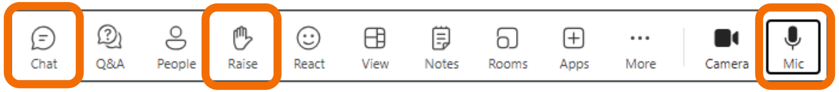
Before we get started…

What compressed air energy-saving projects are you planning?

Answer in chat or raise hand and unmute



MARCH 19, 2024

Save on Energy webinar: Estimating project savings – compressed air

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Energy Coach

Ron Marshall
Marshall Compressed Air Consulting

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- Chat window

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ESTIMATING COMPRESSED AIR PROJECT SAVINGS

PARTICIPANT HANDOUT

How do you know if an energy-saving opportunity is worth pursuing? After identifying an opportunity, you'll likely want to estimate the savings to evaluate if it's worth putting more effort and resources into.

Understanding how to develop a reasonable estimate of energy savings with limited information can be very useful, but it's important to understand what tools or calculations to use, what assumptions are going into those estimates, and under what conditions they're valid.

IN THIS WORKSHOP, PARTICIPANTS WILL:

- Learn how to estimate energy savings from compressed air projects.
- Understand when to apply different estimation approaches depending on applicability and available data.
- Have questions about estimating savings answered by, compressed air expert, Ron Marshall.

This workshop will be hosted over Teams.

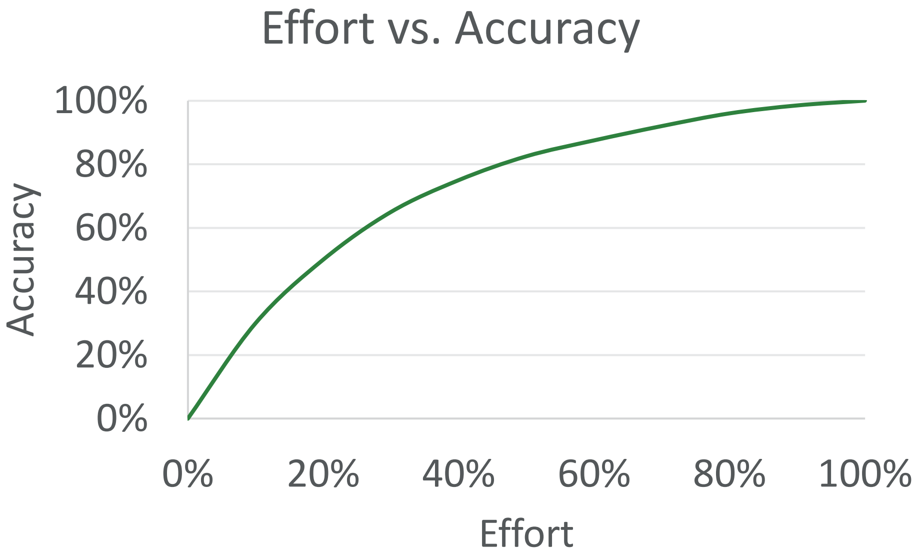
Pathway to estimating project savings

1. Good practices for estimating savings
2. Compressed air fundamentals
3. Estimating compressed air project savings

Good practices for estimating savings

1. Consider how accurate your estimate need to be
2. Assess your data availability
3. Get a good baseline
4. Understand the mechanism of savings
5. Understand the calculation method, tools, rules of thumb, and their respective limitations

Appropriate accuracy



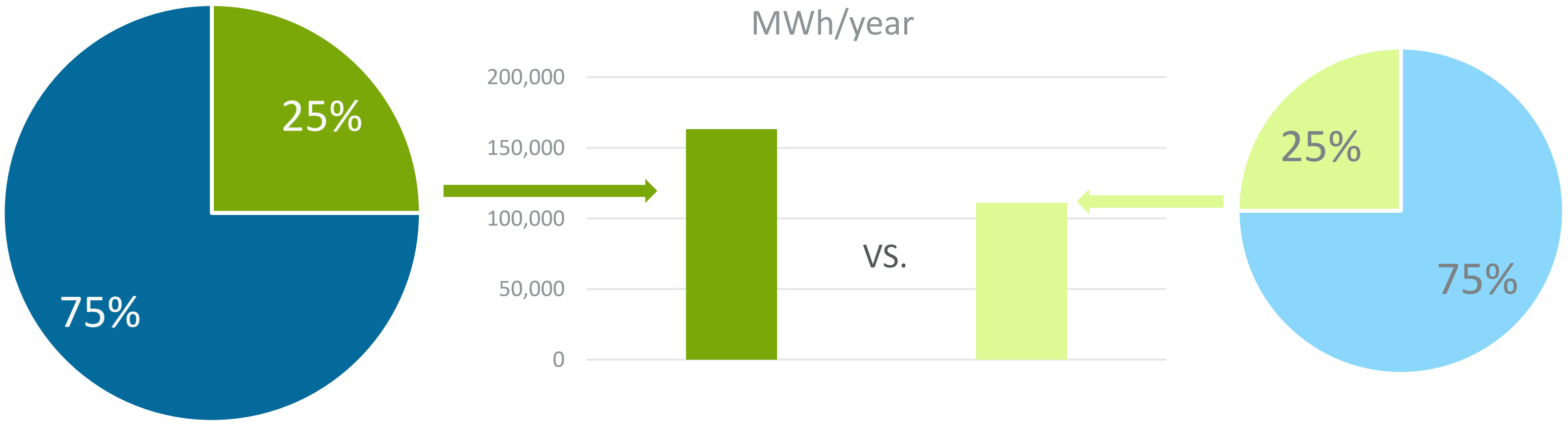
- What decision are you trying to make?
- What are the risks associated with the decision?

Decision / Risk Examples

- Capital spend / Underperformance
- Proceed with further study / Non-viable
- Trial a setpoint change / Reverse decision

You need to start with an accurate baseline

Example: "25% energy savings" on a 100 hp compressor



No baseline measurements

25% x 100hp x 0.746 kW/hp x 8760hrs

= 163 MWh/year of savings

With baseline measurements

25% x 100hp x 0.746 x $0.85_{\text{(load factor)}}$ x

$0.80_{\text{(duty cycle)}}$ x 8760 = 111 MWh/year

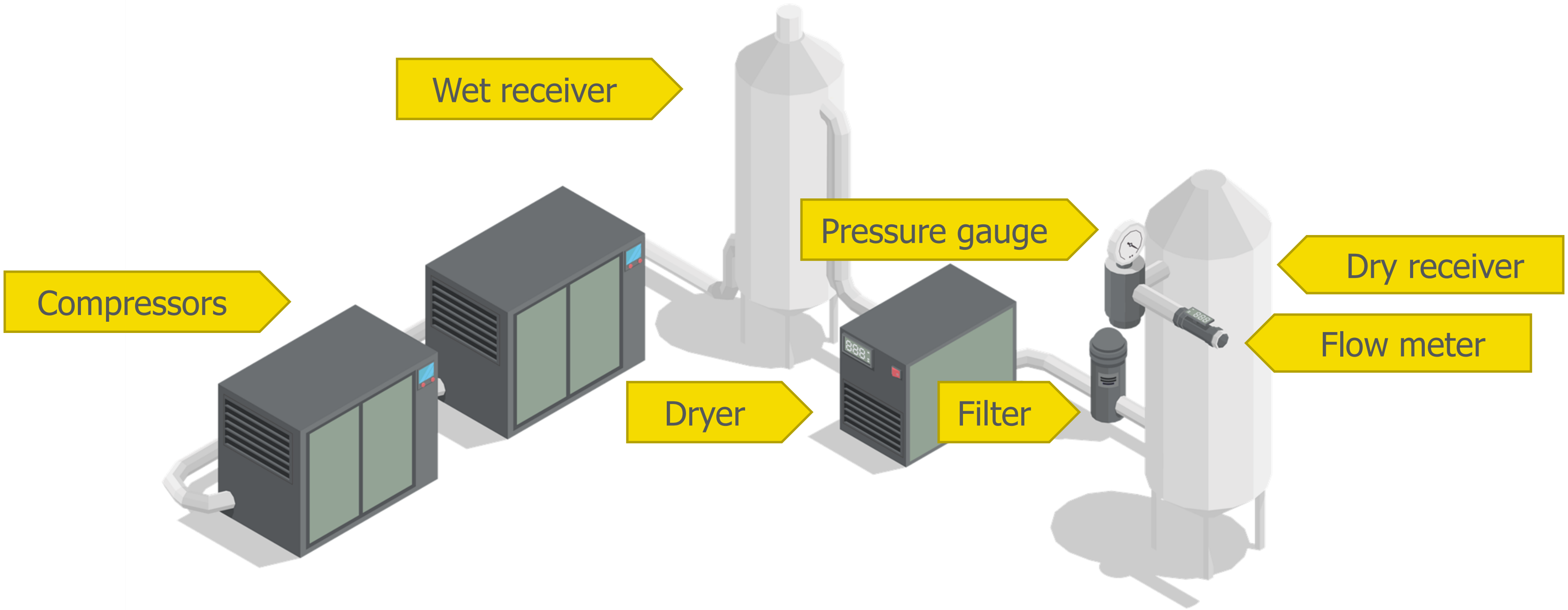
Compressed air – mechanisms of savings

- Reduce flow
- Reduce pressure
- Increase efficiency
- Heat recovery

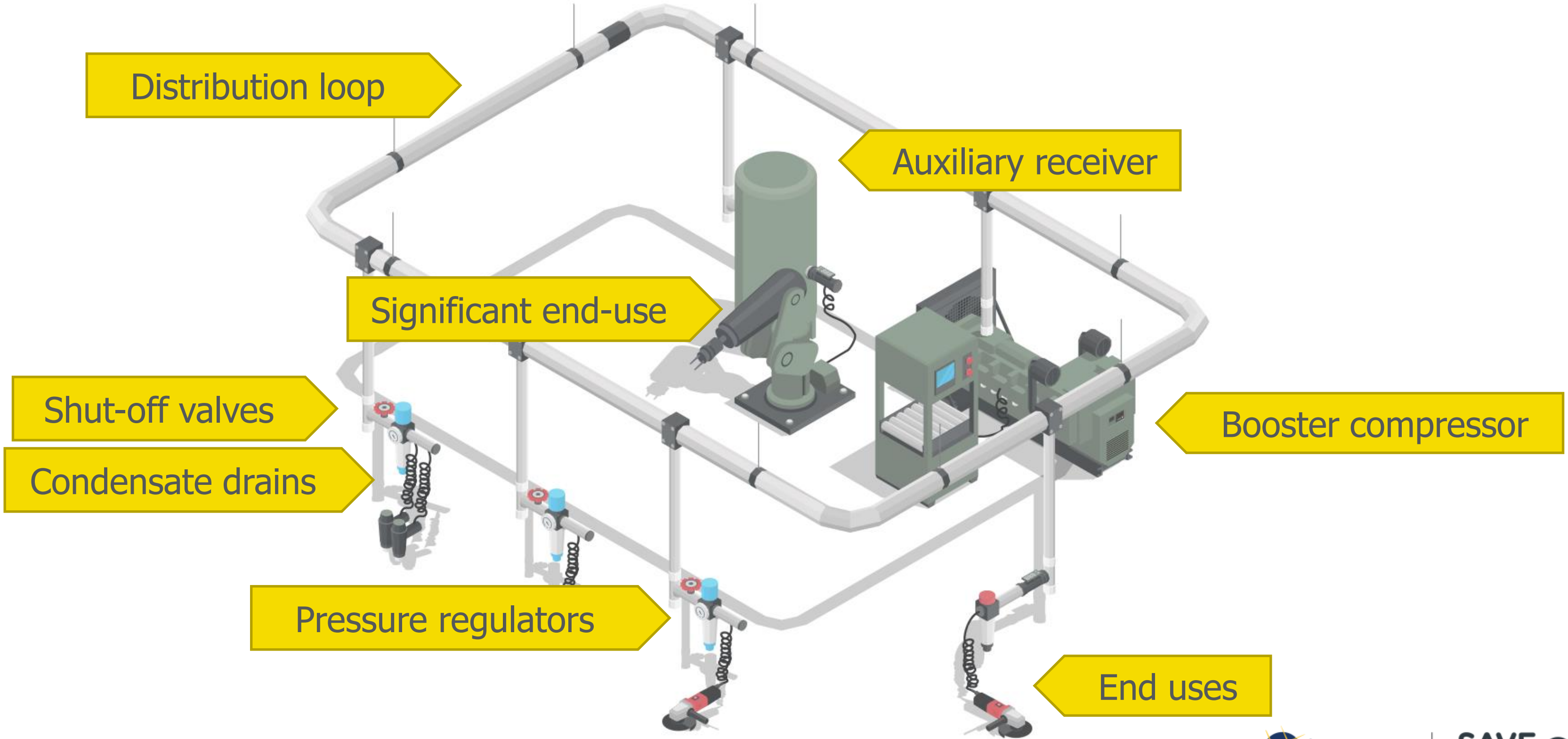
Introducing: Ron Marshall

- Consultant MCAC
- 38 years with Power Utility
- 29 years Technical CA Support
- CAC Level 2 Instructor
- International Trainer UNIDO
- 600+ projects completed

Understanding your compressed air system - supply



Understanding your compressed air system - demand



Types of compressors

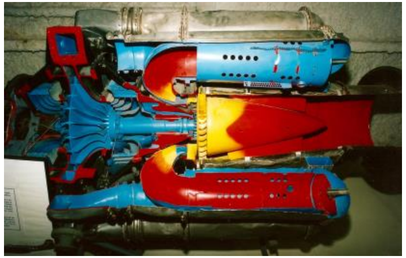
Rotary screw compressor

Axial compressor

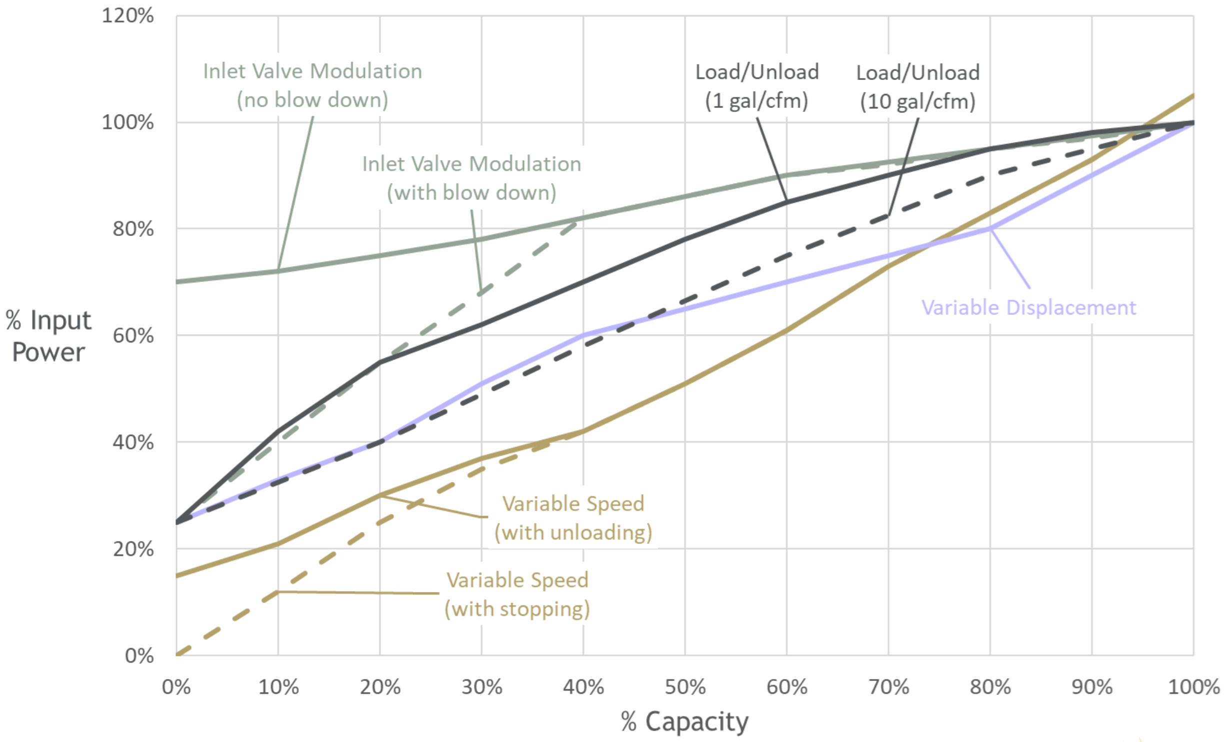
Rotary vane compressor

Reciprocating compressor

Centrifugal compressor



How are your compressors controlled?



Establishing compressed air baselines

Estimating power and energy consumption

If you've got nothing but the motor nameplate…

$$P_m = hp_{nameplate} \times 0.746\ [kW/hp] \times LF$$

Where:

$Hp_{nameplate}$ is the nameplate horsepower

P_m is motor power

LF (Load Factor) is between 0% - 100%

$$P_e = \frac{P_m}{\eta_{motor}}$$

Where:

P_e is electrical power

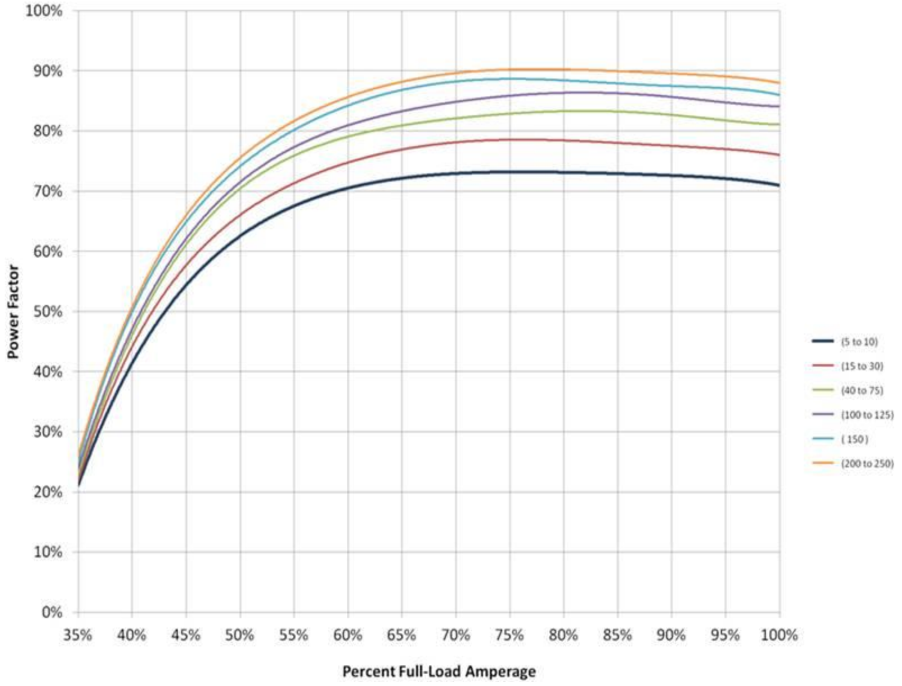
P_m is motor power

η_{motor} is motor efficiency

Estimating power from amps

$$P_e = \frac{V \times I \times PF \times \sqrt{3}}{1000}$$

Where:
P_e = Three-phase electric power [kW]
V = RMS voltage, mean line-to-line of 3 phases [V]
I = RMS current, mean of 3 phases [A]
PF = Power factor as a decimal



Power Factor: for typical power factor v. motor load by motor sizing, see Figure 4.5 (page 63) of the US Department of Energy's (DOE) Premium Efficiency Motor Selection And Application Guide

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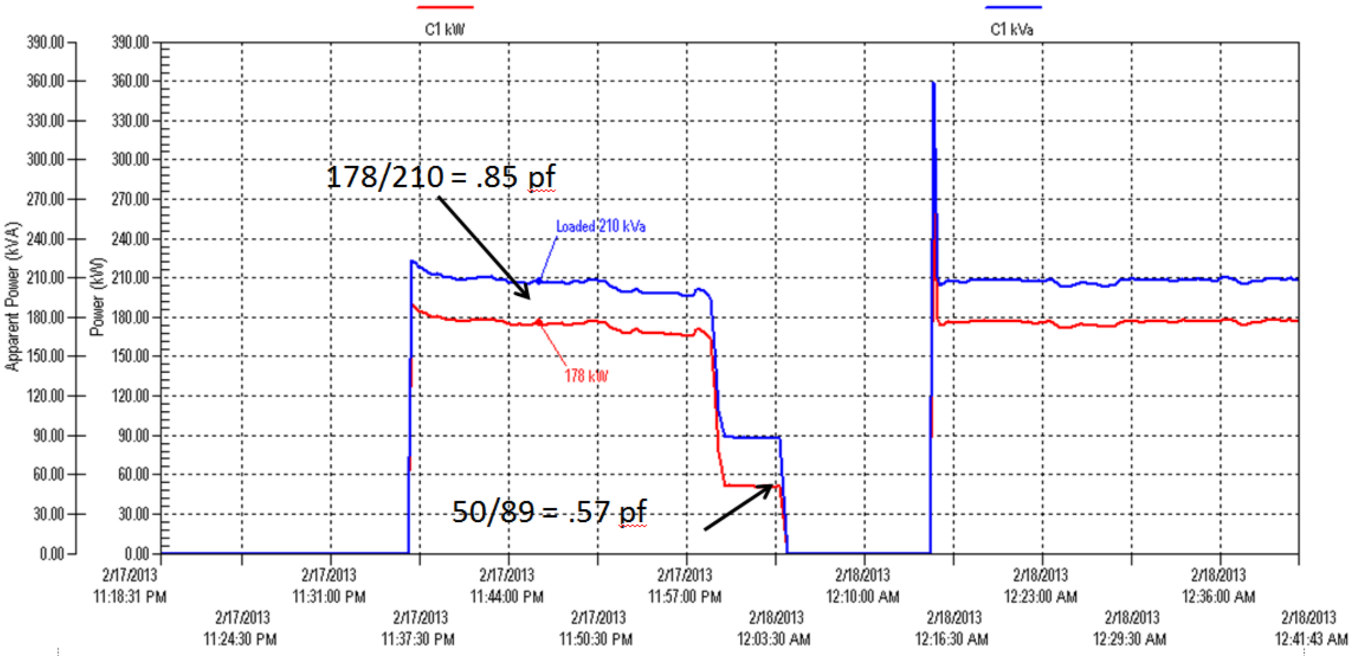
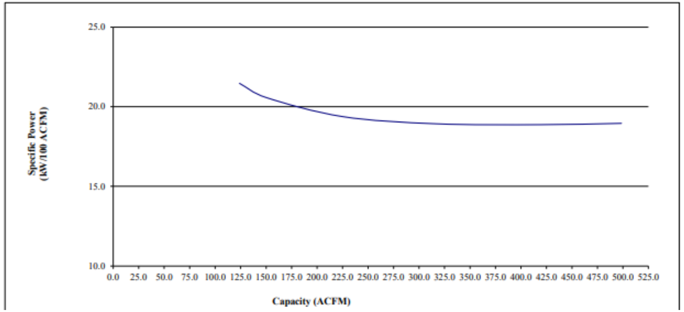
Calculating baseline power – power factor issues



Calculating baselines – using CAGI data sheets

- CAGI – Compressed Air and Gas Institute
- Useful for estimating flow from power, or vice versa
- Widely available for newer compressors
- Must be corrected for pressure
- Particularly useful for variable speed drives (VSDs)

2	[X] Air-cooled [ ] Water-cooled	Type:	Screw
		# of Stages:	1
3	Full Load Operating Pressure[b]	138	psig[b]
4	Drive Motor Nominal Rating	100	hp
5	Drive Motor Nominal Efficiency	96	percent
6	Fan Motor Nominal Rating (if applicable)	2.6	hp
7	Fan Motor Nominal Efficiency	79	percent
8*	Input Power (kW)	Capacity (acfm)[a,d]	Specific Power (kW/100 acfm)[d]
	94.5 Max	498.6	19.0
	79.1	419.2	18.9
	59.9	316.5	18.9
	43.6	225.0	19.4
	30.9	150.2	20.6
	26.6 Min	123.9	21.5
9*	Total Package Input Power at Zero Flow[c, d]	1.1	kW
10	Isentropic Effeciency	82.95	%
11			



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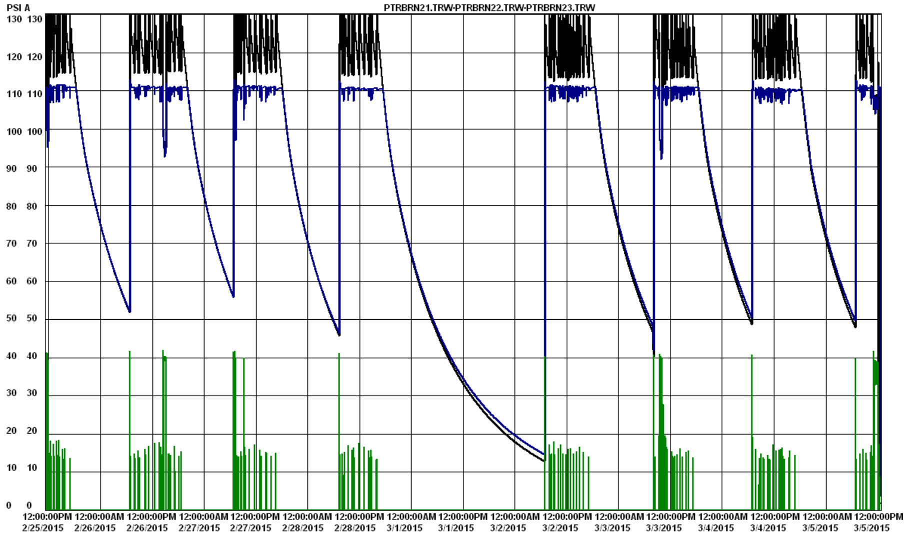
Operating hours considerations

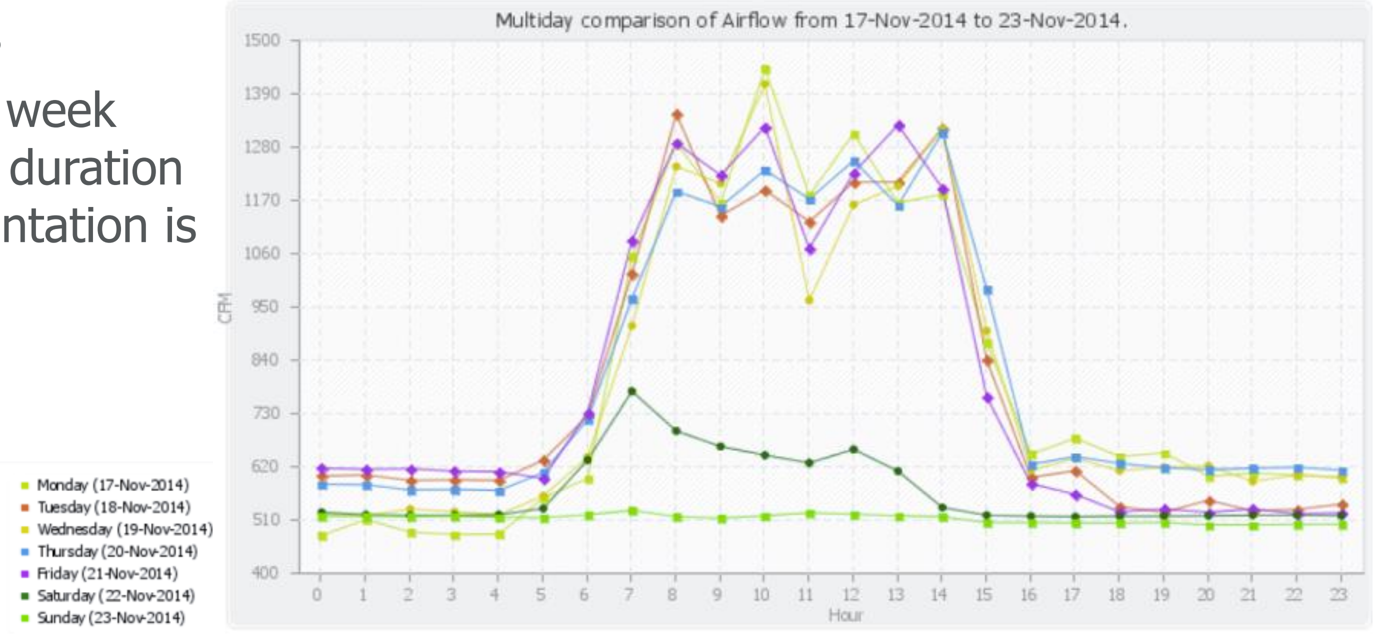
- Seasonal duty
- Statutory holidays
- Plant shutdowns
- Non-production modes – common for one or more compressors to run, but often mostly to feed leaks.



Determining the baseline

Good practices

- Minimum one week measurement duration
- Visual representation is important



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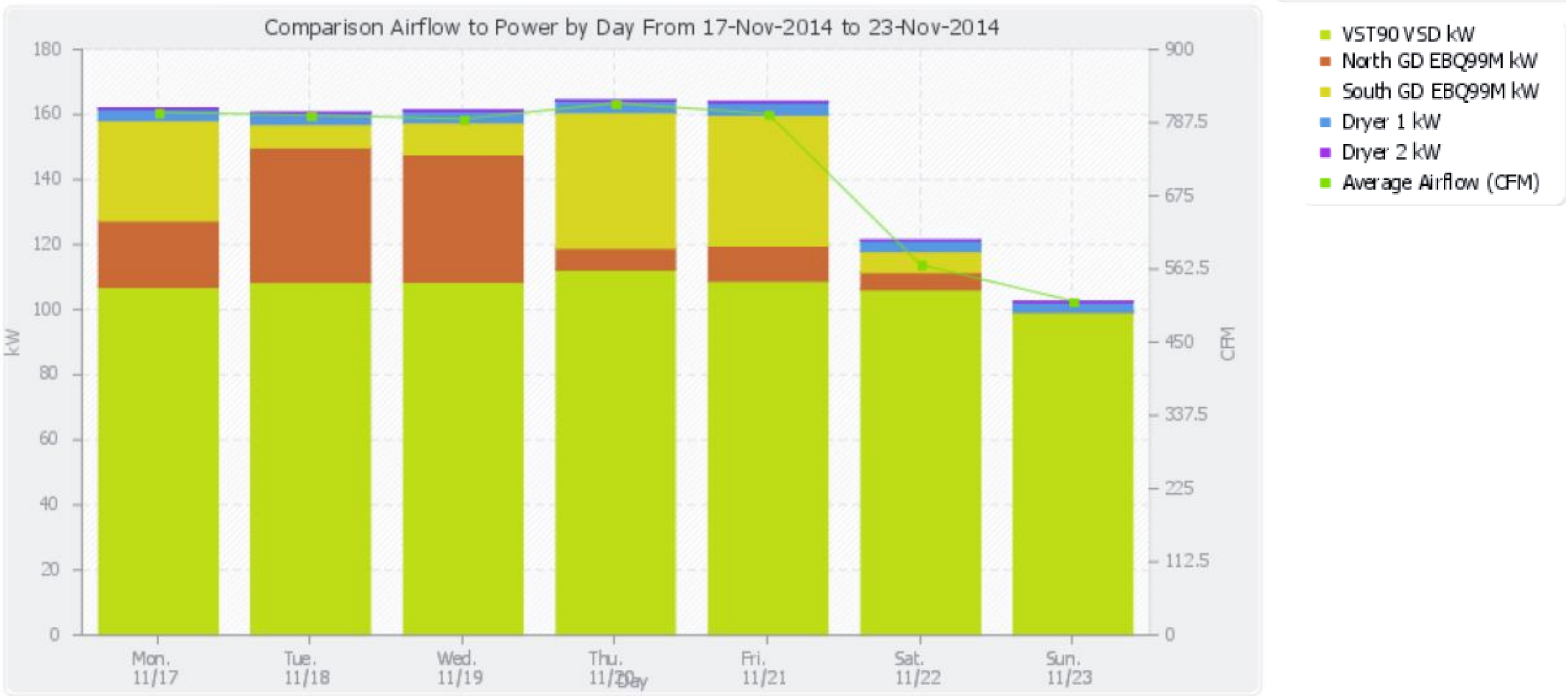
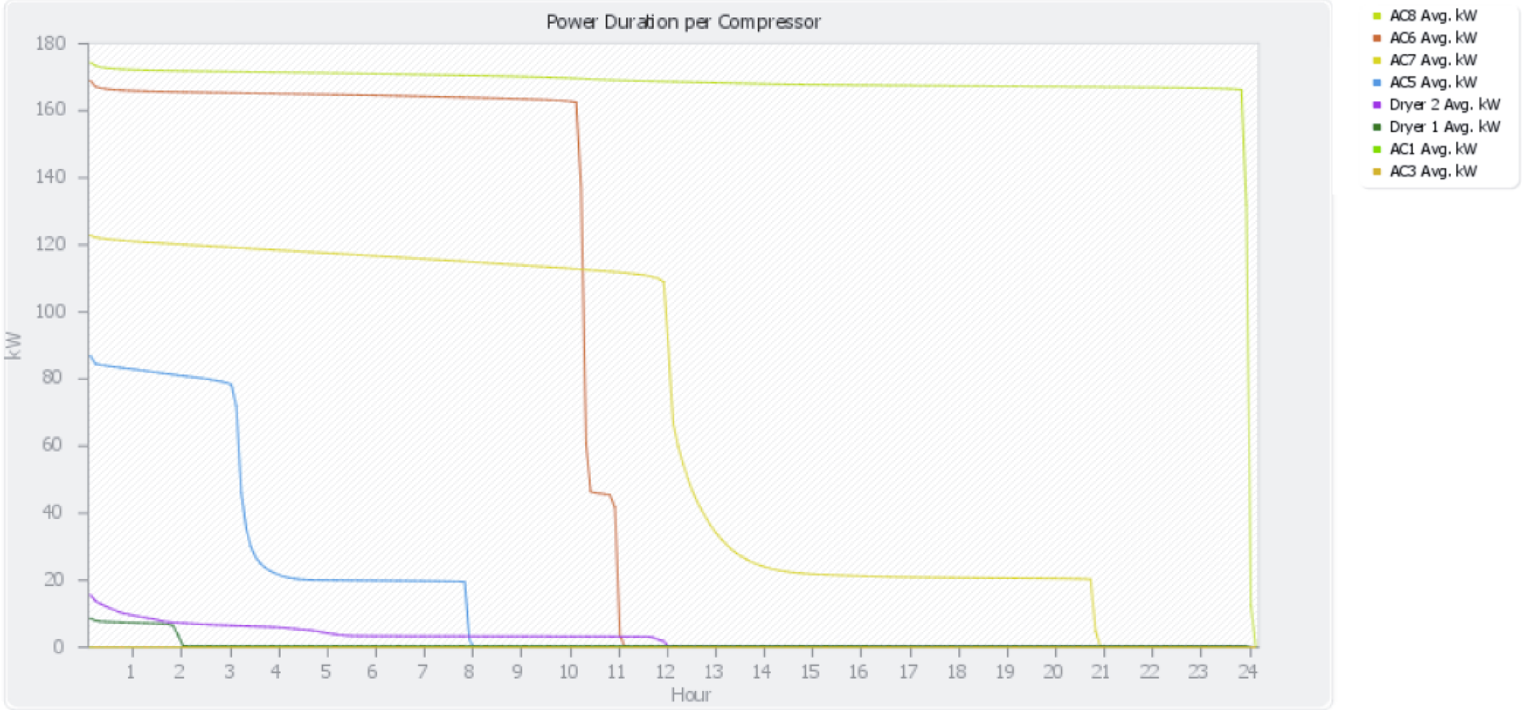
Determining the baseline



Determining the baseline



Determining the baseline

Use annual operating hours and day types to calculate baseline

ASME EA-4G–2010

Table 3 Example Baseline Summary

Day Type	Total Operating Hours	Average Airflow, acfm	Average Airflow, %Cs.	Peak Demand, kW	Load Factor, %	Annual Energy, kWh	Annual Energy Cost, $ / yr
Production	6,000	538	40.9	182.5	58.9	769,950	$30,798.00
Weekends	400	630	47.9	103.6	47.5	41,440	$1,637.00
System totals	6,400	544	41.4	182.5	58.2	811,390	$32,435.00

Determining the baseline - data presentation

Daily average CFM consumption midweek (Mon-Fri)

% of Max. CFM	Hours	Average CFM	Avg. kW	Specific Power	Daily kWh	Daily Cost	Annual kWh	Annual Cost
70	0.5	2,933.21	517.57	17.65	258.78	$13.97	64,696	$3,494
65	4.3	2,758.94	504.48	18.29	2,169.27	$117.14	542,317	$29,285
60	5.3	2,575.89	483.12	18.76	2,560.56	$138.27	640,139	$34,568
55	2.8	2,364.70	442.53	18.71	1,239.08	$66.91	309,770	$16,728
50	1.2	2,148.06	408.43	19.01	490.11	$26.47	122,528	$6,616
45	0.8	1,934.59	365.31	18.88	292.25	$15.78	73,062	$3,945
40	1.2	1,675.02	293.00	17.49	351.60	$18.99	87,900	$4,747
35	3.9	1,492.41	264.92	17.75	1,033.20	$55.79	258,300	$13,948
30	2.1	1,291.85	225.77	17.48	474.12	$25.60	118,530	$6,401
25	1.8	1,080.28	209.36	19.38	376.86	$20.35	94,214	$5,088
15	0.1	603.93	68.70	11.38	6.87	$0.37	1,718	$93
5	0.1	79.21	18.50	23.35	1.85	$0.10	463	$25
Totals	**24**	**2,094.43**	**385.45**	**18.40**	**9,254.54**	**$499.74**	**2,313,635**	**$124,936**

Daily average CFM consumption on weekend (Sat-Sun)

% of Max. CFM	Hours	Average CFM	Avg. kW	Specific Power	Daily kWh	Daily Cost	Annual kWh	Annual Cost
50	0.1	2,038.10	354.03	17.37	35.40	$1.91	3,540	$191
40	0.1	1,815.88	332.70	18.32	33.27	$1.80	3,327	$180
35	0.1	1,428.92	319.50	22.36	31.95	$1.73	3,195	$173
30	3.7	1,221.59	198.39	16.24	734.03	$39.64	73,403	$3,964
25	19.9	1,094.60	187.48	17.13	3,730.85	$201.47	373,085	$20,147
10	0.1	496.60	118.05	23.77	11.81	$0.64	1,181	$64
Totals	**24**	**1,120.16**	**190.74**	**17.03**	**4,577.31**	**$247.19**	**457,731**	**$24,717**

Annual carbon cost for weekend period: 380 tons of CO_2.

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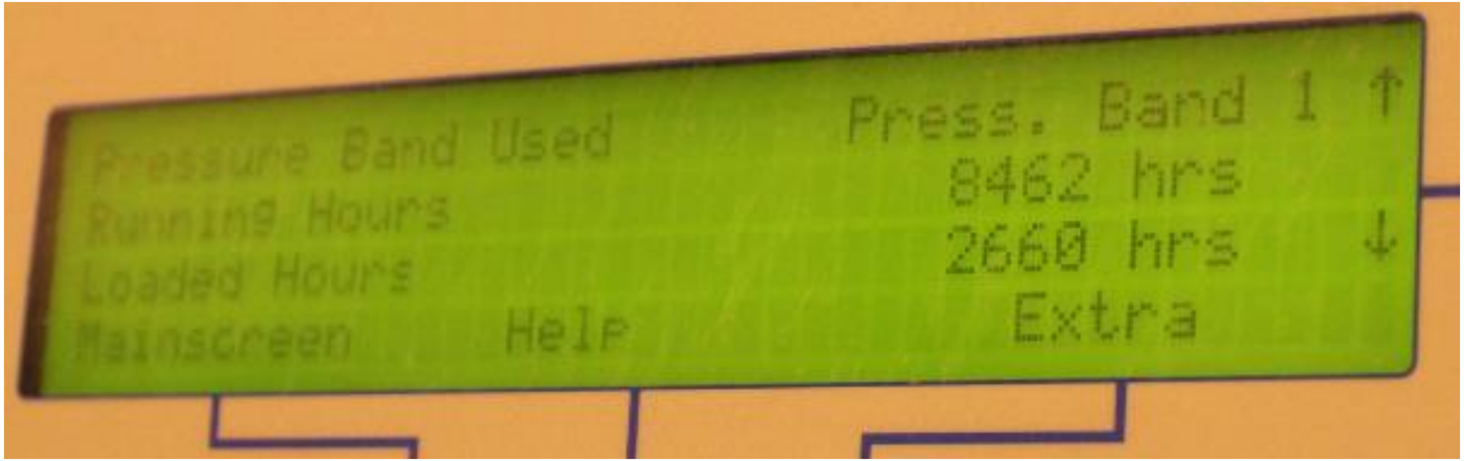
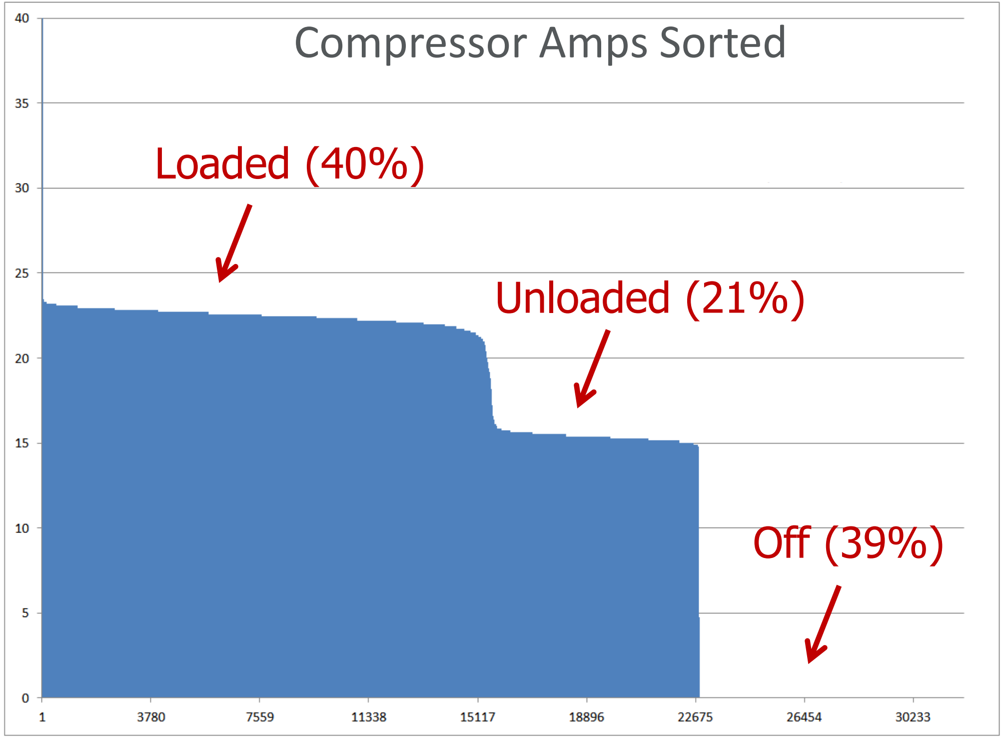
Determining the baseline – alternative methods

Calculating flow from compressor status



Estimating flow from compressor status

- Take hour readings from compressor logs at start and end of measurement period
- Some compressor controllers track average flow, amps, and/or kW (typically VSDs)



Estimating flow from compressor status

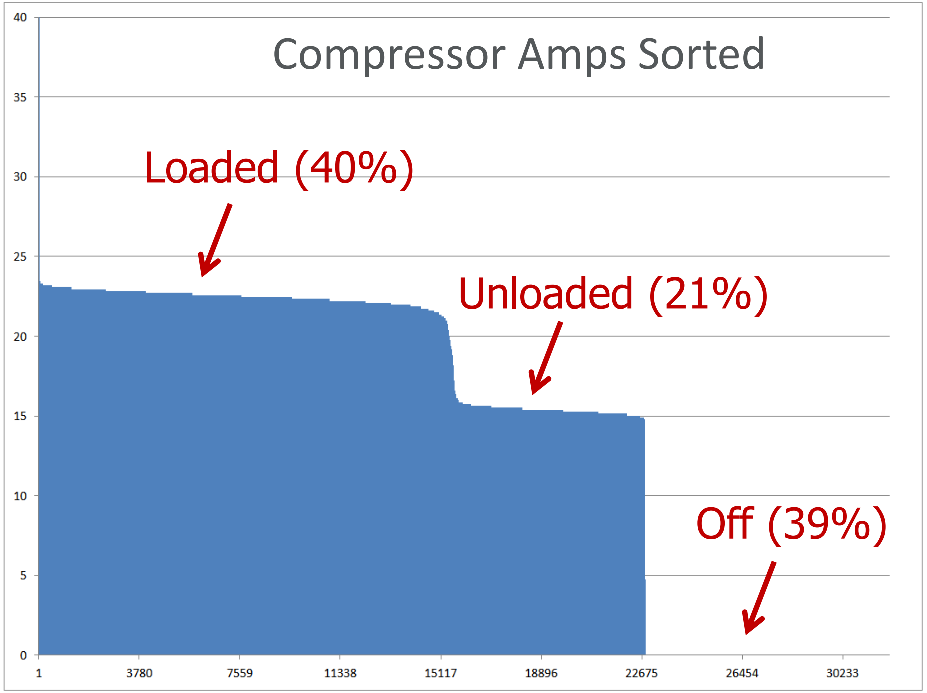
- Rated flow 100 cfm
- To find avg flow in period

  40% x 100 = 40 cfm
- To find avg flow while system active

  System active 61%

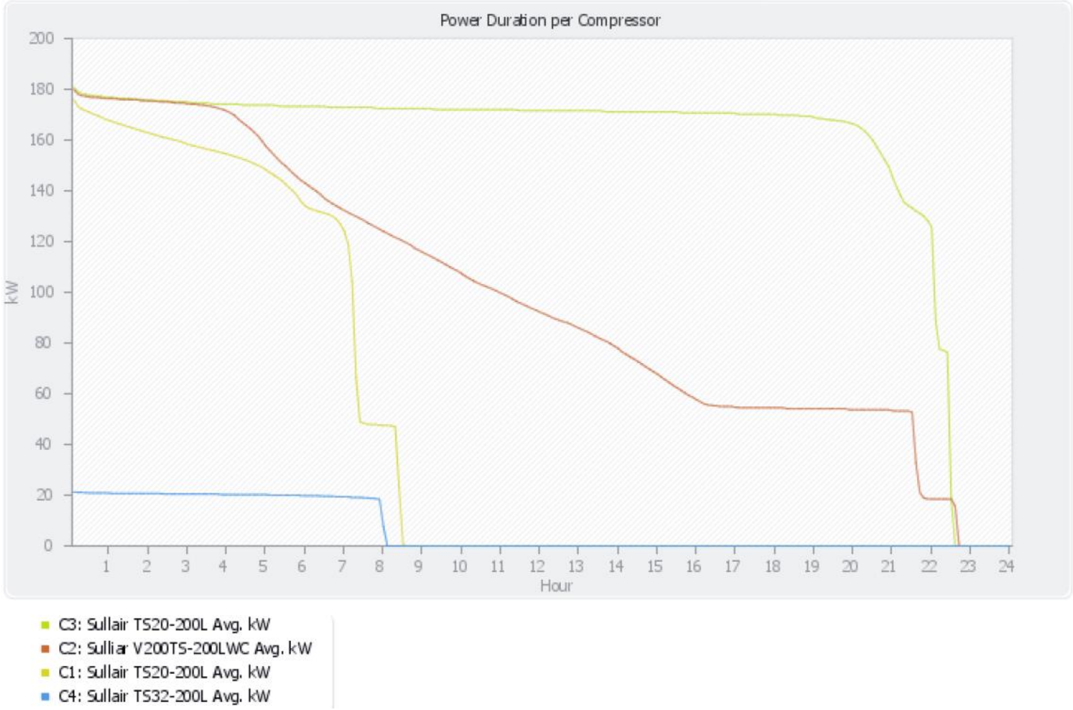
  40/61 = 66%

  66% x 100 = 66 cfm



Estimating flow from compressor status

- Load duration plots
- Calculate flow in each segment
- Use rated flows from CAGI
- Use characteristic curves



Estimating power from compressor status

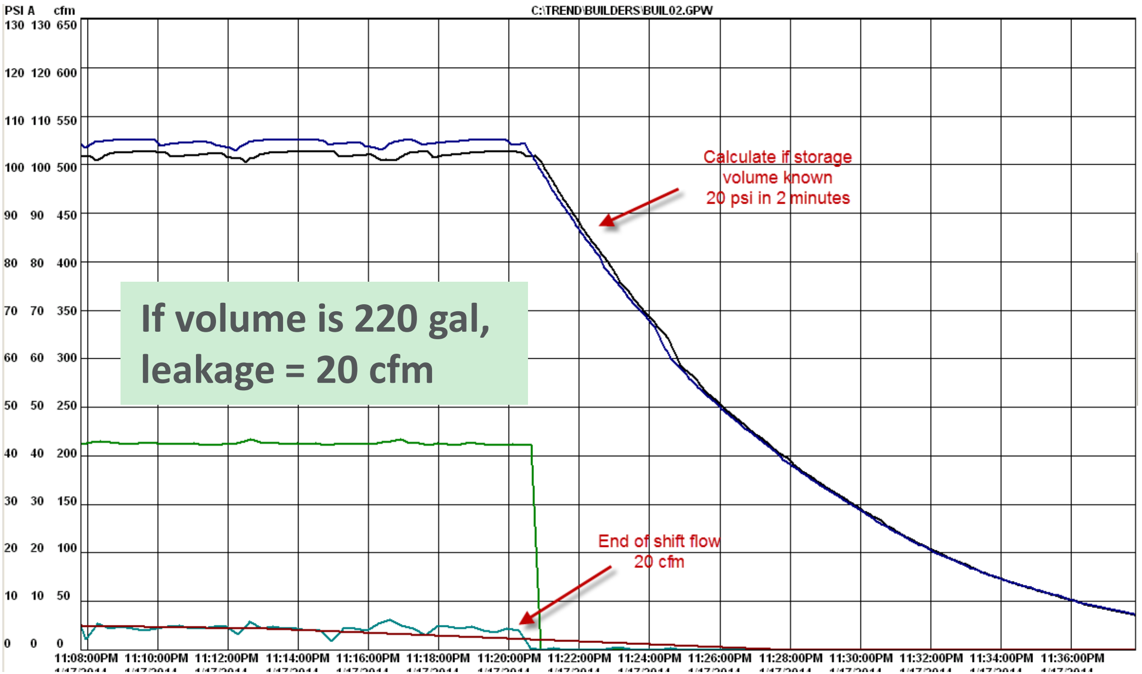
- Load duration plots
- Calculate flow and power in each segment
- Use rated flows from CAGI and measured or calculated power
- Use characteristic curves or test
    - Modulation
    - Capacity control
    - Load Unload
    - VSD

	8760								
Comp 3	Duty %	Ave. Amps	Rated Amps	pf	Rated kW	% Cap	Rated cfm	System kW	System cfm
System	100.0%								
1	18.6%	107.0	111.0	0.8	88.8	100%	440	15.9	81.9
2	13.7%	86.8	103.0	0.8	82.4	100%	440	9.4	29.9
3	0.6%	64.6	74.0	0.78	57.7	10%	44	0.3	0.2
4	1.3%	49.4	51.0	0.65	33.2	0%	0	0.4	0.0
5	65.8%	0.2	47.0	0.65	30.6	0%	0		
								26.0	112.0

Estimating your leak flow baseline

Leak testing methods:

- Flow meter
- Compressor cycles
- Pressure drawdown



If volume is 220 gal, leakage = 20 cfm

$$\text{Leakage (cfm free air)} = \left[\frac{V \times (P_1 - P_2)}{T \times P_a}\right]$$

V = cf (7.48 gal/cf)

T = minutes

Pa = ambient psi

Leak flow example calculation

Determine leak flow rate by a cycle timing test

Conditions: 500 cfm system running in load/unload mode

Measure load and unload cycle times when there is no production

Measured times: Load = 1 Minutes, Unload = 7 Minutes

Calculate the duty cycle: 1/(1+7) = 0.125

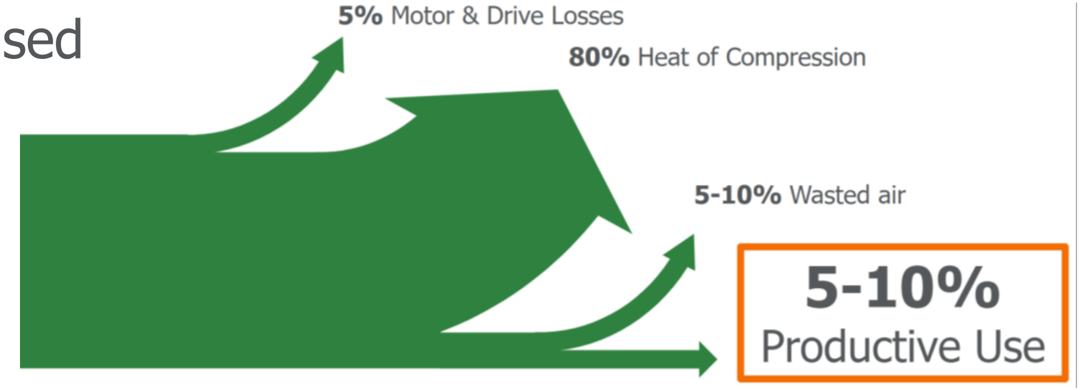
Leak Rate = 500 * 0.125 = 62.5 cfm

Compressed Air Project Savings

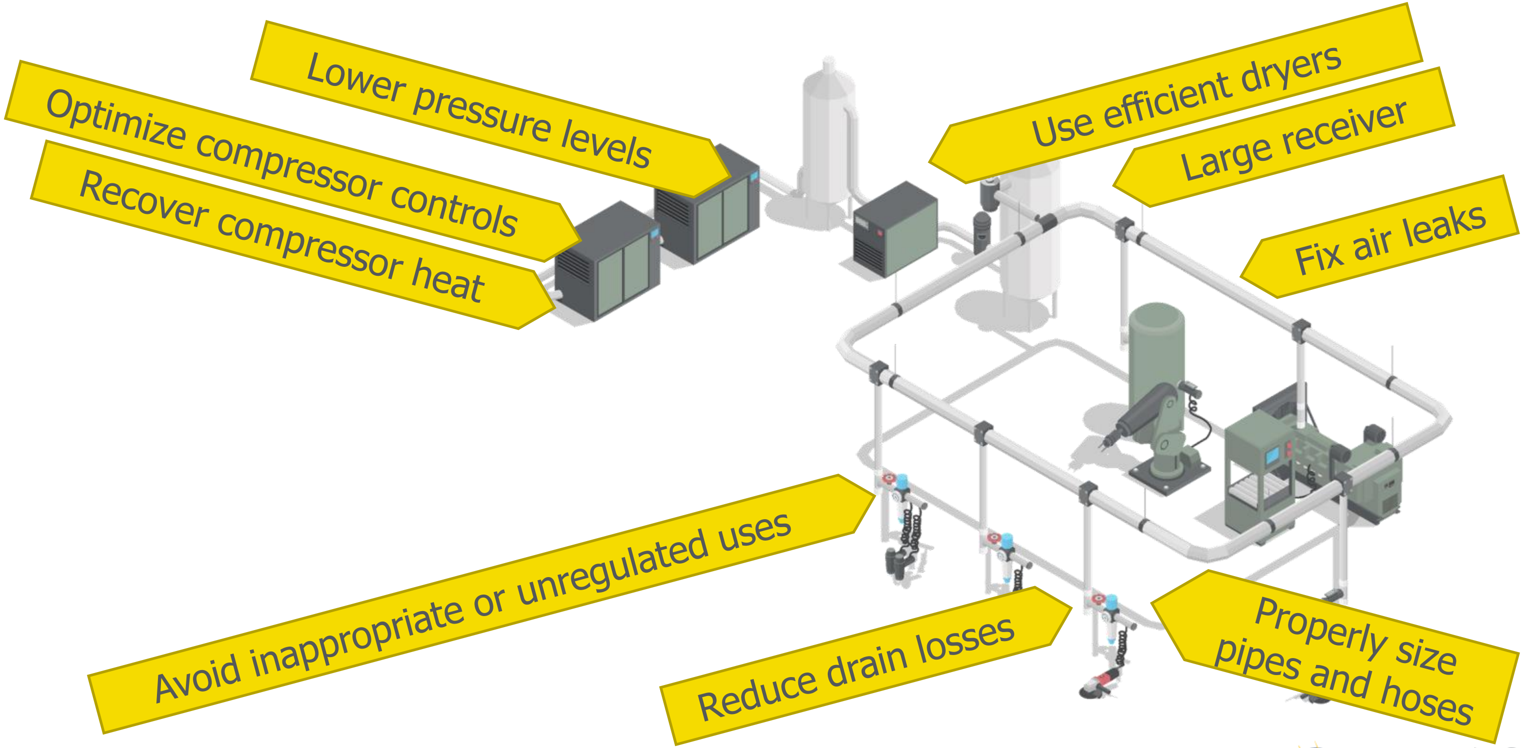
Compressed air project savings

Optimization occurs when:

- Efficiency of compressed air production is improved
- Less compressed air is produced
- Heat of compression is used



The compressed air system - where do you start?



Consider the demand side and supply side

Assess

Reduce Air Demand
- Consumption by end uses
- Leakage, artificial demand, and inappropriate uses

Reduce Pressure
- Eliminate avoidable pressure losses
- Connections, fittings, filters, etc.

Improve Efficiency of Supply
- Produce compressed air more efficiently
- Improve control strategy

Act

Estimating savings – leak repair

Mechanism of Savings: Reduce air flow demand > control signal > reduces air production > compressor control mechanism > reduces input power

Calculation Methods

Methods for estimating air flow reduction:

Db measurement (inaccurate),

Flow measurement during non-production,

Pressure drawdown, or cycle timing test for load/unload system

Determine specific power (kw/100 cfm)

Pitfalls: Poorly controlled systems don’t react precisely to flow reductions

Leak repair example

Modulating compressor system at an average of 2,000 cfm and 450kW

Estimated leak rate: 250 cfm, per cycle timing test

Assume you fix 80% of leaks → 200 cfm

Typical compressor loading between 85-100%

Per characteristic curve,

- 10% flow reduction = 3.33% power reduction
- 0.0333 * 450 kW = 15 kW
- System specific efficiency = 22.5 kW/100cfm
- Effective impact of leak repair = 7.5 kW/100 cfm

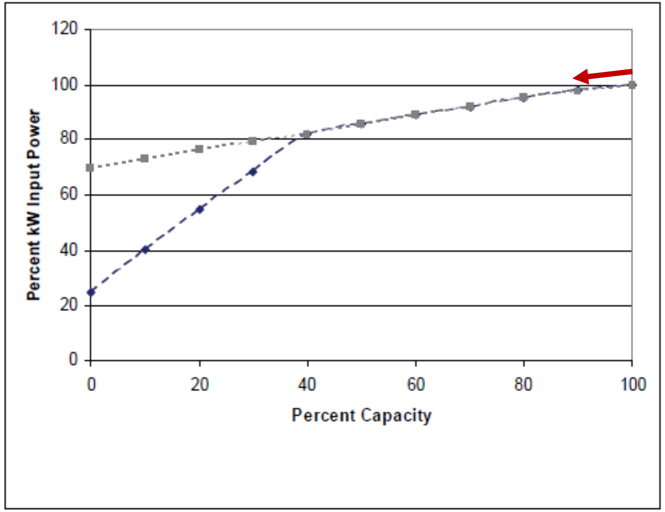
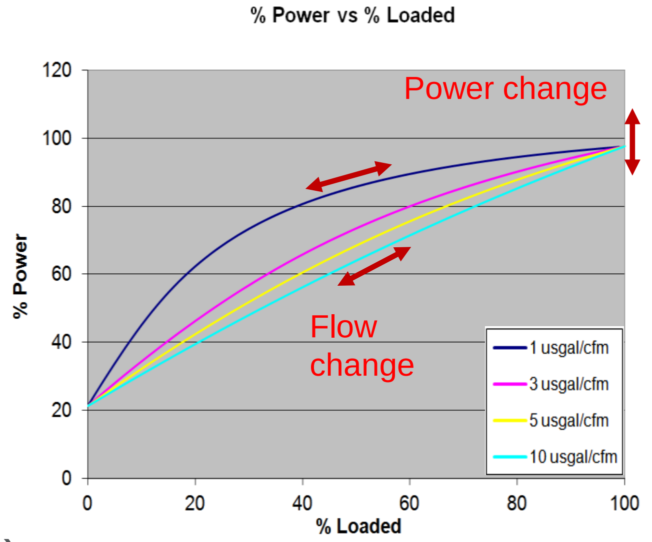


Figure 8 - Rotary Screw Compressor with Inlet Modulation Control (Courtesy Compressed Air Challenge)

Estimating savings – discharge pressure reduction

Mechanism of Savings: Reduce compressor discharge pressure > reduces the work to produce the same volume of air > reduces input power

Calculation Method: Approximately 1% input power reduction for every 2-psi pressure reduction, for systems operating between ~80 – 120 psi



Pitfalls:

Ensure plant can run at lower pressure.

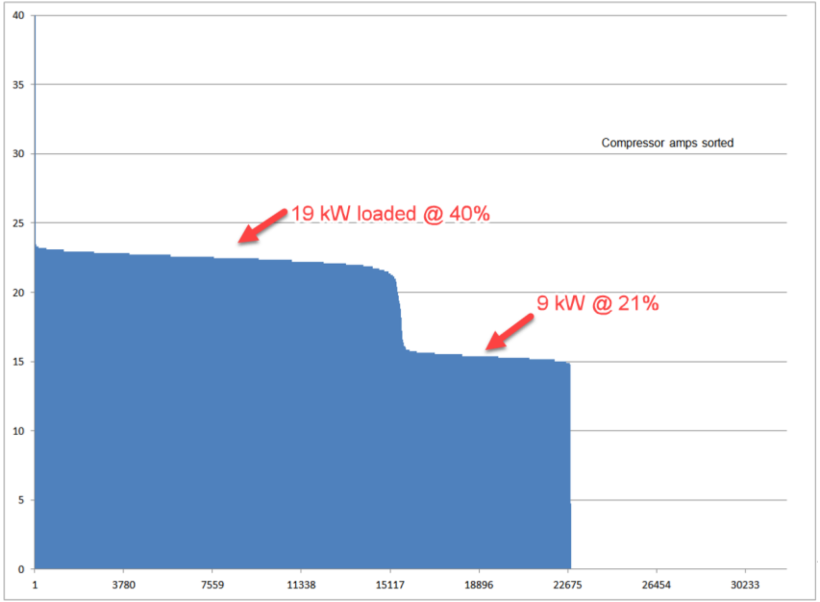
Reduces loaded kW only.

Windfalls: Reducing plant pressure results in air flow reductions with unregulated air users (~1% of kW per psi).

Pressure reduction example

100 psi load/unload system

- 15 psi pressure reduction
- Unloaded kW unchanged
- 1% reduction for every 2 psi when loaded
- 19 kW x .075 = 1.43 kW
- Avg reduced 1.43 kW x 0.4 = 0.57 kW
- Flow reduction ignored in this case
- Unregulated demand reduces with pressure reduction



Estimating savings – more efficient compressor

Mechanism of Savings: Efficiency of air production is improved

Calculation Method:

- Starting with the baseline flow, determine the % capacity (cfm) for the new compressor, at the average operating flow (simple) or for the full flow range (detailed)
- Use CAGI sheet, generic or model-specific Capacity vs. Power charts to plot the % capacity and interpolate the % power.
- Multiply the % power by the (pressure adjusted) full-load input power
- Subtract the new power estimate from baseline power to get kW savings

Pitfalls:

- Adjust for discharge pressure
- Factor for the slope/intercept of the characteristic curve – not the full-load kW/100 cfm
- Some control methods (Load/unload) not linear

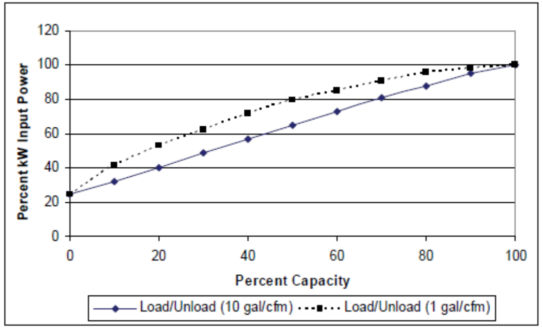
More efficient compressor example

Baseline: 100 HP modulating compressor

- Average flow = 200 cfm; Peak flow = 400 cfm
- Average power = 80 kW; or 40 kW/100 cfm
- Discharge pressure = 110 psi

New 100 HP load/unload compressor with 2,000 gals

- Rated pressure = 125 psi, Discharge pressure = 110 psi
- Full load power = 90.3 kW @ 125 psi, adjust for lower pressure
- (125-110)/125 = 12% pressure reduction → 6% power reduction
- New full load power = 90.3 * 0.94 = 84.9 kW
- % Loaded = 200/444 = 45% → % Power ~ 61%
- New power ~ 52 kW
- Average savings = 80 – 52 = 28 kW
- 28 kW x 8760 hours = 245,280 kWh/year



MODEL DATA - FOR COMPRESSED AIR			
3*	Rated Capacity at Full Load Operating Pressure [a, e]	444	acfm [a,e]
4	Full Load Operating Pressure [b]	125	psig [b]
5	Maximum Full Flow Operating Pressure [c]	125	psig [c]
6	Drive Motor Nominal Rating	100	hp
7	Drive Motor Nominal Efficiency	95.4	percent
8	Fan Motor Nominal Rating (if applicable)	3	hp
9	Fan Motor Nominal Efficiency	89.5	percent
10*	Total Package Input Power at Zero Flow [e]	19.3	kW [e]
11	Total Package Input Power at Rated Capacity and Full Load Operating Pressure [d]	90.3	kW [d]

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More efficient compressor example (VSD)

Baseline: 100 HP modulating compressor

- Average flow = 200 cfm; Peak flow = 400 cfm
- Average power = 80 kW; or 40 kW/100 cfm
- Discharge pressure = 110 psi

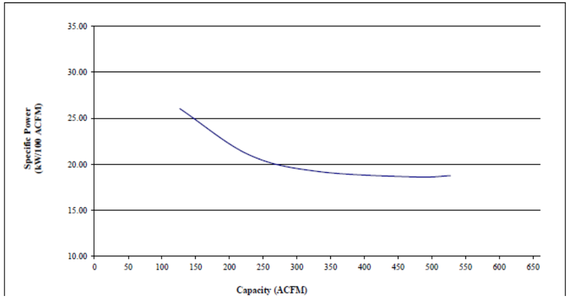
New 100 HP VSD compressor

- Average power ~ 41 kW @ 22 kW/100 acfm
- Average savings = 80 – 41 = 39 kW
- 39 kW x 8760 hours = 341,640 kWh

2	[X] Air-cooled [ ] Water-cooled	Type:		Screw
	[X] Oil-injected [ ] Oil-free	# of Stages:		1
3	Rated Operating Pressure		125	psig[b]
4	Drive Motor Nominal Rating		100	hp
5	Drive Motor Nominal Efficiency		95.0	percent
6	Fan Motor Nominal Rating (if applicable)		1.9	hp
7	Fan Motor Nominal Efficiency		86.5	percent
	Input Power (kW)		Capacity (acfm)[a,d]	Specific Power (kW/100 acfm)[d]
	99.0	Max	528	18.77
	89.0		478	18.62
	63.7		331	19.22
	48.2		229	21.04
	32.9	Min	126	26.05
9*	Total Package Input Power at Zero Flow[c, d]		0.0	kW

Adjust for pressure

10



Estimating savings – more efficient controls

Mechanism of Savings:

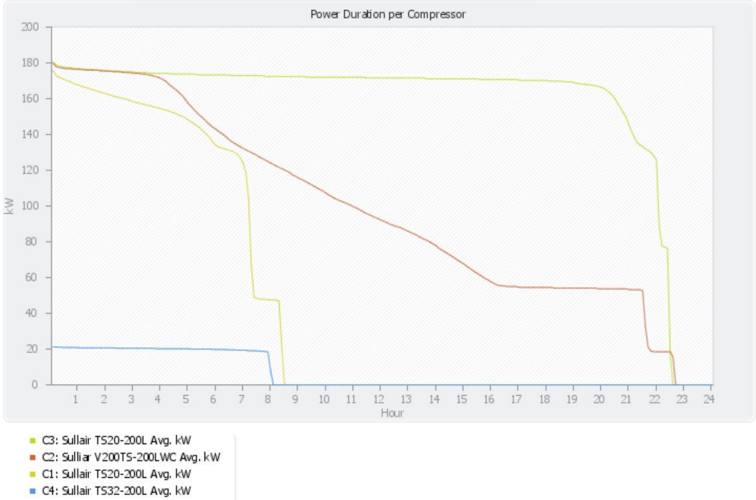
Improved efficiency of air production

Calculation Method:

- Determine load/**unload** run time & energy
- Otherwise, determine the optimal compressor configuration (kW/100 cfm) for each baseline operating modes, and calculate the difference

Pitfalls

- Theoretical savings may not match actual savings
- Savings depends on compressor type and size
- Difficult to achieve full savings if demand is highly variable

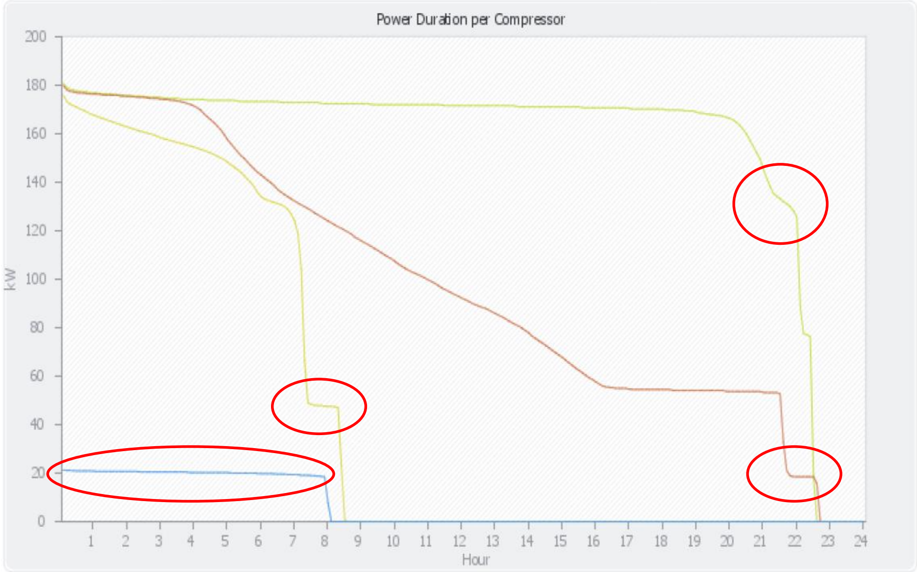


Improved controls worked example

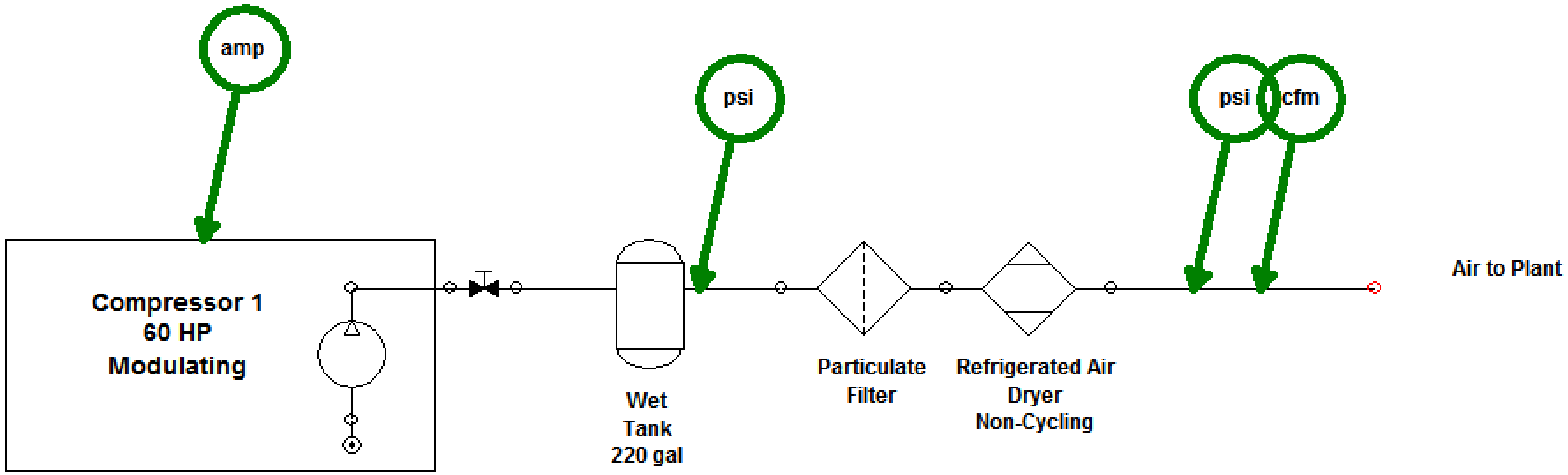
The detected unloaded run time is the control waste.

Theoretical savings for perfect system control:

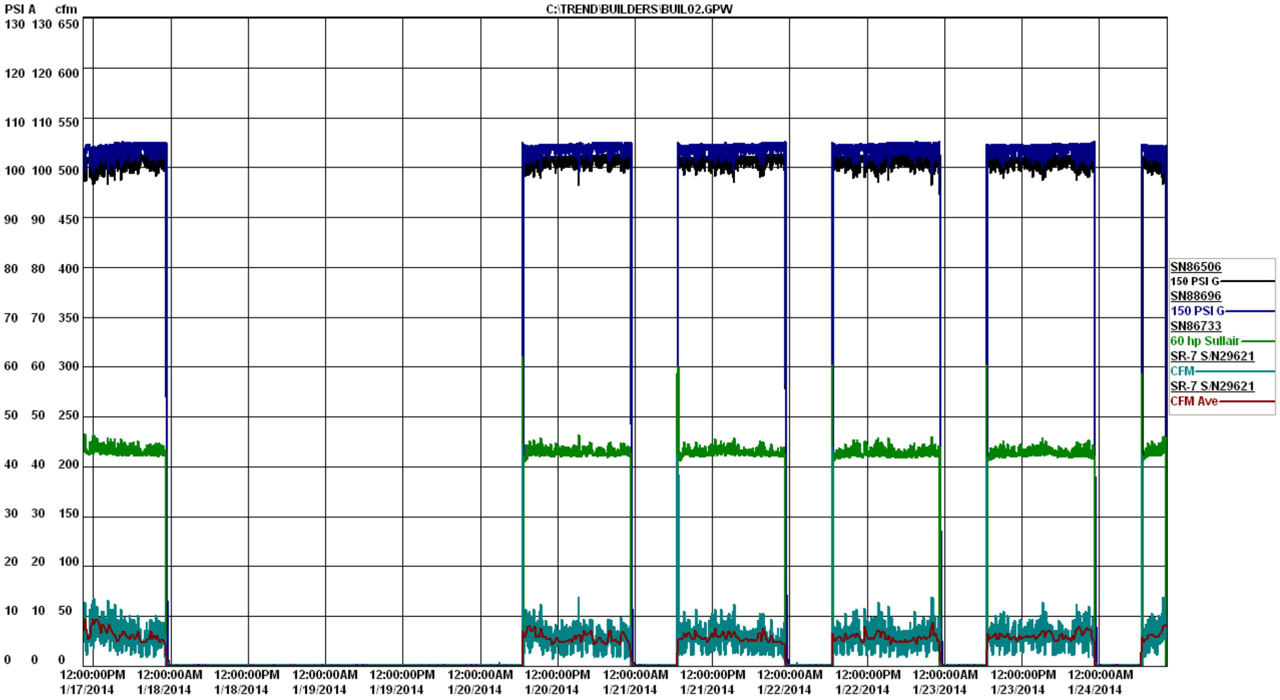
- 8 hours at 20 kW = 160 kWh
- 1 hour at 50 kW = 50 kWh
- 1 hour at 20 kW = 20 kWh
- 2 hour at 130 kW = 260 kWh
- Yearly total: 490 kWh x 365= 178,850 kWh



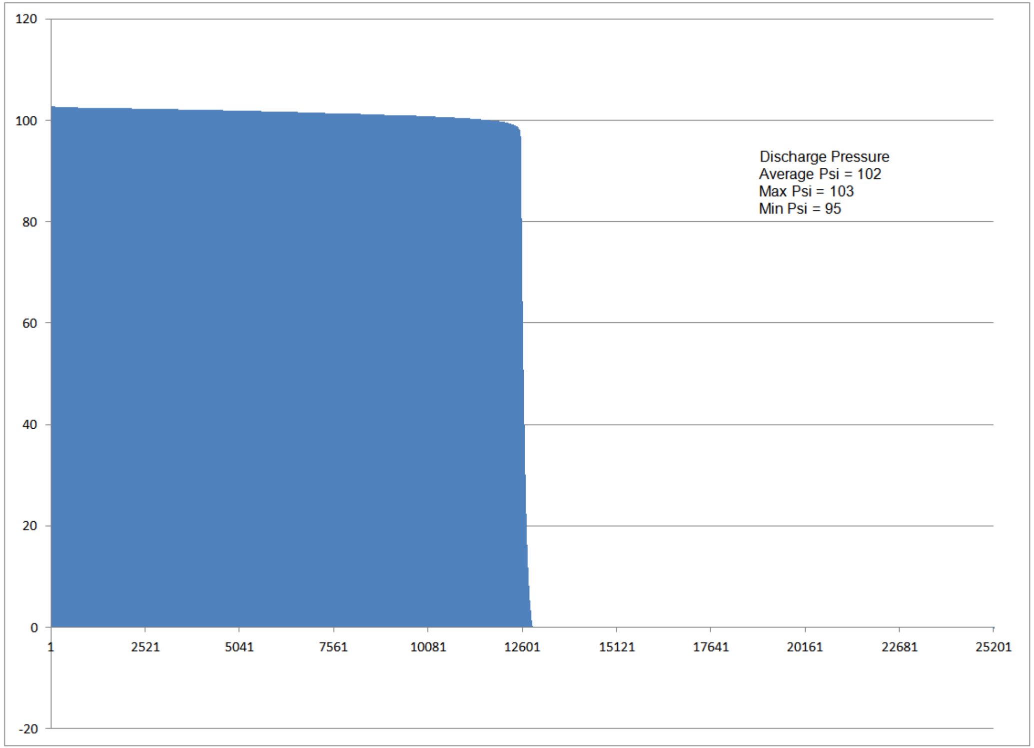
Example project: cabinet making facility



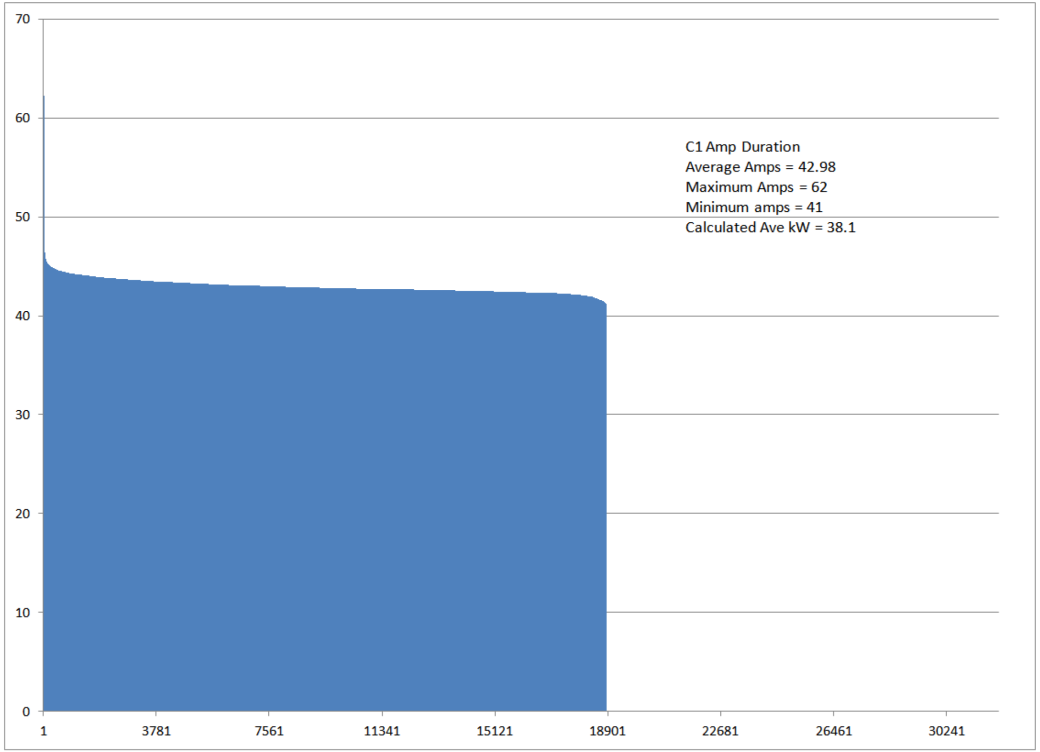
Example project: cabinet making facility (continued)



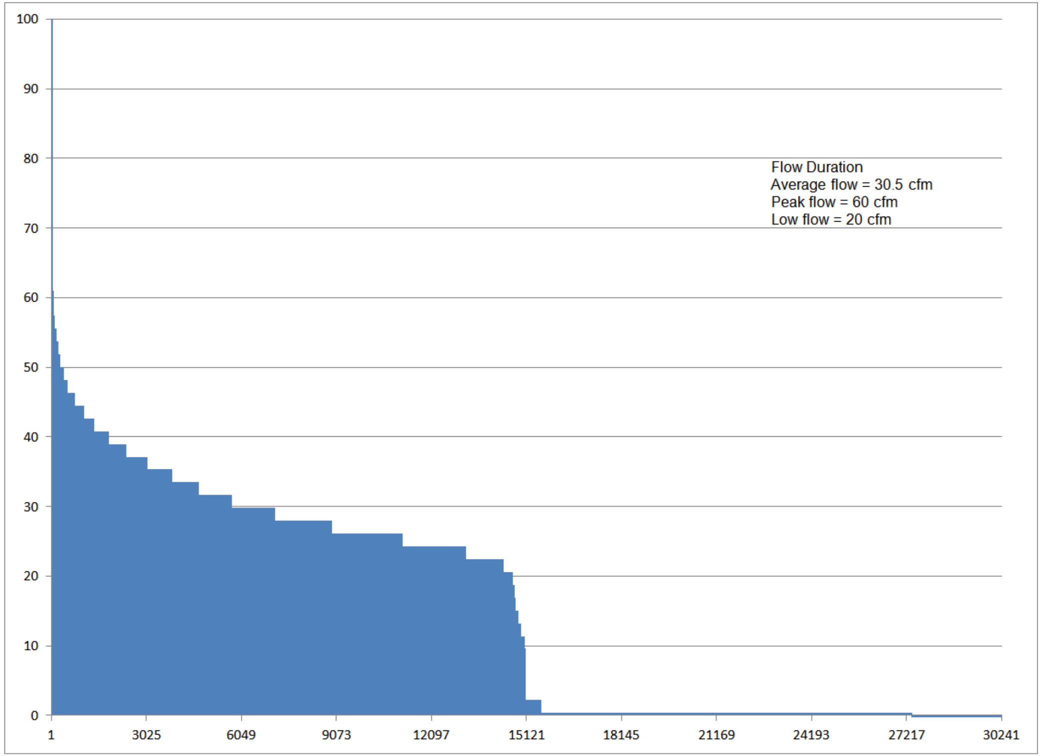
Example project: cabinet making facility (continued)



Example project: cabinet making facility (continued)



Example project: cabinet making facility (continued)



Example project: cabinet making facility (continued)

Base Case:

Compressor

4200 hours x 38.2 = 160,230 kWh

Dryer

4200 hours x 1.9 = 7,980 kWh

Total = 168,210 kWh

Peak = 40 kW

Specific Power = 123 kW/100 cfm

Example project: cabinet making facility (continued)

Upgrades

Compressor

- 4200 hours x 8.33 kW = 34,986 kW
- Includes discharge pressure reduction

Dryer

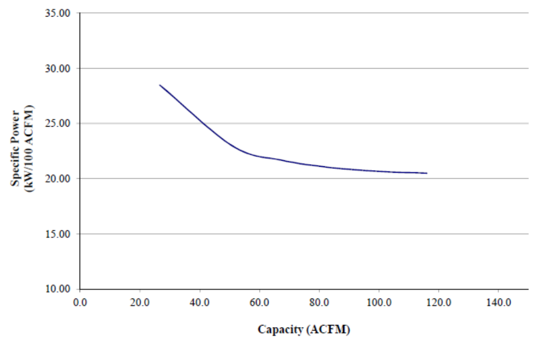
- 4200 hours x .2 = 840 kWh

Total = 35,826 kWh

Peak = 9 kW

Specific Power = 28 kW/100 cfm

	Input Power (kW)		Capacity (acfm)[a,d]	Specific Power (kW/100 acfm)[d]
8*	23.8	Max	**116.0**	**20.49**
	20.6		**99.8**	**20.66**
	17.5		**83.5**	**21.01**
	14.6		**67.3**	**21.68**
	11.7		**51.0**	**22.95**
	7.6	Min	**26.7**	**28.48**
9*	Total Package Input Power at Zero Flow[c, d]		**0.0**	kW
10				



Note: Graph is only a visual representation of the data in Section 8
Note: Y-Axis Scale, 10 to 35, + 5kW/100acfm increments if necessary above 35
X-Axis Scale, 0 to 25% over maximum capacity

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Estimating savings wrap-up

Methods

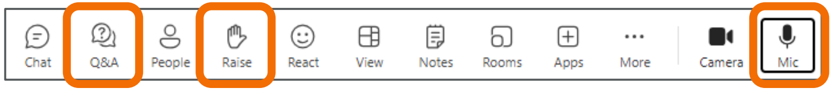
- Consider the appropriate accuracy
- Assess your data availability
- Start with a good baseline
- Consider your operating hours
- Identify the savings mechanism
- Understand the limitations of your calculation

Tips and tools

- How to use CAGI Sheets
  - ➢ Adjusting for discharge pressure
- Getting the applicable kW/100 cfm
- Estimating flow from comp. status
- Leak rate estimation methods
- Different solutions and calculations for different compressor controls

Questions and answers with Ron Marshall

Post in Q&A window or raise hand and unmute



Additional Resources

RETScreen - Compressed Air Calculator

Feasibility - Individual measure - Compressed air - Compressor

Template assignment

Base case
- Rotary screw compressor
- 200 cfm system, 75 hp motor, 100 psig
- Usage: 100 cfm
- Leakage: 20 cfm
- Capacity control with inlet throttling
- System is never turned off

Proposed case
- Variable speed control
- Reduce usage by 20%
- Fix 75% of leaks
- Automatic shutdown of system outside working hours (60 hours per week)
- Estimate cost for efficiency measures $70,000
- Reduction in service costs: $500 (O&M)

Other opportunities
- Upgrade to premium efficiency motor: $5,000
- Modify the air intake location: $10,000

Compressed air

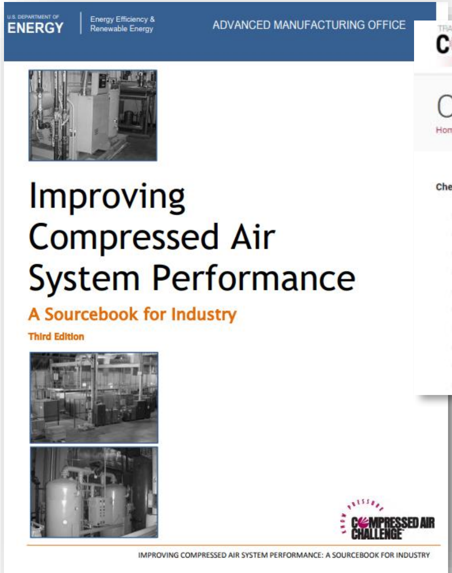
Description	Compressor
Note	

eLearning

Compressed air

Compressor	Unit	Base case	Proposed case	Energy saved
Type		Rotary screw	Rotary screw	
Capacity	cfm	200	200	
Stages		1	1	
System pressure	bar	7.908	7.908	
Friction losses	%	15%	15%	
Motor				
Type		Standard efficiency	Standard efficiency	
Suggested capacity	hp	37.9	37.9	
Capacity	hp	75	75	
Efficiency - full load	%	92%	92%	
Manufacturer				
Model				
Air intake location		Indoor	Indoor	
Capacity control		Inlet throttle	Variable speed	
Average useful air demand	cfm	100	80	
Average air leakage	cfm	20	5	
Leakage rate	%	10%	2.5%	
Load factor	%	60%	42.5%	
Hours of useful air demand	h/d	12	12	
Operating hours	h/w	168	60	
Incremental initial costs	$		70,000	
Incremental O&M savings	$		500	
Number of compressors		1	1	
Electricity	kWh	623,307	168,765	454,542 72.9%

Available through Energy Manager Learning Platform



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MEASUR

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MEASUR is a suite that includes a set of key software platforms and more than 70 calculators that AMO developed over the preceding decades. Altogether, these tools can help manufacturers improve industrial system efficiency and identify potential savings opportunities.

Step	Actions
Determine the Need	Is compressed air needed at all? Can another energy form be used? (especially air motors and cooling)
	Inventory the need for compressed air in terms of:
	flow requirement (SCFM)
	pressure requirement
	quality (temperature, moisture content, oil content, etc.)
	point(s) in the distribution system
	Document when compressed air is required.
	Is the real demand for compressed air growing? — or simply the leaks?
Match the Need	Implement a plant-wide awareness program for compressed air management.
	Eliminate leaks:
	Use ultrasonic leak detector to track down leaks and FIX.
	Isolate with valves appliances and equipment when not in use.
	Manage end-use:
	Eliminate unnecessary uses (floor sweeping).
	Consider intensifying nozzles instead of simple cutoff pipe nozzles.
	Minimize main supply pressure.
	Avoid pressure reduction at point of end-use, segregate large low-pressure uses and provide separate low-pressure supply — consider high-pressure blowers.
	Use treatment appropriate to quality requirement — segregate low-volume, high-quality users and provide separate supply.
	Ensure that controls for treatment (drying) are not set lower than required.
	Ensure that compressor capacity on-line follows the demand for air:
	Base-load compressors with poor capacity control (throttling) — check motor load when air delivery from compressor is low.
	Sequence compressors to ensure that unit with best capacity control follows the load
	Ensure that idling compressors shut down promptly.
	Optimize the compressor plant with properly sized receivers, demand control devices and comprehensive system control.
Maximize Efficiency	Ensure that inlet air temperature is as cool and dry as possible — use outside air during cold seasons.
	Ensure that inlet filters are clean with minimal pressure drop.
	Ensure that filtration and treatment equipment impose minimal pressure drop.
	Ensure that line sizing is appropriate to flows to minimize pressure drop.
	Ensure good piping practices to avoid excessive pressure drops at T connections, elbows, unions and other fittings.
	Ensure appropriate compressor room temperature.
	Consider compressor replacement with a more appropriate, newer and/or more efficient unit.
	Consider an energy-efficient motor replacement — not practical in many packaged units.
Optimize Supply	Install the simplest form of heat recovery possible to reclaim heat rejected from the compressors — either water- or air-cooled.
	Consider engine drive compressors with heat recovery.

Free expert support available through Save on Energy!

Post your questions on the Energy Manager Learning Platform discussion forum to get advice, coaching, and support on:

- ❑ Establishing or improving **energy management best practices**
- ❑ Identifying and implementing **industrial energy efficiency projects**

Register for the Energy Manager Learning Platform (emss.goldfin.ca)

For more information: trainingandsupport@ieso.ca

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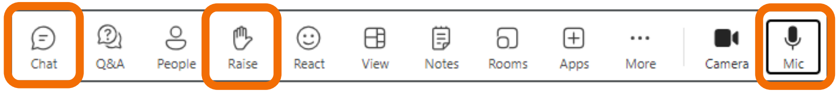
One last question…

What's one tip from today you'll use when estimating savings?

Answer in chat or raise hand and unmute



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