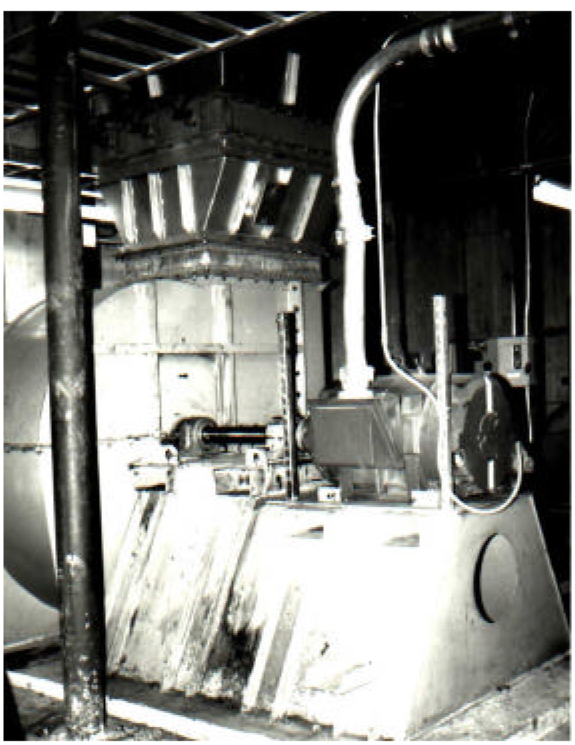
A GUIDEBOOK
for
PERFORMING WALK-THROUGH ENERGY AUDITs
of
INDUSTRIAL FACILITIES



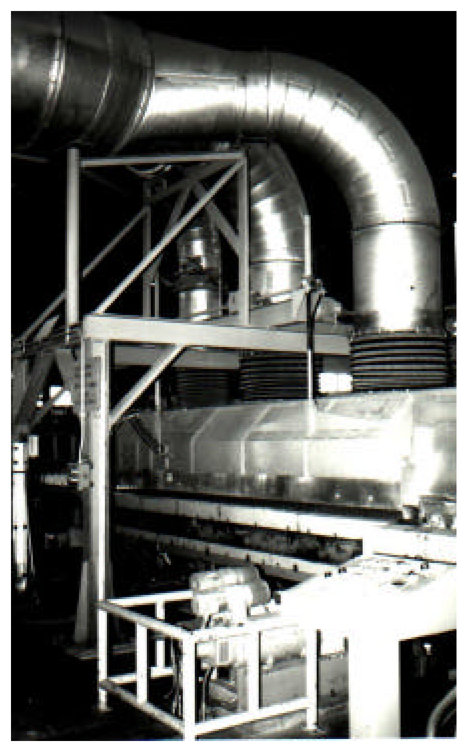


Table of Contents

Audit Information

Facility Name: ________________________________

Address: ______________________________________

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Facility Contact: ______________________________

Facility Phone: ________________________________

Date of Audit: _________________________________

Audited By: ___________________________________

Auditors Phone: _______________________________

Acronyms

1.	AC	Alternating Current
2.	ACFM	Actual cubic feet per minute of air flow
3.	ACFM-FAD	Air flow before filter (Free Air Delivery)
4.	VSD	Adjustable Speed Drive
5.	ASME	American Society of Mechanical Engineers
6.	BHP	Brake Horsepower
7.	BPR	Back Pressure Regulator
8.	CAGI	Compressed Air and Gas Institute
9.	ccf	100 Cubic feet
10.	CFL	Compact Fluorescent Lamps
11.	CFM	Cubic feet per minute of air flow
12.	CSI	Current Source Inverter
13.	CO	Carbon Monoxide
14.	CW	Cool White Fluorescent Lamps
15.	DC	Direct Current
16.	°F	Degrees Fahrenheit
17.	HPS	High Pressure Sodium
18.	HO	High Output
19.	HP	Horsepower
20.	HTD	High Torque Drive
21.	HVAC	Heating Ventilation and Air Conditioning
22.	ICFM	Air flow at inlet flange
23.	IESNA	Illuminating Engineering Society of North America
24.	LPA	Liquid Pressure Amplifier
25.	MH	Metal Halide
26.	O_2	Oxygen
27.	PCB	Polychlorinated Biphenyls
28.	Psi	Pressure in pounds per square inch
29.	Psia	Psi absolute, which is 14.7 as sea level
30.	Psig	Psi gauge, referenced to atmospheric pressure
31.	SCFM	Equivalent air flow at Standard Conditions
32.	PWM	Pulse Width Modulated
33.	VSD	Variable Speed Drive
34.	VSI	Voltage Source Inverter
35.	WW	Warm White Fluorescent Lamps
36.	WWX	Warm White Deluxe Fluorescent Lamps

A Guidebook for Performing Walk-Through Energy Audits of Industrial Facilities

The purpose of this guide is to introduce the user, both technical and non-technical, to common opportunities that may be found in an industrial facility to reduce the electrical energy consumption. It has **not** been developed as a sole reference to support the user in completing an analysis; but it has been developed to be an **aide** in the first and perhaps most critical step in performing an audit: touring the facility and quickly identifying energy savings opportunities. For the technical user this guide can help determine where to focus their effort for a detailed energy audit. For the non-technical user this guide will assist them in developing a list of potential energy saving opportunities to refer to qualified personnel for additional study. This guide may also be used as a checklist when conducting a phone survey with a facility to determine whether or not a detailed energy audit is necessary. Additional copies of this guide are available from the Bonneville Power Administration, Energy Efficiency web site at http://www.bpa.gov/indexmain.shtml

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How to use this Guidebook

1. Before you begin your walk-through of the industrial facility, a meeting should be held with the appropriate plant personnel that are familiar with the physical condition and day-to-day operation of the manufacturing equipment in the facility. The purpose of the meeting is to determine which of the systems, technologies, and equipment listed below actually apply to the facility and where you should focus your attention during the walk-through audit.

Lighting Systems	Material Handling Systems
Motors, Belts and Drives	Hydraulic Systems
Fans and Pumps	Injection Molding or Extrusion
Compressed Air Systems	Veneer Dryers
Steam Systems	Kiln Drying
Refrigeration Systems	Energy Management

   Note: The energy savings opportunities are not limited to the systems, technologies, and equipment listed above. These are just the more common ones.

2. The next step is to go through the checklist of questions in the guidebook that pertain to the facility. All of these questions may not be answered in the meeting and therefore should be "flagged" to be addressed during the walk-through. As you go through the checklist of questions, this is a good opportunity to discuss any concerns that the plant personnel may have with implementing the energy saving measures corresponding with each checklist item. This process will help you to determine the energy savings measures that have already been implemented and those that may or may not be applicable to this facility. At this point you should have a better sense of which areas in the facility to focus your attention on during the walk-through and who should accompany you. The following tools may be useful in performing the walk-through audit:

   Clipboard
   Flashlight
   Camera
   Light Meter
   Phillips and Standard Screwdrivers
   True RMS meter, if not available, a Clamp on Amp Meter.

3. The next step is to tour the facility with the appropriate plant personnel that are familiar with the various areas that you will be auditing. As you tour the facility, refer to the guide to ensure that you answer any remaining checklist questions. The back of each page can be used to record your observations, such as equipment nameplate data, gage readings, meter readings, and to make notes, such as areas that require further study, equipment operators names, phone numbers, etc.

4. After the tour is completed, a wrap up meeting should be held to review your findings. At this point, a list of potential energy saving opportunities that should be considered for additional study can be developed.

Guide Structure

1) The symbols listed below are used throughout this guide to appropriately direct you to the necessary information.

- 🗎 General Notes about the topic being discussed
- ★ Useful Tips
- 👍 Rules of thumb that are commonly used in the trade
- ☠ A Warning or Caveat
- 👓 Look for the following opportunities to save energy as you tour the facility
- Yes☐ No ☐ A checklist of questions that will help you to identify existing conditions that may offer opportunities to save energy
- ⇨ If the response to the checklist question is yes, these are the corresponding energy saving measures to consider for additional study
- ⌨ Suggested data to measure and record that will assist you in identifying energy saving opportunities
- 🗁 Additional information that is available for the topic being discussed
- ☺ Potential advantage of the topic being discussed
- ☹ Potential disadvantage that could result from implementing the energy savings measure
- $ Cost savings estimation[1]

2) Each topic covered in this guide is arranged as follows:

This is the equipment, system, or technology being covered

🗎 General Notes:

This section provides general information pertaining to the equipment, system, or technology being covered, through the use of the symbols above.

👓 Look for or Ask?:

Yes☐ No☐ This section provides a checklist of questions to ask or to look for that will help you to identify existing conditions in the facility that offer opportunities to save energy. If the answer is Yes, a list of energy savings measures are listed below each question, and should be considered. If the answer is No, move on to the next question.

⇨ **For each checklist question answered Yes, these are the corresponding energy saving measures that should be considered for additional study to determine the feasibility of implementing them.**

[1] The following assumptions have been used unless otherwise noted: $.05/kilowatthour (kWh) for electricity, eight hours a day (one typical shift), five days a week, 50 weeks a year. These estimates are intended only for developing "ballpark" estimates of potential energy savings.

General Notes:

- ★ Use binoculars to identify high bay lights – particularly fluorescent lights.
- ★ Another method to identify the type of lights installed is to check the stockroom.
- ★ Light output from a light source is measured in lumens.
- ★ Lumens/Watt is the ratio of the amount of light produced per the input energy. The larger this ratio, the more efficient the fixture is.
- ★ The amount of light "available" at a particular location is measured in foot-candles by a hand held light meter.

Please refer to the following Web Sites for additional information:
http://www.eren.doe.gov/femp/greenfed/index.html,
http://www.northwestlighting.com/,
http://www.lrc.rpi.edu/NLPIP/Online/index.html,
http://ts.nist.gov/ts/htdocs/210/214/scopes/eelit.htm

- ★ Helpful reference tables are listed below:

Common Light Source Characteristics

Type	**Color**	**Lumens /Watt**	**Restrike (Min.)**	**Full Output (Min.)**	**Avg. Lamp Life (1000 Hours)**
Incandescent	Warm yellow	8-24 *	-	-	0.75-3.5
Fluorescent	Varies, a lot of options are available	60-100	-	-	7.5-20
Mercury Vapor	Very blue white – tends to get greenish with time	35-55	3-7	3-7	10–24
Metal Halide	"White", significant color shift with time	60-110	7-15	2-5	6-20
High Pressure Sodium	Yellow orange	40-125	2-6	<1-2	7.5-24
Low Pressure Sodium	VERY monochromatic yellow	70-180	-	7-15	10-18

* The most common incandescent lamps yield approximately 17 lumens/watt

Variations in Fluorescent Lamp and Fixture Choices		
Lamp	**Ballast**	**Relative Energy Consumption for same lighting level as standard lamp and magnetic ballast.**
Standard	Standard Magnetic	100%
Standard	Efficient Magnetic	87%
Standard	Electronic	75%
Efficient	Standard Magnetic	90%
Efficient	Efficient Magnetic	80%
Efficient	Electronic	68%
T8	Matched Electronic Ballast	56%

☺ Example: By changing from standard fluorescent lamps with magnetic ballasts to energy efficient T8 fluorescent lamps with electronic ballasts, the energy consumption can be reduced by approximately 50 percent, while still maintaining the same light level.

Look for or Ask?:

Yes☐ **Are lights on in unoccupied areas?**

Yes☐ **Is the exterior lighting on during the day?**

⇨ **Manually turn off lights.**
Because there is no investment this can be the simplest most cost effective method to save on lighting energy.
☹ *This measure is only as reliable as the operator(s).*

⇨ **Install occupancy sensor or photo electric sensors.**
This offers a more reliable method to obtain savings as it is not operator dependant. Typical applications are pump houses, meeting rooms, bathrooms, warehouse, or storage areas. (one photo sensor can operate multiple light fixtures).

⇨ **Replace high pressure sodium(HPS) lights in low use areas with fluorescent lights for quick on and off control.**
Although HPS lights can operate more efficiently, their long restrike times can make them a poor choice for low use areas. Because they take so long to warm up, they are frequently left on continuously.

⇨ **Replace or maintain faulty photocontrols.**
Often when lights are on during the day it turns out that photocontrols are already installed but have become inoperable.

Yes☐ **Are existing lighting levels higher than the recommended levels?**

Use a hand held light meter to measure the amount of light available in work areas. Hold the meter at work level. Refer to the table below for recommended lighting levels. For additional information, refer to the Illuminating Engineering Society of North America (IESNA) guidelines at http://www.iesna.org/ for more details.

Common Lighting Requirements*			
Type	**Foot-candles**	**Type**	**Foot-candles**
Assembly/Inspection		**Warehouse**	

Simple	20-50	**Inactive**	5-10
Moderate	50-100	**Active**	
Complex	100-200	**Large items**	10-20
Very Complex	200-500	**Small items**	*20-50*
Exacting	*500-1000*	**Boiler Room**	*20-50*
Machine Shops			
Rough Bench	*20-50*		
Fine bench or Machine work	*200-500*		
Control Room	*20-100*	**Corridors, Lobbies**	*10-20*
Mechanical Room	*20-50*	**Office**	*40-100*

*See IESNA guidelines for much more detail.

⇨ **Reduce lighting levels where appropriate.**

It is common for some areas to have excessive lighting; particularly warehouse space, walk-in freezers, and hallways. There are a number of strategies for reducing lighting: lamps can be removed (for fluorescent fixtures the ballast will still consume some energy), fixtures can be rewired to allow partial to full lighting, or new efficient fixtures can be installed with a reduced design point for the lighting level.

- ☹ *Lighting level may be perceived as a "health and happiness" issue. Even if an area may have higher lighting levels than recommended by IESNA it may go against the local culture to reduce lighting.*

⇨ **Reduce overall lighting and install task lighting.**

This approach can provide better lighting at the point of use, while reducing the overall lighting in an area.

- ☹ *Unless task lighting is installed to be easily modified, an excellent task lighting layout can quickly become obsolete as manufacturing operations and layouts change.*

Yes☐ **Are incandescent lights installed?**

⇨ **Replace incandescent lights with T8 Fluorescent lamps and matched electronic ballasts.**

- ☺ *The fluorescent fixtures of today are extremely rugged and versatile. These fixtures can operate in ambient temperatures down to 0° F, can be operated as BI-level lighting or dimmed without reducing the rated lamp life. These fluorescent fixtures provide flicker-free operation and can operate with Total Harmonic Distortion of less than 5 percent and Power Factor greater than 90 percent.*
- ☝ *Energy consumption can be reduced by 50 percent.*

⇨ **Replace incandescent lamps with compact fluorescent lamps (CFLs).**

Compact fluorescent lamps offer a quick and simple opportunity to retrofit to more efficient lighting.

- ☝ *Estimate 80 percent increase in efficiency*[2].
- ☹ *For persistence of savings, fixtures that can only accept CFL's should be installed.*

[2] Efficiency increase estimates assume maintaining same lighting level.

⇨ **Replace high bay incandescent fixtures with high pressure sodium (HPS) lamps in areas where the color of the light is not important.**

- 👍 *Estimate 80 percent increase in efficiency.*[2]
- ☹ *Some might not like the yellow orange light. It may also be unacceptable where good color recognition is required (Example: a product inspection/grading area).*
- ☹ *HPS lamps take time to restrike and then come up to full output when first turned on.*

⇨ **Replace incandescent fixtures with higher efficiency metal halide (MH) fixtures in areas where color is important such as product grading areas.**

MH lamps offer a "white" light preferred by some. Generally they are not as efficient as HPS lights.

- 👍 *Estimate: 80 percent increase in efficiency.*[2]
- ☹ *MH lamps also take time to restrike and come up to full light output when first turned on.*

Yes☐ **Are standard fluorescent lamps installed?**

⇨ **Replace standard fluorescent and magnetic ballasts with T8's and matched electronic ballasts.**

- 👍 *Estimate: 35-45 percent increase in efficiency.* [2]
- ☹ *It can be problematic to have T8 and standard fluorescent fixture at the same facility. Although standard fluorescent lamps fit in T8 fixtures, the ballasts are not matched and may create problems.*

⇨ **Replace fluorescent fixtures with low bay MH fixtures.**

MH lights are more commonly chosen for their white light than their efficiency. Savings will only be available for specific selections of MH fixtures. For some combinations of existing fluorescent fixtures replaced with metal halide fixtures, energy use could increase.

Yes☐ **Are magnetic ballasts installed on the existing fluorescent lights?**

⇨ **Install electronic ballasts.**

- 👍 *Estimate: 10-25 percent increase in efficiency.*
- ☹ *It can be difficult to determine the type of ballast installed without a visual inspection.*

Yes☐ **Are Mercury Vapor lights installed?**

☹ *In the past, Mercury Vapor lights were selected because of their long lamp life. These lamps are not energy efficient because as they age, their lumen output decreases but they continue to consume the same amount of energy.*

⇨ **Replace Mercury Vapor fixtures with higher efficiency metal halide (MH) fixtures in areas where color is important such as product inspection areas.**

MH lamps offer a "white" light preferred by some. Generally they are not as efficient as HPS lights.

- 👍 *Estimate: 80 percent increase in efficiency.*[2]
- ☹ *MH lamps take time to re-strike and come up to full light output when first turned on.*

⇨ **Replace Mercury Vapor fixtures with T8 Fluorescent lamps and matched electronic ballasts.**

- ☺ *Again, the fluorescent fixtures of today can handle temperatures down to 0 F, can be operated as BI-level lighting or dimmed without reducing the rated lamp life. These fixtures can provide excellent color rendering for areas that require this, such as inspection areas.*
- ☹ *The mounting height for these fixtures may have to be lowered in order to achieve adequate light distribution. This could create interference problems with overhead cranes.*

General Notes:

- For additional information, please refer to the following web sites: http://www.execpc.com/~hgmurphy/, http://www.oit.doe.gov/bestpractices/, http://www.ecw.org
- Some rules of thumb to estimate the electrical energy use of motors*:

Estimates regarding motor operation	
Cost to operate a motor at 75% load for a full year	$60/horsepower (HP)
Electrical Power Requirement	3 kilowatt (kW) for each 5 HP of motor loading
Full Load Amps for a 460 Volt 3 phase system**	1.2 amps for each HP of motor loading
Full Load Amps for a 230 Volt 3 phase system**	2.4 amps for each HP of motor loading

*Assumes motor is 75 percent loaded and has a full load efficiency of 90 percent. $.05/kilowatthour (kWh) for electricity, Motor runs eight hours a day (one typical shift), five days a week, 50 weeks a year. ** Full load amps may be stamped on the motor nameplate.

- The following table can be used to estimate motor costs and efficiencies:*

Motor Horsepower	**Cost for Standard Motor per Horsepower**	**Premium for High Efficiency Motor per Horsepower**	**Increase in Efficiency**	**Annual Savings (for one shift @ full load)**
5 HP - 10 HP	$55 - $70 per HP	$13 - $20 per HP	5.0% - 3.5%	$5.00 - $3.00 per HP
15 HP - 30 HP	$55 - $60 per HP	$10 - $15 per HP	same as above	$4.50 - $3.00 per HP
40 HP – 125 HP	Same as above	same as above	3.5% - 3.0%	$3.00 - $2.50 per HP
150 HP - 300 HP	Same as above	same as above	2.0%	$2.00 per HP

*This table is only intended for field estimates of potential savings. Much more accurate estimates can be developed with software tools such as MotorMaster at http://www.oit.doe.gov or by contacting your motor supplier.

- ★ Motors have relatively constant power factor and efficiency down to approximately 50 percent of full load (within +/- 5 percent), then power factor and efficiency degrades rapidly.
- ★ Larger motors are typically more efficient than smaller motors.
- The installation of Variable Speed Drives (VSDs) may induce harmonics into the electrical distribution system. A system with many capacitors installed can be particularly vulnerable unless "tuned" by a professional. Some installations are relatively insensitive; others are

VERY sensitive to this problem. Be particularly careful if a facility already has experienced power quality problems, such as, equipment tripping off, computer glitches, unusual motor or light ballast failures, overheated transformers or capacitors, high 3 phase neutral currents or significant neutral to ground voltage. Also be careful in facilities with heavy rectifier loads - charging equipment or induction furnaces, or significant computer and other electronic loads.

- ☠ Existing motors can be overheated by VSDs (refer to http://www.oit.doe.gov, and http://www.oit.doe.gov/bestpractices// for more information)
- ★ There are three types of VSDs: Voltage Source Inverter (VSI), Current Source Inverter (CSI), and Pulse Width Modulated (PWM). Refer to the web sites listed above for more information.

Look for or Ask?:

Yes☐ **Are standard efficiency motors installed?**

⇨ **Replace standard motors with high efficiency motors.**

Even if specific motors have been identified as targets for replacement with efficient motors it may not be economical to replace them immediately. In such cases it is a useful strategy to mark them so it is clear that an efficient motor should be used when replacement is required for other reasons

- *For 5 to 30 HP motors estimate 5 percent to 3.5 percent increase in efficiency.*
- *For 40 to 125 HP motors estimate 3.5 percent to 3 percent increase in efficiency.*
- *For motors 150 HP and above estimate 2 percent increase in efficiency.*
- *The annual energy cost savings can be estimated by the following equation:*

$$ES = .746 \times Hp \times \%L \times N \times C \times \left[\frac{1}{E_{StndEff}} - \frac{1}{E_{HighEff}}\right]$$

Where:
ES = The annual energy cost savings($/yr)
Hp = Motor Horsepower
%L = Percent Motor Load divided by 100
N = Annual Hours of Operation at this load
C = Cost of electricity ($/kWh)
$E_{Stnd\ Eff}$ *= Standard Motor Efficiency, as a fraction*
$E_{High\ Eff}$ *= High Efficiency Motor Efficiency, as a fraction*

Yes☐ **Are standard drive belts (V-belts) installed?**

⇨ **Replace standard V-belts that are notched and/or sheaves with high torque drive (HTD) V-belts.**

The slightly increased cost of notched V-belts should be offset by an increased life expectancy. Notches on the inside radius of the belt reduce energy loss and heat generation caused by compressing and decompressing the belt as it arcs around the sheave.

- *Estimate: 2 percent increase in efficiency.*
  HTD belts and sheaves must be replaced because the teeth in the belt mesh with a matched sheave.

- 👍 *Estimate: 4-8 percent increase in efficiency [use 5 percent].*
- ☠ *HTD belts offer no slip under stress and can damage equipment prone to jamming - such as conveyors. During start-up, high torque levels can be induced on the motors and shafts.*
- ☠ *HTD belts can increase sound levels significantly. As sheave rotates, air trapped between belt and sheave is driven out abruptly.*

Yes☐ **Are motors running during periods when the equipment or process they are driving is idle?**

⇨ **Reduce equipment operation time to minimum required.**

Turn off equipment during lunch and breaks, or other times when it is not required.

- ☹ *This measure is only as reliable as the operator(s).*

⇨ **Interlock equipment with a related process.**

If a particular piece of equipment is dedicated to specific process that requires additional equipment, they can all be interlocked so all will be de-energized when the operator turns off one piece of equipment.

⇨ **Operate equipment such as a grinder in batches then shut off.**

A piece of equipment like a grinder may run continuously although material only runs through it occasionally. An alternative approach with no installation cost is to allow material to collect and assign someone to periodically turn it on to process the material in batches.

- ☹ *If material collection is left unmonitored, the collection bin can overflow requiring additional labor for clean up. Jamming problems could also develop.*
- ☹ *Batch processing also has potential for increasing demand charges if the equipment is more heavily loaded.*

⇨ **Install timers, level sensors, material sensors, or other controls for automatic operation and/or to shut off equipment as required.**

For example: Install material sensor and timer on equipment such as a grinder – set to turn on with set accumulation of material and turn off after allowable idle time.

- ☠ *Care must be taken to avoid creating a safety hazard.*

Yes☐ **Does the facility utilize DC generator sets to provide variable speed control of equipment?**

⇨ **Replace generator sets with solid state variable speed drives.**

Before the advent of relatively inexpensive solid state variable speed drives, DC Generator sets were commonly used to achieve variable speed control and to provide high start up torque on a piece of equipment such as a de-barker in a lumber mill. Solid state VSDs are typically more efficient and will provide soft starting of equipment. However, a DC Generator can make up for lower efficiency by providing a regenerative capturing breaking energy in a heavy piece of equipment.

- ☹ *Before recommending this retrofit assess whether regeneration is involved. If so include it in the analysis.*
- 👍 *Estimate: 60 percent-70 percent overall efficiency for the combination of drive, generator, and motor in a DC Generator set.*
- 👍 *Estimate a 25 percent overall efficiency increase for the installation of solid state VSDs.*

Yes☐ **Does the facility utilize Eddy Current drives for variable speed control?**

⇨ **Replace eddy current drives with solid state variable speed drives.**
Eddy current drives are another older and less efficient method of achieving variable speed control. Eddy current clutches can be high maintenance items, replacement parts are expensive and difficult to locate.

- *Estimate: 86 percent efficiency for an eddy current clutch at full speed, 64 percent efficiency at 3/4 speed.*
- *Estimate a 10 percent efficiency increase.*

Yes☐ **Are motors installed that operate continuously at part load?**

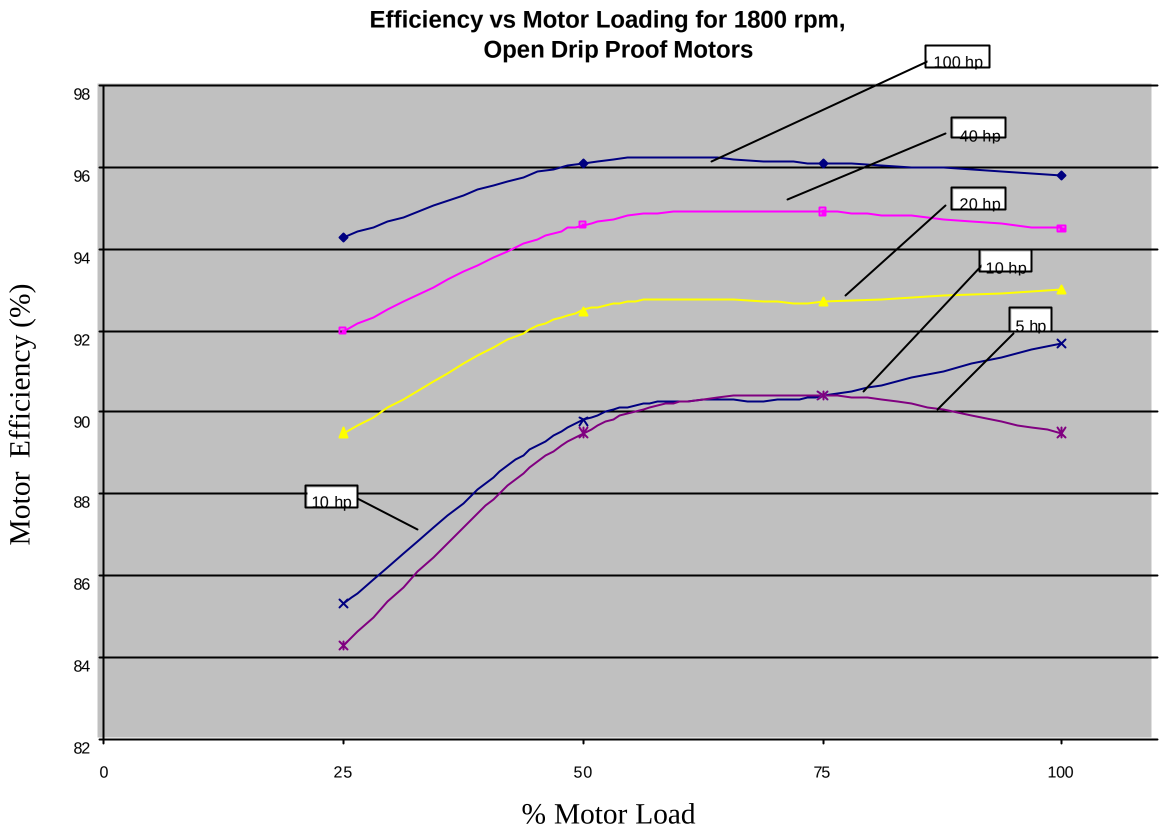
⇨ **Replace oversized motors with properly sized energy efficient motors.**

☠ *Before downsizing a motor verify that it will not be loaded beyond its capacity at some point in its operation.*

It is common for motors to be progressively upsized in a facility as they are replaced. If a motor of the same size is not available, the next size up is installed – just to be on the safe side. If a motor consistently operates at less than half of full load, it is not operating efficiently and is a candidate for a downsizing assessment.

Motors consume the least amount of energy when they operate at their highest efficiency. For most motors, this is from 75 percent to 110 percent of their rated load. As the motor loading drops below 50 percent, the efficiency and power factor drops rapidly. The impact on larger motors (those over 50hp) is less. See the Efficiency vs. Motor Loading graph.

⌨ *Power measurements(kW) to determine motor loading is preferred over amperage readings because kW readings take into account the changes in power factor and amperage that occur as the motor loading changes.*



The percent motor load can be estimated by the following equation:

$$\% \text{ Motor Load} = \left(\frac{\text{Measured kW}}{\text{Calculated kW @ FullLoad}} \right) x\ 100,$$

$$\text{Where: Calculated kW @ Full Load} = \left(\frac{Hp_{rated}}{Mtr.Eff_{full\,load}}\ X\ \frac{.746\,kW}{Hp_{rated}} \right),$$

☺ *Example: A 50 hp motor with a full load efficiency rating of 90 percent was metered and found to be operating at 25 kW. The percent Motor Load is estimated as follows:*

$$\text{Calculated kW @ Full Load} = \left(\frac{50\,Hp_{rated}}{.90_{full\,load\,eff.}}\ X\ \frac{.746\,kW}{Hp_{rated}} \right) = 41\text{ kW},$$

$$\% \text{ Motor Load} = \left(\frac{25\,kW_{measured}}{41\,kW_{calculated}} \right) X\ 100 = 60\%$$

General Notes:

- Actual efficiency can easily vary from 50 percent to 80 percent for optimum operation of a particular pump.
- When modifying or replacing pumps and fans, or adjusting their rpm, be sure that they can operate under all conditions anticipated for the given system. System pressure or head should not exceed the maximum pressure or head the fan or pump can sustain. Surge points should be avoided. (Surge points occur when a fan or pump can operate at two different flows at the same pressure).
- For additional information, please refer to the following web sites: http://www.oit.doe.gov/bestpractices/, http://www.ecw.org

Look for or Ask?:

Yes☐ **Are pumps or fans installed that are not sized correctly for the task?**

Pump or fan efficiency is very dependent upon flow and pressure, and the pump or fan's operating characteristics. For a given rpm there is one optimal operating point of flow and pressure. As the pressure changes, flow changes and operating efficiency is also affected. If system conditions have changed since the initial selection of the pump or fan, they may be operating at a higher rpm than is required, therefore wasting energy. An oversized pump or fan often works continuously against a throttle or damper causing even greater inefficiencies.

⇨ **Reduce pump or fan speed using a sheave adjustment or motor replacement.**
It may be possible to tune the speed of a fan or pump so it can operate more efficiently in a given system. If the fan or pump is belt driven the sheaves can be modified in order to change the rpm. A motor that operates at a different rpm may also be installed, particularly if it is oversized. Installing a two-speed motor could also be an option.

⇨ **Trim or replace pump impellers.**
A pump's operating characteristics can be adjusted by re-sizing the impeller. On a given system, it may be possible to achieve greater efficiency with a different pump impeller.

⇨ **Replace fan or pump with a more energy efficient model.**
It may not be possible to achieve an acceptable efficiency on a system with a given pump or fan. New equipment may be the best option.

Yes☐ **Does the facility have a cooling tower(s)?**

⇨ **Install solid state VSD control on the cooling tower fans.**
☺ *The cooling tower fans typically run at a constant speed (60 Hz) or a two-speed motor may drive them. Depending upon the ambient weather conditions (Wet Bulb Temperature) at the tower location and the cooling loads placed on the tower, the installation of VSDs on the cooling tower fan motors can produce significant energy savings. Air is forced or drawn through the tower in order to cool the incoming water. The Wet Bulb Temperature is an indication of the amount of moisture in the air that flows through the tower. The VSDs will vary*

the fan speed to maintain the set-point temperature of the cooling water leaving the tower. During periods when the cooling demands are at a minimum, such as 2nd or 3rd shifts, the tower fans run at minimum speed and consume less energy.

The tower fans can be turned off during periods when the ambient air conditions will sufficiently cool the water without the aide of the fans. The energy consumption is significantly reduced to just the cost of circulating the water through the tower.

In addition, the following energy savings opportunities should be evaluated for each Cooling Tower:

- ⇨ **Replace the tower fill material with cellular film fill to improve the heat transfer efficiency.**
- ⇨ **Install non-clogging, non-corroding spray nozzles to improve water distribution through the tower.**
- ⇨ **Install energy efficient airfoil fans.**
- ⇨ **Install energy efficient motors on the cooling tower fans and pumps.**

☺ *Cooling tower optimization reduces the cost to provide colder water for cooling. By reducing the temperature of the cooling water, the efficiency of the equipment or process being cooled is improved.*

Yes☐ **Are pumps or fans being throttled in order to control the flow rate?**

One of the most common and inefficient methods to control a fan or pump is to restrict its flow. As the pressure is increased the flow is reduced. However, work required to deliver the reduced flow is greater than would otherwise be required. The following recommendations apply best to systems with variable flow (such as a boiler feed-water pump or an induced draft fan.). If flow is constant at a reduced level see recommendations for incorrectly sized pumps or fans.

⇨ **Replace throttle control on pump with on-off control.**

On-off control works when a pump is maintaining a reservoir level instead of a constant flow. The pump can be set to operate only at optimum efficiency, fill the reservoir, and then shut off.

☹ *This measure could create excessive cycling.*

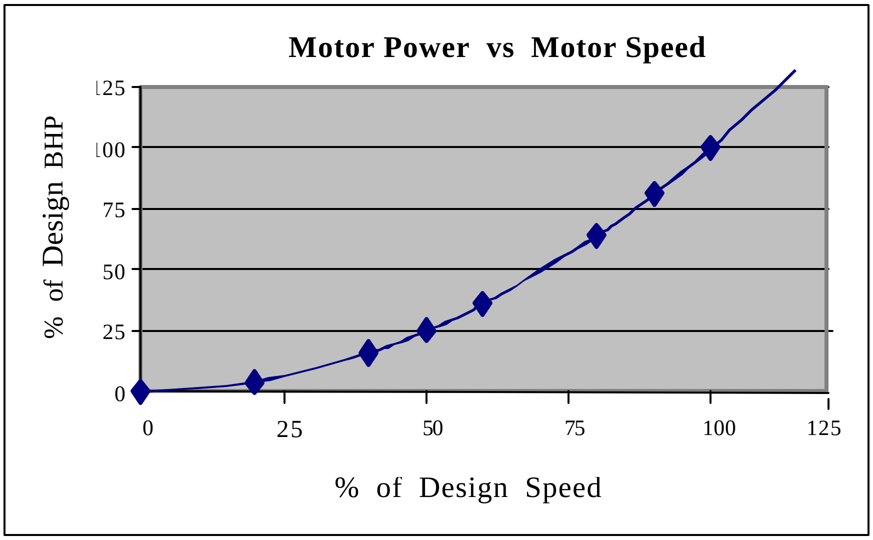
⇨ **Replace throttle control on pump or fan with solid state VSD control.**

- 👍 *VSD's can provide significant energy savings. Quick savings estimates vary greatly with conditions, however VSDs frequently pay off in a year or two if they replace a throttle control that operates at 60-70 percent of full flow or less most of the time. The impact on the fan or pumping system due to variations in speed should be evaluated when considering this measure.*
- ☠ *Be careful when applying VSDs to turbine pumps. Damaging vibrational harmonics may develop at certain operating frequencies. Be sure to avoid vibration frequencies in the VSD control profile.*

👍 *Use the following table and Motor Power vs. Motor Speed graph for a first estimate of energy savings with reduced flow for VSD's controlling fans or pumps on systems where pressure is allowed to drop with reduced flow.*

Potential Energy Savings from Reducing the Speed of Centrifugal Machines

Percent of Full Flow	Percent Energy Saved
100%	0%
90%	19%
80%	36%
60%	64%
50%	75%
40%	84%



☺ **Example: If the speed (rpm) of a 50 hp motor driving a pump or fan can be reduced from 1800 rpm to 900 rpm (50 percent), and still provide the necessary flow and pressure for the task at hand, the horsepower required is reduced from 50 hp to 13 hp resulting in a power reduction of 75 percent.**

⇨ **Replace throttle control on fan discharge with inlet vane control.**

Inlet vanes are a good option for applications like dust collection systems where the air volume (cubic feet per minute (CFM) of air flow) required changes, while the air velocity and associated pressure drop must remain relatively constant. By pre-spinning inlet air, inert guide vanes can reduce airflow without affecting the pressure the fan must overcome. They are not as efficient as VSDs in applications where system pressure can be allowed to drop with reductions in airflow.

☹ *At extreme reductions in airflow (less than 30 percent) an inlet vane acts like a throttle and its efficiency drops off significantly.*

Yes☐ **Is bypass control being utilized to vary the flow out of the Pump?**

Although less common, bypass control can be an extremely inefficient method for controlling flow. In the best case, pump energy use is constant regardless of delivery to an end use. In the worst case, energy use increases with reduced delivery to the end use. As less flow is required at the end use, the excess is diverted to the bypass circuit and re-circulated. The diverted fluid does not add any value to the finished product. The pump discharge remains at high capacity, as do the pumping costs during periods of low demand, which makes this control very costly.

⇨ **Replace throttle control on pump or fan with solid state VSD control.**

- *VSD's can provide significant energy savings. Quick savings estimates vary greatly with conditions, however VSDs frequently pay off in a year or two if they replace a throttle control that operates at 60-70 percent of full flow or less most of the time. The impact on the fan or pumping system due to variations in speed should be evaluated when considering this measure.*
- *Be careful when applying VSDs to turbine pumps. Damaging vibrational harmonics may develop at certain operating frequencies. Be sure to avoid vibration frequencies in the VSD control profile.*

☹ *This method of modulation control may cause cavitation in the pump.*

General Notes

- ★ Many air compressors include capacity and pressure gages, including pressure drop across the oil separator and dryer.
- ★ Look for high-pressure drops through equipment and lines.
- ★ Look for intentional pressure reductions, such as with valves and pressure regulators.
- Record gage readings of percent capacity and pressure for the air compressors and air dryers. Record nameplate data for the air dryers, air compressors, and drive motors.
- For additional information, please refer to the following web sites: http://www.knowpressure.org/html/where.html, http://www.cagi.org/glossary1.htm, and http://www.ecw.org
- ★ Common compressed air terms are shown below:

Term	Meaning
CFM	Cubic Feet per Minute of Air Flow
ICFM	Air flow at inlet flange
ACFM	Actual air flow delivered after compressor losses
ACFM-FAD	Air flow before filter (Free Air Delivery)
SCFM	Equivalent air flow at Standard Conditions (2 different standards use this same term)
Psi	Pressure in pounds per square inch
Psig	Psi gauge, referred to atmospheric pressure
Psia	Psi absolute, which is 14.7 as sea level
Standard Conditions	
- CAGI (Compressed Air & Gas Institute):	14.7 psia, 60°F, 0% rh (relative humidity)
- ASME	14.7 psia, 68°F, 36% rh

- ★ Typical dryer dewpoints: Refrigerated Dryers +35°F to +38°F, Desiccant Dryers - 40°F
- Each CFM of compressed air at 100 psig requires: 1/3 to 1/5 hp, ~ 1/4 to 1/7 kW, ~ $10 to $20 per year
- Estimate 3 to 5 CFM per HP

Look for or Ask?:

Yes☐ **Are large compressors serving minimal system needs during off-hours such as maintaining the minimum pressure requirements for a Dry Fire Suppression System?**

⇨ **Install a smaller air compressor dedicated to serve minimal after hour needs, and isolate from main plant air system.**

It is common to leave a large compressor on continuously ~ 7 days a week to serve a small use such as pressurizing a dry fire suppression system. The compressor may operate for long periods at an extremely inefficient part load condition. System leaks also consume air and energy continuously. It is *generally cost effective to install a separate dedicated compressor for such a need and separate it from the main compressed air system to avoid losing air and energy to system leaks during non-production times.*

Yes☐ **Does the facility have Centrifugal Screw Compressors that operate at less than full load capacity for more than 70 percent of the Time?**

Yes☐ **Is throttle control used to modulate the compressor output capacity?**

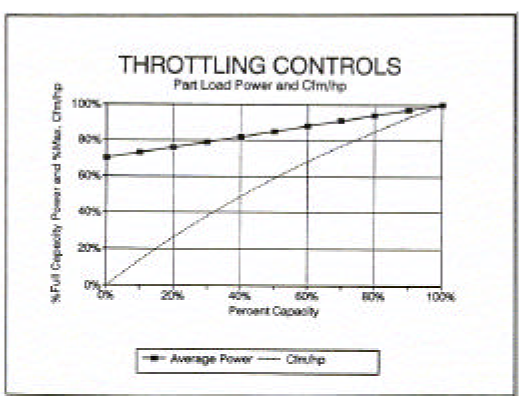
⇨ **Replace throttle control with Load-Unload controls.**

- ☹ It is not energy efficient for a throttle-controlled screw compressor to operate below 70-80 percent capacity. Throttling is not desirable if extended low load periods are expected.
- ♘ *A throttle-controlled compressor consumes approximately 70 percent of its full load power when delivering no air. (See the following "Throttling Controls" graph)*

Throttle Control

How does it work? Throttling modulation works by starving the compressor of air. The mechanism itself is usually a butterfly valve or a slide valve that is installed upstream of the compressor inlet. When the system pressure sensor perceives that the pressure is **decreasing** (because plant air demand has exceeded the storage capacity), the valve opens and the compressor begins to build pressure. When the system pressure sensor perceives that the pressure is **increasing** (because plant air demand has decreased below the storage capacity), the valve starts to close. This creates a partial vacuum at the compressor inlet. Consequently, the air entering the compressor is less dense and less air mass enters the compression chamber between the screws. This reduces the mass flow rate(cfm) of air delivered to the system.

☹ **Energy Use:** This method of control is often not efficient. Because the compressor constantly works against system pressure at the discharge port, the motor never really gets a chance to unload. As the compressor capacity drops below 70 percent, the compressor efficiency declines rapidly, therefore consuming considerable energy while producing minimal air.



☹ The "Throttling Controls" graph above indicates that the compressor can operate continuously at any point between 0 percent and 100 percent capacity.

This graph also indicates that 70 percent of full load power is consumed when the compressor is providing no air, and 85 percent of full load power is consumed when the compressor is operating at 50 percent capacity.

Applications: Throttling is desirable when over-all plant demand is high or erratic, when receiver size is small, or when the acceptable range for system pressure is small. Modulation-only control is a low-risk option because of mechanical simplicity, small pressure variation, and cycling is avoided. Consequently, it is a common control strategy.

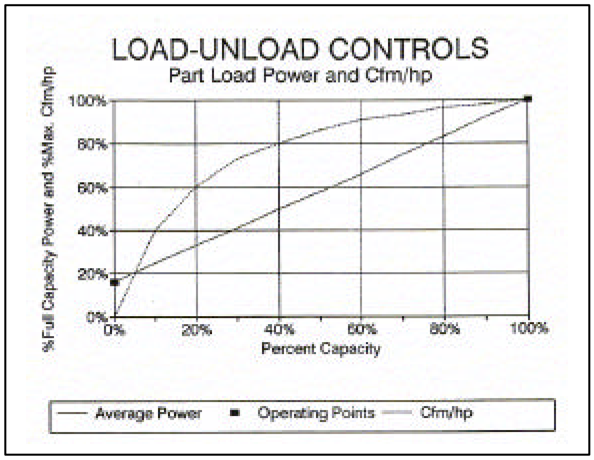
Load-Unload Control

How does it work? Load-Unload controls on screw compressors allow the compressor to operate at only two points: fully loaded at 100 percent capacity, maximum efficiency and unloaded at 0 percent capacity. This control strategy is similar to On-Off control except that the motor and compressor never completely shut off. When the system pressure falls below it's maximum pressure set-point (usually 100 – 120 psig), the compressor runs at full power and maximum efficiency with the inlet valve 100 percent open until the system pressure increases to maximum pressure. Then the inlet valve is fully closed and an unloading valve at the compressor discharge opens and the air leaving the compressor is vented to a lower pressure.

The most efficient controls use a small oil pump and vent the air all the way to atmospheric pressure (~0 psig). Some manufacturers maintain a pressure of ~ 30 psig to circulate oil through the compressor while it is unloaded. In either case, a check valve installed at the discharge prevents the back flow of air at system pressure when the compressor is unloaded. In the unloaded condition, the compressor does little work, because it is starved of air at the inlet and is working against a minimum pressure at the outlet (0 *or 30 psig).*

- ☺ *Load-unload control allows a compressor to operate either at full output and maximum efficiency or unloaded.*
- ☺ *This control strategy is similar to on-off control except the motor and compressor never completely turn off. Because the compressor does not turn off, the motor is not damaged. However, load-unload control requires larger receiver capacity and a significant variation in system pressure to create an acceptable cycle time.*
- 👍 *An unloaded screw compressor consumes approximately 17 percent to 25 percent of the energy required for the compressor to operate at full capacity, if discharge pressure is reduced to near atmospheric pressure. The energy savings will be less if the compressor discharge pressure drops to an intermediate pressure, such as 30-40 psig, which is usually required to maintain oil circulation.*
- ☹ *Some processes are too sensitive to allow the variation in pressure necessary to produce significant energy savings.*
- ☹ *The load-unload cycle can make maintenance personnel uncomfortable. It is often set to unload at very low capacity causing the compressor to operate at inefficient partial loads for most of the time. The compressor seldom unloads, therefore potential energy savings are lost.*
- ☹ *A small amount of compressed air is released to atmosphere when the compressor unloads. If the compressor cycles too often this air loss can be significant.*

☺ **Energy Use:** Where appropriate, this method of control has very good energy use characteristics since it only produces air at 100 percent capacity and idles with low energy use at other times. There will be a small loss of energy each time the outlet blows down, because any compressed air preceding the check valve will be vented to attain a lower pressure. The simplest way to estimate energy use is to ignore these losses and those that may accrue as the intake valve opens and closes. This may sound too simplistic, but the volume of air lost will usually be less than 2 ft per cycle with most oil separators.



☺ The “Load-Unload Controls” graph above indicates that the compressor operates at two points, full output (100 percent capacity and maximum efficiency) or unloaded (0 percent capacity). This graph is for a compressor that is completely vented to atmospheric pressure. A partially vented compressor at 0 percent capacity will normally be near 25 percent of full load power.

Applications: Load-Unload control is most appropriate when conditions will not cause unloading too often, though it can operate with more unloading cycles than on-off controls can. An on-off controlled compressor would not be suited to restart every 2 minutes, for example, but a load-unload controlled compressor and motor could handle the cycling.

A plant with a large air storage capacity and equipment without exacting pressure requirements is ideally suited for load-unload control. Many lumber mills fit this category because they have extensive piping networks that act as receiver tanks and if necessary, space is usually available to install larger receiver tanks.

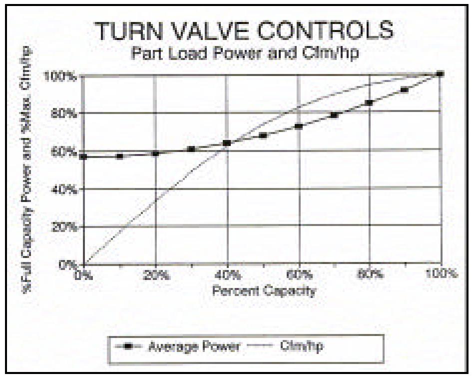
Yes☐ **Is Turn Valve control used?**

⇨ **Replace Turn Valve control with Load-Unload controls.**

Turn Valve Control

How does it work? Turn valves or spiral valves are composed of a spirally threaded shaft and discrete ports placed along the compression chamber wall. The shaft lies parallel to the rotors. When the system pressure falls below it’s maximum pressure set-point (usually 100 – 120 psig), the valves are closed and the compressor runs at full capacity until the maximum pressure is maintained. The turn valves allow the compressor to modulate between full capacity and zero capacity. This modulating control is achieved by gradually rotating the spiral shaft. As the shaft is rotated, the ports in the shaft allow some of the air being compressed in the rotors to escape and return to the compressor inlet which is at atmospheric pressure (~0 psig). The air that does not escape through these ports is discharged at system pressure.

☹ Energy Use: This method is more efficient than throttling. However, since the compressor works against system pressure at all times, this is still a relatively energy-intensive modulation control strategy.



☹ The "Turn V compressor can operate continuously nt capacity. This graph shows good performance at high loads, but about 57 percent of full load power is still consumed when the compressor is producing no air.

Applications: Turn valves are an effective control strategy when over-all plant demand is high or erratic, when receiver size must be small, or when the acceptable range for system pressure is small. Turn Valve modulation is a low-risk option and consequently, a common control strategy. Though more efficient than throttling, turn valve control is not desirable if extended low load periods are expected.

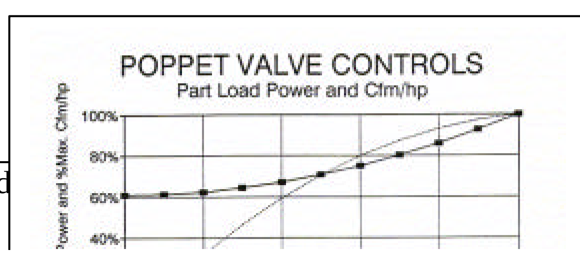
Yes☐ **Is Poppet Valve control used?**

⇨ **Replace Poppet Valve control with Load-Unload controls.**

Poppet Valve Control

How does it work? Poppet valves operate using the same principle as the turn valve: Opening discrete ports in the compression chamber walls reduces the volumetric compression ratio. Instead of using a single rotating shaft, four or five pneumatic valves open and close to expose the ports and allow the compressed air to escape to the inlet, which is at atmospheric pressure.

☹ **Energy Use:** The energy use for **Poppet Valves** is similar to Turn Valve control. The thermodynamics are the same only the mechanics of implementation vary. Poppet Valves are more efficient than throttling but the compressor still works against system pressure. Consequently, Poppet Valves are a relatively energy-intensive control strategy.



☹ The “Poppet Valve Controls” graph above shows good performance at high loads, but about 60 percent of the full load power is still consumed when the compressor is not producing any air.

Applications: Applications for Poppet Valve control are the same as those for Turn Valve modulation controls.

The following is a discussion of additional control methods that might be applicable.

On-Off Control

How does it work? The compressor runs at 100 percent capacity until the system pressure reaches the maximum set point pressure. Then both the compressor and motor completely shut off. A check valve prevents the flow of air back through the compressor. When the compressor shuts off, an unloading valve opens so that air in the discharge port is released to atmospheric pressure. This reduction in discharge pressure makes it easier for the compressor to restart.

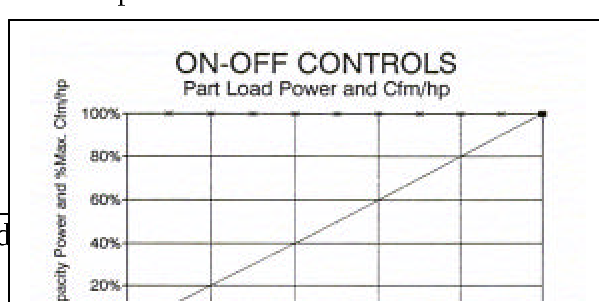
On-off control allows a compressor to operate at full output and maximum efficiency and then turn off. However, on-off control requires larger receiver capacity and a significant variation in system pressure. On-off control is not usually used in an industrial setting except as a secondary control on a compressor that may operate at low to zero capacity for an extended period of time.

☹ *Some processes are too sensitive to allow the variation in pressure required for on-off control.*

☹ *Beware of installing on-off control as a sole control on large motors. The constant on-off cycle can reduce the life of the air compressor and motor.*

☹ *On-off control may not be an option with many compressors.*

☺ **Energy Use:** This control strategy is actually the most efficient mode. Since a compressor operating in this mode only produces air while running at 100 percent capacity and never idles, performance approaches the "ideal," as shown in the “On-Off Controls” graph below. There will be modest losses because any compressed air that is upstream of the system pressure check valve will be lost once the compressor is shut down. For example, a system that runs 6 minutes per cycle will likely have losses of less than 3 percent.



Applications: This type of control strategy works best when the user is confident that there will be long periods of either very high or very low use, and when the maximum and minimum pressures are not close together. Large receivers are required for efficient operation. A small plant with an occasionally used sandblaster would be an appropriate application for this control strategy.

"Low"- Unload Control

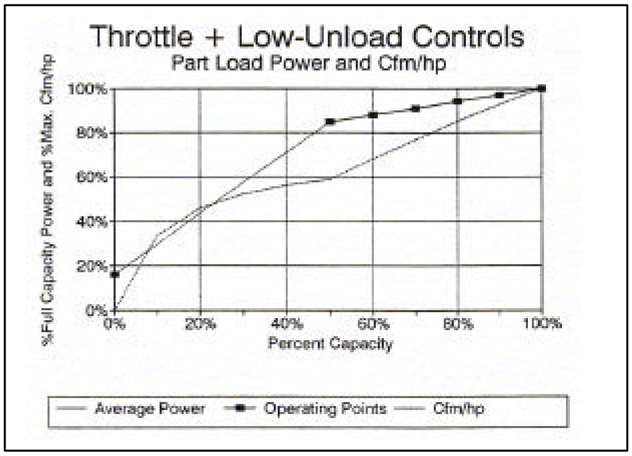
How does it work? "Low"-Unload control is a combination of Load-Unload control and modulation. The modulation may be a throttling valve, a turn valve or a poppet valve. This control strategy is designed to allow the compressor to modulate during periods of high demand and unload if demand drops below a certain percentage of full load capacity. The unloading point is usually set at 40–50 percent capacity and may be permanently pre-set by the manufacturer or it may be manually adjustable.

The compressor runs at 100 percent capacity and gradually increases the system pressure, but before the maximum pressure is reached, the inlet control starts to modulate and the capacity begins to reduce. This modulation continues until it either balances compressed air demand with supply, or until the capacity falls to the unloading point (40-50 percent capacity), whichever comes first. If the unloading point is reached, the compressor drops to an unloaded idle condition, as described in the Load-Unload section, and waits until the system pressure drops to the minimum allowed. At this point, the modulating valve fully opens, the blow-down valve closes, and the compressor returns to full capacity.

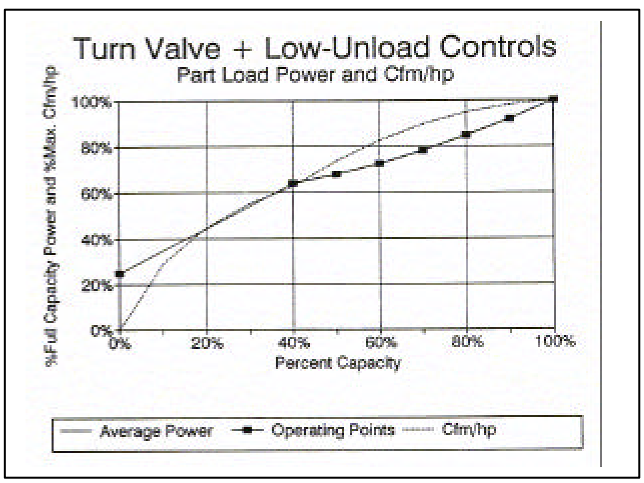
☹ *A low-unload controlled screw compressor is no more efficient than a standard throttle controlled compressor until it unloads. Unfortunately they are often set to unload at low flows, sometimes as low as 40 percent of capacity. Because of this, they only unload during periods of minimum demand, such as breaks or non-production periods. During normal production periods, the compressor capacity is throttle-controlled and potential energy savings are lost.*

👍 *The unloaded compressor consumes approximately 17 percent to 25 percent of full load power when the air is discharged at atmospheric pressure.*

☺ **Energy Use:** The energy efficiency of low-unload controls falls between that of load-unload control and modulation-only control. Since the operating mode varies depending on the magnitude and regularity of the plant air demand, receiver size, pressure range, and unload point, it is not easy to make a simple mathematical model. However, as an example the following simplified form can be used. Assuming inlet throttling modulation is used, the unload point is set at 50 percent, the compressor completely unloads to atmospheric pressure, and unloading losses are ignored, energy use can be approximated as shown in the “Throttle + Low-Unload Controls” graph below:



Note: In cases where the unload point is adjustable, it is recommended that the unload point be increased as high as possible, 80 percent capacity for example, until the cycle time is as short as deemed acceptable for operation. A minimum unloaded time of 30 seconds under normal plant demand conditions is suggested. The energy savings can be seen graphically by looking at the "Throttle + Low-Unload Controls" graph above. If the unloading point is moved to the right (increased), from 50 percent to 80 percent, the total area under the curve is reduced, therefore additional energy savings is possible.



☹ Note: Since spiral/turn/poppet valves are already efficient in the higher capacity region, available savings from increasing the unloading point are less significant for compressors with this type of control. This can be seen by referring to the "Trun Valve + Low-Unload Controls" graph above, if the unloading point is moved from 40 percent to 80 percent, the area under the curve is not significantly reduced.

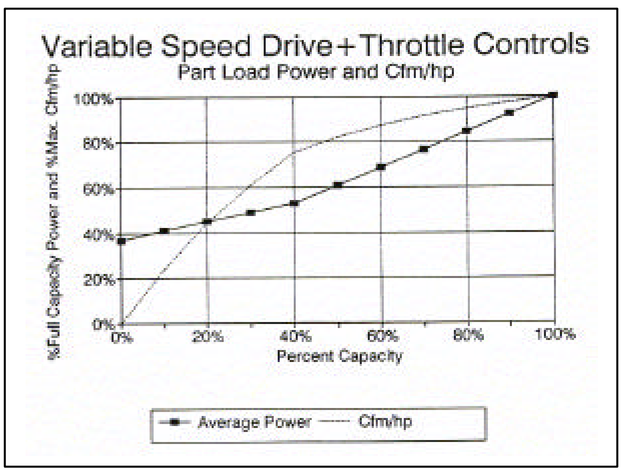
Application: Low-Unload is a good compromise between Modulation and Load-Unload. It does not outperform either of the other two modes if the operating conditions match the requirements of modulation or load-unloading. Low-unload control excels when load conditions vary over the course of a day. An example of an appropriate application of low-unload control would be a plant where there is a steady high load during first shift, intermittent demand on second, and holding pressure for a fire system at night. In this case, the compressor would mostly modulate during first shift, modulate and unload during second shift, and load-unload at night. Since this type of situation is common in industrial facilities, this control strategy is frequently the preferred choice.

Variable Speed Drive (VSD) Control

How does it work? A compressor system with a variable speed drive (VSD) controls the compressor output by changing the rotational rate (rpm) of the screws. When air demand is high, the screws rotate faster and therefore displace more air per minute than when demand is low and rotation is slower. Typically a minimum speed is set based upon the minimum internal pressure required to provide proper sealing of the compression chamber. This may require modulation or unloading control to be incorporated with the VSD control to drop capacity without further slowing the screws.

☺ **Energy Use:** VSD control offers modulation down to low loads while still maintaining efficiency.

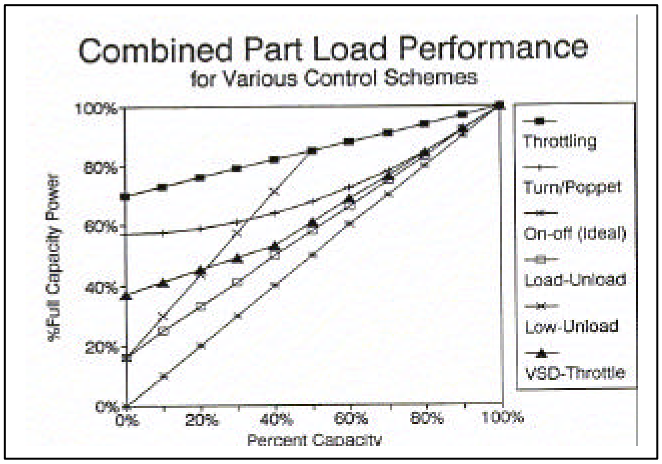
Like low-unload controls, there are two different operating modes. During periods of high demand, the VSD controls the modulation. If the load drops below the minimum level that can be compensated for with the VSD, the drive will stop reducing speed and the capacity will be further reduced with a butterfly, slide, turn, or poppet valve arrangement.



Note: VSD + Throttle Controls graph shows VSD control down 40% capacity and Throttle Control down zero to 40% capacity.

☺ **Applications:** VSDs can be the most expensive of all of the control options and are not typically offered by compressor manufacturers as a standard configuration. When combined with modulation, however, VSDs have the singular advantage of offering relatively high efficiency across the full capacity range with the convenience of full modulating control. VSDs would be appropriate when extended low demand periods are expected and a range of supply pressures is unacceptable.

The “Combined Part Load Performance” graph compares the performance of all of the control methods discussed.



☞ Look for or Ask ? (continued)

Yes☐ **Does the facility have more than one compressor feeding into a common header? Are these compressors operating at less than full output (cfm) capacity?**

When more than one compressor is operating, all but one should operate at full capacity and efficiency. A final trim compressor can match output to system requirements. In the best case, the “trim” compressor can have more sophisticated controls for greater efficiency at part load operation.

⇨ **Manually sequence multiple compressors.**

Set existing controls to load compressors sequentially so that unneeded compressors can be turned off manually.

⇨ **Install automatic compressor sequencing controls.**

Sequence compressors to avoid operating several compressors at part load and poor efficiently. The largest savings come from the sequencer turning unneeded compressors off. The energy savings usually offset the cost of installing additional receiver capacity.

Yes☐ **Are compressors operating at zero capacity for extended periods of time?**

⇨ **Manually shut of air compressor.**

If an air compressor is left on over the weekend or through the night, it can be turned off manually.

☹ *This measure is only as reliable as the operator(s).*

⇨ **Install shut-off timers on air compressors.**

Shut-off timers can be set to de-energize a compressor if it operates at zero capacity for a set period of time. This can work particularly well if air may be needed for short periods such as during night clean-up. The compressor will shut off at the end of the production shift and only start up again when needed.

Yes☐ **Is the discharge pressure of the compressors higher than 110 psig?**

If compressors are operating in a range higher than 90 to 110 psi, determine if this higher pressure is required. Common end uses frequently require no more than 80 psi. It is also *common to operate from 100 to 110 psi to overcome any potential line losses. It is possible to have end use air requirements greater than 110 psig, but verify them. Even 90 to 110 psi can be higher than required to ensure adequate air delivery to the end use. It wastes energy to compress air to a higher pressure unnecessarily. Higher system pressures also cause unregulated air uses to expend more air. (Any end use that does not include a regulator to keep air pressure from exceeding required pressure is an unregulated air use. System air leaks are an unregulated use common to all compressed air systems)*

- 👍 *The power required to compress air increases by about 0.5 percent for each psi increase in system discharge pressure.*
- ⇨ **Reduce pressure delivered by air compressor to the minimum required by the system.**
  - ★ *Determine required end use pressures on equipment, then group them by requirements. This will help establish the actual discharge pressure required.*
- ⇨ **Install looped piping system.**
  A looped piping system balances pressure throughout the plant. End uses are served from both directions, with line losses at different points balancing out in the two paths. With a balanced system compressor discharge pressures can often be reduced.
- ⇨ **Install larger pipes.**
  Larger pipes reduce the pressure loss in the distribution lines while providing additional surge capacity to reduce pressure fluctuations. Both effects help reduce system pressure, which reduces the energy consumption.

Yes☐ **Is high pressure air being used for tasks that do not require high pressure air?**
Compressed air may be used for inappropriate applications such as part drying or aeration. A low-pressure blower or fan may be a better choice. Power is wasted to compress the air to higher pressures than needed.

- ⇨ **Meet end use requirements with lower pressure air delivery sources such as a blower, fan, or a smaller horsepower air compressor.**

Yes☐ **Does the compressed air system have significant air leaks?**
Most leaks are difficult to pinpoint and quantify on a leak by leak basis. Some leaks are easy to find because of their location, sound, and air volume. Some leaks are intentional; such as an open compressed air line directed to cool a hot bearing.

- ★ *Leaks are easiest to find when the plant is quiet –- plant is not in production operation such as during lunch.*
- ★ *To quantify total air leaks in a plant: take note of air compressor loading and/or air delivery during breaks or other times when there is no air use.*
- ★ *Ultrasonic tools provide the most reliable method to locate air leaks.*
- ★ *Common leak locations: valve packing, pneumatic cylinders, and hoses, quick release hose fittings for hand equipment, hand equipment itself.*
- 👍 *Air leaks exceeding 35 percent of the air used are excessive in any plant (plant load can be determined by subtracting cfm leak load found during the break period from the compressor cfm recorded during plant operation.)*
- 👍 *The table below gives estimates of the annual costs for air leaks. Values are based upon a 1000 ACFM screw compressor operating at 100 psig with a compressor efficiency of 1 hp/ 5 cfm or 20 percent .The compressor motor has an efficiency of 90 percent. Intake air is at 70°F, 14.7 psia. Compressor operates 12 hrs/day x 5*

days/wk x 50 weeks/yr = 3000 hrs/yr. Cost of electricity is $.05/kWhr. This equates to an annual cost of approximately $25/cfm of leaks.

Opening Diameter	1/64"	1/32"	1/16"	1/8"	1/4"	1/2"
Air escaping at each leak	.50 CFM	1.5 CFM	6.5 CFM	26 CFM	104 CFM	415 CFM
Annual kWh	249 kWh	746 kWh	3,233 kWh	12,931 kWh	51,723 kWh	206,393 kWh
Annual cost	$12	$37	$162	$647	$2,586	$10,320

(Savings with reduced air flow depends on the air compressor's part load efficiency)

☺ *Example: For a compressed air system operating at 100 psig, one air leak 1/8"in diameter will loose 26 ft^3 of air per minute. The power loss due to this air leak is:*

$$kWh/yr = \left[(26\,cfm)x\,\frac{1\,Bhp}{5\,cfm}\,x\,\frac{.746\,Kw}{(Bhp)(.90\,eff)}\,x\,\frac{3000\,hrs}{yr}\right] = 12{,}931\ kWh/yr,$$

$$The\ annual\ cost = \left(\frac{12{,}931 kWh}{yr}\right)x\left(\frac{\$.05}{kWh}\right) = \$647/yr$$

⇨ **Repair air leaks**

By reducing the air leaks, the compressors can operate at a lower discharge pressure. In the best cases, reducing the air leaks can allow compressors to be shut off.

* *If the leak reduction does not allow one compressor to be shut off, consider a control strategy for efficient part load operation to realize significant savings.*

Yes **Does the facility have rotary vane air compressors?**

The capacity of rotary vane compressors is commonly controlled by blowing off excess air to atmosphere. In such cases there is no reduction in power with reduced air flow.

⇨ **Replace rotary vane compressors with energy efficient centrifugal screw compressors that are computer controlled to allow sequencing and unloading.**

Yes☐ **Does the facility have desiccant air dryers?**

Desiccant air dryers can produce very dry air, however, they use more energy than refrigerated dryers. Determine if the increased drying capacity is necessary. Heaterless desiccant air dryers purge the most amount of air and can waste the most energy.

- *From 10 percent to 15 percent of total air produced by the air compressor can be purged in regenerating a heaterless desiccant dryer*

⇨ **Replace desiccant air dryers with refrigerated air dryers.**

⇨ **Install a capacity controlled regenerative dryer.**

If drier air is required, control the desiccant recharge cycle to stop when the humidity drops to a set level. The amount of savings will depend on the amount of air being used.

⇨ **Install internally heated desiccant air dryers.**

If drier air is required, internally heated desiccant dryers only require 3to5 percent of the total airflow for purging moisture. Isolate moisture sensitive *equipment if possible, such as pneumatic controls, which can be particularly sensitive to moisture. It is unnecessary to dry all of the plant air to the level required by a minority of the equipment. If the sensitive equipment is grouped on one branch of the compressed air circuit, a desiccant dryer can serve that line only and drying costs can be greatly reduced.*

Yes☐ **Is the compressor cooling water discharged to the sewer?**

⇨ **Use compressor cooling water to replace warm water for other uses, such as cleaning or pre-heating the boiler makeup water.**
This strategy can save on both energy and water costs.

☠ *Oil contamination potential in the compressor cooling water can present a problem to be overcome. Although more costly, a heat exchanger to transfer heat from the air compressor cooling water to preheat the boiler make up water might be a better option.*

Yes☐ **Is the pressure drop across auxiliary equipment such as dryers, oil separators, or filters excessive?**

Some compressors display pressure drop across these devices. Pressure drop should not exceed 8 to 10 psig; for oil separators, 5 psig for a dryer, 0.5 to 1 psig for a filter.

⇨ **Replace filters, overhaul equipment to reduce pressure drop.**
Clogged filters and fouled lines increase air velocity and pressure drop.

⇨ **Size equipment to accommodate air flow with acceptable pressure drop.**
Equipment such as a refrigerated dryer causes excessive pressure drop when air flow exceeds design.

Yes☐ **Is compressed air the best utility for the given application?**

Compressed air is often chosen for its convenience; its safety in explosive situations; and its comparatively high energy density for hand held tools, robotics, or other equipment. Unfortunately it can be an inefficient method of getting the work done.

⇨ **Replace compressed air use with another utility. For example, replace a pneumatic motor with an electric motor or hydraulic motor.**

⇨ **Replace a venturi-type vacuum generator with a vacuum pump.**

Yes☐ **Does the facility utilize any air nozzles?**

Yes☐ **Have the air nozzles been designed for maximum efficiency?**

⇨ **Install engineered nozzles.**
These nozzles are typically used for blowing off parts of equipment, cutting or cooling. Commercially available engineered nozzles have higher efficiencies and use less air.

Yes☐ **Is the Air Compressor on a Regular Maintenance Schedule? Review maintenance logs to verify if the following is being done on a scheduled basis.**

⇨ **Maintain modulating controls.**
Modulating controls on screw compressors can fail over time. The result is a compressor that never operates at full load or unloads properly, reducing both efficiency and capacity.

⇨ **Lubricate compressor.**
Proper lubrication extends compressor life and improves its efficiency.

⇨ **Clean or replace intake filter.**
A clogged intake filter reduces compressor capacity and efficiency.

General Notes:

- A 1/8" hole will lose 600 Mbtu/yr of steam in a 100 PSI system
- Estimate 1 percent reduction in boiler efficiency for every 40°F increase in stack temperature.
- Please refer to the following web sites for additional information: http://www.oit.doe.gov/bestpractices/steam/totalsteam.shtml, http://www.ecw.org

- Combustion efficiency and boiler operating targets for different fuels:

Fuel	Efficiency Target	Excess Air	Oxygen (O2)	Carbon Dioxide (CO2)	Other
Natural Gas	80% - 83%	21% - 28%	4% - 5%	9.0% - 9.6%	400 ppm Carbon Monoxide (CO)
Oil	84% - 87%	22% - 29%	4% - 5%	11.9% - 12.6%	1 - 2 smoke test
Coal	83% - 84%	26% - 34%	4.5% - 5.5%	13.7% - 14.6%	
Wood	65% - 75%	61% - 74%	8% - 9%	11.7% - 12.6%	

Look For or Ask ?

Yes☐ **Is the stack temperature too high?**

- ★ *Optimum stack temperature is typically 50°F to 100°F above saturated steam pressure at high fire in a saturated steam boiler.*
- ★ *A record of the stack temperature after boiler tuning offers a more accurate target for optimum operation.*
- *Stack temperatures higher than these suggest poor heat transfer or too much combustion air.*

Boiler Pressure	Recommended Maximum Stack Temperature
30 psig	375 °F
75 psig	420 °F
100 psig	440 °F
125 psig	455 °F

(No more than 100 °F greater than saturated steam pressure at boiler operating pressure)

- Stack temperatures lower than 275 °F can lead to corrosive condensation

⇨ **Tune the Boiler. [Reduce excess combustion air]**

- ☠ *Be sure not to reduce excess air below minimum required to avoid creation of carbon monoxide.*

⇨ **Clean the boiler to remove water side and fireside fouling.**

- *Soot can usually be removed with a brush during regular maintenance.*
- *Scale on the water side may require extensive chemical treatment if deposits are severe.*

⇨ **Preheat combustion air.**

- *Stack gas temperature should typically be over 400°F on a well tuned boiler for this to pay off.*

Yes☐ **Is the boiler operating at incomplete combustion?**

Incomplete combustion is difficult to ascertain without a stack gas analyzer. Excessive soot buildup, or fuel consumption for the boiler load might be an indicator. A stack gas analyzer will allow the operator to compare O_2 and CO_2 levels to optimum levels for efficient operation.

⇨ **Tune the Boiler.**

Yes☐ **Is the blow-down of the boiler water manually controlled ?**

As water is evaporated to steam, solids in the water remain in the solution. To keep dissolved solids from building up to excessive levels, the boiler water is drained and replaced with fresh water. This is called "blow-down." The difference in temperature between the replacement water and the hot boiler water represents an energy loss. To minimize this loss, blow-down should be set to the minimum required to keep dissolved solids at an acceptable level. The rate of continuous blow-down depends on the quality of the feedwater and the amount of condensate return.

☺ *Reducing the blow-down will also reduce the amount of water treatment chemicals required.*

⇨ *Set the blow-down based upon the amount of total dissolved solids.*

Yes☐ **Does the facility have a significant number of steam traps that are malfunctioning?**

Steam traps are usually designed based upon a maximum back pressure rating. This rating is determined by dividing the outlet pressure by the inlet pressure, absolute (psia). If the back pressure of the present system is greater than the original design pressure, the trap is not able to fully close, and can fail in the open position. When these traps fail open, they blow steam into the return system, which increases the back pressure on other traps in the system, causing them to fail. When the steam is induced into the return piping, the vapor flows over the condensate, eventually causing enough turbulence to create a mass or "slug" of condensate that fills the pipe.

The condensate slug can travel throughout the piping system at the same velocity as the steam until it encounters a sudden change in direction and this energy is transferred into a force referred to as "water hammer". It can be difficult to identify traps that are leaking, failed open or failed closed. When properly designed and maintained, steam traps remove the condensate from the steam and purge air and other non-condensable gases from the steam system which increases it's thermal efficiency.

☺ *The most reliable method to identify traps that are malfunctioning is to use ultrasonic tools.*

⇨ *Initiate a program to identify and repair traps that are malfunctioning. Consider installing continuously discharging thermostatic steam traps.*

Yes☐ **Is the condensate return system open to atmosphere?**

Hot condensate will travel in the direction of high pressure to low pressure. When the feed tank is vented to atmosphere, as the condensate enters the feed tank, it will flash to steam due to the sudden drop in pressure and the steam escapes through the vent to atmosphere. The steam and associated energy is lost.

⇨ **Install properly designed steam traps to reduce the amount of steam lost through the open system.**
⇨ **Install pressurized condensate return system to reduce flash steam losses.**
⇨ **Insulate Condensate Storage Tanks.**

Yes☐ **Is an open condensate return system utilized?(condensate not returned to the boiler)**

If condensate is not returned to the boiler all of the energy in the hot condensate return is lost. Since this condensate also contains water treatment chemicals, these chemicals have to be replaced. The energy and wastewater treatment costs will increase.

☹ *This loss has to be balanced against the significant cost of adding a condensate return system. In large facilities, the installation of a condensate return system may require extensive pumping, piping and valves.*

⇨ **Install a condensate return loop.**

Yes☐ **Does the boiler cycle frequently?**

Boiler efficiency is reduced at partial load. Frequent cycling reduces the overall operation efficiency and the life of a boiler. Continual cycling can be an indicator of an oversized boiler.

⇨ **Install multiple smaller boilers (modular).**
⇨ **Match steam load to the boiler output.**

Yes☐ **Is the efficiency and performance of the steam system being monitored manually?**

⇨ **Install a boiler stack gas thermometer with a maximum indicating hand.**
⇨ **Install a meter to measure the amount of boiler make-up water being consumed.**

Yes☐ **Is the flow rate of the induced draft and forced draft fans being controlled by throttling methods?**

⇨ **Install VSD control on boiler induced draft and forced draft fans.**
★ **Boilers typically operate 24 hours a day, 365 days per year. Improving the efficiency of any equipment associated with the day to day operation of the boiler will produce significant energy savings.**

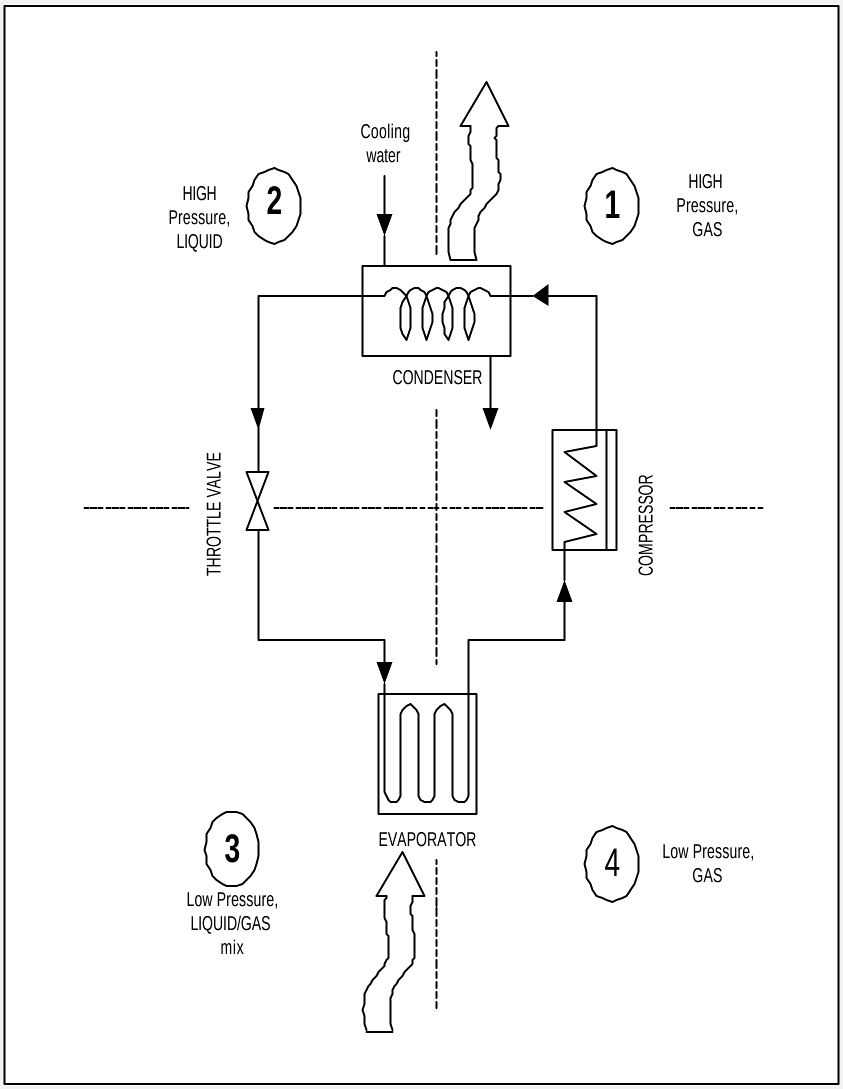
Yes☐ **Are there any opportunities for heat recovery?**

⇨ **Install heat exchangers to use the stack gases to preheat the boiler make up water. Waste heat from air compressors or other equipment can be used for this application. Use high pressure condensate to create flash steam for low pressure heating service.**

General Notes:

- Compressor energy use drops 1 - 1.5 percent for each °F of head pressure drop.
- Compressor energy use drops 2 - 3 percent for each °F of suction pressure increase.
- Please refer to the following web sites for additional information: http://www.ecw.org, http://www.oit.doe.gov, http://www.ecw.org/products/commindu.html#502/

Simple Refrigeration Cycle



Note: The "Simple Refrigeration Cycle" diagram is for information only and will be described in detail at a later time.

☞ Look For or Ask ?

Yes☐ **Can the operation of the existing refrigeration system be optimized by implementing any of the following meausres?**

- ⇨ **Optimize inter-stage pressure.**

  A two-stage system has three separate pressures maintained by high- and low-stage compressors. Choose intermediate pressure so that each compressor has approximately the same pressure ratio to minimize compressor energy use.

- ⇨ **Economized single stage system.**

  For applications that require extremely low temperatures such as a blast freezer, a two- stage compressor is usually preferred. An "economized" single stage system may allow operation at slightly lower suction temperatures while providing the necessary cooling and avoiding the cost of a two-stage system.

- ⇨ **Install 2-speed or VSD speed control on condenser and evaporator fans.**

  By reducing fan speed when full capacity is not needed, the energy consumption of the fan motors is significantly reduced.

- ⇨ **Cycle evaporator and condenser fans.**

  Evaporator fans move air across refrigerant coils to condition the space. Condenser fans remove the heat generated during compression of the refrigerant. Evaporator fans can turn off when not needed for temperature control or to de-stratify air in the space. Cycling fans saves fan and compressor energy. Duty cycles can be reduced as much as 50 percent. A timer can be used to cycle primary fans after a given amount of operation

Yes☐ **Are refrigeration compressors being operated manually or "semi-automatically"?**

- ⇨ **Install computer controls to allow the compressors to operate at their highest efficiency point.**

  Overlap suction pressure switches on compressors connected to a common header to allow their operation to be sequenced.

Yes☐ **Is it necessary to operate at lower suction pressures in order to maintain production rates or to maintain the desired storage temperature?**

Poor cooler/freezer insulation, undersized or dirty evaporators require lower suction pressure and wastes energy.

- ⇨ **Consolidate and re -pipe loads with similar suction requirements. Dedicate a compressor to these loads.**

  Compressors operating at their maximum suction pressure are more energy efficient.

- ⇨ **Reset suction pressure.**

  Raise suction pressure to match the actual pressure required to meet the cooling loads.

  When the suction pressure drop increases, compressor work increases.

- ⇨ **Add evaporator capacity to reduce evaporator approach temperature and raise suction pressure.**

  The compressor savings resulting from operating at higher suction pressures often offset the additional evaporator fan energy consumed.

Yes☐ **Are back pressure regulators (BPRs) used in order to control suction pressures to accommodate a significant portion of the load?**

BPR's control system branch pressure.

⇨ **Eliminate BPR's.**
BPR's control various refrigeration loads on a single system. Loads requiring a lower suction pressure could be separated from loads requiring a higher suction pressure.

Yes☐ **Can the timing of heavy process or other refrigeration loads be distributed better?**

⇨ **Consider load shifting during periods of high energy use and or thermal storage during periods of low energy use to reduce the total energy demand.**

Yes☐ **Are head pressures significantly higher than rated pressures?**

Minimum Head Pressure	
Ammonia	*93 psig*
R12	*72 psig*
R134a	*72 psig*

⇨ **Set the system to operate at lower head pressures.(Minimize the lift)**
Flash gas caused by system losses at low discharge pressure can be avoided with a liquid pressure amplifier (LPA) pump.
★ *LPA pump is a small horsepower pump with a magnetically driven impeller installed at the outlet of the condenser to increase the pressure and subcool the refrigerant before it enters the expansion valve. This allows the compressor to operate with a lower discharge pressure.*

⇨ **Install a Thermosyphon cooling system to cool the compressor oil.**
Oil is used to seal, cool, and lubricate screw compressors. ☹ *Liquid-refrigerant-injection cooling uses 5-15 percent of compressor power to recompress refrigerant.*
★ *A thermosyphon system cools the oil with a heat exchanger by transferring the heat from the oil to the refrigerant, which causes it to change from a liquid to a vapor. The refrigerant vapor rises to a condenser where it condenses to a liquid and the cycle is repeated. This process requires less energy to cool the oil than liquid refrigerant injection.*

⇨ **Install additional condensing capacity to reduce discharge pressure.**
Additional condensing capacity will bring the liquid refrigerant temperature closer to the wet bulb temperature, therefore increasing the heat transfer efficiency.

Yes☐ **Are the compressors on a regular maintenance schedule? If so, verify that the following is being done on a scheduled basis.**

⇨ **Maintain evaporative condensers.**
Water evaporates as it absorbs heat from the condensing refrigerant. The heat exchange surface must be clean and free of corrosion. Air must pass through freely for efficient heat transfer. Water should be treated to reduce scale and corrosion, and reduce biological growth.

⇨ **Purge non-condensable gasses.**
Non-condensable gasses such as air or CO_2 reduces the effective surface area of the condenser used to condense refrigerant vapor, thereby decreasing heat exchanger efficiency. In general, non-condensibles enter the system when the low stage suction pressure is less than atmospheric pressure. Automatic purging controls are readily available. The system can also be purged manually when an operator notices as

increase in the discharge pressure. A refrigeration log helps identify when operating conditions change.

Yes☐ **Can the evaporator defrost control be optimized?**

Evaporator coils must be free of ice for maximum heat transfer.

- ⇨ **Avoid excessive defrost times - reduce defrost times.**
  Warm fluid (refrigerant gas or water) commonly is used to defrost evaporators. Heat will warm the space after the ice has melted. Air flow sensors and thermocouples can control the defrost system to stop as soon as the ice has melted.
- ⇨ **Use Hot gas defrost instead of electric defrost.**
  High-pressure refrigerant is more efficient than electric heaters.
- ⇨ **Use water defrost instead of hot gas defrost.**
  Hot process water can also defrost the evaporator. Additional compressor energy is not required. This can be more efficient and faster in a blast freezer, for example, where the defrost can occur with water without the product being present.

Yes☐ **Are there any opportunities for Heat Recovery?**

- ⇨ **Utilize waste heat off of condensers.**
  Use waste heat to preheat process water.
- ⇨ **Insulate Cooler/Freezer area.**
  Unnecessary heat gain decreases system efficiency.

Material Handling Systems

General Notes:

The following option should be considered when exploring opportunities to save energy with material handling fans and blowers:

For belt driven devices, the speed can be reduced by re-sheaving the motor to determine the minimum speed allowed to move the material and avoid design and safety problems. After this speed is determined, the actual motor rpm can be measured with a tachometer. The proper drive mechanism can be selected.(VSD, two speed motor, an energy efficient motor at reduced rpm and horsepower, etc.)

This approach can provide energy savings at the least cost. The preferred method is to evaluate the entire system and to size the fan and motor to efficiently handle the present operating conditions.

For additional information, please refer to the following web sites: http://www.energy.wsu.edu/industry/research.htm, http://www.ecw.org

Look For or Ask ?

Yes☐ **Does the facility utilize high or low pressure blowers to convey material?**

The following energy savings opportunities should be evaluated:

- **Reduce the speed of the blower or fan to capture the energy savings and reduce the wear and tear on the distribution piping by reducing the velocity.**
- **Replace Dust Collection System Material Handling fans with High Efficiency Clean side fans.**
- **Install high efficiency bag houses.**
- **Replace Pneumatic chip transfer with conveyors or vibrating transfer systems.**

Yes☐ **Does the facility have more than one baghouse and multiple distribution lines feeding into these baghouses?**

- **Determine if these distribution lines can be valved/knifed off when not operating to reduce the load on the fan and baghouse.**
- **Determine if these distribution lines should be re-routed to allow a dedicated fan that requires less horsepower to perform the same task.**

Quite often the pant distribution lines, fans, and blowers have been modified over the years and are not operating under design conditions and could be wasting a lot of energy.

Hydraulic Systems

General Notes:

For additional information, please refer to the following web site: http://www.energy.wsu.edu/industry/research.htm#hydraulic

Look For or Ask ?

Yes☐ **Does the manufacturing process utilize hydraulic pumps?**

The following energy savings opportunities should be evaluated:

- **Install accumulators.**
  Accumulators can improve the efficiency of the hydraulic system by maintaining system pressure and allowing the pump to unload or to do other work. This reduces the amount of times the pumps cycle on and off. They also compensate for changes in pressure due to leaks and thermal expansion of the working fluid.
- **Install a variable speed drive on the hydraulic pump.**
  The variable speed drive varies the pump speed to match the hydraulic oil needs of the system. This provides smooth response and can result in significant energy savings.
- **Install variable displacement pump for variable hydraulic loads.**
- **Install pressure compensation to unload the hydraulic pump.**

Injection Molding or Extrusion

General Notes:

For additional information, please refer to the following web sites:
http://www.energy.wsu.edu/industry/research.htm
http://www.oit.doe.gov/pdfs/bestpractices.pdf
http://www.ecw.org

Look For or Ask ?

Yes☐ **Does the manufacturing process involve Extrusion or Injection Molding?**

The following energy savings opportunities should be evaluated:

- ⇨ **Install a variable speed extruding machine.**
  The drive runs at the minimum speed necessary for the product being produced. The input signal to the drive is typically a 4 to 20mA control signal that maintains the desired set-point.
- ⇨ **Insulate heater bands to reduce thermal losses.**
- ⇨ **Grind and reuse reject parts and trim pieces.**

Yes☐ **Is a chiller used to cool the hydraulic oil?**

- ⇨ **Cool the hydraulic oil with a closed- loop cooling tower circuit.**

Veneer Dryers

General Notes:

For additional information, please refer to the following web sites:
http://www.energy.wsu.edu/industry/research.htm
http://www.oit.doe.gov/pdfs/bestpractices.pdf http://www.amca.org

Look For or Ask ?

Yes☐ **Does the manufacturing process involve the use of Veneer Dryers?**

The following energy savings opportunities should be evaluated:

- **Perform an air balance on the dryer.**
  Provide uniform drying, sufficient air circulation, optimize air contact with product.
- **Install electronic dryer controls (VSD) to control drying time.**
- **Install VSD fan control if there is a significant variation in species and moisture content of the product being dried.**
- **Plastic bearings reduce friction loss and last longer than carbon/steel bearings.**
- **Investigate alternate drying methods**
  - Infra-red
  - Microwave
  - Radio frequency
- **Preheat dryer makeup air with heat from exhaust.**

Kiln Drying

🗎 General Notes:

🗁 For additional information, please refer to the following web sites:
http://www.energy.wsu.edu/industry/research.htm
http://www.oit.doe.gov/pdfs/bestpractices.pdf
http:www.amca.org/

Look For or Ask ?

Yes☐ **Does the manufacturing process involve Kiln Drying?**

The following energy savings opportunities should be evaluated:

- ⇨ **Retrofit kiln fans to maintain optimum speed throughout the drying cycle by installing VSD fan control.**
- ⇨ **Repair baffles, stack lumber and trim ends to prevent the air flow from short circuiting the load.**
- ⇨ **Install zone temperature control to save energy and improve uniformity of drying.**
- ⇨ **Install steam recovery.**

Energy Management

The following energy savings opportunities should be considered:

- ⇨ **Have the utility explain how the total energy consumption, demand charges, and power factor penalties are determined for the facility. Discuss options to reduce these charges.**
- ⇨ **Switch to a different billing schedule if applicable.**
- ⇨ **Consolidate accounts.**
- ⇨ **Install power factor correcting capacitors - individual capacitors on motors, or automatically switching banks at the facility service entrance to minimize power factor penalties.**
- ⇨ **Install demand controller/ load shedder to reschedule/distribute high demand loads to reduce demand charges.**
- ⇨ **Install temporary or permanent meters to validate the billing data for electricity and water consumption.**