Report by **SBW CONSULTING, INC.**

PRELIMINARY ASSESSMENT OF AIR SAVING UNITS (ASUS)

Submitted to
NORTHWEST ENERGY EFFICIENCY ALLIANCE
421 SW Sixth Avenue
Suite 600
Portland, OR 97204

Submitted by
SBW CONSULTING, INC.
2820 Northup Way, Suite 230
Bellevue, WA 98004

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ENERGY + WATER + EFFICIENCY

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1. Background

The Northwest Energy Efficiency Alliance (NEEA) has contracted SBW Consulting (SBW) to investigate the energy saving potential and performance of a compressed-air-saving device called an air saving unit (ASU).

ASUs were developed in Japan by Parker Hannifin (Parker), for the automotive industry as a means of saving energy when blowing dust or other contaminants from car bodies and parts prior to painting. The use of ASUs has expanded both geographically to other Asian countries and Europe, and in their breadth of applications. Parker is in the process of bringing this technology to North America.

Parker Hannifin Corporation (Parker) is a Fortune 250 Company, employing more than 50,000 people in over 300 manufacturing sites around the world. Their Automation Group consists of 16 divisions with 2015 fiscal year revenues of approximately $1.3 billion. Their approach to providing customers with differentiated and energy-efficient devices and products led a major Japanese auto manufacturer to ask Parker to solve an air blow-off issue in their factories. Solving this problem resulted in the development of ASUs and in less than three years, Parker has generated more than $3.0 million dollars in sales for this product line.

Parker has asked NEEA to investigate the energy-saving potential of this technology with the intent of obtaining a positive recommendation for the installation of ASUs as energy-saving devices.

2. ASU DESCRIPTION

Open blowing of compressed air is often used in industry and is nearly always a wasteful means of achieving some end. Examples would include the removal of dust or contaminants from a specific process or area; cooling parts that have been heated during the manufacturing process; drying parts that are wetted as a necessary part of manufacturing; to provide cooling air to employees or overheated bearings; to position parts along a production line; or to achieve numerous other specific effects. Reasons for employing open blowing usually include some combination of the following:

- Lack of understanding of the cost of compressed air
- Ignorance of more efficient means of achieving the desired effect
- Ease of implementation
- Staff that is unaware of its use in "inherited" systems

ASUs save energy by interrupting, at adjustable frequencies, the flow of compressed air to blowing end uses. A mechanical advantage is provided in that a series of impulses is delivered to the end use rather than a steady stream of air. The impulses are delivered with somewhat greater force than a steady stream of air as the pressure in the ASU has an opportunity to recover during the OFF period of each cycle. The effect is similar to the slight "kick" that is felt when the spray head on a garden hose under pressure is first opened. That kick is due to the full pressure of the water starting to flow, but the pressure in the hose then drops quickly to as a steady stream develops. Each time the spray head is closed, the pressure rebuilds and the kick is felt the next time it is opened. The impulses delivered by the ASU are analogous to the spray head only the impulse delivery rate is much faster. Figure 1 shows the initial impulse for each valve opening as well as suggesting the independent settings of ON (flowing) time and OFF (no flow) time.

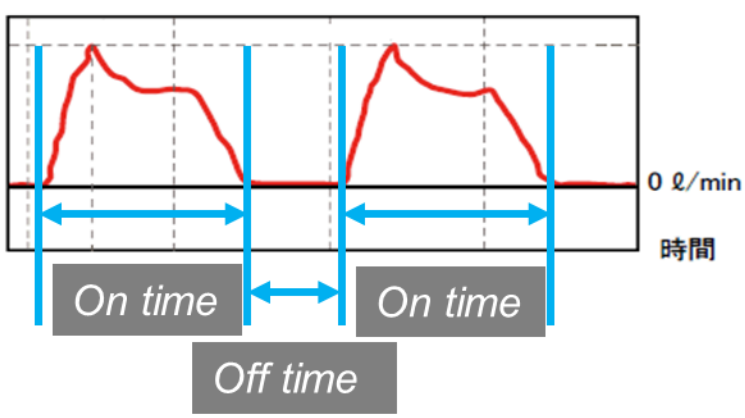

Figure 1: Data plot portraying both the cycling nature of ASU operation and the initial impulse that is delivered each time the ASU is opened.

Seven ASU models are available. Pertinent specifications of each are provided in Table 1 below:

Table 1: ASU product line overview

Part Number	Maximum Rated Flow (CFM)	Pressure Ranges (PSI)		Range of Pulse Rates (Cycles/Sec)	Electrical Requirements (Voltage & Power)
		System Pressure	Pilot Pressure		
ASV200	5.3	43.5 - 116	43.5 - 116	0 - 5	N.A.
ASV2000	70.6	0 - 116	43.5 - 116	0 - 5	N.A.
ASV5000	176.6	0 - 116	43.5 - 116	0 - 5	N.A.
ASV13000	459.1	0 - 116	43.5 - 116	0 - 5	N.A.
ASV15000	529.7	0 - 116	43.5 - 116	0 - 5	N.A.
ASC500	15.9	29 – 101.5	N.A.	2 - 22	24 VDC, 1.2 W
ASO500	15.9	29 – 72.5	N.A.	2 - 22	24 VDC, 1.2 W

There are basically two categories of ASUs, those whose cycle frequency is controlled by a pilot pressure (ASVs) and those whose frequency is controlled electronically (ASC or ASO).

Pneumatically-controlled ASUs (ASVs) have their cycle frequencies set by independently adjusting the durations of open (“ON”) and closed (“OFF”) times that define each cycle. The maximum pulse frequency for all five ASV models is designated as 5 Hz (cycles per second) and their rated airflow capacities range from 5.3 to 530 cfm at 72.5 psig. Each ASV has two pneumatic circuits isolated from each other. The main circuit carries the air that is to be delivered to the end use and is repetitively opened (flowing) and closed (not flowing). The pressure in this circuit can be any value up to a maximum of 116 pounds per square inch (psi). A secondary circuit, the pilot, provides the power necessary to open and close the main circuit. The pilot pressure needs to be between 43.5 and 116 psig and would generally be lower than that of the main circuit’s compressed air. Because the pilot pressure affects the frequency of valve operation, it should be provided via a pressure regulator. Exceeding the specified maximum pressures could affect ASV performance. Figure 2 shows a model ASV2000 ASU with parts common to all ASVs labeled. Not all ASVs have exactly the same configuration.

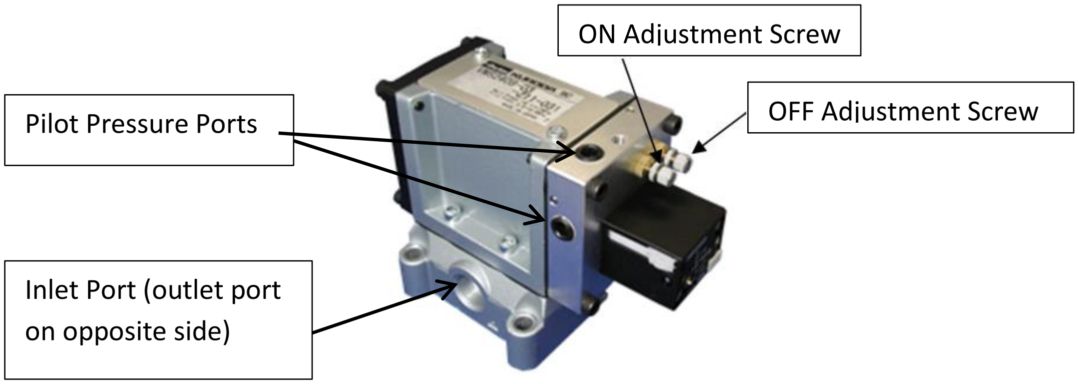

Figure 2: ASV 2000

Electronically-controlled ASUs (specified as ASCs or ASOs) always operate at a 50% duty cycle (both ON and OFF periods are of equal duration) with the frequency set at between 2 and 22 Hz by a single adjusting screw. The ASO model is a normally-open valve and the ASC model is normally closed. There is only one model of each and the capacities of both are rated at 15.9 cfm at 72.5 psig. These models require 24 VDC power, drawing 1.2 W, to operate. Figure 3 shows the configuration common to both the ASC500 and ASO500 models.

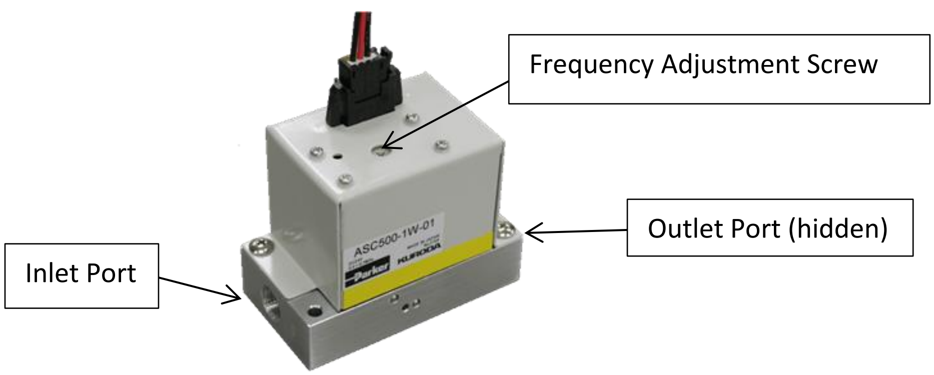

Figure 3: ASC500

For either ASU type, savings are achieved by reducing air flow to the blowing end-use due to the interruption of the compressed air flow during the OFF period of each cycle. The impact of this flow reduction on end-use effectiveness is compensated by the recovery of full or nearly-full system pressure during each OFF portion of the cycle. This results in a brief impulse of higher pressure air at the beginning of each ON portion of the cycle. Following this initial impulse, both the pressure and flow reduce to a steady state condition for the remainder of the ON period; in a steady blow situation, i.e. without an ASU, the reduced pressure and flow conditions would then be continuous. The rapid succession of impulses serves to more effectively dislodge or move whatever the target material might be.

All models can be ordered with standard silicon-based grease or petrolatum grease, the latter for use in painting operations. Parker offers a 1-year warranty from the date of installation; should a failure occur, either a new unit or refund is provided. A Parker 5-Year Extended Warranty is also available on a case-by-case basis. For smaller capacity ASUs (ASV2000 and smaller as well as ASC500 and ASO500) the only serviceable parts are provided along with the appropriate grease in a repair kit (approximately $50) should the customer choose to rebuild a leaking valve on their own. Larger valves are all ASVs and have metal-to-metal seals that are best serviced by trained personnel. These larger valves have expected lives of at least six years operating continuously at their maximum five Hz.

All valves except the smallest (ASV200) are available with standard NPT inlet and outlet ports, with sizes ranging from 1/8” for the ASC/O models to 1-1/4” for the ASV15000 valve. The ASV200 comes with M5 ports. Pilot pressure for the ASVs can be provided via 1/4” tubing and should include a regulator to maintain constant pressure as the pressure setting influences the valve cycle rate.

Adjustment:

Setting the duty cycle and duration of the pulses on the ASVs is accomplished by fully closing the ON adjustment screw and fully opening the OFF adjustment screw as a starting point. Opening the ON screw and closing the OFF screw a prescribed number of turns (specific to each model) achieves an approximate 50% duty cycle and cycle frequencies between 1.5 and 2 Hz (model specific). ON durations can then be decreased by further opening the ON screw, while OFF durations are decreased by further closing the OFF screw. Adjusting the ON and OFF screws asymmetrically (i.e. adjusting one more turns than the other) will change the duty cycle, which may be desirable, for instance in a case where only an occasional pulse of air is necessary. Decreases in either ON or OFF durations will increase cycle frequency and vice versa. It may be necessary to attempt several different settings before achieving one that works well for a particular application. Lock nuts are provided to maintain screw positions once the desired settings are achieved.

Competing products:

Air nozzles, sometimes referred to as engineered nozzles, can be purchased off the shelf. They are designed to focus an air stream in a smaller area than can be achieved by a pipe that has simply been cut off, as well as entraining ambient air to augment the volume of air delivered to the target.

Custom-made devices, such as pipes with drilled holes at regular intervals so that air will blown onto a target along the entire length of the pipe or tubing that has been cut off and crimped to reduce the size of the opening.

3. Estimated Cost Effectiveness of ASUs

Table 2 below provides an indication of the potential cost effectiveness of each ASU model. The results in this table do not take into account the effectiveness of the reduced flow to meet the requirements of any specific application. Values in this table are based on the following assumptions:

- An energy cost of $0.065/kWh, based on average commercial/industrial rates in the Pacific Northwest
- Compressor specific power of 20 kW/100 cfm
- 3840 annual operating hours (16 hours/day, 20 days/month, 12 months/year)
- 3-year simple payback acceptability criterion
- Rated flows and list prices provided by Parker for ASUs incorporating silicon-based grease (petrolatum grease adds 2% to cost of ASVs or 3% to cost of ASC or ASO models)
- Nominal costs assume 4 hours of internal labor at $35/hour for installation and adjustment plus additional equipment (e.g. regulator or electrical power to ASU and miscellaneous fittings, etc.)

Table 2: Estimated reduction from rated maximum compressed air flow necessary to achieve a 3-year simple payback for each ASU model based on assumptions specified in the text.

ASU model	Rated Flow (cfm)	ASU List Price ($)	Nominal Install Cost ($)	Total Cost ($)	Flow Reduction (%)	Flow Reduction (cfm)	Energy Savings ($/year)	Simple Payback (years)
ASV200	5.3	$255	$240	$495	57%	3.0	$165	3.0
ASC500	15.9	$398	$240	$638	25%	3.9	$213	3.0
ASO500	15.9	$398	$240	$638	25%	3.9	$213	3.0
ASV2000	70.6	$429	$240	$669	6%	4.1	$223	3.0
ASV5000	176.6	$461	$410	$871	3%	5.3	$290	3.0
ASV13000	459.1	$930	$410	$1,340	2%	8.2	$447	3.0
ASV15000	529.7	$1,225	$410	$1,635	2%	10.0	$545	3.0

It is unlikely the ASV200 valve could meet the 57% flow reduction necessary to achieve a three-year simple payback based on the assumptions made in developing Table 2.

4. Potential ASU Applications

Literature provided by Parker indicates several potential applications for which ASUs would be effective as follows:

- Removal of cuttings, shavings etc. (i.e. swarf) as a result of machining processes
- PET bottle transfer and cleaning
- Parts feeding
- Paper feeding/ handling
- Providing ionized air for PET bottle or can cleaning process
- Control of Air Knife applications

This list is not considered exhaustive and new applications are expected to be identified as the ASUs are incorporated into more systems.

Those applications using compressed air to move material or objects in some manner, such as blowing away waste material from cutting or machining processes or blowing off dust in preparation for a subsequent process, are most likely to benefit. Applications depending on the quantity of air delivered to achieve an intended effect, such as cooling or drying, would be less likely to benefit as the ASUs reduce the total volume of air delivered. In drying operations where droplets of water could be atomized, as opposed to evaporating in a compressed air stream, might benefit from the use of an ASU.

Industries

The industries listed below have been identified by Parker as having had ASUs applied. This list will likely expand with time, as the open blowing end use is found in most manufacturing facilities where compressed air is in use.

- Micro Electronics
- Food and Beverage
- Pharmaceuticals
- Plastics
- Tooling and Molding
- Automotive
- Tires
- Packaging

5. Planned Means of ASU Distribution

Parker is in the process of launching the distribution of ASUs via three different channels. The first is Parker's own Tri-Tech group, which consists of three distributors of fluid power products (pneumatic, hydraulic and electro-mechanical). Each is well established and has its own specialists in identifying and meeting customer needs. Parker also has relationships with distributors in the Pacific Northwest.

In addition, negotiations are in progress for the other two channels. One of these is with Exair, a major provider of compressed air products. As with the Tri-Tech group, Exair is well established and is well known in the field of compressed air. The intent is for Exair to act as an OEM with ASUs highlighted in their catalog as an energy-saving device.

Negotiations are also underway with Metro Air Compressor, a distributor of multiple lines of compressed air equipment and a significant compressed air system service provider in Michigan. Metro Air provides energy audits as one of their services and their presence in numerous facilities in the state provide opportunities for promoting the use of ASUs. Neither this channel nor the Exair channel will be exclusive agreements, leaving the potential for similar agreements open.

6. Potential Regional Benefits from ASU Implementation

Table 3 provides the derivation of a cursory evaluation of the potential for electrical savings that might be realized from the implementation of ASUs in the Pacific Northwest. Potential demand reduction is on the order of 1 aMW with annual energy savings on the order of 9 GWh. Sources of information and assumptions made in this derivation are provided below the table.

Table 3: Derivation of estimated potential electric energy reductions resulting from the installation of ASUs on compressed air systems in the Pacific Northwest

	Percent	aMW	GWh
Total Pacific NW Electric Demand & Consumption[1]	100%	20,000	175,200
Industrial Share of Total[2]	19%	3,800	33,288
Compressed Air Share of Industrial[3]	12%	456	3,995
Blowing End Use Share of Compressed Air[4]	15%	68	599
Potential Penetration of Blowing End Uses Over 20 Years[5]	30%	20.5	180
Potential Average ASU Savings[6]	30%	**6.2**	**54**

Sources:	1 - aMW value from NWPPC 6th Plan; GWh value assumes 8760 hours/year at aMW
	2 - Percent value derived from NWPPC 6th Plan
	3 - Percentage derived from USDOE Advanced Manufacturing Office 2010 report by Energetics, Inc.
	4 - Percentage estimated based on field experience
	5 - Cumulative savings over 20 years - percentage is estimated
	6 - 30% potential savings is a conservative estimate based on manufacturer's estimate of 40%

In addition to reducing electrical energy generation needs, ASUs could also provide the following non-electric benefits:

- Power plant emission reductions
- Reduced compressed air system maintenance requirements
- Improved product quality (e.g. better, more consistent paint on finished products)
- Reliability (ASUs reduce wasted air, improving overall air supply system)
- Productivity due to improved product quality – fewer rejects

7. Preliminary Testing of ASUs

In February of 2016, SBW visited Parker's Pneumatic Division in Richland, Michigan for an introduction to and preliminary testing of the ASU technology. Parker's laboratory allowed for testing of two ASUs (models ASV2000 and ASV5000) during the site visit. While the tests were preliminary in nature, they provided valuable experience in determining the potential for reductions in compressed air usage, adjustments to the valve settings and challenges in obtaining measurements of their performance.

The test apparatus consisted of the following:

- Two compressors with combined capacity sufficient to serve testing efforts
- Piping manifold allowing any combination of four pipe sizes supplying compressed air
- Pressure regulator to allow adjustment of the pressure upstream of the manifold
- IFM SD2001 in-line air flow meter with digital readout
- Pressure transducer measuring pressure upstream of the ASVs
- Pressure regulator to maintain constant ASV pilot pressure
- Outlet piping from the ASVs terminating in a 3/8" open pipe
- Data collection system recording pertinent parameters during testing

The test stand and in-line flow meter are shown in Figure 1 and Figure 2, respectively.

Figure 4: Test stand utilized for preliminary testing of ASVs at Parker's lab.

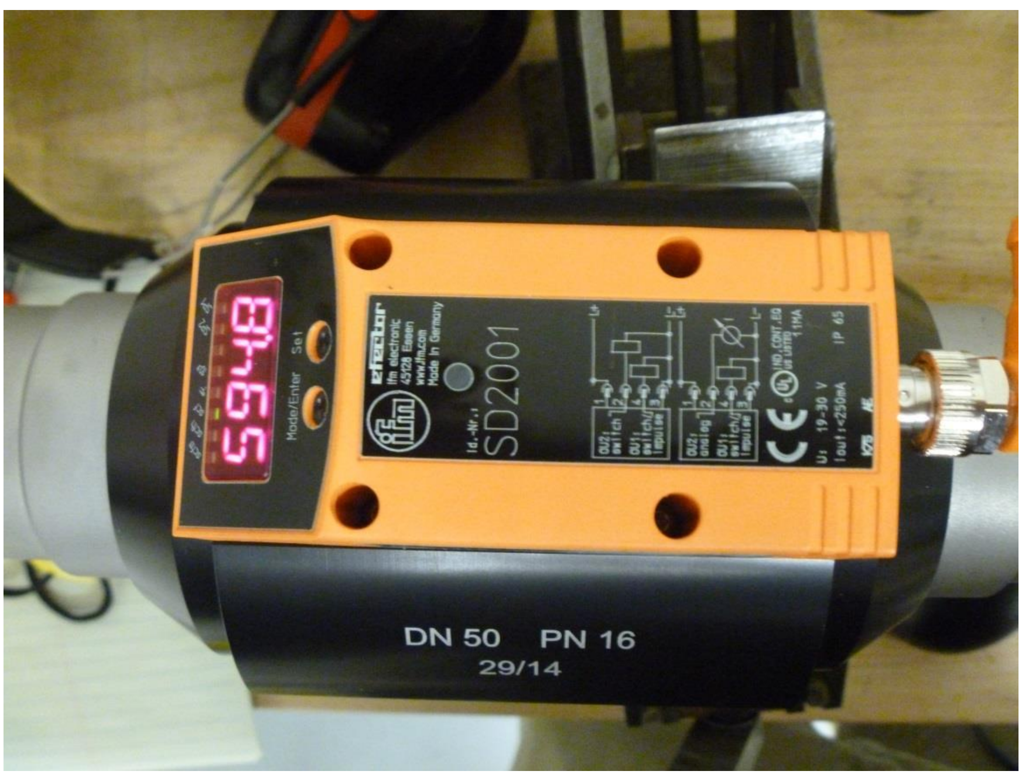

Figure 5: In-line flow meter used in preliminary testing at Parker's lab.

During testing, it was realized that the in-line flow meter was not providing precise instantaneous flow measurements through the ASVs. While readings were being taken at 40 Hz, they were imprecise because the volume of the system piping allowed compression and expansion of the supply air that, while caused by the cyclical operation of the ASVs, was neither synchronized with nor fully representative of the degree of pressure changes at the ASVs. Rather than rely on summing the instantaneous readings, the totalizing function of the flow meter was used to record accumulated flow at the beginning and end of periods timed with a stop watch, providing the necessary information to calculate an average flow rate over each such period. Between readings, the ON and OFF adjustment screws were methodically adjusted to provide an indication of the impact of the adjustments on average flow rates.

Figure 3 and Figure 4 provide clear evidence that airflows change as the ON and OFF adjustment screws are adjusted. In both figures, the topmost horizontal line shows the airflow that would occur under an open blowing condition, i.e. with the respective ASVs fully open with no ON/OFF cycling. The remaining lines show the airflows associated with different combinations of settings of the ON and OFF screws. Each line shows the change in airflow for a given setting of the ON screw while the OFF screw adjustment is changed. For example, the orange line shows flows with the ON screw set at 1.5 turns when the OFF screw is adjusted to 1.5, 3, 4.5 or 6 turns, from left to right. The figures also provide a comparison of ASV performance at constant OFF screw settings with varying ON screw settings by moving vertically from line to line. Again, in Figure 3, with the OFF screw at 4.5 turns, the flows are approximately 44, 32, 21 and 20 scfm with the ON screw adjusted to 1.5, 3, 4.5 or 6 turns, respectively. In addition to the changes in flow rates, these plots also show the relationship between flow rates and screw settings to be quite linear.

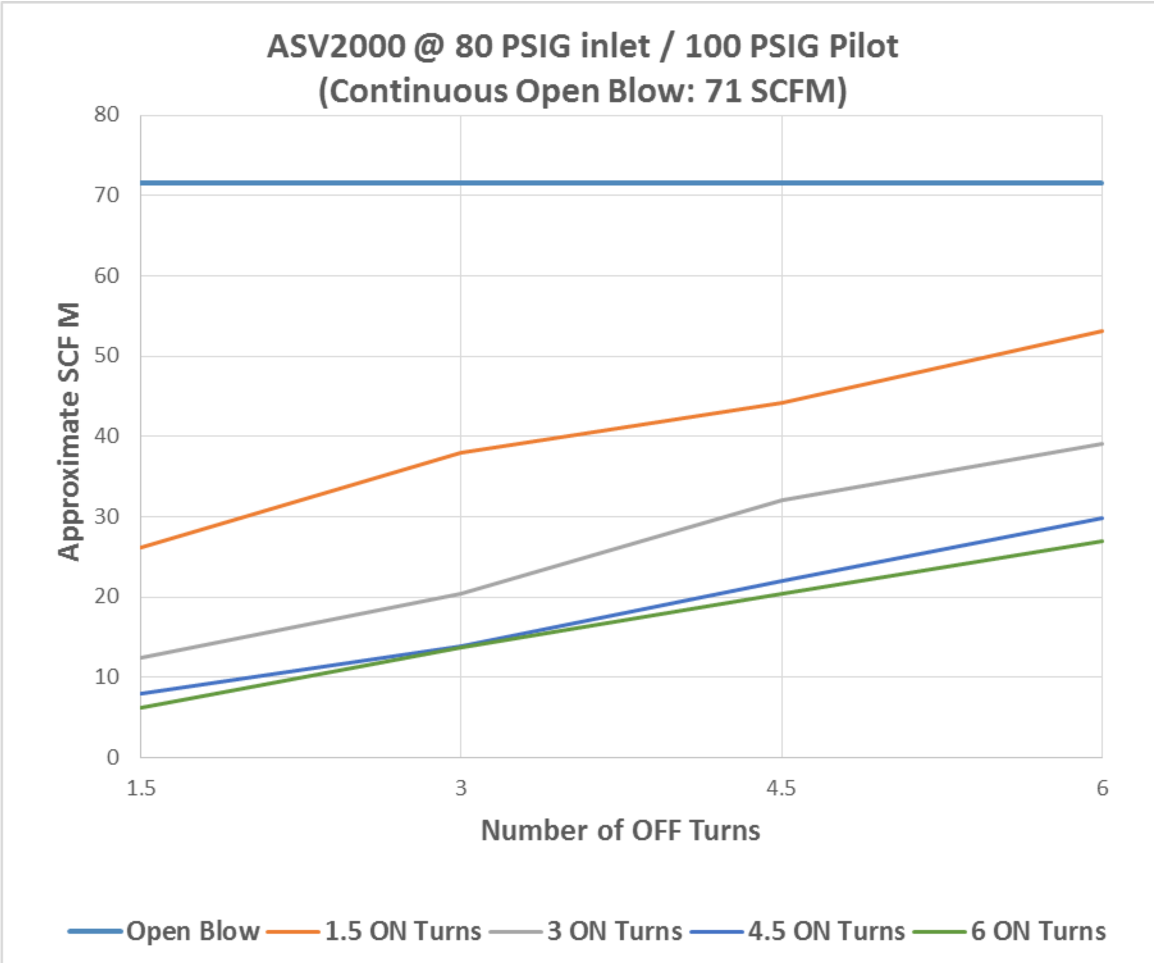

Figure 6: Approximate average air flow rates obtained by setting ON and OFF adjusting screws the specified number of turns on an ASV2000 valve. The top-most line represents the flow with no ASV in place, i.e. open blowing. Each remaining line represents the variation in SCFM obtained by opening the OFF screw (CCW: decreasing OFF duration) from the fully-closed position the number of turns indicated on the x-axis. A comparison of lines indicates the variation in SCFM obtained by closing the ON screw (CW: decreasing ON duration) from the fully-open position by the number of turns indicated in the legend.

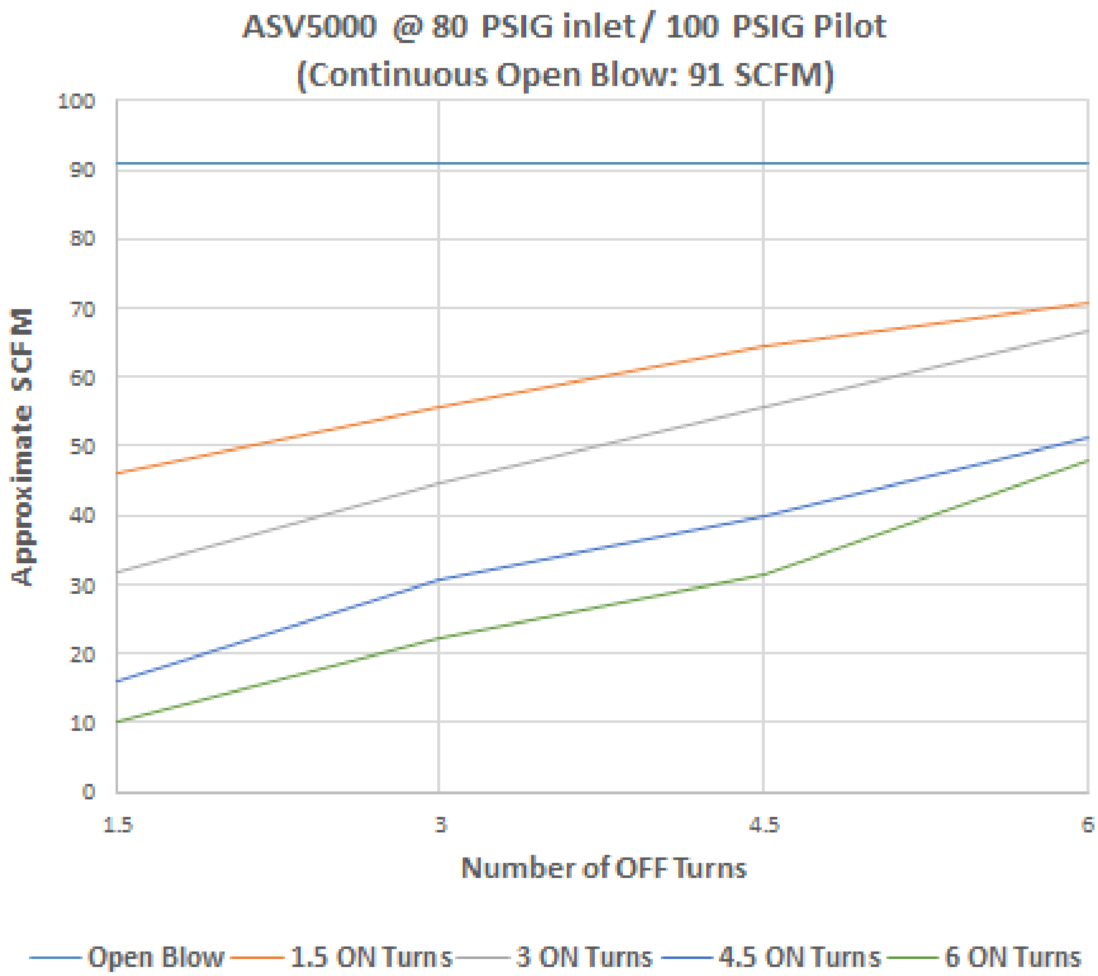

Figure 7: Approximate average air flow rates obtained by setting ON and OFF adjusting screws the specified number of turns on an ASV5000 valve. Each line represents the variation in SCFM obtained by opening the OFF screw (CCW: decreasing OFF duration) from the fully-open position by the number of turns indicated on the x-axis. A comparison of lines indicates the variation in SCFM obtained by closing the ON screw (CW: decreasing ON duration) from the fully-open position by the number of turns indicated in the legend.

NOTE: Errors in Figure 7 were corrected 9/30/16.

8. Recommendations

Based on the findings of this study, we recommend a second phase of investigation to measure the ASU performance in actual industrial applications, resulting in case studies and more definitive conclusions as to their applicability, ease of use and cost effectiveness. A proposal of actions to achieve these goals and the costs involved will be submitted under separate cover.

Listed below are the recommended next steps Phase II:

- Install five to ten units in the field in different applications with pre- and post-monitoring
- Survey and interview personnel about:
  - ASU effectiveness compared to effectiveness of baseline method
  - Satisfaction with ASUs in terms of installation, setup, operation, likelihood of adoption
- Investigate non-energy benefits and associated estimate of additional value
- Interview other compressed air professionals and seek professional advice and input regarding potential ASU applications and best ways for NEEA to promote their adoption
- Run cost benefit analysis for the tested applications
- Present findings to NEEA and or other interested utilities in the Pacific Northwest
- Determine whether or not to work with the RTF to develop a measure for ASUs