Facilities' Guide for Reducing Costs through Pneumatic Tool Replacement

Motivation

Why should manufacturers care about changing out compressed air-driven—*pneumatic*—tools with direct electric motor-driven—*corded/cordless*—tools? The answer is simple, money. The cost of running pneumatic tools is too often ignored by companies who could save hundreds or thousands of dollars each year by considering other options. Most compressed air systems use considerably more energy than is needed to support the demand. With typical compressed air systems having a very low wire-to-work efficiency of around 10%, it is surprising that only about 5% of manufacturers track the amount of energy spent in compressed air systems and only 24% have staff or equipment dedicated to detecting and controlling compressed air system leaks[1,2]. Clearly, there is a lack of general knowledge of the relative inefficiency of compressed air and a large opportunity for energy efficiency improvements in manufacturing companies all across the country. This guide, along with MnTAP's cost comparison calculator will help manufacturers estimate how much it costs to run pneumatic tools and how much could be saved by switching to direct electric-driven alternatives.

Compressed Air 101

Since the measure of pneumatic tool efficiency depends on the efficiency of the air compressor providing the pneumatic tool compressed air, it is helpful first to better understand how compressed air is generated and used. Air compressors take in air at atmospheric pressure through an inlet valve and compress it into a smaller volume, thus increasing the pressure, or force per area at the output. The two most common types of compressors are rotary screw compressors and piston type compressors. Rotary screw compressors work by having two large screws in an air tight chamber. The spinning motion of the screws reduces the volume where the air can reside thus increasing the pressure. Piston type compressors use a piston to reduce the volume and increase pressure.

The efficiency of a compressed air system is typically measured by the specific power: the number of kilowatts of power it takes to produce 100 cubic feet per minute (CFM) of compressed air at a given pressure. The efficiency of a given compressed air system is, to a large extent, determined by the compression method and control system. The goal of a control system is to match the air supplied with the demand while keeping the compressor system running as efficiently as possible. All compressed air systems have some amount of operating time where the demand for air is less than the maximum capacity of the compressed air system. Thus, the compressed air system will be controlled to operate at a fraction of the maximum capacity which can significantly lower the efficiency of a system in varying amounts depending on the control strategy.

---

[1] "Number of Establishments by Participation in Specific Energy-Management Activities." Energy Information Administration (n.d.): n. pag. July 2013. Web. 1 Sept. 2016.

[2] "Performance Opportunity Roadmap." Improving Compressed Air System Performance: A Sourcebook for Industry. 3rd ed. Washington, D.C.: Industrial Technologies Program, U.S. Dept. of Energy, Energy Efficiency and Renewable Energy, 2003. 18. Web. 22 Aug. 2016.

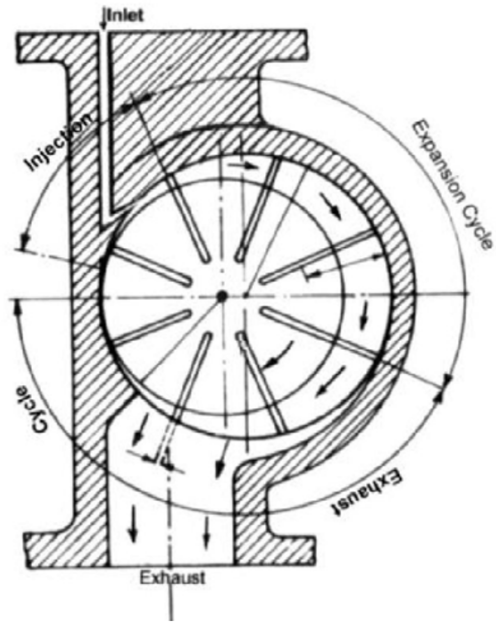
Figure 1 Piston type compressor on the middle and rotary screw compressor on the left.

That is to say, compressors operate at their most efficient specific power at full load; however, since demand for air is typically lower than what can be provided, a significant fraction of time can be spent at part-load, where specific power increases and efficiency decreases. One exception is an on/off control strategy that runs the compressor at either maximum capacity or completely off. This strategy can be efficient but can put unnecessary additional wear and tear on the compressor. The very common load/unload or dual-strategy runs the compressor at either maximum capacity or in an unloaded state – whereby the compressor mechanism is disengaged from the motor, which is left to spin “unloaded” which limits on/off damage. The unloaded state won’t produce any air but will still consume 15-35% of the maximum power draw of the compressor which can make this control strategy inefficient[3]. An inlet modulation strategy partially closes the inlet valve (where the air that is about to be compressed comes in) which reduces the amount of air that goes into the compressor. The inlet modulation strategy is inefficient when applied to the two most common types of compressors; rotary screw and piston type. Variable speed drive (VSD) is the most efficient control strategy for reduced load operation because VSD’s have a roughly constant efficiency at any amount of output capacity, but provide no additional benefit when operated at full load. Since the speed of a compressor is proportionate to the CFM output, adjusting the speed allows the CFM output to be easily changed depending on the demand for air.

Pneumatic tools generally work in one of two ways. Most pneumatic power tools use rotary vane air motors which transform the kinetic energy from the high pressure air into mechanical energy in the rotor. Power tools use this mechanical energy to rotate nuts, screws, bolts, etc. In the second method, there is a piston at the top of an air tight chamber and a spring at the bottom. An inlet valve allows the compressed air to push the piston down and compress the spring. As the spring is compressed there is a point where the outlet valve, which is normally covered by the piston, is uncovered and the air is released. Since there is no more air pushing the piston down, it moves back to the original position at the top. Power tools use this linear motion as the power source for air hammers, reciprocating saws, staplers, etc.

[3] https://www.compressedairchallenge.org/library/sourcebook/Improving_Compressed_Air-Sourcebook.pdf

Figure 2 Rotary Vane Air Motor[4]



Performance

Manufacturers care about making the highest quality products in the least expensive and fastest way possible. The question is whether or not electric motor-driven tools can provide the same level of performance as pneumatic tools. Performance has been measured in **functionality** (consistency of performance and practical considerations), **ergonomics** (weight, size, portability, and comfortability), and **cost** (expected lifetime, purchase cost, and energy cost). Albeit rare, there are certain use cases where no electric tool on the market can achieve the required torque rating, rotational speed, and/or power that pneumatic tools can offer. Pneumatic tools should also be used over electric tools whenever there are spark hazards. However, MnTAP's findings suggest that in most cases, electric power tools can deliver a similar and occasionally superior level of performance at reduced cost, as compared to pneumatics.

Functionality

When using tools for hours at a time, **consistency of performance** is key to a quality product. During interviews with manufacturing companies, no company responded that the performance of any of their tools, pneumatic or electric, was inconsistent. Most tools perform at an acceptable level, even with little maintenance, until they break. This suggests that the average quality of tools that are being manufactured today is fairly good.

There are some **practical considerations** that should be accounted for when determining which power tools should be used. One major consideration is how the power tools are powered. Cordless tools rely on a battery with a finite amount of energy to do work while corded electric and pneumatic have an effectively never-ending supply of energy. Cordless tools that are used a lot per day will need multiple batteries in order to reduce downtime otherwise spent waiting for the batteries to be recharged. In applications that don't require much portability or maneuverability, corded electric tools are typically superior to cordless because there is no need for expensive batteries. Electric tools rated for a low duty cycle used continuously for hours at a time may become too hot to operate and both

---

[4] http://www.intechopen.com/books/the-impact-of-air-pollution-on-health-economy-environment-and-agricultural-sources/influence-of-the-air-engine-on-global-warming-issues-21st-century-fuel-technology

pneumatic and electric tools will have reduced lifetimes if used in this manner. For tools that need to be used continuously for hours at a time, high duty cycle industrial tools should be used.

Ergonomics

Ergonomics (weight, size, portability, and comfortability) is an important factor to consider, ensuring that a tool's operator will not suffer from fatigue or health and safety issues through prolonged use.[5] There is a wide variety of designs available for pneumatic and electric tools of a given function making direct comparisons difficult. While there were observed to be some exceptions, in general, electric-driven tools tend to be larger and heavier compared to pneumatic tools. This is a result of housing a small electric motor of their own; pneumatics use air motors that require fewer internal parts, which allows for generally smaller overall size and weight. Cordless electric tools tend to be even heavier and larger since they further need to accommodate an energy source (battery). Three common tools: half-inch drills, half-inch impact wrenches, and 4-½'' grinders were investigated for weight and size differences. Cordless tools, on average, weighed 16% more than pneumatic tools while corded weighed 7% more. Cordless tools, on average, were 21% longer than pneumatic tools while corded were 46% longer[6]. Cordless tools are the most portable as they do not require a constant electrical cord or pneumatic hose connection which hinders portability and maneuverability. Tools that are not maneuverable enough can be awkward and uncomfortable to operate. No interviewed businesses reported discomfort through hours of use with any of their hand power tools, despite the measurable differences in ergonomics between tool types. Although none of the interviewed businesses reported discomfort, MnTAP emphasizes that it is important to have preventative measures against prolonged discomfort which may result in injuries.

Table 1 Ergonomics of the different tool types relative to pneumatic tools.

Power Source	Weight	Length
Cordless Electric	116%	121%
Corded Electric	107%	146%

Cost

Expected **lifetime, initial cost**, and **energy costs** are influential parameters in the calculation of the total cost to use power tools. The expected **lifetime** of a power tool varies based on how often the tool is used, how hard it is used, how much maintenance is performed on the tool, and the tool type. Because many different factors affect the expected lifetime of a power tool, your facility may experience different results than the average lifetimes outlined below. During interviews with over 60 manufacturing companies, the average reported cordless tool lifetime was 2.5 years, the pneumatic tool lifetime was 2.7 years, and the corded electric was 2.6 years. The averages show that electric tools do not last as long as pneumatic tools do; that does not necessarily mean that pneumatic tools are more cost effective to use. While specific comparisons may yield different results, MnTAP observed that the **initial cost** of corded electric tools is generally less than pneumatic tools while cordless are the most expensive[5].

The differences in **initial cost** are small relative to the difference in **energy costs** over the lifetime of a tool. Pneumatic tools use about 8-10 times as much energy as an equivalent electric-driven tool to perform the same job. This massive imbalance in energy usage can add up to a significant energy cost difference between pneumatic and electric tools. This difference is the primary reason to switch out pneumatic tools with electric. The energy cost difference for running a tool will be higher than average if

[5] Refer to additional references 7, 8, 9, 10 for more information.
[6] Grainger Online Catalog. Web. 20 July 2016.

that tool requires lots of energy to operate and/or is used frequently. Conversely, the energy cost difference will be smaller than average if that tool doesn't require much energy to operate and/or is used infrequently. Tools with the highest energy cost difference should be the ones considered to be replaced first. Refer to the associated cost calculator for more information on costs.

Cost Savings Calculator

MnTAP has developed a cost-savings calculator to help industrial facilities to compare current costs of running pneumatic tools to the new costs associated with running electric tools. The tool shows how much energy and money the facility spends on pneumatic tools, and how much energy and money would be spent on replacement with electric tools. It provides an annual savings as well as an estimated payback period associated with making a change.

The purpose of the tool is to show shop managers the costs and potential savings associated with their tool options. Running tools with compressed air tends to be much more expensive and resource intensive than using electric tools.

The basic calculator takes in:

- Tool type
- Quantity of tools
- Hours per day
- Days per year
- Replacement Type (corded or cordless)

The calculator uses data from various tool catalogues collected in 2017 to estimate the airflow (cfm) needed to run the pneumatic tools, and to estimate the amount of energy (kWh) needed to run an electric equivalent. Pneumatic tool energy (kWh) is calculated by taking that amount of airflow, and plugging the value into both efficient and inefficient compressor airflow generation values. Efficient compressors use roughly 20 kW to generate 100 cfm of compressed air, while inefficient compressors use roughly 30 kW to generate 100 cfm. The power in kW is multiplied by the total number of hours per year the tool runs to calculate its energy use in kWh.

The tool also accounts for compressed air system leaks, maintenance costs, tool costs, tool lifetime, blended energy rate, and compressor efficiency. The basic tab uses standard, default values for these parameters which were estimated based on informational interviews with plant managers and compressed air experts. The advanced tab allows users to go into more depth, modifying these assumptions to more perfectly match their own situation as desired. Below is an example showcasing an example of the difference in energy consumption between a pneumatic and electric drill.

Table 2. Cost comparison for using a 3/8'' drill for 2 hours per day[3].

		Pneumatic	Corded Electric	Cordless Electric
Expected Tool Lifetime (years)		2.7	2.6	2.5
Cost ($)	**Initial**	$128	$84	$141
	Annual Energy	$226	$29	$29
	Total Cost Per Year	**$273**	**$61**	**$85**

Each tool type has its own strengths and weaknesses which are laid out in the table below.

Table 3. Summary of general performance attributes of different power tool types.

Power Type	Pros	Cons
Battery/Cordless Electric	• Portable • No trip hazard • Low energy costs • Quiet • Quality Assurance Opportunity	• High initial cost • Less powerful • Shortest lifetime • Spark hazard • Overheating • Battery cost • Heavier/Longer
Pneumatic/Compressed Air	• No spark hazard • No overheating • Longest lifetime • Highest power to weight ratio • Shorter/Lighter	• 8-10x energy cost of electric • Limited portability • Requires expensive compressed air system • Loud compressor • Trip hazard
Corded Electric	• Quiet • Low energy costs • Low initial cost	• Limited portability • Requires electrical outlet • Spark hazard • Overheating • Heavier/Longer • Trip hazard

Other Considerations/Information

Facilities should spend time figuring out what performance requirements their power tools need to deliver. Consider future needs, quality, and scalability as well. This ensures that the tool purchases are always meeting the facility's needs. When considering replacing pneumatic tools with electric alternatives, conducting a preliminary test with a small amount of tools may help alleviate unforeseen problems. Look at reliable tools as productivity multipliers that make profit for the facility above what one employee could do by hand. From this perspective, the choice of tools becomes a crucial business decision that should be made with care.

Problems with electrical outlets may arise when many electric-driven tools are being used. When planning on using cordless tools, the number of outlets needed depends on how many batteries you have and how many batteries one charger can charge. When planning on using corded electric tools, make sure there are enough ground fault circuit interrupting (GFCI) outlets where the work is done. Many outlets are rated at 20 amps which, according to electrical codes, have a max load of 80% of the outlet rating or 16 amps. If more or higher rated outlets are needed, call a local electrician. Keep these costs in mind as it will affect payback times.

Call the local electric utility! Many utilities have programs that give rebates for lower electrical usage. Rebates may be given out for buying a higher efficiency compressor, using a variable speed drive compressor, using zero-loss air drains, retiring an inefficient compressor before it breaks, reducing leaks, or other energy saving measures. These are great ways to reduce energy usage and save extra money all in one fell swoop. Besides giving out rebates, utilities often will provide funding toward energy audits or compressed air leak studies to help find places to save money.

It is clear that cordless tools are becoming increasingly popular, but why is that? One of the main factors that contribute to their popularity is the rapidly improving lithium-ion battery technology. Lithium-ion batteries have been around commercially since 1992 and are still being actively researched and improved. Lithium-ion batteries have lower maintenance, lower self-discharge, no memory effect, and are lighter compared to the older nickel-cadmium or nickel-metal hydride batteries[7]. Besides the vast improvement in battery technology, cordless tools offer one obvious advantage over all other tools: extreme portability. All of these combined allow for the genesis of cordless power tools that can compete with corded electric and pneumatic tools.

Conclusion

This guide has described the varying benefits and drawbacks to pneumatic, cordless, and corded power tools. The performance of power tools was measured by their functionality, ergonomics, and cost. All of the manufacturers that were interviewed thought the performance of all of their tools, electric or pneumatic, was consistent. Although all are consistent, some have better suited functionality for different applications. If portability is needed, cordless tools typically perform the best. If portability is not needed then corded electric tools typically perform the best. If there is a spark hazard, pneumatic tools should be used for safety reasons. The most important ergonomic factors include weight, length and maneuverability. Electric tools usually are heavier and longer than pneumatic tools while cordless tools are the most maneuverable. The largest difference between power tools types is the cost of the energy to run them. The energy costs to run electric tools are 8-10 times less than similar pneumatic tools. Over the course of a year, this large difference can lead to thousands in savings. Additional information can be found in the references.

Additional Notes on Reducing Compressed Air Costs

MnTAP understands that it is not always possible to switch out pneumatic tools with electric. Due to this, some suggestions for reducing the cost of compressed air at a facility will be discussed. Reducing leaks is one of the simplest and most effective ways to lower the cost of compressed air. Leaks create pressure drops near end uses which can increase energy costs. Either operators will manually set the compressor to a higher pressure to compensate for lost flow, or the compressor will run longer to compensate for the constant loss of air (depending on the compressor type and control strategy). Either way, compensating for lost flow costs money. Leaks are commonly found are around valves, disconnects, and fittings, so checking those areas first is a good idea. Keep in mind that just because a leak isn't audible does not mean that there isn't a leak. An ultrasonic detector is the best tool for identifying compressed air leaks. Alternatively, much in the same way one could find a leak in an automobile tire, bubbles reveal air leaks in lines covered in soapy water. Leaks in compressed air lines and fittings can then be taped up, or lines and fittings can be replaced, depending on the severity of the

---

[7] "Lithium-based Batteries Information." *Battery University*. N.p., 3 May 2016. Web. 26 Sept. 2016.

leak. Eliminating inappropriate end uses stops another form of ‘leak,’ commonly referred to as *artificial demand* reducing compressed air usage and saving money.[8]

Another way to reduce the cost of compressed air is by reducing the system pressure. System pressures are often set higher than necessary to create artificial storage or in order to offset pressure drops from leaks, dryers, filters, and other compressed air system components. Pressure set points should be optimized after addressing system leaks by comparing the compressor pressure set point to the highest pressure requirement in the facility and then compensating for normal pressure drop throughout the compressed air system. A rule of thumb is that for every 2 PSI decreased the system will use 1% less energy.

Table 4. List of power tool vendors.

Vendor	**Offered**	**Website**
Black & Decker	electric	http://www.blackanddecker.com/en-us/support/find-a-retailer
Bosch	electric	https://www.boschtools.com/us/en/dl/dealerlocator/dealersearch/
Central McGowan	Pneumatic, electric	http://www.centralmcgowan.com/contact/locations/
Chicago Pneumatic	Pneumatic, electric	http://www.cp.com/usen/contactus/industrialtools/
DeWalt	Pneumatic, electric	http://www.dewalt.com/en-us/support/find-a-retailer
Dynabrade	Pneumatic, electric	http://www.dynabrade.com/dyn10/content.php?page=wtb
Fein	electric	https://fein.com/en_us/dealer-repair/
Grainger	Pneumatic, electric	https://www.grainger.com/
Hitachi	Pneumatic, electric	http://www.hitachipowertools.com/us/main-navigation/find-a-retailer-service-center
Ingersoll Rand	Pneumatic, electric	https://myir.com/contactus/find
Mars Supply	Pneumatic, electric	http://www.marssupply.com/default.aspx?Page=Contact+Us
Metabo	electric	https://www.metabo.com/us/enus/storefinder/
Milwaukee	electric	https://www.milwaukeetool.com/buy-now
Minnesota Industries	pneumatic, electric	http://minnesotaindustries.com/index.php?page=contact-us
Northern States Supply	Pneumatic, electric	https://www.northernstatessupply.com/contactus.aspx
Positec	electric	https://www.positecgroup.com/our_brands/rockwell
Ryobi	electric	https://www.ryobitools.com/power-tools/support/parts
Snap-On	Pneumatic, electric	https://store.snapon.com/FindFranchisee.aspx

[8] Refer to additional references 14, 15, 16, 17, 18, 19 for more information.

References

Air Compressor and Motor Operating Principles

1. A video showing how piston type compressors work.
   https://www.youtube.com/watch?v=E6_jw841vKE
2. A video showing how rotary screw compressors work.
   https://www.youtube.com/watch?v=YDh2X0cn-3E
3. A video showing how rotary vane air motors work.
   https://www.youtube.com/watch?v=BD9-VvSRgME

Compressed Air Uses

4. The seventh edition of the Compressed Air & Gas Institutes' Compressed Air & Gas Handbook. This is a great resource for finding compressed air uses.
   http://www.cagi.org/pdfs/cagi_electhb_ch1.pdf
5. A brief list of several common applications of compressed air as well as the various quality levels of compressed air.
   http://www.ecompressedair.com/library-pages/compressed-air.aspx
6. A brief discussion of air compressors and also a list of applications of compressed air.
   http://www.quincycompressor.com/applications-of-air-compressors/

Ergonomics

7. A comparison of the ergonomics of DC and air tools for horizontal drilling. These results cannot be generalized to all DC and air power tools.
   http://www.sciencedirect.com/science/article/pii/S0169814104001118
8. An article on how power tool manufacturers have addressed ergonomics.
   www.assemblymag.com/articles/92192-ergonomics-and-fastening-tools-go-hand-in-hand
9. How to use power tools in order to reduce work place injuries.
   https://www.ccohs.ca/oshanswers/ergonomics/handtools/tooldesign.html
10. These statistics show that the number of injuries relating to power tool is significant.
    http://www.legalmatch.com/law-library/article/work-tools-accident-statistics.html

Air Consumption of Common Power Tools

11. http://www.engineeringtoolbox.com/air-consumption-tools-d_847.html
12. http://www.industrialairpower.com/wp-content/uploads/Air-Compressor-Consumption-Charts.pdf
13. The MnTAP Pneumatic-to-Electric Power Tool Energy Savings Calculator.
    http://z.umn.edu/ToolCalc

Compressed Air Leaks

14. One method for estimating compressed air leak costs.
    https://www.energystar.gov/ia/business/industry/compressed_air3.pdf
15. A method for estimating leaks for load/unload compressors.
    https://www.compressedairchallenge.org/library/factsheets/factsheet07.pdf
16. Real world savings from fixing leaks is often lower than what some resources would suggest. This article talks about why that is the case, how to fix it, and that fixing leaks is still worth it.
    http://www.airbestpractices.com/system-assessments/leaks/are-compressed-air-leaks-worth-fixing
17. Another article on the real world savings achievable from fixing leaks and how the control system has to be modified to "cash in" on the savings.

http://www.maintenancetechnology.com/2011/09/are-you-wasting-money-fixing-compressed-air-leaks/
18. Brief overview of leaks in compressed air systems. http://www.quincycompressor.com/how-to-find-and-fix-leaks-in-your-air-compressor-system/
19. A list of inappropriate compressed air uses which should be minimized. http://www.industrialaircompressors.biz/page/1003390

Miscellaneous Compressed Air References

20. A compendium of resources covering both supply-side and demand-side compressed air energy efficiency topics. https://www.compressedairchallenge.org/library/
21. A recently updated general compressed air reference which touches on all the most important compressed air topics. https://www.compressedairchallenge.org/library/sourcebook/Improving_Compressed_Air-Sourcebook.pdf
22. The costs of real compressed air systems are usually higher than what references say. http://www.airbestpractices.com/system-assessments/leaks/compressed-air-system-costs-meet-real-world
23. Different control methods are discussed along with their differing efficiencies. http://cascousa.com/compressed-air-101/types-of-compressors/compressor-control-methods/
24. A very short overview of compressed air costs. http://www.silvent.com/energy-optimization/compressed-air-energy/
25. A site that links to compressed air tip sheets and compressed air case studies. Note that many of the tip sheets are old but may still have useful information. http://www.energy.gov/eere/amo/compressed-air-systems
26. This article discusses how DC power tools can give feedback on how they are used in order to control the process and aid with quality assurance. http://www.assemblymag.com/articles/91277-new-trends-in-electric-tools
27. A step by step guide on how to set the pressure controls on load/unload air compressors. http://www.air-compressor-guide.com/learn/air-compressor-parts/air-compressor-pressure-switch/air-compressor-pressure-switch-setting
28. Manufacturing energy usage can be found here. https://www.census.gov/econ/overview/ma0400.html