCFM @	EMERGING	BASELINE AVERAGE	% SAVINGS
0 in. H2O	0.156	0.559	72.2
0.0625 in. H2O	0.203	0.595	65.8
0.125 in. H2O	0.386	0.629	38.5
0.161 in. H2O	0.450	0.647	30.5
0.25 in. H2O	NA	15.3	NA

ABBREVIATIONS AND ACRONYMS

AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
CEUS	California Commercial End-Use Survey
CFM	Cubic Feet per Minute
DAQ	Data Acquisition
EC	Electrically Commutated
HP	Horsepower
IAQ	Indoor Air Quality
in. H2O	Inches Water Column
kilowatt-hour	kWh
Pa	Pascals
PPM	Parts per Million
PSC	Permanent Split Capacitor
RPM	Revolution per Minute
SCFM	Standard Cubic Foot per Minute
VAC	Volts Alternating Current
VDC	Volts Direct Current
VFD	Variable-Frequency Drive
W	Watt
WCEC	Western Cooling Efficiency Center

CONTENTS

EXECUTIVE SUMMARY ____ II

ABBREVIATIONS AND ACRONYMS ____ III

INTRODUCTION ____ 1

BACKGROUND ____ 2

ASSESSMENT OBJECTIVES ____ 3

TECHNOLOGY/PRODUCT EVALUATION ____ 3

Baseline Technology: Downblast Roof Ventilators 3

Emerging Technology: Hybrid Ventilator with EC Motor 4

TECHNICAL APPROACH – LAB TESTING ____ 6

Apparatus Construction 6

Test Setup 6

Instrumentation Plan 8

Procedure 8

RESULTS ____ 10

Manufacturer D Type 2 12

Manufacturer D Type 1 13

Manufacturer A with EC Motor Option 14

Annualized Energy Savings 15

CONCLUSIONS ____ 17

RECOMMENDATIONS ____ 18

APPENDICES ____ 19

Emerging Product Type 2 Tabulated Data 19

Emerging Product Type 1 Tabulated Data 20

Baseline Manufacturer C Tabulated Data 22

Baseline Manufacturer A with EC Motor Option Tabulated Data 23

Manufacturer A with PSC Motor Tabulated Data 26

Manufacturer B Tabulated Data 28

FIGURES

Figure 1: Exploded View from Emerging Product Data Sheet 5
Figure 2: Diagram Indicating Apparatus Assembly 7
Figure 3: Airflow vs. Static Pressure at Full Speed for All Six Fans Tested 10
Figure 4: SCFM per W for All Fans at Full Speed. 11
Figure 5: SCFM per W (lower pressure range emphasized). 12
Figure 6: Emerging EC-2 Airflow vs. Static Pressure 12
Figure 7: Emerging EC-2 Airflow Efficiency vs. Static Pressure 13
Figure 8: Emerging EC-1 Airflow vs. Static Pressure 13
Figure 9: Emerging EC-1 Efficiency vs. Static Pressure 14
Figure 10: Manufacturer A with EC Motor Option vs. Static Pressure . 14
Figure 11: Manufacturer A with EC Motor Option Efficiency vs. Static Pressure 15

TABLES

Table 1: Summary of Energy Savings for One Fan in Terms of kWh/year/SCFM at Five Static Pressures ii
Table 2: Baseline Products Tested 4
Table 3: Emerging Technology Products Tested 5
Table 4: List of Sensors and Control Devices 8
Table 5: Comparing Fan Efficiency for 0-0.25 in. H2O. 15
Table 6: kWh/year/SCFM Saved Using Emerging Technology vs. Baseline 15
Table 7: Emerging Product Type 2 Test Results at 100% Speed 19
Table 8: Emerging Product Type 2 Test Results at 75% Speed 19
Table 9: Emerging Product Type 2 Test Results at 50% Speed 20
Table 10: Emerging Product Type 2 Test Results at 25% Speed 20
Table 11: Emerging Product Type 1 Test Results at 100% Speed 20
Table 12: Emerging Product Type 1 Test Results at 75% Speed 21
Table 13: Emerging Product Type 1 Test Results at 50% Speed 21
Table 14: EP400 Test Results at 25% Speed 21
Table 15: Manufacturer C Test Results 22
Table 16: Manufacturer A with EC Motor at 100% Speed 23
Table 17: Manufacturer A with EC Motor at 75% Speed 24

Table 18: Manufacturer A with EC Motor at 50% Speed..... 25
Table 19: Manufacturer A with EC Motor at 25% Speed..... 25
Table 20: Manufacturer A with PSC Motor..... 26
Table 21: Manufacturer B Results..... 28

EQUATIONS

Equation 1: Airflow Rate Calculation Using Tracer Gas Measurement Technique 6

INTRODUCTION

This project evaluated the potential of hybrid ventilation fans to reduce the energy needed to meet exhaust air requirements in commercial and industrial settings. Hybrid ventilation fans, in combination with high-efficiency motors and operating in low- or zero-power mode, can harness wind to reduce power demand. This report describes the laboratory evaluation comparing two emerging technology models to four baseline models with similar flow rates. Wind-powered operation was not tested in this evaluation.

Laboratory Evaluation

- **Baseline:** The baseline included downblast exhaust fans of between 1,500-2,500 Cubic Feet per Minute (CFM) at zero static pressure. We chose three blower wheel fans and one axial-style fan. Three of the baseline models used traditional single-speed Permanent Split Capacitor (PSC) motors. One of the baseline models included a high-efficiency motor.

- **Emerging Technology:** The emerging technology consisted of hybrid ventilators with two flow rates of between 1,500 – 2,500 CFM at zero static pressure. Both models included high-efficiency variable-speed motors.

For the laboratory evaluation, we constructed a test apparatus conforming to American National Standards Institute and Air Movement and Control Association (ANSI/AMCA) standard 210 Type "A" for fans with an open inlet/open outlet flow condition. We measured flow rates and power use at different static pressures and motor speeds (for variable-speed models) to obtain performance results.

BACKGROUND

Sufficient ventilation is key to maintaining a healthy Indoor Air Quality (IAQ) for building occupants. Failure to provide adequate ventilation can result in excessive humidity, odors, high carbon dioxide levels, and hazardous contaminate accumulation. Exhaust fans help alleviate these concerns by removing air from the building, and are typically placed near the source of the contamination. This exhausted air is replaced by fresh air though a relief damper, leaks in the building envelope, or a supply fan elsewhere in the building. Some common examples of exhaust fans are bathroom fans, kitchen hoods, and laboratory fume hoods. Exhaust fans may also be used in unconditioned spaces (for example, warehouses) to maintain building temperature.

In addition to improving occupant comfort, ventilation is required by code. The California Building Energy Efficiency Standards (Title 24) specify ventilation rates for building spaces, as well as exhaust rates for kitchens, laboratories, nail salons, etc. Exhaust fans contribute to building energy use in two ways: 1) the energy required to run the exhaust fan; and 2) the energy required to condition the building's make-up air. Therefore, it is important to select high-efficiency exhaust fans and ensure exhaust flow rates are sufficient to meet IAQ requirements without over-ventilating.

The two most common rooftop exhaust fan types are downblast and upblast. Downblast fans direct exhausted air back down at the roof the building. Upblast fans are typically more expensive, but are built to direct contaminated air up and away from the building. Each of these styles has additional options and subcategories.

Fans are usually either centrifugal (blower wheel) or axial (propeller) type. The motors may be belt or direct drive, but are almost always PSC. A few high-efficiency EC motors are available, and can offer additional savings through increased motor efficiency and easily-integrated speed controls.

ASSESSMENT OBJECTIVES

The objective of this project was to characterize the performance of the emerging product compared to the baseline products in an unbiased laboratory setting. The main variables of interest were flow rate, power input, and static pressure. For completeness, we recorded other variables, such as Revolution per Minute (RPM) and ambient conditions. The metric for comparison is SCFM per Watt (W) at a specific static pressure. We also tested products featuring variable-speed motors at 25%, 50%, 75%, and 100% speed.

TECHNOLOGY/PRODUCT EVALUATION

BASELINE TECHNOLOGY: DOWNBLAST ROOF VENTILATORS

The scope of the baseline products we researched is limited to the emerging technology's market competitors. This included exhaust fans with direct drive and flow rates of 1,500 – 2,500 CFM at zero static pressure. Additionally, these fans are not built to handle contaminated air and/or air from Type II kitchen hoods. This limitation is imposed by current emerging technology models, which are not specifically designed to handle hazardous air.

The goal of this section is to identify and describe baseline products tested at the WCEC laboratory. Due to lab constraints, the test was limited to fans with maximum flow rates of 2,500 CFM at zero static pressure. To further narrow down the scope, we selected different criteria to get a good representation of baseline products. These aspects include:

- Blower wheel vs. axial fan
- Curved vs. flat blower wheel blades
- PSC vs. EC motor
- Brand availability in California

With these criteria in mind, the list of baseline products was narrowed down to four specific fans (**Table 2**). The first two fans were from Manufacturer A, and were identical except for the motor type. Both fans featured the same blower wheels with backward-inclined, curved blades. They had the same specified RPM and flow rates in their respective data sheets.

The difference was in the high-efficiency motor option, which can be specified at the time of purchase. The basic motor was a standard 1/3 HP PSC motor with no built-in speed control. The high efficiency option was a 1/3 HP EC motor running with built-in speed controls that could be adjusted manually or with a remote 0-10 VDC signal. These two fans were chosen because they were readily available from a common vendor, and allowed us to characterize the differences between motors without changing other variables.

The third fan was also a blower-wheel type, but had straight instead of curved backward-inclined blades. It used a traditional PSC motor at 3/4 HP, with no built-in speed controls. However, we noted the motor could be hardwired to run at a lower speed, if desired. In this test, we wired the motor at full speed as directed by the installation manual. We chose this

fan due to availability, blade type, and the much larger motor, which provided a good contrast to the first two fans.

The fourth fan had a similar 1/3 HP motor to the first one described above, but used an axial fan instead of a blower wheel. We chose this product to show the differences between axial and blower-type fans. Additionally, the manufacturer of this fan appeared to be the most readily-available of all those surveyed.

TABLE 2: BASELINE PRODUCTS TESTED

KEY	MANUFACTURER	MOTOR TYPE	SPEED CONTROL	FAN TYPE	BLADES
BASE-A-PSC-CENTRIFUGAL	A	PSC 1/3 HP	No	Centrifugal	Backwards inclined
BASE-A-EC-CENTRIFUGAL	A	EC 1/3 HP	Yes	Centrifugal	Backwards inclined
BASE-B-PSC-CENTRIFUGAL	B	PSC 3/4 HP	No	Centrifugal	Backwards inclined
BASE-C-PSC-AXIAL	C	PSC 1/3 HP	No	Axial	4 Blade Propeller

All four baseline fans were similarly-constructed in general. To protect the motor and roof opening from weather and directed airflow out and downward, they all featured aluminum domes fastened by four acorn nuts. Under the domes were baseplates, junction boxes, and motor mounts. All four baseline products featured wire screens to keep animals out, and square bases for curb mounting. The fourth fan lacked silicone caulking around areas of potential leaks, but still appeared to be well protected from rain. It should be noted that all surveyed vendors had different options for mounting, dampers, electrical connections, etc. WCEC chose the more basic and/or readily available options that met the test criteria. Additionally, the COVID-19 pandemic may have affected general pricing and product availability during this project.

EMERGING TECHNOLOGY: HYBRID VENTILATOR WITH EC MOTOR

Readers may be familiar with the turbine-style passive ventilators commonly used in non-critical applications. These fans are designed to use wind and convective currents to increase ventilation rates in attics, barns, and similar spaces.

The earliest references to these devices date back well over 150 years. The ventilators were used to increase chimney draft while preventing backflow, but not often used in spaces requiring a specific airflow rate, since their effectiveness depends on ambient conditions. Hybrid ventilation fans overcome this limitation by including a motor to maintain flow rates when winds are not favorable. Also, when there is sufficient wind, an intelligently-designed motor controller allows the fans to operate with less (or even zero) power input.

Adding a motor to create a hybrid turbine ventilator allows this emerging product to be used in commercial or industrial applications, where traditional downblast fans would normally be used. Currently, this product is generally marketed to warehouses, data centers, schools, offices, and other low-static pressure applications. Additionally, these fans are not

specifically designed to handle hazardous air, so they do not replace upblast fans or any others used to handle dangerous contaminates.

The product's defining feature is the large turbine/impeller with backward-curved vertical vanes (**Figure 1**). These vanes have the dual function of acting as centrifugal blowers while simultaneously capturing wind energy to aid operation. The emerging products are physically larger than comparable baseline products, to capture more wind and operate at lower RPM with the same airflow. However, the small motor, aluminum construction, and thin flashing make it much lighter than the baseline models.

The motor is high-efficiency EC, with integrated electronics. These motors use significantly less power than PCM motors, even at maximum speed. The emerging technology products are variable speed, with a 0 – 10V input signal. Additionally, the motor controllers can connect directly to building management systems over Modbus. We tested two models from the same manufacturer, with different flow rates and motor sizes (**Table 3**).

TABLE 3: EMERGING TECHNOLOGY PRODUCTS TESTED

KEY	MANUFACTURER	MOTOR TYPE	SPEED CONTROL	FAN TYPE	BLADES
EMERGING-EC-CENTRIFUGAL-1	D	EC 60 W	Yes	Centrifugal	Backward curved vertical vanes
EMERGING-EC-CENTRIFUGAL-2	D	EC 100 W	Yes	Centrifugal	Backward curved vertical vanes

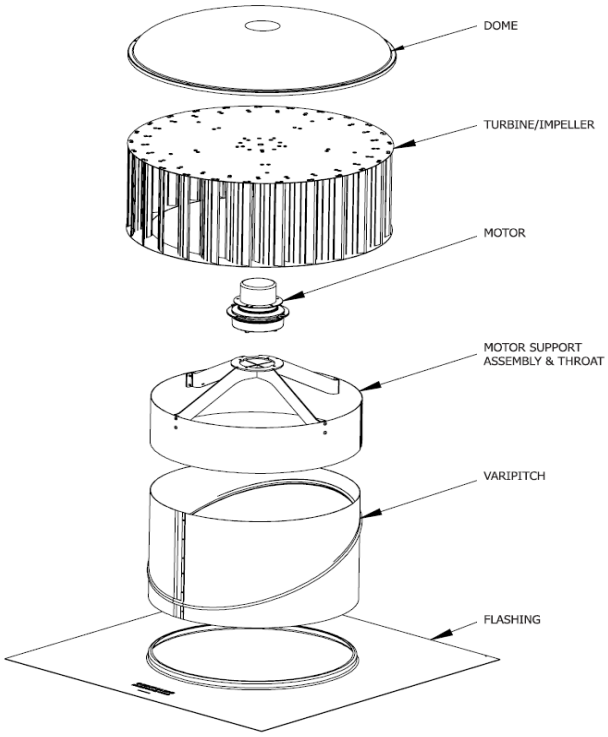


FIGURE 1: EXPLODED VIEW FROM EMERGING PRODUCT DATA SHEET

TECHNICAL APPROACH – LAB TESTING

APPARATUS CONSTRUCTION

The testing apparatus was a modified version of the ANSI/AMCA 210 Type "A" test for free inlet and outlet fans. Normally, this type of test requires long portions of duct and flow straighteners to achieve accurate readings for a pitot tube traverse. However, the WCEC used a tracer gas technique to obtain highly-accurate flow measurements. This technique does not require any special ducting, provided the air is well mixed between the injection and measurement points.

Although flow straighteners are not necessary, ANSI/AMCA 210 requires a wire screen with 50 – 60% open area inside the inlet chamber before the fan. This screen absorbs the upstream jet's kinetic energy, allowing normal expansion as if in an unconfined space, such as an attic or plenum.

The supply to the chamber was 20" spiral duct made from galvanized steel. Outdoor air was supplied by a Variable-Frequency Drive (VFD)-controlled fan. Connections were sealed with a combination of tape and calk. Airtight cord grips were installed on the inlet ports, for tracer gas injection. Four injection ports were equally spaced at 90° around the inlet duct.

The chamber was framed with 4x4 and 2x4 pressure-treated lumber, and covered with 3/8" CDX plywood. We used airtight connections to add ports for pressure, tracer gas, temperature, and humidity measurements. Wire screen with a 50 – 60% open area was installed in the chamber above the inlet, but 48" below the fan opening. Prior to testing, the chamber was sealed with calk and pressurized to 50 Pa to check for airtightness using the tracer gas method. No leakage was detected at 50 Pa. Also, a smoke generator was routinely used during testing, to check for leaks and ensure the sealant had not cracked or deteriorated.

TEST SETUP

Each fan was installed per the manufacturer's instructions for flat roofs. The top of the chamber was replaced as needed to meet different roof opening dimensions and curb requirements. Curbs were constructed from 2"x4" wood, when needed. All flashing and curbs were sealed with caulk. Power and variable-speed controls (if used) were wired back to a junction box. Power input was measured at the junction box using current clamps and a dedicated metering device.

The airflow rate was measured using the tracer gas technique. Carbon dioxide at 99.9% purity was injected at the indicated ports shown in **Figure 2**. The resulting concentration was measured downstream directly below the fan through a 1/4" tube inserted into the chamber. Background CO_2 concentration was measured upstream from the injection ports. Airflow was calculated using the following equation:

EQUATION 1: AIRFLOW RATE CALCULATION USING TRACER GAS MEASUREMENT TECHNIQUE

$$\dot{Q}_{airflow} = \frac{\dot{Q}_{CO2}\left(10^6 - C_{bg}\right)}{C_{result} - C_{bg}} - \dot{Q}_{CO2}$$

Where $\dot{Q}_{airflow}$ is volumetric flow rate, C_{bg} is the background concentration of CO_2 in parts per million (ppm), and C_{result} is the measured CO_2 concentration upstream. All flow rates are calculated at standard conditions (20 degrees C, 1 atm, dry air).

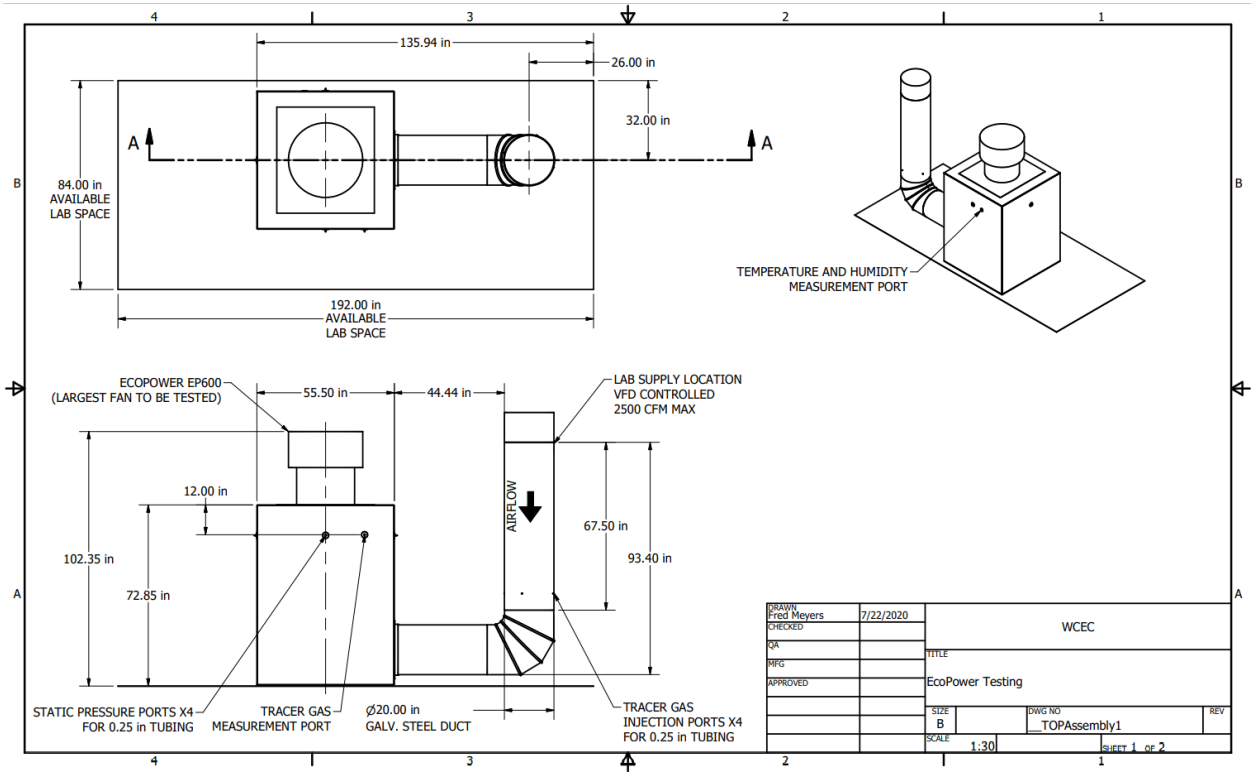


FIGURE 2: DIAGRAM INDICATING APPARATUS ASSEMBLY

Instrumentation Plan

The following table summarizes the instruments used to measure or control variables during the test.

Table 4: List of Sensors and Control Devices

Variable	Mfg./Model	Signal type	Accuracy	Sample Rate/Control signal update
CO_2 Concentration	PP Systems/SBA-5	Serial connection	5 ppm	0.625 Hz
CO_2 Mass Flow Controller	Alicat/MC-200SCCM	Serial Connection	±0.4% of reading and ± 0.2% of full scale	0.625 Hz
Pressure	TEC/DG700	Serial connection	1 Pa	10 Hz
Temperature	Vaisala/HMP110	0-10 VDC	±0.2 °C	10 Hz
Humidity	Vaisala/HMP110	0-10 VDC	±1.5 %	10 Hz
RPM	Honeywell/ SNG-QPDB-000	5 VDC	<1 RPM	0.1 Hz
Volts, Amps, W, and Power Factor	Dent/3037 Powerscout	Modbus	0.01 Amp, 0.1 Volt, 0.01 W	10 Hz
VFD Control	ABB ACH550	Modbus	NA	10 Hz
Supply Damper Control	Belimo non-Spring Return damper actuator	2-10 VDC	NA	10 Hz

Voltage-based inputs and outputs were measured using a National Instruments USB 6008 Data Acquisition (DAQ) device. Serial and Modbus communications were performed using USB adapters and National Instruments LabVIEW. The data was recorded to a timestamped spreadsheet file using a custom LabVIEW program. Data was saved at a rate of 0.625 Hz (once every CO_2 data point). Variables that recorded faster were averaged over that time period, and variables that recorded slower were saved with the last reported value.

Procedure

At the start of the test, the exhaust fan was turned on at full speed, and the supply damper was closed to produce the maximum-possible static pressure in the chamber (negative with respect to the environment). Then, a smoke generator was used to ensure the sealant had not degraded since the original pressure test. Next, the damper was opened and the VFD-controlled supply fan was adjusted so the static pressure in the chamber was zero (within 0.004 in. H_2O).

To perform measurements, the mass flow controller supplied CO_2 to the injection ports until the downstream concentration measurement stabilized. These conditions were held steady for at least 160 seconds (100 CO_2 data points). Then, the CO_2 supply was shut off, and the

concentration returned to within 20 ppm of background. The results reported below, and in the Appendix, are the average values over that 160-second period.

After the airflow measurement was complete, the VFD and/or supply damper was adjusted, and the process was repeated. Measurements were taken every 0.040 in. H_2O (10 Pa). However, higher static pressures caused the control signal to become too sensitive to small changes. In this case, the smallest possible step was made. For fans with variable-speed controls, the whole process was repeated for 75%, 50%, and 25% speeds.

RESULTS

The metrics of interest for comparing the emerging products to the baseline are power consumed, flow rate, and efficiency at each static pressure data point. Additional variables, including power factor, air temperature, humidity, and RPM, are included in the Appendix. **Figure 3** shows the airflow vs. static pressure at full speed for all fans tested in this project.

In general, the four baseline products performed as expected. Manufacturer B's brand exhaust fan was able to maintain higher airflow, likely due to the much-larger motor and blade design. The non-linear relationship between airflow and pressure is typical of the flat blades used. Likewise, the linear relationship seen in Manufacturer A's results is typical of the curved blades used in their design. The Manufacturer C baseline product uses an axial fan, and the sharp drop in airflow is expected.

The two emerging products performed according to their data sheets. These turbine-style hybrid ventilators are capable of high flow rates, but only work at lower static pressures. Low-static pressure applications include warehouses, data centers, auditoriums, offices, and similar buildings. A hybrid ventilation fan would not be a good fit for applications in which long ducts cause significant pressure loss, or in buildings without relief mechanisms. This is visualized in **Figure 3** where the emerging product flow rates quickly drop off.

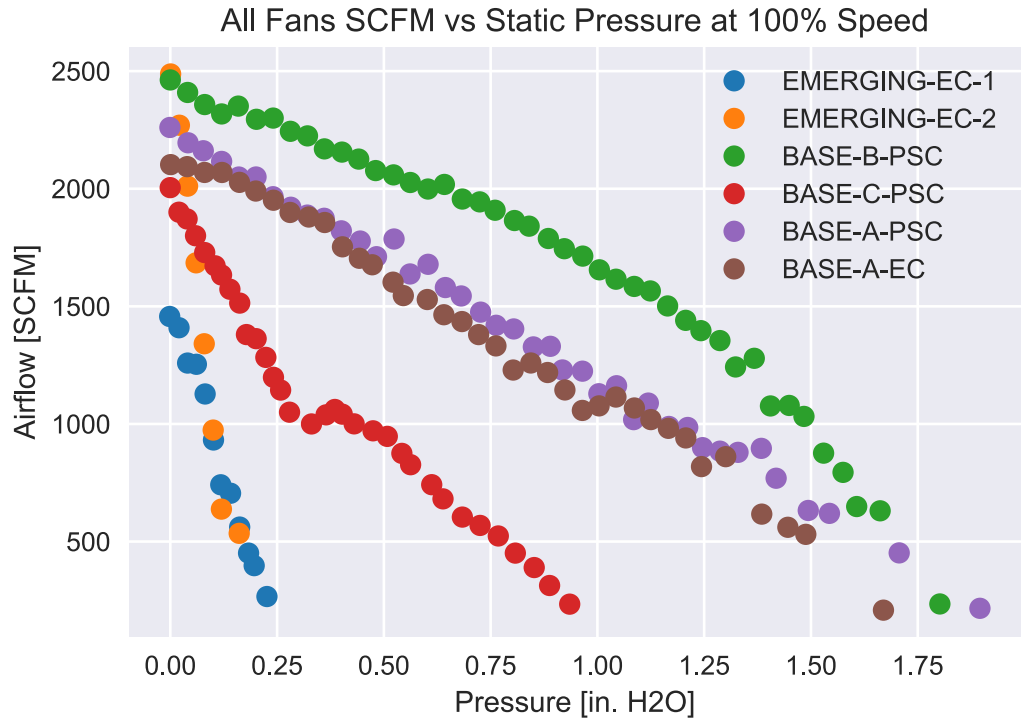


FIGURE 3: AIRFLOW VS. STATIC PRESSURE AT FULL SPEED FOR ALL SIX FANS TESTED

In this report, fan efficiency is quantified in terms of SCFM per W. The true power input (W) was calculated internally by the power meter specified in the instrumentation plan section. Flow rate in SCFM was calculated according to **Equation 1**. This results in the plot seen in **Figure 4**.

Typically, axial fans are efficient at low static pressures, which is the major reason behind Manufacturer C's relatively-good performance up until ~0.125 in. H_2O. PSC motor products from Manufacturers A and B are both reverse-inclined blower wheel fans, resulting in similar efficiency. It appears the difference in motors and blade design did not greatly affect the results for those two specific products. The same Manufacturer A fan with an EC motor is seen to be significantly more efficient, even without changing any other part of the design.

However, at low pressure, the emerging product is much more efficient than the baseline fans. This is emphasized in **Figure 5** where the plot is limited to the lower pressure range. Manufacturer A's EC model is a smaller unit that maintains better efficiency with increasing pressure, even though the total flow rate is lower. Manufacturer A's PSC model has higher flow rates, but the efficiency drops off faster than the Type 1 model. Furthermore, energy saved from wind-powered operation was not studied. The emerging product was designed with wind-powered operation in mind; thus, a motor-only experiment may underestimate the energy savings.

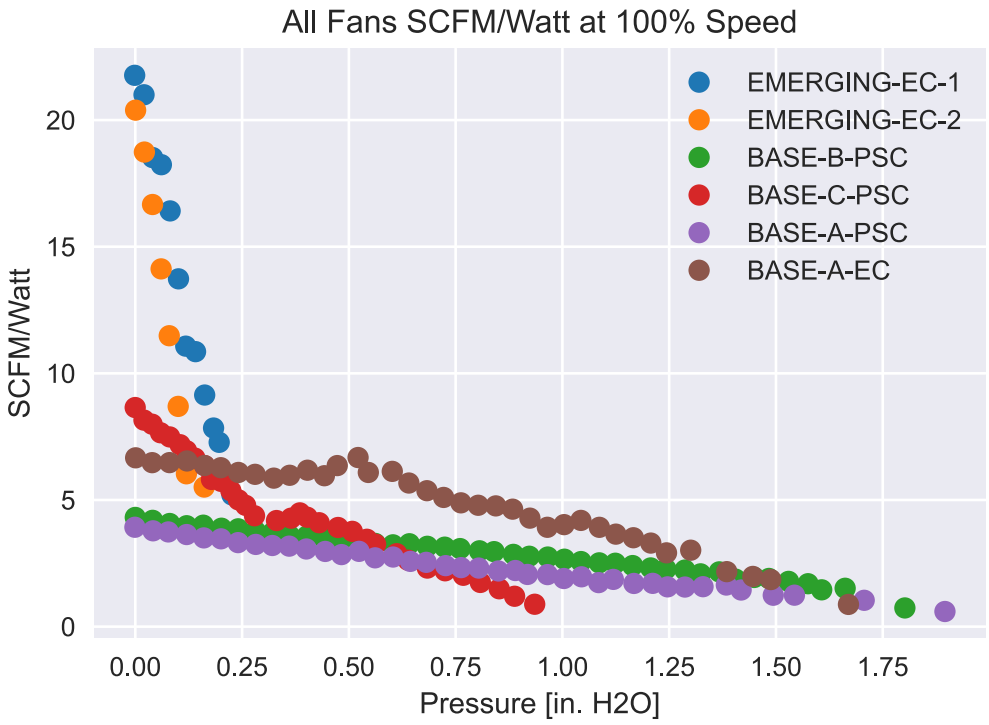


FIGURE 4: SCFM PER W FOR ALL FANS AT FULL SPEED.

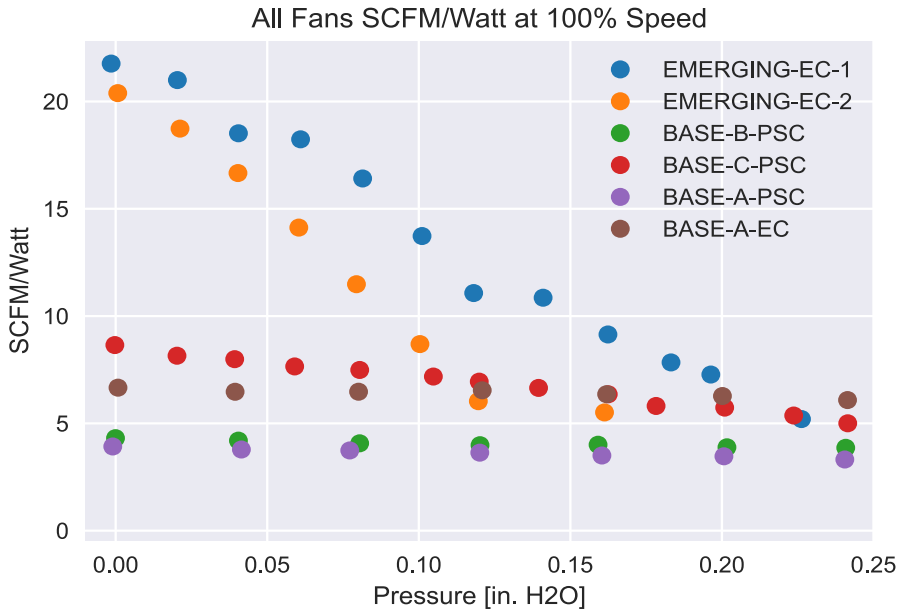


FIGURE 5: SCFM PER W (LOWER PRESSURE RANGE EMPHASIZED).

The following sections include additional data taken for the variable-speed fans. Results are presented in the order in which they were tested.

MANUFACTURER D TYPE 2

Type 2 is the larger of the two emerging products studied in this project. Measured flow rates were consistent with the published data sheet, within the margin of error. The WCEC noted no issues during installation or testing.

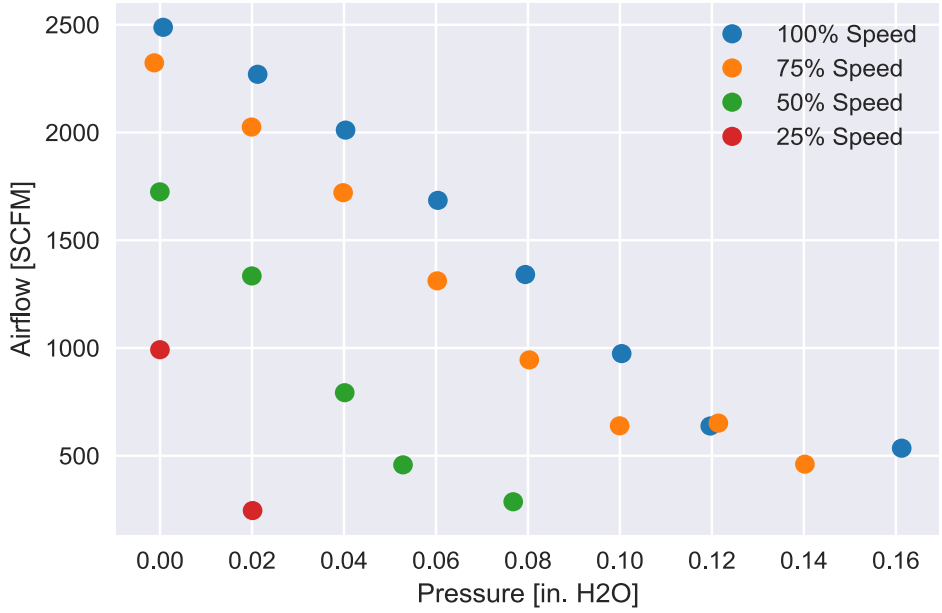


FIGURE 6: EMERGING EC-2 AIRFLOW VS. STATIC PRESSURE

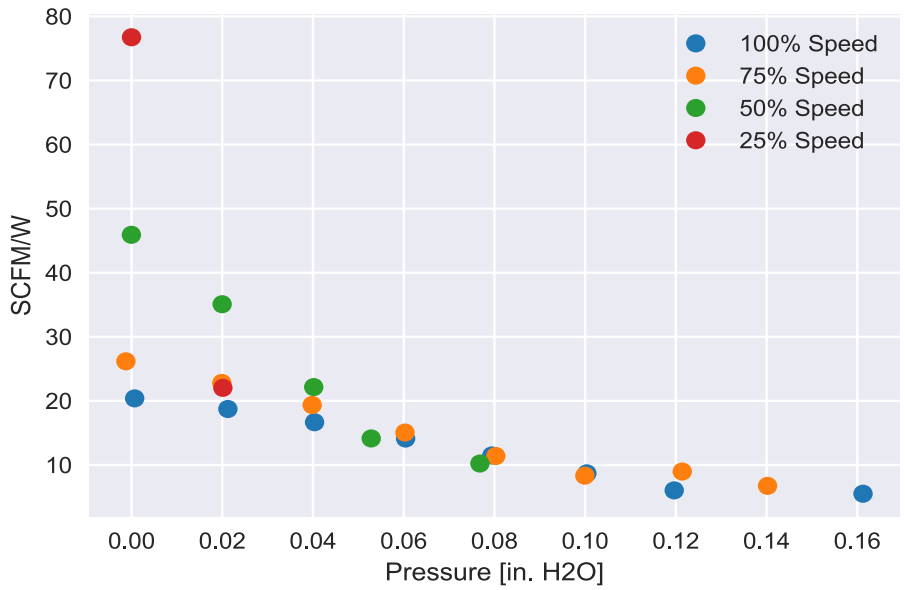


FIGURE 7: EMERGING EC-2 AIRFLOW EFFICIENCY VS. STATIC PRESSURE

MANUFACTURER D TYPE 1

Type 1 is the smaller of the two emerging products we studied. The measured flow rates were consistent with the published data sheet, within the margin of error. The WCEC noted no issues during installation or testing.

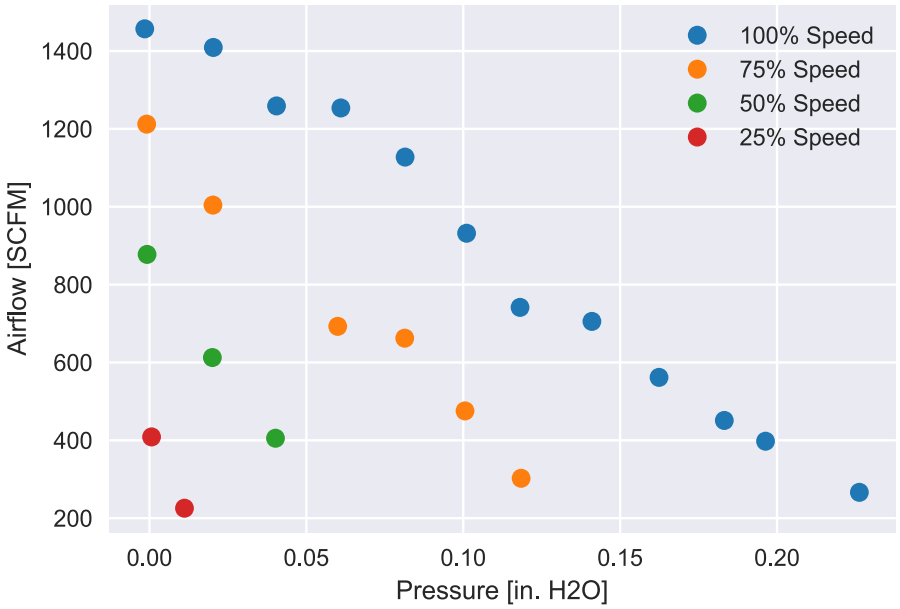


FIGURE 8: EMERGING EC-1 AIRFLOW VS. STATIC PRESSURE

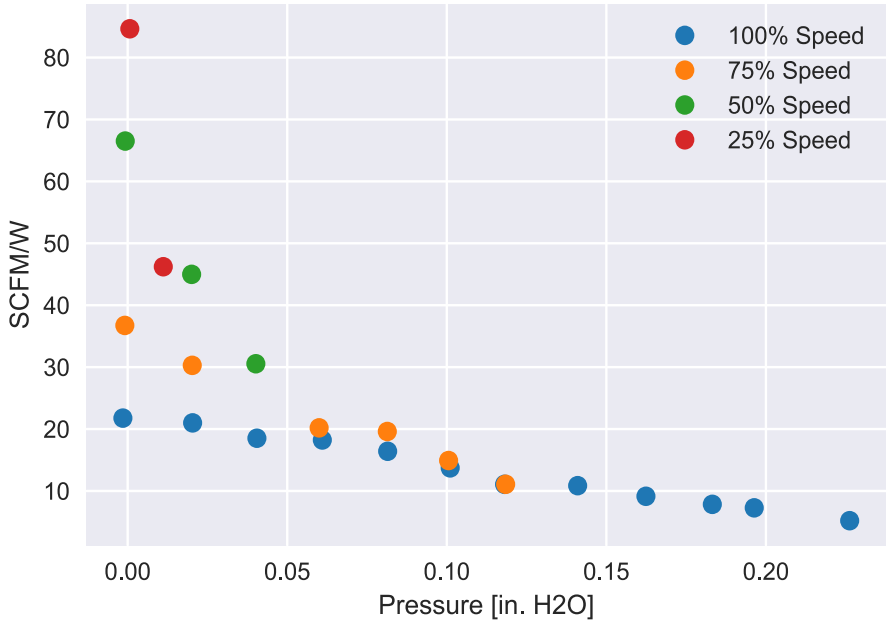


FIGURE 9: EMERGING EC-1 EFFICIENCY VS. STATIC PRESSURE

MANUFACTURER A WITH EC MOTOR OPTION

This product's EC motor ran at a lower full-speed RPM (2,100) than advertised (2,500). WCEC contacted the manufacturer and design engineer to notify them of the difference. A test at a higher RPM is expected to increase airflow but maintain a similar efficiency, as show in the measured trends.

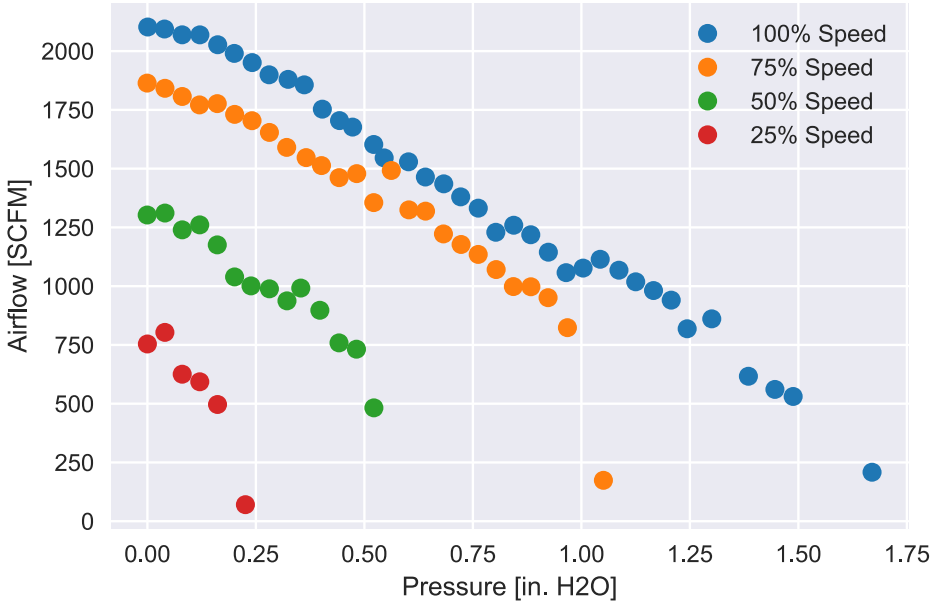


FIGURE 10: MANUFACTURER A WITH EC MOTOR OPTION VS. STATIC PRESSURE

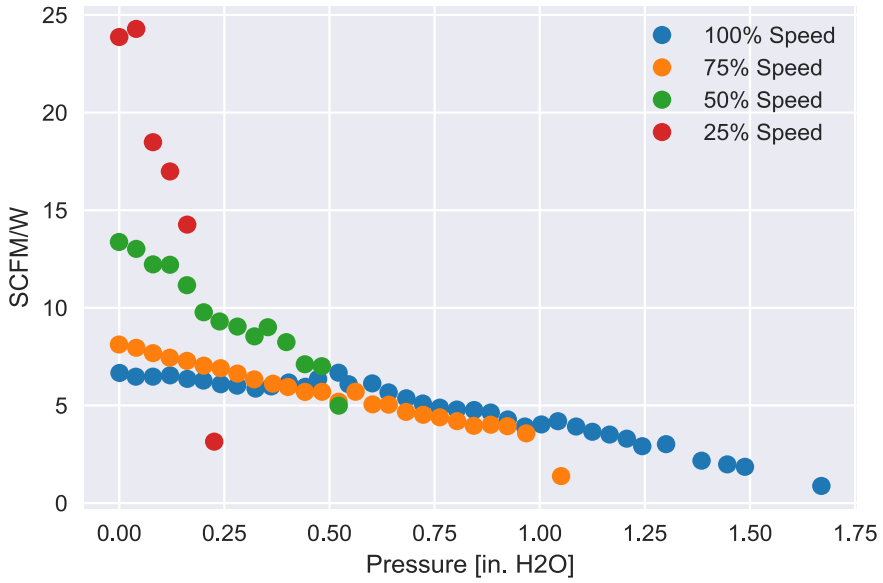


FIGURE 11: MANUFACTURER A WITH EC MOTOR OPTION EFFICIENCY VS. STATIC PRESSURE

ANNUALIZED ENERGY SAVINGS

Annual energy savings over the baseline is calculated assuming the fan runs nine hours per day year-round for a total of 3,285 hours per year. This assumption is based on the average runtime for exhaust fans, as reported by the 2006 California Commercial End-Use Survey (CEUS). The fan efficiency averaged for both emerging product models is compared to the baseline average (**Table 5**). Using that data and the runtime assumption above, the average savings for various static pressures is shown in **Table 6** by kWh/year/SCFM.

TABLE 5: COMPARING FAN EFFICIENCY FOR 0-0.25 IN. H2O.

AVERAGED SCFM/W AT:	EMERGING	BASELINES
0 in. H2O	21.1	5.9
0.0625 in. H2O	16.2	5.5
0.125 in. H2O	8.5	5.2
0.161 in. H2O	7.3	5.1
0.25 in. H2O	NA	4.7

TABLE 6: KWH/YEAR/SCFM SAVED USING EMERGING TECHNOLOGY VS. BASELINE

KWH/YEAR/SCFM AT:	EMERGING	BASELINES	% SAVINGS
0 in. H2O	0.156	0.559	72.2
0.0625 in. H2O	0.203	0.595	65.8
0.125 in. H2O	0.386	0.629	38.5
0.161 in. H2O	0.450	0.647	30.5
0.25 in. H2O	0.0	15.3	NA

This data represents a single baseline fan being replaced by one of the emerging technology products. As discussed, this may not be feasible for certain applications, depending on typical static pressures. The cost of installation was not considered for this report, due to unreliable supply chains created by the COVID pandemic. Distributors noted significant supply shortages, because manufacturers had to scale back production operations.

CONCLUSIONS

This emerging product greatly outperformed baseline models for low static pressures. However, the emerging product performance relative to the baseline decreased as static pressures increased. The emerging product only worked in applications with a differential static pressure of less than 0.25 in. H_2O.

Buildings with large doors, open spaces, short ducting to the exhaust fan, or mechanical pressure relief mechanisms are likely to benefit from this technology. At low static pressures, the emerging technology can attain efficiencies as high as 21 CFM/W, while the best baseline model attained 9 CFM/W under the same conditions.

Based on the laboratory data, hybrid turbine ventilators can reduce exhaust fan power consumption between 25% to 75%, depending on conditions. Since wind-powered operation was not part of this study, there is potential for more savings. Additionally, since the EC motor used by this emerging product had Modbus capabilities, there is also potential for connectivity with a building management system. A well-managed building could leverage this connectivity to reduce fan speeds on demand, thereby increasing energy savings.

RECOMMENDATIONS

Based on the lab test results, the WCEC recommends any product incentives be carefully targeted by application. A combination of surveys, field studies, and outreach efforts would help this emerging product reach the target market and transition into SCE's rebate and incentive programs, more specifically for buildings with exhaust fans that operate at a low static pressure, especially in climates known to have strong winds.

As discussed, this product has significant energy saving potential. However, it is not a blanket solution for every exhaust fan application. Future projects involving hybrid ventilators should perform field measurements of the baseline product *in situ* to verify typical static pressure operating points.

APPENDICES

EMERGING PRODUCT TYPE 2 TABULATED DATA

TABLE 7: EMERGING PRODUCT TYPE 2 TEST RESULTS AT 100% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
245	2488	68	-0.001	0.97	122.0	20.4	24.0	12.8	215.0	0.584
245	2270	60	-0.021	0.98	121.2	18.7	24.4	12.7	213.9	0.580
241	2011	55	-0.040	0.97	120.7	16.7	24.5	12.5	214.1	0.580
241	1685	62	-0.060	0.96	119.3	14.1	24.5	12.1	214.1	0.580
247	1341	54	-0.079	0.97	116.8	11.5	24.5	12.5	213.9	0.560
268	974	34	-0.100	0.97	112.0	8.7	24.6	12.6	213.5	0.540
274	638	26	-0.120	0.95	105.7	6.0	24.7	12.4	213.6	0.520
294	535	31	-0.161	0.95	97.1	5.5	25.3	12.1	212.3	0.480
331	-	-	-0.221	0.95	78.9	-	25.4	13.0	213.8	0.390

TABLE 8: EMERGING PRODUCT TYPE 2 TEST RESULTS AT 75% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
222	2323	55	0.001	0.94	88.7	26.2	19.8	28.1	215.3	0.438
221	2025	48	-0.020	0.94	88.8	22.8	19.8	28.7	215.6	0.437
223	1721	40	-0.040	0.94	88.9	19.4	19.9	28.0	215.8	0.438
225	1312	28	-0.060	0.94	87.1	15.1	20.1	28.1	216.0	0.430
234	945	18	-0.080	0.94	82.9	11.4	20.2	27.6	216.1	0.410
250	639	17	-0.100	0.93	76.7	8.3	20.3	27.4	216.3	0.380
260	651	35	-0.121	0.93	72.6	9.0	20.4	27.0	216.0	0.360
270	461	17	-0.140	0.93	68.4	6.7	20.5	26.9	215.9	0.340
296	-	-	-0.177	0.93	56.6	-	20.7	26.9	215.9	0.282

TABLE 9: EMERGING PRODUCT TYPE 2 TEST RESULTS AT 50% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
167	1725	48	0.000	0.88	37.6	45.9	23.2	21.3	214.1	0.200
166	1334	29	-0.020	0.88	38.0	35.1	23.4	22.1	214.2	0.201
172	793	14	-0.040	0.87	35.8	22.2	23.6	21.7	214.4	0.192
177	458	8	-0.053	0.84	32.4	14.1	24.1	20.4	213.5	0.181
199	286	7	-0.077	0.78	28.0	10.2	24.1	21.3	213.7	0.169
212	-	-	-0.090	0.78	23.8		24.1	21.3	213.5	0.143

TABLE 10: EMERGING PRODUCT TYPE 2 TEST RESULTS AT 25% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/ W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
98	992	27	0.000	0.552	12.9	76.7	24.3	20.1	213.4	0.110
108	246	5	-0.020	0.519	11.1	22.0	21.9	25.1	214.9	0.100
118	-	-	-0.028	0.483	10.4	-	22.0	25.6	214.4	0.100

EMERGING PRODUCT TYPE 1 TABULATED DATA

TABLE 11: EMERGING PRODUCT TYPE 1 TEST RESULTS AT 100% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
386	1457	35	0.001	0.51	66.9	21.8	15.1	20.2	212.2	0.621
384	1409	40	-0.020	0.51	67.1	21.0	14.5	20.9	211.9	0.626
380	1259	32	-0.040	0.51	68.0	18.5	13.8	21.7	212.0	0.634
380	1254	32	-0.061	0.51	68.7	18.2	14.3	21.1	211.9	0.638
378	1127	26	-0.081	0.51	68.7	16.4	14.2	20.7	211.7	0.636
380	932	20	-0.101	0.51	67.9	13.7	14.0	21.5	211.9	0.634
380	741	15	-0.118	0.51	67.0	11.1	14.0	21.3	211.6	0.624
384	705	20	-0.141	0.50	65.0	10.9	14.1	20.6	211.5	0.609
394	562	13	-0.162	0.50	61.4	9.1	14.2	21.5	211.0	0.580
408	451	8	-0.183	0.50	57.5	7.8	14.4	21.0	211.5	0.545
418	398	13	-0.196	0.50	54.7	7.3	14.9	20.9	211.8	0.511
438	266	6	-0.226	0.50	51.2	5.2	14.7	20.4	214.6	0.480
460	-	-	-0.259	0.50	44.1	-	15.2	22.2	214.2	0.410

TABLE 12: EMERGING PRODUCT TYPE 1 TEST RESULTS AT 75% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
302	1212	40	0.001	0.51	33.0	36.7	14.8	19.0	212.5	0.304
300	1004	27	-0.020	0.51	33.2	30.3	14.4	19.4	211.9	0.307
300	693	13	-0.060	0.50	34.3	20.2	14.4	20.4	214.3	0.318
304	662	18	-0.081	0.51	33.8	19.6	14.8	18.7	214.8	0.311
312	476	9	-0.101	0.50	31.9	14.9	15.1	19.7	215.2	0.294
326	302	8	-0.118	0.51	27.3	11.1	15.7	18.1	212.8	0.251
350	-	-	-0.151	0.51	21.2	-	15.8	19.0	212.5	0.197

TABLE 13: EMERGING PRODUCT TYPE 1 TEST RESULTS AT 50% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
214	878	31	0.001	0.52	13.2	66.5	15.8	17.6	212.3	0.120
210	613	15	-0.020	0.52	13.6	45.0	15.3	17.7	212.2	0.123
214	405	13	-0.040	0.52	13.3	30.5	15.2	18.3	213.1	0.121
244	-	-	-0.072	0.52	9.4		15.5	19.9	213.0	0.085

TABLE 14: EP400 TEST RESULTS AT 25% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
112	409	14	-0.001	0.54	4.8	84.6	15.8	17.3	212.8	0.042
112	226	8	-0.011	0.53	4.9	46.2	15.8	17.1	213.1	0.043
112	-	-	-0.012	0.54	4.7	-	15.9	18.0	212.3	0.041

Baseline Manufacturer C Tabulated Data

Table 15: Manufacturer C Test Results

RPM	Airflow [SCFM]	Uncertainty [SCFM]	Pressure [in. H2O]	Apparent Power Factor	True Power [W]	CFM/W	Temp [C]	Humidity [%]	Volts	Amps
1170	2005	36	0.000	0.86	231.8	8.6	11.1	66.6	120.9	2.240
1181	1900	34	-0.020	0.86	233.1	8.2	11.0	68.3	121.0	2.248
1192	1872	41	-0.039	0.86	234.2	8.0	10.9	69.0	121.1	2.255
1203	1800	44	-0.059	0.86	235.2	7.7	10.9	69.7	121.2	2.262
1215	1729	49	-0.081	0.87	230.8	7.5	12.4	66.2	119.2	2.236
1227	1672	46	-0.105	0.87	232.8	7.2	12.2	67.3	119.5	2.247
1239	1633	43	-0.120	0.86	235.2	6.9	12.2	68.2	120.4	2.263
1251	1573	40	-0.140	0.86	236.4	6.7	12.2	68.6	120.7	2.271
1263	1514	37	-0.162	0.87	238.2	6.4	12.2	68.2	120.6	2.282
1275	1380	31	-0.178	0.86	237.5	5.8	12.0	68.7	120.8	2.274
1287	1363	38	-0.201	0.86	237.6	5.7	12.0	69.2	120.9	2.275
1299	1283	33	-0.224	0.86	239.1	5.4	12.3	69.4	121.0	2.289
1311	1198	29	-0.242	0.86	239.4	5.0	12.4	69.6	121.2	2.290
1324	1144	27	-0.258	0.86	239.0	4.8	12.6	69.3	121.1	2.286
1337	1050	22	-0.279	0.86	239.9	4.4	12.9	67.7	121.3	2.290
1350	1000	23	-0.331	0.87	238.8	4.2	13.3	65.1	120.7	2.284
1363	1039	29	-0.365	0.87	242.6	4.3	13.4	64.2	121.0	2.310
1376	1062	31	-0.385	0.87	236.4	4.5	16.7	41.0	118.8	2.286
1389	1042	29	-0.402	0.87	241.2	4.3	16.7	39.9	120.1	2.320
1402	1000	27	-0.430	0.87	243.9	4.1	16.7	39.5	120.2	2.336
1416	971	26	-0.475	0.87	248.0	3.9	16.8	39.4	120.3	2.363
1430	947	24	-0.508	0.88	251.8	3.8	16.9	39.1	120.5	2.385
1444	875	31	-0.542	0.88	253.7	3.4	16.8	40.0	120.5	2.403
1458	827	19	-0.563	0.88	254.3	3.3	17.0	37.8	119.8	2.407
1472	742	18	-0.612	0.88	257.7	2.9	17.2	37.7	120.1	2.431
1486	682	15	-0.638	0.88	259.8	2.6	17.4	38.0	120.4	2.444
1500	604	12	-0.684	0.88	261.3	2.3	17.4	37.5	120.4	2.456
1515	569	13	-0.725	0.88	258.0	2.2	18.0	37.7	119.3	2.452
1530	524	11	-0.768	0.88	258.5	2.0	18.0	37.0	119.1	2.452
1545	451	9	-0.808	0.89	258.5	1.7	18.0	37.1	119.0	2.452
1560	390	8	-0.852	0.88	260.8	1.5	18.2	37.5	119.8	2.462
1575	313	6	-0.888	0.88	261.3	1.2	18.1	37.7	119.9	2.464
1590	234	9	-0.935	0.89	264.8	0.9	14.8	62.3	120.5	2.479

Baseline Manufacturer A with EC Motor Option Tabulated Data

Table 16: Manufacturer A with EC Motor at 100% Speed

RPM	Airflow [SCFM]	Uncertainty [SCFM]	Pressure [in. H2O]	Apparent Power Factor	True Power [W]	CFM/ W	Temp [C]	Humidity [%]	Volts	Amps
1390	2103	40	-0.001	0.62	315.5	6.7	12.1	36.6	117.5	4.314
1384	2094	45	-0.039	0.63	323.5	6.5	11.6	37.6	119.3	4.310
1378	2069	44	-0.080	0.62	319.6	6.5	11.1	38.6	119.4	4.322
1374	2069	50	-0.121	0.62	316.3	6.5	11.1	39.2	119.2	4.296
1368	2027	48	-0.162	0.62	318.7	6.4	11.1	39.1	119.1	4.315
1366	1990	46	-0.200	0.62	317.2	6.3	11.1	39.0	119.1	4.309
1354	1951	44	-0.241	0.62	320.6	6.1	11.1	39.0	118.9	4.337
1352	1899	42	-0.280	0.61	315.9	6.0	11.1	39.4	118.3	4.363
1348	1880	41	-0.324	0.62	320.6	5.9	11.1	39.2	118.5	4.381
1348	1856	40	-0.361	0.60	310.7	6.0	11.4	38.6	118.4	4.372
1344	1753	42	-0.403	0.55	283.9	6.2	11.5	38.4	118.5	4.386
1340	1704	39	-0.443	0.55	286.1	6.0	11.5	38.3	118.5	4.366
1346	1677	38	-0.473	0.51	263.7	6.4	15.0	40.1	119.0	4.349
1338	1603	35	-0.522	0.47	240.1	6.7	14.0	41.7	118.6	4.347
1338	1546	39	-0.546	0.49	253.9	6.1	13.9	42.4	119.9	4.310
1332	1529	38	-0.602	0.48	249.5	6.1	13.9	43.3	120.8	4.304
1332	1464	35	-0.641	0.50	258.3	5.7	14.0	43.2	120.7	4.304
1332	1435	34	-0.683	0.51	267.5	5.4	14.2	43.2	120.8	4.301
1332	1380	31	-0.722	0.52	270.5	5.1	14.2	44.0	120.8	4.296
1330	1332	29	-0.762	0.53	272.5	4.9	14.2	42.0	120.6	4.285
1332	1229	25	-0.803	0.49	256.5	4.8	14.2	41.2	120.7	4.310
1330	1259	32	-0.844	0.51	264.2	4.8	14.3	39.8	120.5	4.309
1334	1219	30	-0.883	0.51	262.8	4.6	14.4	39.1	120.4	4.297
1344	1145	27	-0.924	0.51	267.2	4.3	15.7	41.0	119.6	4.344
1348	1058	23	-0.965	0.52	269.7	3.9	15.8	39.3	120.4	4.330
1350	1077	24	-1.004	0.51	267.4	4.0	15.7	40.6	120.4	4.317
1352	1114	29	-1.043	0.51	265.8	4.2	15.8	41.5	120.1	4.325
1360	1068	27	-1.087	0.53	272.4	3.9	15.8	40.5	120.0	4.322
1366	1019	24	-1.125	0.54	279.0	3.7	15.9	40.9	119.9	4.332
1374	981	22	-1.166	0.54	279.7	3.5	15.9	39.5	119.9	4.308
1384	941	21	-1.207	0.55	285.1	3.3	15.8	38.9	119.8	4.312
1396	819	16	-1.244	0.55	281.1	2.9	15.8	38.7	119.5	4.291
1414	861	30	-1.300	0.56	285.3	3.0	15.8	39.7	119.6	4.277
1472	561	13	-1.446	0.55	282.9	2.0	15.8	39.2	119.6	4.268
1448	617	16	-1.385	0.56	284.1	2.2	15.8	40.3	118.8	4.282
1490	531	12	-1.488	0.56	285.7	1.9	15.8	40.2	118.9	4.280

RPM	Airflow [SCFM]	Uncertainty [SCFM]	Pressure [in. H2O]	Apparent Power Factor	True Power [W]	CFM/ W	Temp [C]	Humidity [%]	Volts	Amps
1554	208	7	-1.670	0.60	237.7	0.9	16.3	40.7	120.0	3.300

Table 17: Manufacturer A with EC Motor at 75% Speed

RPM	Airflow [SCFM]	Uncertainty [SCFM]	Pressure [in. H2O]	Apparent Power Factor	True Power [W]	CFM/ W	Temp [C]	Humidity [%]	Volts	Amps
1232	1864	47	0.001	0.60	229.5	8.1	15.7	40.4	120.0	3.194
1230	1842	46	-0.040	0.60	231.6	8.0	14.7	43.0	119.9	3.223
1232	1807	44	-0.080	0.60	235.3	7.7	14.3	44.7	119.8	3.267
1230	1771	43	-0.120	0.60	237.9	7.4	13.9	46.1	120.0	3.303
1230	1777	43	-0.161	0.60	243.9	7.3	13.7	47.2	119.9	3.374
1230	1731	41	-0.201	0.60	245.9	7.0	13.6	47.7	119.7	3.397
1230	1704	39	-0.241	0.60	246.6	6.9	13.8	47.6	119.6	3.409
1232	1654	37	-0.281	0.61	249.4	6.6	13.7	48.3	119.7	3.438
1232	1590	34	-0.321	0.61	251.0	6.3	13.6	48.7	119.7	3.459
1232	1547	32	-0.366	0.61	253.0	6.12	13.5	49.0	119.5	3.482
1230	1513	31	-0.401	0.61	254.5	5.95	13.5	49.3	119.6	3.493
1230	1462	35	-0.442	0.61	256.8	5.69	13.5	49.4	119.5	3.516
1230	1479	36	-0.482	0.61	259.4	5.70	13.5	49.9	118.7	3.563
1232	1356	30	-0.522	0.61	261.1	5.19	13.4	50.4	118.4	3.588
1230	1492	52	-0.562	0.61	261.7	5.70	13.3	51.0	119.7	3.572
1232	1325	41	-0.603	0.61	262.0	5.06	13.3	51.3	119.8	3.570
1230	1319	40	-0.641	0.61	261.7	5.04	13.2	51.7	120.4	3.560
1230	1222	35	-0.682	0.61	261.7	4.67	13.0	52.0	120.4	3.562
1232	1177	32	-0.723	0.61	260.4	4.52	12.9	52.8	120.5	3.533
1230	1135	30	-0.762	0.62	258.4	4.39	13.3	51.9	120.2	3.440
1230	1071	27	-0.804	0.64	255.2	4.19	13.0	52.6	120.1	3.342
1232	998	23	-0.843	0.64	252.2	3.96	12.9	53.5	120.0	3.296
1230	997	23	-0.884	0.63	248.5	4.01	12.9	53.3	120.2	3.266
1230	951	37	-0.923	0.63	241.6	3.94	12.9	52.9	120.2	3.187
1230	823	28	-0.968	0.63	230.6	3.57	13.0	53.0	120.9	3.027
1230	174	5	-1.051	0.57	126.0	1.38	13.7	52.4	120.8	1.828

TABLE 18: MANUFACTURER A WITH EC MOTOR AT 50% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
902	1303	24	0.001	0.58	97.4	13.4	12.5	54.1	119.4	1.414
900	1311	35	-0.040	0.58	100.7	13.0	12.3	54.7	119.5	1.452
902	1240	31	-0.080	0.58	101.4	12.2	12.2	56.1	120.7	1.448
902	1261	32	-0.121	0.58	103.3	12.2	12.2	56.1	120.8	1.471
902	1176	28	-0.161	0.58	105.4	11.2	12.2	55.9	120.6	1.494
902	1039	22.0	-0.201	0.59	106.4	9.8	12.7	54.9	120.8	1.505
900	1001	20	-0.239	0.58	107.6	9.3	12.8	54.9	120.4	1.540
902	989	27	-0.281	0.58	109.4	9.0	12.8	54.9	120.2	1.556
902	938	24	-0.322	0.58	109.8	8.5	12.9	54.4	120.3	1.566
902	992	27	-0.353	0.59	110.1	9.01	12.9	54.6	120.3	1.564
900	897	22	-0.397	0.583	108.9	8.24	12.9	54.1	120.6	1.550
902	759	19	-0.442	0.578	106.7	7.11	13.0	54.1	120.7	1.529
902	732	22	-0.482	0.577	104.4	7.01	13.0	53.9	120.7	1.498
902	482	10	-0.522	0.576	96.7	4.99	13.4	53.2	121.0	1.387

TABLE 19: MANUFACTURER A WITH EC MOTOR AT 25% SPEED

RPM	AIRFLOW [SCFM]	UNCERTAINTY [SCFM]	PRESSURE [IN. H2O]	APPARENT POWER FACTOR	TRUE POWER [W]	CFM/W	TEMP [C]	HUMIDITY [%]	VOLTS	AMPS
572	754	15	0.000	0.524	31.6	23.9	13.6	48.7	121.2	0.497
572	803	21	-0.040	0.530	33.1	24.3	13.7	49.1	120.9	0.516
570	625	16	-0.080	0.529	33.8	18.5	14.0	49.5	120.8	0.530
572	593	14	-0.121	0.530	34.9	17.0	14.1	49.4	120.8	0.546
570	497	10	-0.162	0.531	34.8	14.3	14.4	49.1	120.5	0.544
570	70	1.4	-0.226	0.518	22.4	3.1	14.4	49.9	120.5	0.359

Manufacturer A with PSC Motor Tabulated Data

Table 20: Manufacturer A with PSC Motor

RPM	Airflow [SCFM]	Uncertainty [SCFM]	Pressure [in. H2O]	Apparent Power Factor	True Power [W]	CFM/ W	Temp [C]	Humidity [%]	Volts	Amps
1456	2261	46	0.001	0.97	576.1	3.9	10.5	63.7	119.8	4.972
1435	2195	56	-0.041	0.97	580.4	3.8	9.9	65.4	119.8	5.008
1444	2162	54	-0.077	0.97	578.2	3.7	9.4	66.7	119.9	4.987
1430	2116	52	-0.120	0.97	582.0	3.6	9.0	68.0	119.9	5.019
1430	2050	57	-0.160	0.97	585.1	3.5	8.8	69.0	119.8	5.045
1421	2050	57	-0.201	0.97	591.4	3.5	8.6	70.1	119.8	5.100
1414	1966	52	-0.241	0.97	592.8	3.3	8.5	70.4	119.7	5.122
1410	1921	50	-0.282	0.97	591.9	3.2	8.4	71.2	119.3	5.116
1388	1888	48	-0.321	0.97	589.4	3.2	8.3	71.6	117.8	5.176
1400	1874	48	-0.360	0.97	589.8	3.2	8.5	72.3	118.0	5.174
1392	1821	45	-0.400	0.97	594.0	3.1	8.5	72.3	118.1	5.200
1375	1778	51	-0.445	0.97	598.8	3.0	8.4	72.6	119.3	5.180
1385	1711	48	-0.483	0.97	601.6	2.8	8.4	72.9	119.1	5.203
1380	1786	52	-0.524	0.97	601.1	3.0	8.6	73.0	119.1	5.210
1372	1638	44	-0.561	0.97	603.0	2.7	8.5	73.2	119.1	5.229
1375	1679	46	-0.604	0.97	610.9	2.7	8.7	73.7	118.9	5.308
1370	1580	41	-0.644	0.97	613.4	2.6	8.8	74.1	119.0	5.336
1370	1544	39	-0.681	0.97	608.4	2.5	8.8	74.0	118.9	5.300
1375	1475	35	-0.727	0.97	612.7	2.4	9.0	73.1	118.7	5.345
1364	1420	33	-0.763	0.97	609.3	2.3	8.8	73.7	118.7	5.312
1360	1404	32	-0.804	0.96	607.2	2.3	8.7	74.2	118.8	5.302
1369	1328	29	-0.850	0.97	604.1	2.2	8.7	74.4	118.6	5.275
1360	1330	36	-0.890	0.97	600.5	2.2	8.7	75.0	118.7	5.214
1365	1230	31	-0.918	0.97	596.8	2.1	8.7	75.0	118.0	5.212
1365	1225	31	-0.965	0.97	596.1	2.1	8.7	75.3	118.7	5.200
1360	1129	26	-1.003	0.96	594.0	1.9	8.7	75.4	118.6	5.193
1371	1162	28	-1.045	0.97	590.9	2.0	8.7	75.7	118.6	5.143
1375	1018	21	-1.085	0.97	586.0	1.7	8.8	75.5	118.3	5.100
1382	1089	24	-1.119	0.97	583.8	1.9	8.8	75.7	118.2	5.104
1382	989	20	-1.167	0.97	580.3	1.7	8.9	75.6	118.6	5.060
1392	985	20	-1.211	0.97	576.6	1.7	8.7	76.1	118.6	5.000
1404	899	17	-1.246	0.97	572.6	1.6	8.7	76.2	118.8	4.994
1410	884	16	-1.287	0.97	565.9	1.6	8.9	76.3	118.7	4.900
1423	879	16	-1.329	0.97	557.7	1.6	9.0	76.2	118.9	4.825
1430	896	22	-1.384	0.98	545.7	1.6	9.1	76.1	118.8	4.708
1438	769	16	-1.418	0.97	532.3	1.4	9.2	75.9	117.9	4.676

RPM	Airflow [SCFM]	Uncertainty [SCFM]	Pressure [in. H2O]	Apparent Power Factor	True Power [W]	CFM/ W	Temp [C]	Humidity [%]	Volts	Amps
1457	632	16	-1.494	0.96	510.3	1.2	9.3	75.7	118.0	4.492
1490	620	16	-1.543	0.98	499.3	1.2	9.4	75.5	118.7	4.300
1510	452	17	-1.707	0.98	434.6	1.0	9.1	74.5	119.4	3.727
1592	216	4	-1.896	0.96	362.1	0.6	10.2	74.3	119.7	3.139

Manufacturer B Tabulated Data

Table 21: Manufacturer B Results

RPM	Airflow [SCFM]	Uncertainty [SCFM]	Pressure [in. H2O]	Apparent Power Factor	True Power [W]	CFM/W	Temp [C]	Humidity [%]	Volts	Amps
1571	2463	70	0.000	0.96	571.2	4.3	13.4	61.7	212.6	2.799
1576	2409	68	-0.040	0.96	574.2	4.2	13.1	62.8	212.4	2.802
1535	2358	65	-0.080	0.97	579.1	4.1	12.9	63.9	212.7	2.815
1495	2318	62	-0.120	0.96	581.9	4.0	12.7	64.2	212.6	2.848
1533	2351	64	-0.159	0.96	587.1	4.0	13.0	64.1	213.2	2.878
1494	2295	61	-0.202	0.96	590.8	3.9	13.0	63.9	214.1	2.877
1472	2300	61	-0.241	0.96	595.7	3.9	12.9	63.8	214.2	2.905
1465	2244	59	-0.281	0.96	595.3	3.8	12.9	63.9	214.0	2.904
1474	2225	58	-0.321	0.96	599.5	3.7	12.8	64.1	214.0	2.907
1483	2169	55	-0.361	0.96	602.6	3.6	12.9	64.4	213.9	2.934
1492	2156	54	-0.402	0.96	602.3	3.6	12.9	64.2	214.3	2.932
1443	2126	53	-0.441	0.96	606.3	3.5	12.9	64.2	214.1	2.963
1469	2077	50	-0.481	0.96	608.2	3.4	13.1	64.9	214.1	2.963
1436	2059	49	-0.523	0.96	612.1	3.4	13.3	64.0	214.0	2.995
1433	2027	48	-0.562	0.96	617.2	3.3	13.4	63.1	214.0	3.009
1460	1999	46	-0.603	0.96	619.0	3.2	13.5	62.9	214.1	3.015
1429	2018	47	-0.642	0.96	616.8	3.3	13.6	62.5	214.1	3.000
1427	1956	44	-0.684	0.96	616.8	3.2	13.5	62.8	214.2	3.000
1470	1944	44	-0.724	0.96	619.6	3.1	13.5	62.6	214.2	3.008
1484	1909	42	-0.760	0.96	619.5	3.1	13.6	63.0	214.1	3.000
1485	1865	40	-0.806	0.96	622.9	3.0	13.7	62.3	214.2	3.035
1427	1841	39	-0.840	0.97	621.9	3.0	13.8	61.5	214.2	3.000
1444	1788	37	-0.885	0.95	626.9	2.9	13.8	61.7	213.9	3.072
1431	1745	35	-0.923	0.95	628.1	2.8	13.7	61.8	214.1	3.073
1492	1714	34	-0.966	0.96	623.8	2.7	13.8	61.6	213.4	3.058
1451	1655	37	-1.005	0.96	621.7	2.7	13.9	60.7	213.8	3.016
1484	1615	35	-1.044	0.96	628.9	2.6	13.9	60.3	213.8	3.063
1474	1585	34	-1.086	0.96	629.3	2.5	13.9	59.8	213.6	3.065
1449	1565	33	-1.124	0.96	625.4	2.5	14.4	59.2	213.9	3.040
1499	1502	31	-1.164	0.96	622.9	2.4	14.4	58.6	213.9	3.027
1505	1440	28	-1.207	0.96	621.7	2.3	14.5	58.8	213.7	3.029
1481	1397	27	-1.242	0.96	614.2	2.3	14.6	58.4	213.1	3.000
1503	1355	25	-1.287	0.95	606.5	2.2	14.6	58.3	212.9	3.000
1525	1242	22	-1.323	0.97	596.2	2.1	14.7	57.4	212.7	2.900
1489	1279	24	-1.367	0.96	591.6	2.2	15.0	56.4	213.4	2.900
1512	1077	20	-1.405	0.96	573.9	1.9	15.0	56.3	212.9	2.800

RPM	Airflow [SCFM]	Uncertainty [SCFM]	Pressure [in. H2O]	Apparent Power Factor	True Power [W]	CFM/W	Temp [C]	Humidity [%]	Volts	Amps
1553	1079	24	-1.449	0.96	555.8	1.9	14.9	55.9	213.7	2.700
1531	1032	22	-1.484	0.97	542.6	1.9	15.0	55.7	213.5	2.631
1573	876	16	-1.530	0.96	490.4	1.8	15.1	55.4	213.8	2.400
1586	794	15	-1.575	0.95	468.9	1.7	15.3	53.5	213.9	2.300
1611	649	12	-1.607	0.95	446.6	1.5	15.4	53.1	213.8	2.200
1564	631	16	-1.662	0.98	416.5	1.5	15.5	52.5	213.6	2.000
1660	235	4	-1.802	0.93	318.4	0.7	15.4	52.4	213.5	1.600