

ERDC/CERL TR-00-37

Construction Engineering
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**US Army Corps
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Engineer Research and
Development Center

Compressed Air System Survey at Sierra Army Depot, CA

Mike C.J. Lin, Ahmad R. Ganji, Shy-Sheng Liou, and
Bryan Hackett

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Executive Summary

Compressed air (CA) is one of the major utilities at Sierra Army Depot (SIAD). Air compression consumes about 3.4 percent of electrical energy at SIAD, amounting to about 3.2 percent of the total energy costs. A detailed survey of the compressed air system at SIAD revealed that implementing certain measures could yield significant savings and operational improvements. Table ES-1 summarizes the quantifiable energy efficiency measures related to compressed air systems. Details of these measures are presented in Chapter 6 (p 58).

Table ES-2 summarizes operational improvements in production and use of compressed air that also result in cost savings, but which could not be quantified. Details of these measures are presented in Chapter 6.

In the course of the CA audit, the audit team identified certain other measures that have potential for significant savings at the plant. Table ES-3 summarizes these measures. Details of these measures are presented in Chapter 6

It is also recommended that the main technician in charge of the compressed air system go through a formal training for operations and maintenance (O&M) of the Gardner Denver compressor, and a formal log-book be established for maintenance of the compressed air system.

Table ES1. Summary of quantifiable energy efficiency measures related to compressed air system.

EEO No. & Description	Potential Energy Conserved	Demand Savings (kW)	Potential Savings (\$/yr)	Resource Conserved	Implem. Cost (\$)	Simple Payback (years)
<i>Low or No-Term Measures</i>						
1 Repair Compressed Air Leaks	79,478 kWh/yr	21.91	6,587	Electricity	0	immediate
2 Change the Air Compressor Control to Low Demand Mode	41,711 kWh/yr	11.50	3,677	Electricity	0	immediate
3 Disconnect the Air Receiver from the Oil/Water Separator	10,282 kWh/yr	2.83	906	Electricity	35	immediate
4 Duct Outside Air into the Air Compressor Room	8,450 kWh/yr	2.33	745	Electricity	335	0.4
5 Install Sensor-Type Valves on the Purifier Pre-Filters	20,564 kWh/yr	5.67	1,813	Electricity	1,270	0.7
<i>Short-Term Measures</i>						
6 Replace the Timer-Type Drain Valves with Sensor-Type Valves	20,564 kWh/yr	5.67	1,813	Electricity	2,540	1.6
<i>Long-Term Measures</i>						
7 Install a Natural Gas Engine-Driven Air Compressor*	366,036 kWh/yr -37,228 therms/yr	100.92	17,326	Electricity Natural Gas	177,925	10.3
Total Energy Savings	(Electricity)†, ‡	139,338 kWh/yr				
	(Natural Gas)	-37,228 therms/yr				
Total Demand Savings†		49.9 kW				
Total Cost Savings‡			\$29,190/yr			
Total Implementation Cost					\$182,105	
Simple Payback Period						6.23 years
<p>* EEO would increase the amount of natural gas consumed at this facility, which is represented as a negative savings. See specific EEO for details.</p> <p>† Excludes potential electrical energy and demand savings from EEO No. 7.</p> <p>‡ Excludes potential savings from EEO No. 2</p>						

Table ES2. Summary of unquantifiable energy efficiency measures related to compressed air system.

EEO Description		Potential Energy Conserved	Demand Savings (kW)	Potential Savings (\$/yr)	Resource Conserved	Implem. Cost (\$)	Simple Payback (years)
Install an Air Cooler in the Back-Up Compressor Room		NA	NA	NA	Electricity	NA	NA
Install an Oil-Free Air Compressor to Produce the Breathing Air		NA	NA	NA	Electricity	\$51,000	NA
Replace Air Powered Tools with Electric Powered Tools		NA	NA	NA	Electricity	NA	NA
Total Energy	(Electricity)	NA kWh/yr					
Savings	(Natural Gas)	NA therms/yr					
Total Demand Savings			NA kW				
Total Cost Savings				\$NA/yr			
Total Implementation Cost						\$51,000	
Simple Payback Period							NA years

Table ES3. Summary of energy efficiency measures unrelated to compressed air system.

EEO Description		Potential Energy Conserved	Demand Savings (kW)	Potential Savings (\$/yr)	Resource Conserved	Implem. Cost (\$)	Simple Payback (years)
Electrical Distribution System for the Industrial Area		NA	NA	NA	NA	NA	NA
Install Occupancy Sensors in the Paint and Shot Blaster Booths		25,139 kWh/yr	6.93	2,216	Electricity	360	0.2
Turn-Off Dust Collector Equipment During Non-Operating Hours		32,795 kWh/yr	9.04	2,892	Electricity	0	immediate
Use of Natural Gas Heaters		NA	NA	NA	Natural Gas	NA	NA
Total Energy	(Electricity)	57,934 kWh/yr					
Savings	(Natural Gas)	NA therms/yr					
Total Demand Savings			15.97 kW				
Total Cost Savings				\$5,108/yr			
Total Implementation Cost						\$360	
Simple Payback Period							0.1 years

Foreword

This study was conducted for the Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 40162784AT45, "Facility Infrastructure Technology;" Work Unit XB0, "Industrial Energy Technology Optimization." The technical monitor was Richard Faith, AMXEN-C, AMC I&SA.

The work was performed by the Energy Branch (CF-E) of the Facility Division (CF), U.S. Army Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Mike C.J. Lin. The technical editor was William J. Wolfe, Information Technology Laboratory. Larry Windingland is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Gary Schanche. The Acting Director of CERL is Dr. William D. Goran.

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1 Introduction

Like electricity and water, compressed air (CA) is an indispensable commodity used in manufacturing and maintenance facilities. In most plants/shops, CA is centrally generated and distributed to users through a pipe network. Although a very convenient power source, CA systems are not cheap to operate. The annual cost of electricity needed to run an air compressor is near or more than the initial cost of the compressor. About 20 percent of the power input to the compressor is lost as heat. Cooling of the compressor represents 5 percent of generation costs. Leakage is often the largest waste of energy associated with CA usage. Air leaks may consume as much as 30 percent of the total compressor output. Yearly maintenance charges, and costs of labor and material must be added to get the true CA cost. An analysis of the cost breakdown of a CA system shows that as little as 10 percent of the input power supplied to the compressor is delivered as CA to the system. Assuming an average electricity cost of \$0.04/KWh, by the time the CA is used, the equivalent energy cost to purchase the usable CA is approximately \$0.40/KWh. Nearly all industrial plants can realize 25 to 40 percent savings on the power costs for the CA system without additional capital expenditures.* Complete CA system audits and surveys will reveal these opportunities.

Objectives

The objectives of this project were to perform a detailed survey of the compressed air system at the Sierra Army Depot (SIAD), and to recommend cost-effective methods to improve the operation and maintenance of the system and to promote more efficient use of the compressed air at the plant.

* Henry L. Kemp, Jr., Strategic Air Concepts, <http://www.strat-air.com/index.html> (Qualified instructor for the Compressed Air Challenge Program).

Approach

A CA system survey was conducted from 10 July 2000 through 13 July 2000. The site visit included an initial meeting with Depot personnel involved with the CA system operation, a tour of the CA facilities, an equipment inventory, inspection and tagging of air leaks, development of CA system drawing, system measurements, a review of data and manuals, interviews of personnel, and a summary meeting at the end of the visit.

Chapter 3 gives details of the compressed air system. Chapter 4 describes the operation and maintenance of the compressed air system. Chapter 5 outlines the procedure used to survey the system. Chapter 6 describes the specific measures the audit team proposed, which were found to result in substantial cost savings in the operation of the compressed air system. During the audit of the compressed air system, the team also observed other energy conservation measures that could be implemented that have potential for substantial cost savings. These measures are also described in Chapter 6.

Scope

The CA system survey included the following three tasks:

1. Develop work plan.
2. Conduct CA system audit.
3. Prepare technical documentation.

The audit included the following features:

- Detailed background of the compressed air system including, manufacturer, sizes and vintage of compressors and the accessories, air distribution system, and various uses of the compressed air
- Details on the operation and maintenance of the CA system and recommendation for any potential improvement
- Identification and detailed engineering analysis of energy efficiency opportunities (EEOs) related to CA system
- Economic analysis of implementation of the recommended measures and any alternative strategies.

Mode of Technology Transfer

The results of this study will be furnished directly to the sponsoring organization, and will also be published via the World Wide Web (WWW) at URL:

<http://www.cecer.army.mil/>

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 in.	=	2.54 cm
1 ft	=	0.305 m
1 yd	=	0.9144 m
1 sq in.	=	6.452 cm ²
1 sq ft	=	0.093 m ²
1 sq yd	=	0.836 m ²
1 cu in.	=	16.39 cm ³
1 cu ft	=	0.028 m ³
1 cu yd	=	0.764 m ³
1 gal	=	3.78 L
1 lb	=	0.453 kg
1 kip	=	453 kg
1 psi	=	6.89 kPa
°F	=	(°C x 1.8) + 32

2 Overview of the Sierra Army Depot

Mission and Functions

The Sierra Army Depot (SIAD) is a government owned and operated facility located in Herlong, Lassen County, CA, on the east side of the Sierra Nevada Mountains. The Depot's mission is to provide customers with services in receipt, storage, repair, and issue of equipment and components for Operation Project Stock. SIAD also receives, stores, issues, maintains, and demilitarizes conventional ammunition.

SIAD has a maintenance/manufacturing facility consisting of three warehouse type buildings as well as two arcades (which are the focus of this report). The total enclosed area (three buildings) comprises approximately 54,000 sq ft.

The three buildings that were surveyed in this project are designated as:

1. *Painting Shop*: The area is used for finishing (sand and shot blasting, painting) of various types and sizes of equipment. It has one large shot blast booth with three shot blast lines and a small manual shot blast booth. There are also two paint booths in this area, one small booth with one paint line and one much larger booth with six paint lines. This building is also referred to as Building 210.
2. *Metal Shop*: This area is used for a wide variety of metal works including welding, pressing, sheering, drilling, riveting, and numerous other metal works. This building is also referred to as Building 209.
3. *Maintenance Shop*: This area is dedicated to maintenance and testing of equipment and machinery. This building is also referred to as Building 208.

Electric and Gas Utilities at SIAD

Table 1 summarizes the energy consumption and corresponding energy costs at this facility, for a 12-month period. The electrical and natural gas energy data are from May 1999 through April 2000. The total energy cost for this period is \$1,026,201 per year. The Lassen Municipal Utility District (LMUD) supplies electricity to the facility under rate schedule 70.

Table 1. Annual energy summary.

Electricity					Natural Gas		
Usage (kWh)	Demand (kW)	Usage Cost	Demand Cost	Other * Costs	Total Cost	Usage (therms)	Total Cost
10,929,526	2,151	\$710,415	\$180,699	\$-654	\$890,463	485,510	\$135,738
Average Unit Costs		\$0.065/kWh	\$7.00/kW	—	—	—	\$0.2796/therm

*Other costs include: primary voltage credit, service charge, and all state and local taxes and fees.

Table 2. Summary of electrical consumption and costs.

Month	Usage (kWh)	Demand (kW)	Usage Cost (\$)	Demand Cost (\$)	Other* Costs (\$)	Total Cost (\$)
May-99	868,083	1,964	56,425	13,748	-63	70,110
Jun-99	891,022	2,051	57,916	14,357	-58	72,215
Jul-99	871,252	2,062	56,631	14,434	-62	71,003
Aug-99	923,880	2,162	60,052	15,134	-52	75,134
Sep-99	831,873	2,049	54,072	14,343	-70	68,344
Oct-99	904,049	2,272	58,763	15,907	-56	74,614
Nov-99	887,747	2,261	57,704	15,825	-59	73,469
Dec-99	1,010,850	2,324	65,705	16,267	-35	81,937
Jan-00	1,012,206	2,294	65,793	16,059	-34	81,819
Feb-00	905,602	2,229	58,864	15,604	-56	74,413
Mar-00	938,688	2,092	61,015	14,645	-49	75,611
Apr-00	884,274	2,054	57,478	14,375	-60	71,793
Totals	10,929,526	25,814	710,419	180,699	-654	890,463
Averages	910,794	2,151	59,202	15,058	-55	74,205

Notes: Other costs include service charge, primary voltage credit, and state and local energy taxes.

The average electrical usage cost for this meter is \$0.065/kWh, and the average electrical demand cost is \$7.00 per kW. The average cost of electricity is \$0.08147/kWh. This includes the energy cost, the demand cost, and all other costs, including sales tax.

Natural gas is purchased from Texas Ohio Energy, and is delivered via transmission and distribution pipelines constructed and owned by Tuscarora Gas Transmission Company. The average cost of gas in this period was \$0.2796/therm, which includes procurement charge, transmission charges, and all local and State taxes.

The electrical energy usage is tabulated by months for the period of May 1999 through April 2000 in Table 2. Annual gas usage for the facility is tabulated in Table 3 for the period of May 1999 through April 2000.

Table 3. Summary of natural gas consumption and costs.

Month	Gas Usage (therms)	Total Cost (\$)
May-99	12,650	3,074
Jun-99	590	145
Jul-99	0	0
Aug-99	0	0
Sep-99	430	133
Oct-99	18,910	5,541
Nov-99	66,730	22,421
Dec-99	93,480	24,211
Jan-00	91,140	22,786
Feb-00	81,000	21,546
Mar-00	72,880	20,188
Apr-00	47,700	15,693
Totals	485,510	135,738
Averages	40,459	11,312

Figures 1 and 2 show the electrical energy usage and maximum electrical demand. Figure 3 shows annual electrical costs. Figures 4 and 5 show annual gas energy consumption and costs. These figures show the trends and irregularities in energy usage and costs which highlight the need for energy conservation and load management.

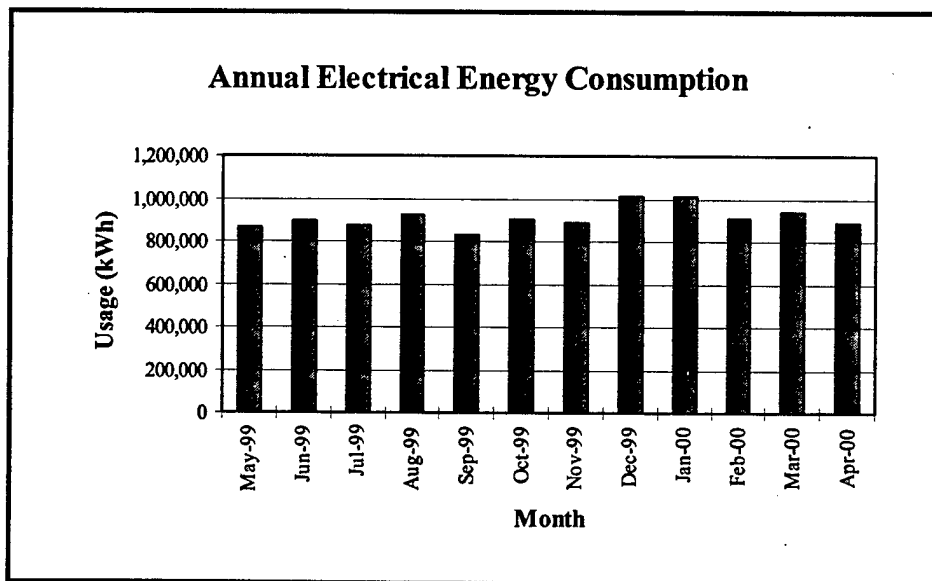


Figure 1. Annual electrical energy usage.

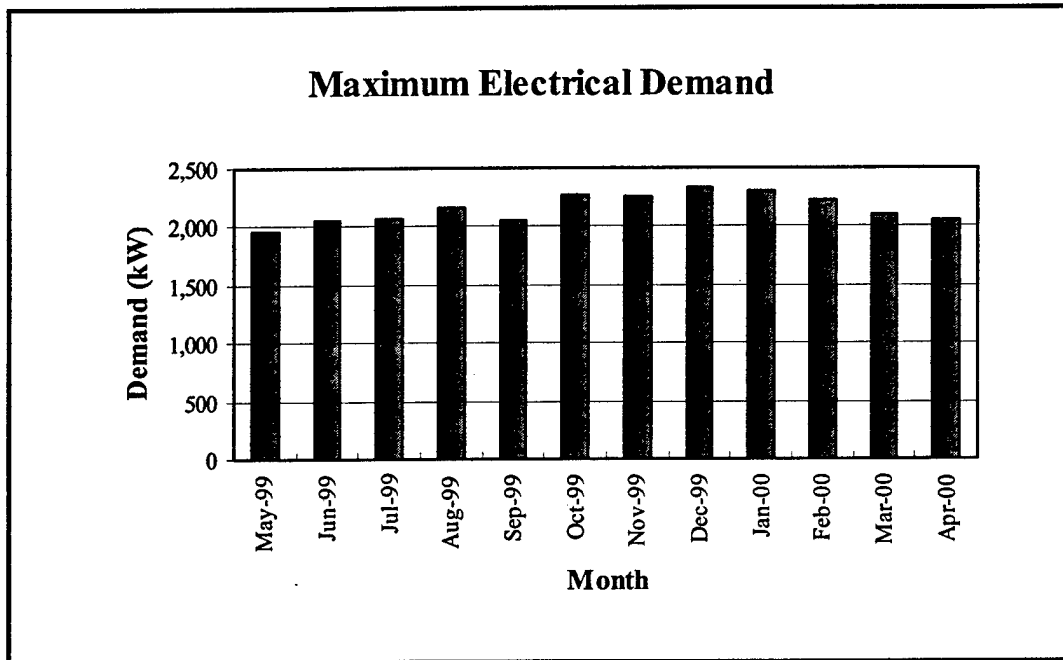


Figure 2. Maximum electrical demand.

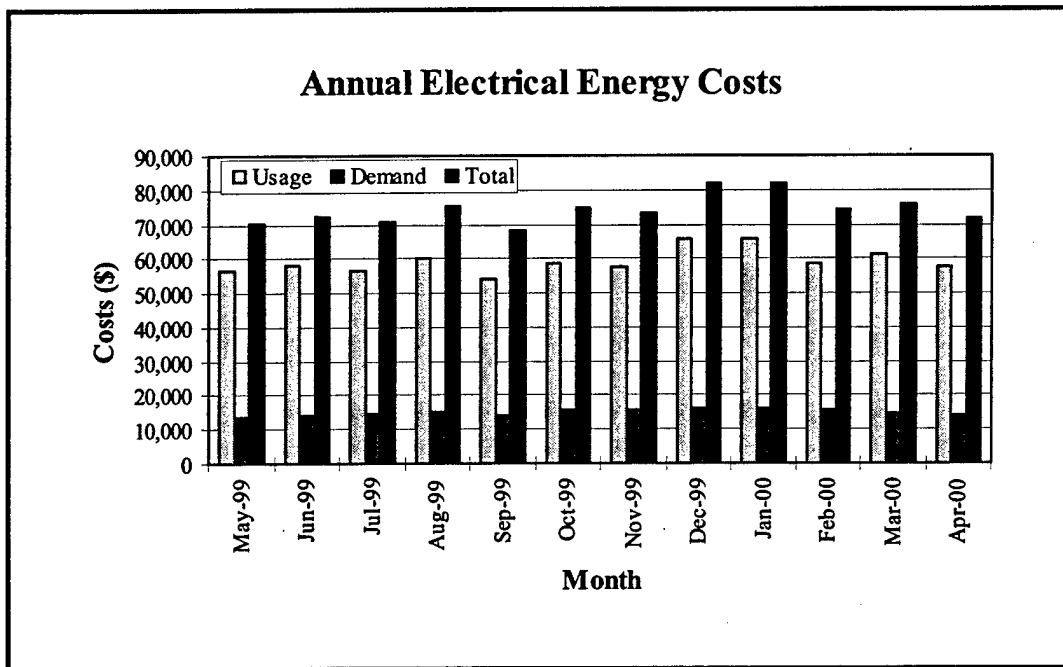


Figure 3. Annual electrical energy costs.

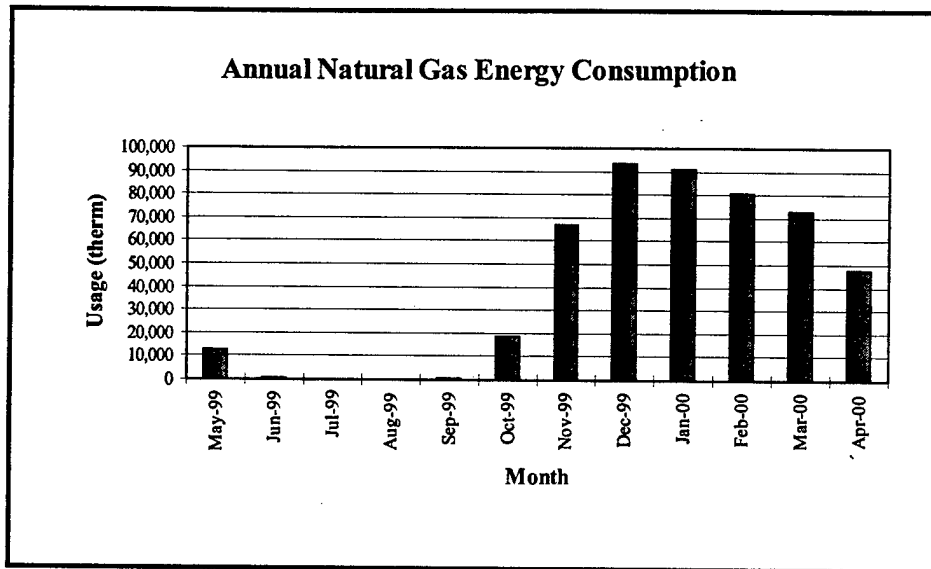


Figure 4. Annual natural gas energy usage.

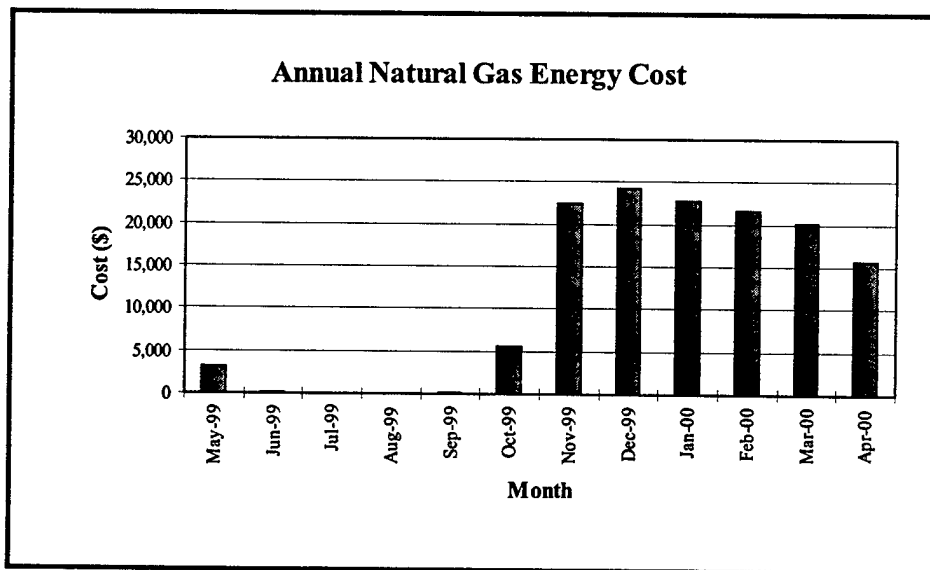


Figure 5. Annual natural gas energy costs.

Compressed Air System Issues at SIAD

Personnel at SIAD have expressed concerns about two issues: the quality of breathing air and air capacity when a large volume of air is needed. The breathing air is provided by a Gardner Denver compressor through a Nomonox purifier. Two carbon monoxide (CO) monitors direct breathing air continuously for both painting booths and the shot blaster booth. Plant personnel indicate that the breathing air is tested by an outside firm (TRI/Environmental, Inc.) every 6 months. One of the CO monitors goes off limit randomly, including some morn-

ings even before the compressor is in full operation. The audit team was told that the monitors are calibrated with span gas on a regular basis.

The capacity issue arises when they use a portable shot blaster called Vacu Blast, which takes about 400 SCFM of air. The heavy compressed air usage is due to the fact that the Vacu Blast creates the necessary suction through a venturi using compressed air. When necessary, the personnel may boost the air capacity using a 200 hp Ingersoll-Rand back-up compressor. There is concern for using the air for breathing purposes when the air capacity is boosted because the back-up compressor introduces excessive moisture and oil into the lines. Because of this and other problems with the Vacu Blast, SIAD personnel indicated that it is only occasionally used.

Considering the fact that a considerable amount of air is wasted through leaks and unnecessary intentional air vents, current compressed air capacity seems adequate for present level of usage and applications at SIAD. The issue will be addressed in Chapter 6.

3 Compressed Air System at SIAD

The compressed air system consists of three compressors, two air dryers, two air purifiers (for breathing air), two storage tanks, various filters and other components, and an overhead air distribution system with numerous drop lines. Major system components are described below.

Compressors

The system has three compressors.

1. The Gardner Denver is the main air compressor, which is used on a continuous basis. Its air is used both for tool operation and breathing air. It is located in a shed next to the Paint Shop (Building 210). Table 4 lists the specifications for the Gardner Denver air compressor.

Table 4. Specifications for Gardner-Denver 125 hp air compressor.

Specification	Value
Compressor	Gardner Denver
Model	EDMQNA
Serial No.	U17020
Vintage	12/94
Nominal Power	125 hp
Rated Pressure	100 psig
Electrical Connect	460V/60Hz/3ph
Control Voltage	115 V
Air Capacity	600 acfm @ 100 psig
Motor Information	460V/140 amp/125 hp 3565 RPM 92.4 percent NEMA Eff. 90 percent PF

2. The 200 hp Ingersoll-Rand backup compressor is used only occasionally if the Gardner Denver compressor is down, or it cannot meet the facility air demand. This 200 hp compressor is located in the compressor room inside the Metal Shop (Building 209). Table 5 lists specifications for the 200 hp Ingersoll-Rand air compressor.

Table 5. Specifications for Ingersoll-Rand 200 hp air compressor.

Specification	Value
Compressor	Ingersoll-Rand
Model	SSR EP200
Serial No.	D8J89U89E-S
Vintage	1989
Nominal Power	200 hp
Rated Pressure	125 psig
Maximum Pressure	135 psig
Electrical Connect	460V/60Hz/3ph
Control Voltage	120 V
Air Capacity	892 acfm at 125 psig

3. The 150 hp Ingersoll-Rand air compressor was moved to SIAD from Sacramento Army Depot. It has never been used. This 150 hp compressor is located in the compressor room inside the Metal Shop (Building 209). Table 6 lists specifications for the 150 hp Ingersoll-Rand air compressor.

Table 6. Specifications for Ingersoll-Rand 150 hp air compressor.

Specification	Value
Compressor	Ingersoll-Rand
Model	SSR EP150
Serial No.	D8188U89E-S
Acquisition Date	1989
Nominal Power	150 hp
Rated Pressure	125 psig
Maximum Pressure	135 psig
Electrical Connect	460V/60Hz/3ph
Control Voltage	115 V
Air Capacity	670 acfm at 125 psig

Compressed Air Distribution System

The compressed air system is comprised of four distinct parts: (1) the main air compressor room (next to Building 210), (2) the back-up air compressor room (inside Building 209), (3) the air distribution system, and (4) the breathing air distribution system. These parts will be briefly described below. Figure 6 shows an overall schematic of the compressed air system. Figures 7 to 9 show detailed schematics for each major portion of the system.

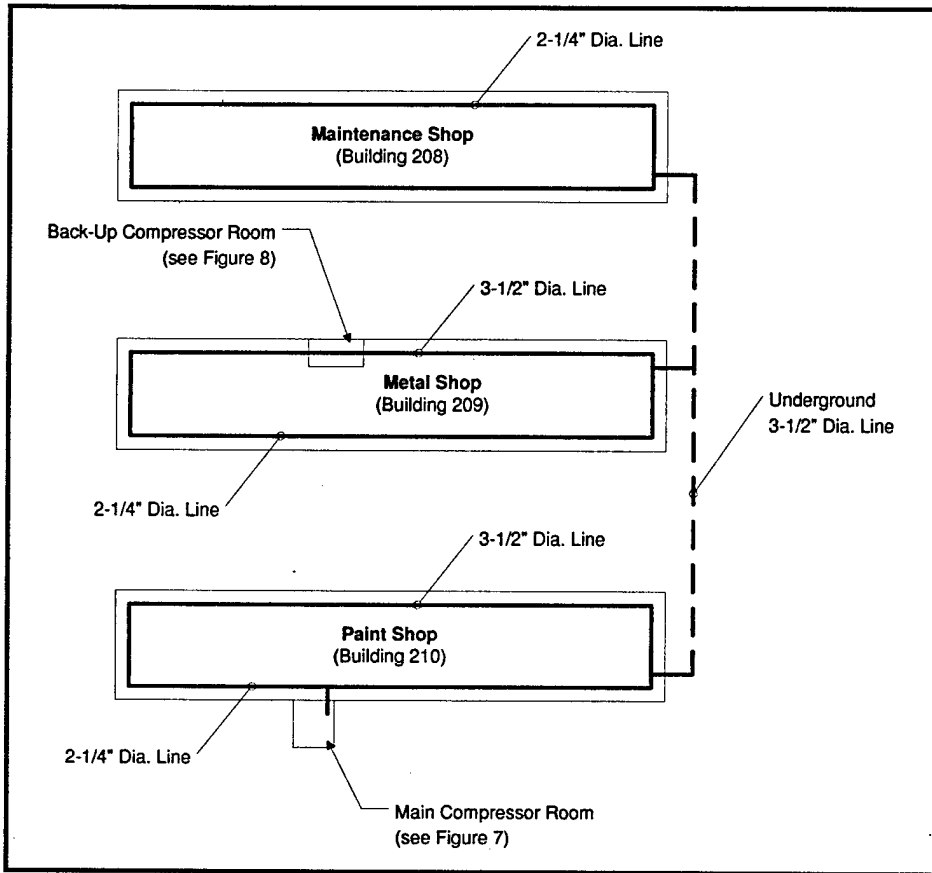


Figure 6. Plan diagram of the compressed air system at SIAD.

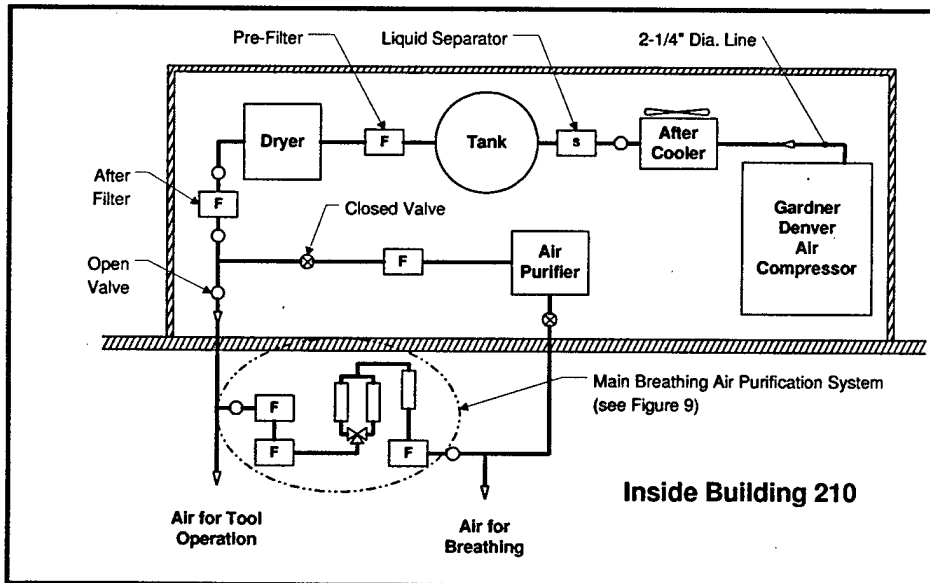


Figure 7. Equipment arrangement in the main compressor room.

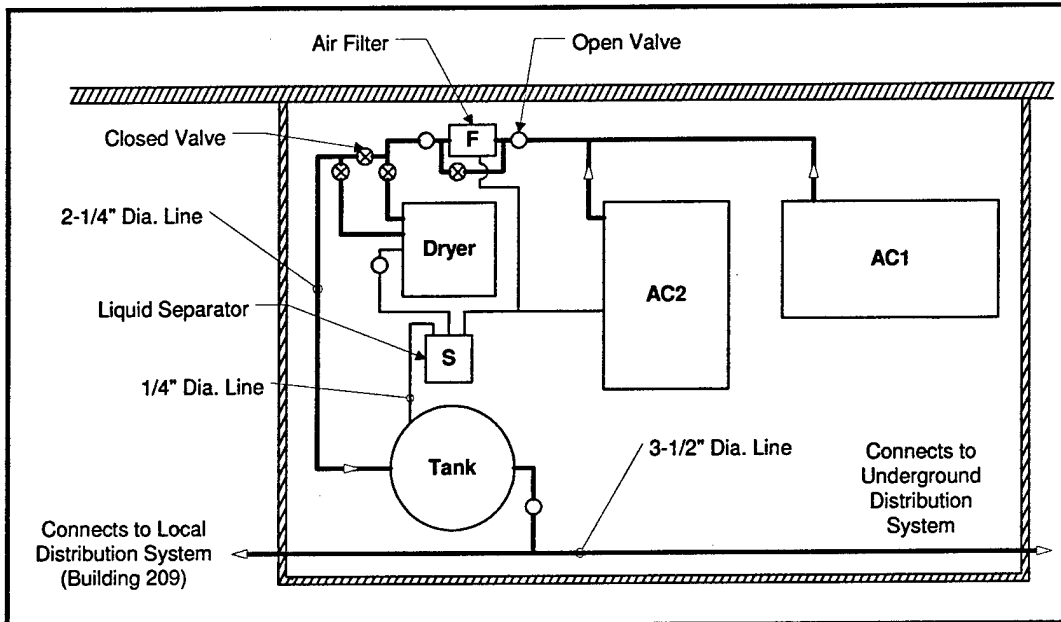


Figure 8. Schematic of the equipment arrangement in the back-up air compressor room.

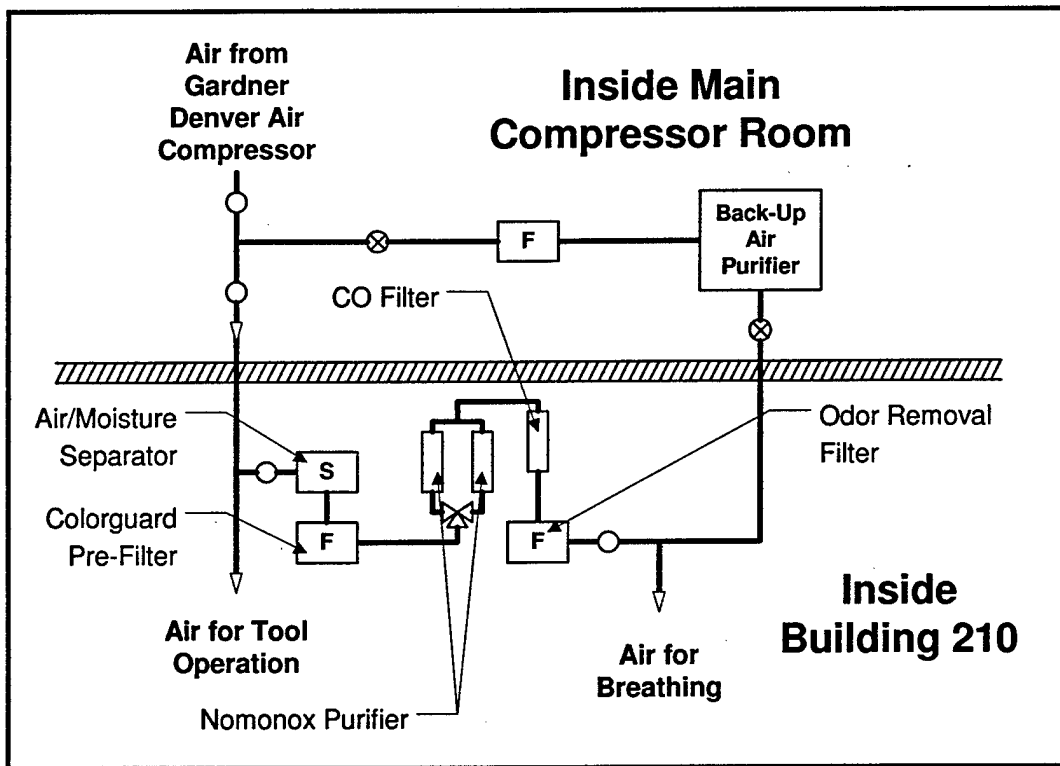


Figure 9. Main breathing air purifier system inside Bldg 210.

Main Compressor Room

Figure 7 shows the schematic and arrangement of the components in the main compressor room (next to Building 210). The main components in this compressor room are:

1. Gardner Denver Air Compressor, described previously
2. Air-to-air after cooler: The unit is equipped with a 3 hp air fan to cool the compressed air before it passes through the dryer. Heat from the after cooler is ducted to the outside.
3. An air reservoir (tank) with a capacity of approximately 290 gal.
4. A Gardner Denver refrigeration air dryer (Model 7000100) with a rated capacity of 800 SCFM at 39 °F (at 100 psig, 100 °F inlet and 100 °F ambient temperature). Considering the capacity of the dryer compared to the compressor, the dryer should have enough capacity to dry the air.
5. Three filters (a liquid separator, pre-filter, and after filter).

The pre-filter, after filter, air reservoir, and dryer all use electric timer drain valves that are set to open at prescribed periods of time. All electric drains are connected to a single ¼-in. copper tube, which drains into a bucket. Between the four drain valves, the air continuously discharges into the bucket, producing a major source of system air loss.

Back-Up Compressor Room

Figure 8 shows the schematic and arrangement of the components in the back-up compressor room (inside Building 209). The main components in this compressor room are:

1. Ingersoll-Rand 200 hp compressor (AC1) described in the previous section. This is the back-up compressor for the Gardner Denver unit.
2. Ingersoll-Rand 150 hp compressor (AC2) described in the previous section. This compressor has never been used at this location.
3. An air reservoir (tank) with a capacity of 1000 gal.
4. A Zeks air dryer model 800NCAA400 with a drying capacity of 800 standard cubic feet per minute (SCFM).
5. A compressed air filter for oil aerosol removal with a capacity of 500 SCFM.

The filter, air tank, and dryer all use electric timer drain valves, which direct their drain into a liquid (oil/water) separator. One or more of the drain valves and potentially some of the isolating valves leak and cause a permanent air leak into the oil/water separator.

The problem with the excessive moisture in the air from the back-up compressor can be traced to the available equipment. Potential causes are:

1. Lack of an after cooler to reduce the moisture load on the dryer.
2. The capacity of the dryer (800 SCFM) is less than the rated output of the 200 hp Ingersoll-Rand air compressor (892 CFM).
3. The capacity of the aerosol filter (500 SCFM) is less than the air compressor's rated output of 892 CFM.
4. The system does not have an after filter downstream of the air dryer (Figure 8).

Breathing Air System

Currently the breathing air system is supplied by the Gardner Denver compressor to the paint and shot blast booths. Figure 9 shows a schematic of breathing air compressed air system. Dried compressed air is treated by a Nominox Purifier Model CDP806S with a capacity of 172 SCFM (at 100 psig). Upstream of the purifier there are two filters, one air/moisture separator (Hankinson Model A350-16-5-G) and one colorguard pre-filter (Zeks Model F500). There are also two filters downstream of the purifier: one for CO removal and one for odor removal (Zeks Model 330 PC). Before introduction into the booths, two Toxgard gas monitors monitor the CO content of the breathing air.

A back-up air purifier has been installed in the main compressor room. The system set up is the same as that shown in Figure 9, but its capacity is 301 SCFM at 100 psig.

Tool Air Distribution System

In each shop there is an overhead loop for compressed air distribution consisting of 2-1/4-in. and 3.5-in. steel lines. The loops in the shops are interconnected through 3.5-in. underground distribution lines. Victaulic connections have been used in the compressed air system throughout the facility. This is a preferred method to welding and other plumbing methods because of the cost and ease of repair.

The drop-lines are welded to the overhead loops. There are a total of 62 drop-lines in the facility, 9 in the Paint Shop, 30 in the Metal Shop, and 23 in the Maintenance Shop.

Application of Compressed Air in the Plant

Compressed air has the following applications:

1. Paint Shop

- a. **Paint Booths:** There are a total of seven paint stations, four of which may be used at the same time. Each station uses a paint gun (mostly HVLP guns with a capacity of 5 SCFM are used, but occasionally HPLV guns with a capacity of 8 SCFM may be used) and an air breathing supply (with a capacity of 15 SCFM). The total capacity needed for the paint booths is estimated at 80 SCFM.
- b. **Shot Blasting Booth:** There are two stations. Both have an air breather. Each shot blaster has a capacity of 75 SCFM. The total capacity required for both stations is 180 SCFM, which includes the breathing air.
- c. **Small Shot Blaster:** This system is only used occasionally and has a capacity of 25 SCFM.
- d. **Air release from the two CO monitors for a total of 30 SCFM.**
- e. **Occasional application of air guns, one unit at a given time, 5 SCFM.** Currently there is a continuous and intentional air release from the two filters upstream of the air purifier for an estimated total of 17 SCFM. The total air need of the Paint Shop is estimated at 315 SCFM. This does not include the air for Vacu Blaster, which is about 400 SCFM.

3. Metal Shop

- a. This shop used various types of air tools. The major air users include air hammers, drills, sanders, air guns, and impact wrenches. Pneumatic control in some shear machines and a plasma cutter also use air.
- b. At the shop's current level of operation, the maximum of nine air tools are used simultaneously with an estimated air consumption of 162 SCFM.

4. **Maintenance Shop.** Most of the air application in the Maintenance Shop is for tools and some testing such as for air brakes. The air usage in this shop is minimal compared to the other two shops. For this evaluation, the assumed maximum air usage will be equivalent to five air tools, approximately equivalent to 90 SCFM.

5. Other Air Applications

- a. Other compressed air applications in the shops include air release from the Blue Moisture Indicator (at approximately 5 SCFM), and two air purifier filters at approximately 20 SCFM.
- b. Based on the above analysis, the total maximum air demand for the compressed air in the three shops, excluding the air leaks and Vacu Blast, is about 600 SCFM.
- c. Figure 10 shows a breakdown of the major consumers of compressed air at SIAD by function.

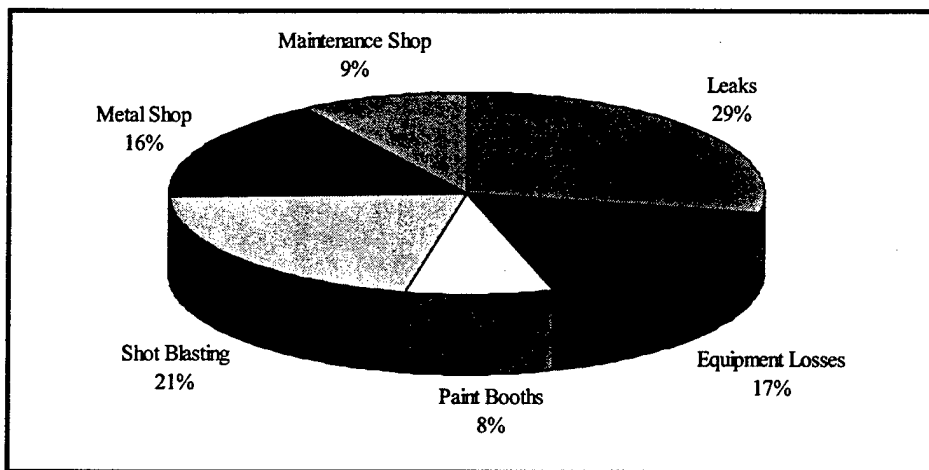


Figure 10. Compressed air usage by function

4 Operation and Maintenance of the Compressed Air System

Table 7 lists the annual production hours of the compressed air based on data provided by facility personnel.

Table 7. Annual operating hours of the compressed air system.

	hr/day	days/yr	hr/yr
First Shift (M–Th)	10.5	200	2,100
First Shift (Friday)	10.5	42	441
First Shift (Saturday)	10.5	12	126
Second Shift (M–Th)	10	96	960
Total			3,627

The Gardner Denver air compressor located next to the Paint Shop (Building 210) is capable of operating in four different control modes: *constant run*, *low demand*, *automatic*, and *sequence*. In *constant run* mode, the compressor will start and run continuously using its modulation controls to match air system demand. *Low demand* mode reduces power consumption by relieving pressure in the reservoir during unloaded operation. *Automatic* mode provides automatic start and timed stop, with operation during periods of demand or moderately long unloaded periods identical to the low demand mode. *Sequenced* mode provides for communication between multiple compressors, and is not applicable to this air system. Currently, the air compressor is operating in *constant run* mode, which is the least energy efficient operating mode.

According to facility personnel, the air compressor is set to *constant run* mode because setting to either *automatic* or *low demand* modes results in low electrical system voltage during motor start-up. Low voltage in the local electrical system causes a low voltage protection switch on the dust collection system to trip. This issue is addressed in Chapter 6.

The Issue of Breathing Air

Breathing air is needed for the paint booths and shot blast booth operators. Current breathing air system was discussed in the previous section. Breathing

air is tested every 6 months by an outside firm (TRI/Environmental, Inc.). Carbon monoxide (CO) is continuously monitored on line for both operations. According to the painting operation personnel, the CO monitor for the painting booth does not behave consistently and may need inspection by the equipment manufacturer.

Operation and Maintenance Training Needs

An outside firm performs major maintenance of the compressors including overhauls. The 200 hp Ingersoll-Rand compressor has been repaired recently and the Gardner Denver compressor is scheduled for maintenance in the near future. The plant maintenance personnel conduct routine maintenance including changing oil and filters. It was observed that the Gardner Denver compressor is using the recommended lubricating oil, AEON.

The audit team observed that:

- The oil filter needs to be changed per advice of the compressor control panel.
- The dryer is not working at its capacity because after an overnight operation of the system there was a significant moisture buildup in the line, observable through air leaks at the connections upstream of the air purifier. This signifies that it is not operating at its rated capacity and there is a need for some maintenance of the dryers and filters.
- The electric drain valves in the compressor room have a significant open-time that can be reduced after the dryer operates at its rated capacity.

Training Needs of the Personnel

The audit team understood that, despite the expertise of the maintenance personnel in operation and maintenance of the compressor air systems, maintenance had no formal training for the specific type of compressor and breathing air system. The audit team recommends that the main person in charge of maintaining the system go through a formal training for operation and maintenance of the Gardner Denver compressor and for the breathing air system. A formal log-book for maintenance of the system should be developed. While using manufacturer-recommended parts and oil, the log-book needs (at a minimum) to include the following data:

- Date of inlet air filter change
- Date of oil filter change
- Date and details of maintenance of line filters

- Date of oil change
- Location and date of repair of air leaks
- Date and details of major maintenance of equipment.

5 Audit Procedure of the Compressed Air System

The audit team consisted of two base staff with mechanical and electrical expertise and the project manager from The U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL). The site visit was done in 3.5 working days, from which one half day was spent in the initial and exit meetings with SIAD technical management personnel. After the initial meeting, SIAD personnel took the audit team through a tour of the compressed air systems. The audit team then engaged in collection of numerous data, discussed various issues with the plant personnel, and made selected measurements.

Information Collected

The following information were collected at the plant:

1. Details of the operating hours of the compressed air system
2. SIAD utilities (gas and electricity)
3. Some details on SIAD electrical and gas systems connections
4. Compressors operation modes and procedures
5. Compressed air requirements
6. Compressed air usage
7. Compressed air system
8. Compressed air application points
9. Compressed air system maintenance
10. Air leak locations and size estimation.

Measurements

The following measurements were made at the plant:

1. Detailed measurement of power of the compressor under the three modes of:
 - Constant Run
 - Low Demand
 - Automatic.

2. These measurements were made during regular plant operation. Measurements were made using two types of data loggers: BMI 3030A Power Profiler and a Dranetz 4300 Power Platform.
3. Detailed measurement of power of the compressor under Automatic and Low Demand modes during nonoperating hours of the plant (overnight) using the data loggers. The intention of this measurement was to establish the base load for air leaks.
4. Blow down test of the compressed air system. The test was performed by measurement of pressure versus time when the compressor was turned off. The pressure was measured from the pressure gages on the air reservoir and the control panel indicator.
5. Spot measurement of power of the dust collector motor.
6. Locating the compressed air leaks using an ultrasonic leak detector.

The collected data are the basis for preparation of this report.

6 Recommendations for Improving the Compressed Air Systems

Energy Efficiency Opportunities (EEOs)

Table 8 summarizes energy efficiency opportunities (EEOs), for which the cost and savings could be quantified. The EEOs are categorized into Low or No-Term, for measures with payback of less than 1 year, Short-Term, for measures with payback of 1 to 4 years, and Long-Term, for measures with payback of greater than 4 years. Details of the measures are presented after the table.

Table 8. Summary of savings and costs for energy efficiency opportunities.

EEO No. & Description	Potential Energy Conserved	Demand Savings (kW)	Potential Savings (\$/yr)	Resource Conserved	Implem. Cost (\$)	Simple Payback (years)
<i>Low or No-Term Measures</i>						
1 Repair Compressed Air Leaks	79,478 kWh/yr	21.91	6,587	Electricity	0	immediate
2 Change the Air Compressor Control to Low Demand Mode	41,711 kWh/yr	11.50	3,677	Electricity	0	immediate
3 Disconnect the Air Receiver from the Oil/Water Separator	10,282 kWh/yr	2.83	906	Electricity	35	immediate
4 Duct Outside Air into the Air Compressor Room	8,450 kWh/yr	2.33	745	Electricity	335	0.4
5 Install Sensor-Type Valves on the Purifier Pre-Filters	20,564 kWh/yr	5.67	1,813	Electricity	1,270	0.7
<i>Short-Term Measures</i>						
6 Replace the Timer-Type Drain Valves with Sensor-Type Valves	20,564 kWh/yr	5.67	1,813	Electricity	2,540	1.6
<i>Long-Term Measures</i>						
7 Install a Natural Gas Engine-Driven Air Compressor*	366,036 kWh/yr -37,228 therms/yr	100.92	17,326	Electricity Natural Gas	177,925	10.3
*This EEO would increase the amount of natural gas consumed at this facility, which is represented as a negative savings. See EEO for details.						

EEO No. 1 – Repair Compressed Air Leaks

Recommended Action

Reduce compressed air leaks in the plant by inspecting and tightening loose fittings and valves on a bimonthly basis. Table 9 lists the estimated savings that should result from repairing compressed air leaks.

Table 9. Estimated savings resulting from repairing compressed air leaks.

Savings Type	Amount / Payback Period
Estimated Electrical Usage Savings	79,478 kWh/yr
Estimated Demand Savings	21.91 kW
Estimated Electrical Usage Cost Savings	\$5,166/yr
Estimated Yearly Demand Cost Savings	\$1,841/yr
Estimated Annual Maintenance Cost	\$420/yr
Estimated Total Cost Savings	\$6,587/yr
Estimated Implementation Cost	\$0
Simple Payback Period	immediate

Background

Compressed air is produced by a 125 hp Gardner-Denver, model EDMQNA rotary-screw air compressor. The compressed air system also includes a 200 hp Ingersoll-Rand, model SSR-EP200 rotary-screw air compressor, and a 150 hp Ingersoll-Rand, model SSR-EP150 rotary-screw air compressor. The two Ingersoll-Rand air compressors serve as back-up units to the main Gardner-Denver unit, and both Ingersoll-Rand compressors are located in a room within Building 209 (Metal Shop). Based on data provided by facility personnel, compressed air is generated during the first shift for 10.5 hours per day, 254 days per year, and is produced during the second shift for 10 hours per day, 96 days per year, for a total of 3,627 hours per year. The air compressors have a discharge pressure of about 101 psig (115.7 psia). A 290-gal air receiver is located in the compressor room outside of Building 210 (Paint Shop), and a 1000-gal receiver is located in the compressor room inside of Building 209 (Metal Shop). The average line pressure is estimated to be 100 psig (114.7 psia).

While at the plant, the audit team inspected all buildings for air leaks. Leaks were found in many different areas. All air leaks were clearly tagged. It is recommended that each facility be checked for air leaks during nonoperating hours. A regular, bimonthly survey is suggested. Air leaks represent lost compressor horsepower, which translates directly into increased energy use for facility operation.

Anticipated Savings

The energy savings attained by repairing an air leak can be found by determining the amount of compressor horsepower used to supply air to the leak. Table 10 summarizes the leaks identified during the audit.

Table 11 lists the estimated electrical usage savings (EUS), demand savings (DS), electrical usage cost savings (EUCS), and yearly demand cost savings (YDCS) for the leaks identified during the audit.

Since the implementation of this recommendation consists of inspecting and tightening loose fittings and valves on a bi-monthly basis, the maintenance cost should be considered in the total cost savings. It is estimated that it would take 12 hours, at \$35 per man-hour, to fix all air leak sources listed in the tables, for a total of \$420/yr.

Table 10. Summary of identified plant air leaks.

Location	Number of Leaks	Leak Size* (inch)	Line Pressure (psig)	Volumetric Flow (acfm)	Power Loss (hp)
Bldg 209 - Main Loop	1	5/32	100	27.8	6.0
Bldg 209 - Next to Shear	1	1/16	100	4.4	1.0
Bldg 209 - Drop Next to Shear	1	3/32	100	10.0	2.1
Bldg 209 - Above Iron Worker	1	1/8	100	17.8	3.8
Bldg 209 - Bay #5 Air Crane Mover	1	3/32	100	10.0	2.1
Bldg 208 - Air Drop	1	1/32	100	1.1	0.2
Bldg 210 - Main Line Above South Entrance	1	3/16	100	40.0	8.6
Bldg 210 - Connection After Purifier	1	1/8	100	17.8	3.8
Bldg 210 - Quick Connect #1 Blast Booth	1	1/16	100	4.4	1.0
Bldg 210 - Hot Respirator Connector	1	3/32	100	10.0	2.1
Bldg 210 - Small Shot Blaster Filter	1	1/16	100	4.4	1.0
Bldg 210 - Below Dust Collector	1	1/8	100	17.8	3.8
Bldg 210 - Tool Air Connection #1 Left	1	3/32	100	10.0	2.1
Bldg 210 - Tool Air Connection #2 Left	1	1/32	100	1.1	0.2
Bldg 210 - Tool Air Filter #2 Right	1	1/16	100	4.4	1.0
Bldg 210 - Breathing Air Connection Next to Purifier	1	3/32	100	10.0	2.1
Bldg 210 - Connection Next to Purifier	1	1/16	100	4.4	1.0
Totals	17			195.6	42.0
* 1/4 in. - very large, 1/8 in. - large, 1/16 in. - medium, 1/32 in. - small, 1/64 in. - very small					

Table 11. Summary of energy and cost savings.

Location	Number of Leaks	Leak Size (inch)	EUS (kWh/yr)	DS (kW)	EUCS (\$/yr)	YDCS (\$/yr)
Bldg 209 - Main Loop	1	5/32	11,289	3.11	734	261
Bldg 209 - Next to Shear	1	1/16	1,806	0.50	117	42
Bldg 209 - Drop Next to Shear	1	3/32	4,064	1.12	264	94
Bldg 209 - Above Iron Worker	1	1/8	7,225	1.99	470	167
Bldg 209 - Bay #5 Air Crane Mover	1	3/32	4,064	1.12	264	94
Bldg 208 - Air Drop	1	1/32	452	0.12	29	10
Bldg 210 - Main Line Above South Entrance	1	3/16	16,257	4.48	1,057	377
Bldg 210 - Connection After Purifier	1	1/8	7,225	1.99	470	167
Bldg 210 - Quick Connect #1 Blast Booth	1	1/16	1,806	0.50	117	42
Bldg 210 - Hot Respirator Connector	1	3/32	4,064	1.12	264	94
Bldg 210 - Small Shot Blaster Filter	1	1/16	1,806	0.50	117	42
Bldg 210 - Below Dust Collector	1	1/8	7,225	1.99	470	167
Bldg 210 - Tool Air Connection #1 Left	1	3/32	4,064	1.12	264	94
Bldg 210 - Tool Air Connection #2 Left	1	1/32	452	0.12	29	10
Bldg 210 - Tool Air Filter #2 Right	1	1/16	1,806	0.50	117	42
Bldg 210 - Breathing Air Connection Next to Purifier	1	3/32	4,064	1.12	264	94
Bldg 210 - Connection Next to Purifier	1	1/16	1,806	0.50	117	42
Totals	17		79,478	21.91	5,166	1,841

The total cost savings (TCS) is simply the sum of the EUCS and the YDCS minus the annual maintenance cost:

$$\text{TCS} = \text{EUCS} + \text{YDCS} - (\text{annual maintenance cost})$$

Eq 1

$$\text{TCS} = \$5,166/\text{yr} + \$1,841/\text{yr} - \$420/\text{yr}$$

$$\text{TCS} = \$6,587/\text{yr}$$

Implementation Cost

Implementation of this EEO involves tightening loose fittings and valves, and repairing punctured lines. The maintenance cost is included in the total cost savings, so there is no implementation cost.

Notes

The compressed air system losses were also measured using two alternate methods: system pressure loss rate and compressor power monitoring.

The compressed air system losses can be estimated by turning off the compressor and recording the system pressure at regular intervals. The system air loss can be estimated based on the rate at which the system pressure decreases. The volumetric air loss rate is estimated by the following two relations:

$$Mf = \frac{\Delta P \times V \times C_1}{\Delta t \times R \times T_{abs}} \quad \text{Eq 2}$$

and

$$Vf_{std} = \frac{Mf \times C_2}{\rho_{std}} \quad \text{Eq 3}$$

Where:

Mf = mass flow rate of air, lbm/sec

ΔP = change in system pressure, lbf/sq in.

V = total system volume, 292.5 cu ft

C_1 = conversion constant, 144 sq in./sq ft

Δt = change in time, sec

R = gas constant, 53.33 lbf-ft/lbm-R

T_{abs} = average temperature of CA system, 540 R (80 °F)

Vf_{std} = volumetric flow of air at standard conditions, scfm

C_2 = conversion constant, 60 sec/min

ρ_{std} = density of air at standard conditions, 0.075 lbm/cu ft.

Standard conditions are taken as 70 °F (530 R) and 14.7 psia. The system volume was calculated to be 292.5 cu ft and includes both air receivers, underground distribution line, each building's overhead distribution system and drop lines. The system pressure was monitored from a gage on the air receiver in the main compressor room. The system pressure was recorded to drop from 100 psig to 95 psig in 25 seconds. Thus, the mass flow (Mf) rate of air is estimated as:

$$Mf = [(5)(292.5)(144)]/[(25)(53.33)(540)] \quad \text{Eq 4}$$

$$Mf = 0.293 \text{ lbm/sec.}$$

The volumetric flow (Vf) of air loss from the CA system can be estimated as:

$$Vf = (0.293)(60)/(0.075)$$

$$Vf = 234 \text{ SCFM.}$$

Table 10 lists the estimated total air loss due to leaks to be 195.6 acfm (about 165 SCFM). Other discharges — from the CO monitors, Blue Moisture Indicator, two air purifier filters, and drain valves — are estimated to total 100 SCFM. The total system loss rate of 265 SCFM is in close agreement with the volumetric flow rate calculated above, 234 SCFM.

The power demand of the air compressor was monitored and recorded in the three buildings for the period after production is over for the day. Figure 11 shows a graph of power consumption for a 1-hr period. The graph is based on power measurements taken at 1-min intervals, and shows a high variance in maximum and minimum power draw.

When all air uses have ended, the remaining system air demand is the result of losses through leaks and cycling drain valves. Theoretically, the system losses can be estimated by measuring the power consumption of the air compressor during the nonproduction period. To make a reasonable estimate of the air output of the compressor, the output curve (SCFM vs kW input) of the compressor must be known. However, the characteristic output curve for the Gardner Denver compressor was not obtained for the *Automatic* or the *Low Demand* operating modes, and so the amount of air produced by the compressor could not be accurately estimated from the recorded power data.

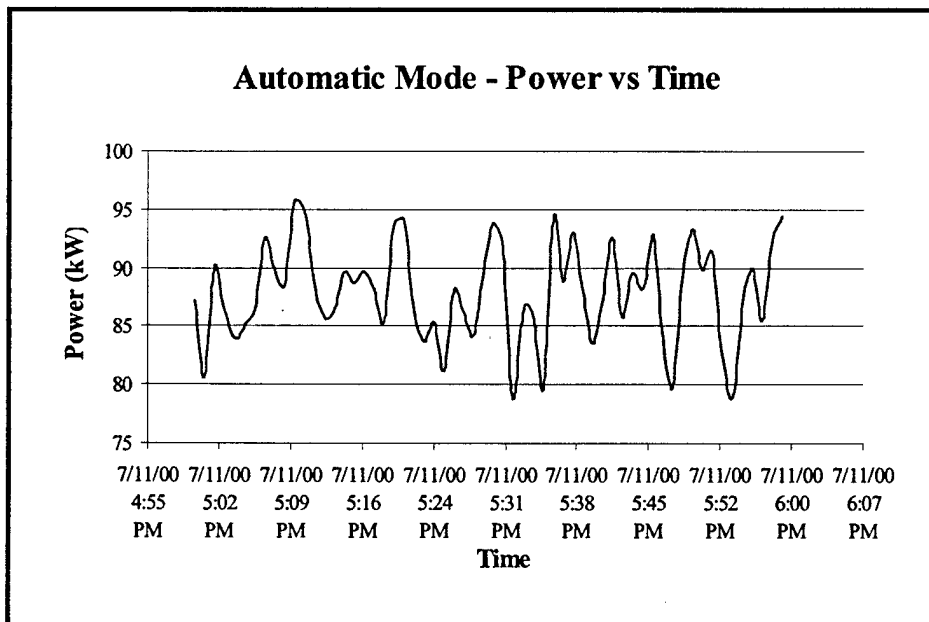


Figure 11. Power consumption of air compressor after production hours

EEO No. 2 – Change the Air Compressor Control to Low Demand Mode

Recommended Action

Change the Gardner Denver air compressor control from constant run mode to low demand mode. Table 12 lists the estimated savings resulting from changing air compressor to low demand mode.

Table 12. Estimated savings resulting from changing air compressor to low demand mode.

Savings Type	Amount / Payback Period
Estimated Electrical Usage Savings	41,711 kWh/yr
Estimated Demand Savings	11.50 kW
Estimated Electrical Usage Cost Savings	\$2,711/yr
Estimated Yearly Demand Cost Savings	\$966/yr
Estimated Total Cost Savings	\$3,677/yr
Estimated Implementation Cost	\$0
Simple Payback Period	Immediately

Background

The Gardner Denver air compressor located outside the Paint Shop (Building 210) is capable of operating in four different control modes: *constant run*, *low demand*, *automatic*, and *sequence*. In *constant run* mode, the compressor will start and run continuously using its modulation controls to match air system demand. *Low demand* mode reduces power consumption by relieving pressure in the reservoir during unloaded operation. *Automatic* mode provides automatic start and timed stop, with operation during periods of demand or moderately long unloaded periods identical to the *low demand* mode, but does not depressurize the oil reservoir. *Sequenced* mode provides for communication between multiple compressors, and is not applicable to this air system. Currently, the air compressor is operating in *constant run* mode, which is the least energy efficient operating mode.

According to facility personnel, the air compressor is set to *constant run* mode because setting to either *automatic* or *low demand* modes results in low electrical system voltage during motor start-up. Low voltage in the local electrical system causes a low voltage protection switch on the dust collection system to trip. This issue is addressed in Chapter 6.

Anticipated Savings

During the facility audit, the voltage and power draw of the Gardner Denver air compressor was monitored and recorded by a data acquisition system (DAS) while in the *constant run*, *low demand*, and *automatic* operating modes. Figure 12 shows a chart of the power draw of the air compressor while operating in *constant run* mode. The dashed line represents the average power trend (in kW) during the time period. Figure 13 shows a chart of the power draw of the air compressor while operating in *low demand* mode. The dashed line represents the average power (in kW) during the time period.

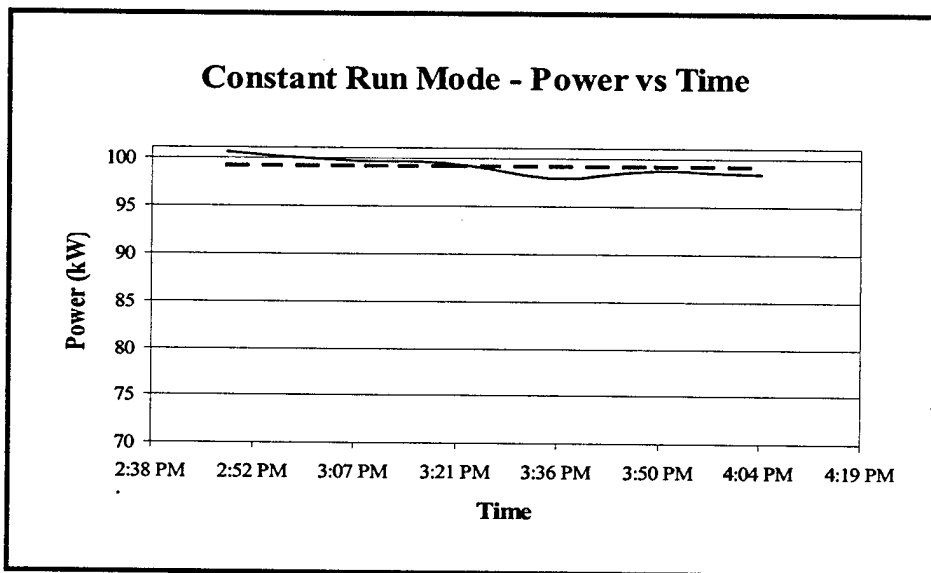


Figure 12. Power draw while in "Constant Run" mode.

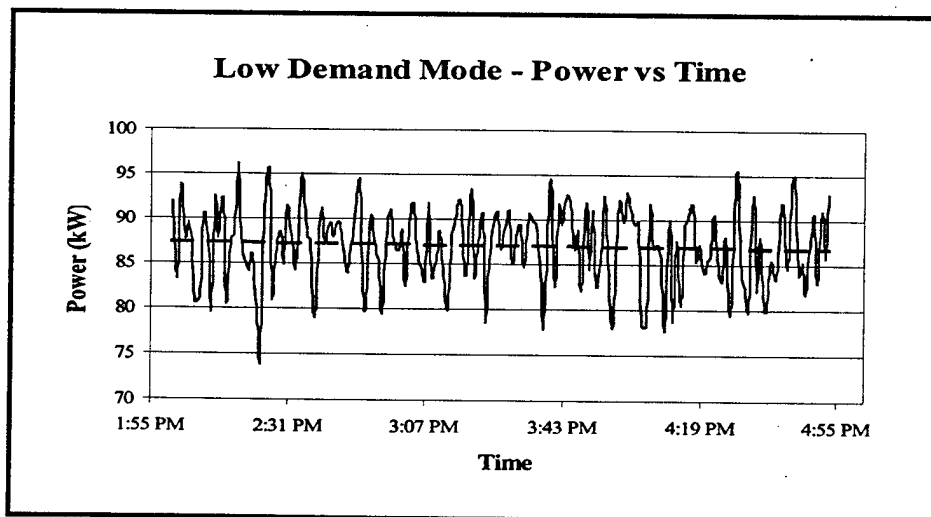


Figure 13. Power draw while in "low demand" mode.

As can be seen by dashed lines representing the average power draw of the compressor while in the two operating modes, the *low demand* mode draws significantly lower power than the *constant run* mode. The two figures show that the average power draw for *constant run* and *low demand* modes are about 99 kW and 87.5 kW, respectively. The potential electrical usage savings (EUS_{pot}) can be conservatively estimated by the following:

$$EUS_{pot} = (P_{CR} - P_{LD}) \times H \quad \text{Eq 5}$$

Where:

P_{CR} = power draw of the compressor while in *constant run* mode, 99 kW

P_{LD} = power draw of the compressor while in *low demand* mode, 87.5 kW

H = annual operating hours of the compressor, 3,627 hr/yr.

Thus,

$$EUS = [(99) - (87.5)](3,627)$$

$$EUS = 41,711 \text{ kWh/yr.}$$

The annual electrical usage cost savings (EUCS) can be estimated as:

$$EUCS = EUS \times (\text{average electrical cost})$$

$$EUCS = (41,711 \text{ kWh/yr})(\$0.065/\text{kWh})$$

$$EUCS = \$2,711/\text{yr.}$$

The demand savings is simply the difference in the power draw of the compressor while operating in *constant run* and *low demand* modes. The electrical DS is conservatively estimated to be 11.5 kW. The YDCS is estimated as:

$$YDCS = DS \times (\text{average demand cost}) \times (\text{number of months per year})$$

$$YDCS = (11.50 \text{ kW})(\$7.00/\text{kW-month})(12 \text{ months per year})$$

$$YDCS = \$966/\text{yr.}$$

The TCS is simply the sum of the EUCS and the YDCS, which is estimated to be \$3,677.

Noted that the current air distribution system is plagued with significant air loss via leaks and inefficient drain valves. Because the air system losses are estimated to be 200 acfm, which is 1/3 of the main air compressors rated output, the average power draw during *low demand* mode will be much lower when the air

system losses have been fixed. Fixing the system air losses and changing to *low demand* mode will result in energy and cost savings three times greater than estimated above.

Implementation Cost

Implementation consists of correcting the electrical system's low voltage problems (see Chapter 6) and changing the control system operation from *constant run* to *low demand* mode. Because the air compressor's controller is highly automated, the labor cost to change operating modes is considered insignificant. Thus, there is no implementation cost for this EEO and the simple payback period is immediate.

EEO No. 3 – Disconnect the Air Receiver from the Oil/Water Separator

Recommended Action

Disconnect the ¼-in. line that connects the 1000-gal air receiver from the oil/water (liquid) separator in the back-up compressor room. Table 13 lists the estimated savings resulting from disconnecting the air receiver from the oil/water separator.

Table 13. Estimated savings resulting from disconnecting the air receiver from the oil/water separator.

Savings Type	Amount / Payback Period
Estimated Electrical Usage Savings	10,282 kWh/yr
Estimated Demand Savings	2.83 kW
Estimated Electrical Usage Cost Savings	\$668/yr
Estimated Yearly Demand Cost Savings	\$238
Estimated Total Cost Savings	\$906/yr
Estimated Implementation Cost	\$35
Simple Payback Period	immediately

Background

The compressed air system in the back-up compressor room in Building 209 (Metal Shop) is used very infrequently. Facility personnel close the valves connecting the main compressed air distribution system to the back-up air compression system when the back-up compressors are not needed. A 1000-gal air receiver in the back-up compressor room is left connected to the main air distribution system when the back-up compressors are not needed, which provides additional storage for the main system. The audit team noted that the

oil/water separator in the back-up compressor room discharges compressed air even when the back-up air compression system is not operating. This is because a ¼-in. air line connects the 1000-gal receiver with the oil/water separator, and the electric drain valve is either malfunctioning or is set to continuously discharge oil/water from the system. This arrangement results in a tremendous waste of compressed air, and can be easily fixed by disconnecting the oil/water separator from the 1000-gal air receiver and fixing the drain valve. The air receiver is already equipped with a timer-type drain valve, so the connection to the oil/water separator is redundant (it is not needed).

Anticipated Savings

Compressed air is expensive to generate. Wherever possible, its use should be minimized. Based on the experience of the audit team members, it was estimated that the oil/water separator discharges air equivalent to an 1/8-in. air leak. The electrical usage savings ($EUS_{\text{Discharge}}$) can be calculated as:

$$EUS_{\text{Discharge}} = L \times H \times C_1 \quad \text{Eq 6}$$

Where:

- L = power used by the air compressor, hp
- H = annual operating hours of the air compressor, 3,627 hr/yr
- C₁ = conversion factor, 0.746 kW/hp.

The power used by the air compressor, L, is estimated as the power required to compress the volume of air discharged through an orifice, V_f , from atmospheric pressure, P_{atm} , to the compressor discharge pressure, P_d . For choked flow, the volumetric flow, V_f , for the amount of air discharging through the oil/water separator is estimated to be 17.8 acfm. The power used by the air compressor to produce 17.8 acfm of compressed air is estimated to be 3.8 hp. Therefore, by using Equation 6, the electrical usage saving (EUS) is:

$$\begin{aligned} EUS_{\text{Discharge}} &= L \times H \times C_1 \\ EUS &= (3.8)(3,627)(0.746) \\ EUS &= 10,282 \text{ kWh/yr.} \end{aligned}$$

The electrical usage cost savings (EUCS) is found by:

$$\begin{aligned} EUCS &= EUS \times (\text{unit cost of electricity}) \quad \text{Eq 7} \\ EUCS &= (10,282 \text{ kWh/yr})(\$0.065/\text{kWh}) \\ EUCS &= \$668/\text{yr (rounded off)}. \end{aligned}$$

The electrical demand savings (DS) for disconnecting the air receiver from the oil/water separator can be estimated as:

$$DS = L \times CF \times C_1 \quad \text{Eq 8}$$

Where:

L = power used by the air compressor, hp

CF = coincidence factor (estimated fraction of demand savings that will affect the peak demand of each month), no units

C₁ = conversion factor, 0.746 kW/hp.

The demand savings (DS) for using sensor-type drain valves is estimated as:

$$DS = (3.8)(1)(0.746)$$

$$DS = 2.83 \text{ kW.}$$

The yearly demand cost savings (YDCS) (Equation 9) is found by:

$$YDCS = DS \times (\text{average demand cost}) \times (\text{number of months per year}) \quad \text{Eq 9}$$

$$YDCS = (2.83 \text{ kW})(\$7.00/\text{kW-month})(12 \text{ month/yr})$$

$$YDCS = \$238/\text{yr} \text{ (rounded off).}$$

The total cost savings (TCS_{NonMaint}) is simply the sum of the electrical usage cost savings and the yearly demand cost savings as given below:

$$TCS_{\text{NonMaint}} = \text{EUCS} + \text{YDCS} \quad \text{Eq 10}$$

$$TCS_{\text{NonMaint}} = \$668/\text{yr} + \$238/\text{yr}$$

$$TCS_{\text{NonMaint}} = \$906/\text{yr.}$$

Implementation Cost

Implementation of this EEO involves disconnecting the ¼-in. air line that connects the 1000-gal air receiver to the oil/water separator and properly setting the drain valve. It is estimated that it will take one technician an hour (@ \$35 per hour) to cut and cap the ¼-in. line. The total cost saving of \$906/yr will pay for the implementation cost of \$35 immediately.

EEO No. 4 – Duct Outside Air into the Air Compressor Room

Recommended Action

Duct outside air to the intake of the air compressor. Table 14 lists the estimated savings resulting from ducting outside air into the air compressor room.

Table 14. Estimated savings resulting from ducting outside air into the air compressor room.

Savings Type	Value / Payback Period
Estimated Electrical Usage Savings	8,450 kWh/yr
Estimated Demand Savings	2.33 kW
Estimated Electrical Usage Cost Savings	\$549/yr
Estimated Yearly Demand Cost Savings	\$196/yr
Estimated Total Cost Savings	\$745/yr
Estimated Implementation Cost	\$335
Simple Payback Period	0.4 years

Background

Compressed air is produced by a 125 hp Gardner-Denver, model EDMQNA rotary-screw air compressor. The compressed air system also includes 200 hp Ingersoll-Rand, model SSR-EP200 rotary-screw air compressor, and a 150 hp Ingersoll-Rand, model SSR-EP150 rotary-screw air compressor. Based on data provided by facility personnel, compressed air is generated during the first shift for 10.5 hours per day, 254 days per year, and is produced during the second shift for 10 hours per day, 96 days per year, for a total of 3,627 hours per year. The air compressors have a discharge pressure of about 101 psig (115.7 psia).

The Gardner-Denver compressor is housed in a room outside of Building 210 (Paint Shop). The air temperature at the inlet to the air compressor was measured at 102 °F, while the outside air was measured to be 89 °F. Since cooler air is denser than warmer air, the compressor motor will work less to pressurize air from ambient pressure (14.7 psia) to discharge pressure (115.7 psia). For these calculations, an average temperature differential between indoor air temperature and outdoor air temperature will be assumed to remain at 13 °F. By ducting outside air into the compressor room, energy required by the compressor can be reduced.

An additional and important benefit of ducting outside air to the intake of the air compressor is that outside air is less prone to having chemical contaminants, which can adversely affect the breathing air produced by the system.

Anticipated Savings

The compressor work for the usual operating conditions in the plant is proportional to the absolute temperature of the intake air. Thus, the fractional reduction in compressor work (WR) resulting from lowering the intake air temperature is estimated as:

$$WR = (\Delta T)/(T_i + 460) \quad \text{Eq 11}$$

Where:

ΔT = average temperature difference, 13 R

T_i = average temperature at the inlet to air compressor, 75 °F.

The fractional reduction in compressor work due to lowering the compressor intake air temperature, as explained previously, can be estimated as:

$$WR = (13)/(75 + 460)$$

$$WR = 0.0243.$$

The annual electrical usage savings (EUS_{Annual}) can be estimated from the following relationship:

$$EUS_{\text{Annual}} = (HP/EFF_M) \times LF \times H \times UF \times WR \times C_1 \quad \text{Eq 12}$$

Where:

HP = nominal compressor motor power rating, 125 hp

EFF_M = efficiency of compressor motor, 0.924 no units

LF = fraction of rated motor power drawn by compressor (measured), 0.95 no units

H = annual hours of operation, 3,627 hr/yr

UF = fraction of operating hours that the compressor is in use, 1 no units

WR = fraction in reduction of compressor work, no units

C_1 = conversion constant, 0.746 kW/hp.

Thus, the estimated electrical usage savings for the 125-hp compressor (using Eq 12) are:

$$EUS_{\text{Annual}} = (HP/EFF_M) \times LF \times H \times UF \times WR \times C_1$$

$$EUS_{\text{Annual}} = [(125)/(0.924)](0.95)(3,627)(1)(0.0243)(0.746)$$

$$EUS_{\text{Annual}} = 8,450 \text{ kWh/yr.}$$

The annual electrical usage cost savings (EUCS) is estimated as:

$$\text{EUCS} = \text{EUS} \times (\text{unit cost of electricity}) \quad \text{Eq 13}$$

$$\text{EUCS} = (8,450 \text{ kWh/yr})(\$0.065/\text{kWh})$$

$$\text{EUCS} = \$549/\text{yr.}$$

Demand Savings

By reducing the amount of work necessary to produce an equivalent pressure currently being generated by this compressor, there will be an equivalent reduction in the electrical demand for this compressor. The estimated demand savings (DS) that can be realized can be estimated as:

$$\text{DS} = (\text{HP}/\text{EFF}_M) \times \text{LF} \times \text{CF} \times \text{WR} \times C_1 \quad \text{Eq 14}$$

Where:

HP = nominal compressor motor power rating, 125 hp

EFF_M = compressor motor efficiency, 0.924 no units

LF = fraction of rated motor power drawn by compressor, 0.95 no units

CF = coincidence factor (estimated fraction of demand savings that will affect the peak demand of each month), 1 no units

WR = fractional reduction of compressor work, no units

C_1 = conversion factor, 0.746 kW/hp.

Therefore the estimated demand savings for the 125-hp compressor is:

$$\text{DS} = [(125)/(0.924)](0.95)(1)(0.0243)(0.746)$$

$$\text{DS} = 2.33 \text{ kW.}$$

The yearly demand cost savings (YDCS) (using Eq 9) for the compressor is estimated as:

$$\text{YDCS} = \text{DS} \times (\text{average demand cost}) \times (\text{number of months per year})$$

$$\text{YDCS} = (2.33 \text{ kW})(\$7.00/\text{kW-month})(12 \text{ months/yr})$$

$$\text{YDCS} = \$196/\text{yr.}$$

Therefore the total annual cost savings (TCS) (using Eq 10) is simply the sum of the estimated annual electrical usage cost savings and estimated yearly demand cost savings:

$$TCS_{\text{NonMaint}} = \text{EUCS} + \text{YDCS}$$

$$TCS_{\text{NonMaint}} = \$549/\text{yr} + \$196/\text{yr}$$

$$TCS_{\text{NonMaint}} = \$745/\text{yr}.$$

Implementation Cost

A material that can be used for ducting outside air to the compressor intake is round, galvanized steel ducting (or other suitable material such as PVC). One end of the duct is attached to the air cleaner intake or to the housing air intake, and the other end is vented through the roof of the compressor room. The distance from the intake to the roof was measured to be 4 ft. The duct should extend approximately 2 to 3 ft above the roof, and should include a vented-cap to provide rain protection. The total implementation cost for the ducting consists of the cost of the material and the labor for installation. The total implementation costs is \$125 for material (8-in. diameter piping) and \$210 for labor (6 hours labor at \$35 per hour). Thus, the total cost savings of \$745 a year would pay for the implementation cost of \$335 in about 0.4 years.

EEO No. 5 – Install Sensor-Type Valves on the Purifier Pre-Filters

Recommended Action

Install sensor-type drain valves on the two filters before the air purifier to reduce air consumption and compressor energy usage. Table 15 lists the estimated savings resulting from installing sensor-type valves on the purifier pre-filters.

Table 15. Estimated savings resulting from installing sensor-type valves on the purifier pre-filters.

Savings Type	Value / Payback Period
Estimated Electrical Usage Savings	20,564 kWh/yr
Estimated Demand Savings	5.67 kW
Estimated Electrical Usage Cost Savings	\$1,337/yr
Estimated Yearly Demand Cost Savings	\$476
Estimated Total Cost Savings	\$1,813/yr
Estimated Implementation Cost	\$1,270
Simple Payback Period	0.7 years

Background

During the course of the compressed air (CA) system audit, it was noted that the two filters positioned before the air purifier were discharging an unusually large

amount of compressed air. It is recommended that sensor-type drain valves be installed to control the amount of air that is used to purge the filters. The sensor-type drain valves will only use compressed air to drain water from the CA system when water is present, which will nearly eliminate compressed air consumption of these two filters.

Anticipated Savings

Compressed air is expensive to generate. Wherever possible, its use should be minimized. Currently, the two filters are discharging compressed air without any type of control. The sensor-type drain valves may use a magnetic reed switch or a capacitance device to detect the amount of condensed water present and operate (discharge) only when drainage is needed.

The electrical usage savings (EUS) (Eq 6) can be calculated as:

$$EUS = L \times H \times C_1$$

Where:

- L = power used by the air compressor, hp
- H = annual operating hours of the air compressor, 3,627 hr/yr
- C₁ = conversion factor, 0.746 kW/hp.

Each filter discharges air at a rate equivalent to a 1/8-in. air leak. The power used by the air compressor, L, is estimated as the power required to compress the volume of air discharged through a filter, V_f, from atmospheric pressure, P_{atm}, to the compressor discharge pressure, P_d. For choked flow, the volumetric flow, V_f, for the average amount of air supplied to the two filters by the air compressor is calculated to be 35.5 acfm. The power used by the air compressor to produce 35.5 acfm of compressed air is estimated to be 7.6 hp. Therefore, the electrical usage saving (EUS) (Eq 6) is:

$$EUS = L \times H \times C_1$$

$$EUS = (7.6)(3,627)(0.746)$$

$$EUS = 20,564 \text{ kWh/yr.}$$

The electrical usage cost savings (EUCS) (Eq 7) is found by:

$$EUCS = EUS \times (\text{unit cost of electricity})$$

$$EUCS = (20,564 \text{ kWh/yr})(\$0.065/\text{kWh})$$

$$EUCS = \$1,337/\text{yr (rounded off).}$$

The electrical demand savings (DS) for installing sensor-type drain valves on the two filters (Eq 8) can be estimated as:

$$DS = L \times CF \times C_1$$

Where:

- L = power used by the air compressor, hp
- CF = coincidence factor (estimated fraction of demand savings that will affect the peak demand of each month), no units
- C₁ = conversion factor, 0.746 kW/hp.

The demand savings (DS) for installing sensor-type drain valves is estimated as:

$$DS = (7.6)(1)(0.746)$$

$$DS = 5.67 \text{ kW.}$$

The yearly demand cost savings (YDCS) (Eq 9) is found by:

$$YDCS = DS \times (\text{average demand cost}) \times (\text{number of months per year})$$

$$YDCS = (5.67 \text{ kW})(\$7.00/\text{kW-month})(12 \text{ month/yr})$$

$$YDCS = \$476/\text{yr} \text{ (rounded off).}$$

The total cost savings (TCS_{NonMaint}) (Eq 10) is simply the sum of the electrical usage cost savings, and the yearly demand cost savings as given below:

$$TCS_{\text{NonMaint}} = EUCS + YDCS$$

$$TCS_{\text{NonMaint}} = \$1,337/\text{yr} + \$476/\text{yr}$$

$$TCS_{\text{NonMaint}} = \$1,813/\text{yr.}$$

Implementation Cost

According to a vendor of air compressors and air compressor accessories,* the cost for a sensor-type drain valve will be \$600 including taxes. Installation is estimated to be 1 hour per filter at a cost of \$35/hr, for a total installation cost of \$70. The total cost to purchase and install four sensor-type drain valves is esti-

* Cannon Compressor, 1618 Doolittle Drive, San Leandro, CA 94577, (510) 895-8333.

mated to be \$1,270. The total cost saving of \$1,813/yr will pay for the implementation cost of \$1,270 in about 0.7 years.

EEO No. 6 – Replace Timer-Type Drain Valves with Sensor-Type Valves

Recommended Action

Replace the existing timer-type drain valves with sensor-type drain valves to reduce air consumption and compressor energy usage. Table 16 lists the estimated savings resulting from replacing timer-type drain valves with sensor-type valves.

Table 16. Estimated savings resulting from replacing timer-type drain valves with sensor-type valves.

Savings Type	Value / Payback Period
Estimated Electrical Usage Savings	20,564 kWh/yr
Estimated Demand Savings	5.67 kW
Estimated Electrical Usage Cost Savings	\$1,337/yr
Estimated Yearly Demand Cost Savings	\$476
Estimated Total Cost Savings	\$1,813/yr
Estimated Implementation Cost	\$2,540
Simple Payback Period	1.4 years

Background

During the course of the compressed air (CA) system audit, the audit team noted that some drain valves were discharging an unusually large amount of compressed air. Three drain valves in the main compressor room outside of Building 210 and one drain valve in the compressor room of Building 209 were observed to discharge air more than 50 percent of the time. Timers control the “blowdown” of water and air from the drain valves, and for this reason this type of electrically operated solenoid valve is also called a “time cycle blowdown” valve. It is recommended that sensor-type drain valves be installed in place of the existing timer-type drain valves. The sensor-type drain valves will only use compressed air to drain water from the CA system when water is present, which will significantly reduce compressed air consumption of these four drain valves.

Anticipated Savings

Compressed air is expensive to generate. Wherever possible, its use should be minimized. In the case of the existing timer controlled drain valves, compressed air is used whether condensed water exists behind the valve or not. And when the valve does open, it often stays open much longer than is necessary to drain

the condensed water from the system. The net result is a tremendous waste of compressed air and the energy required to produce it. The sensor-type drain valves may use a magnetic reed switch or a capacitance device to detect the amount of condensed water present and operate (discharge) only when drainage is needed.

The electrical usage savings (EUS) (Eq 6) can be calculated as:

$$\text{EUS} = L \times H \times C_1$$

Where:

- L = power used by the air compressor, hp
- H = annual operating hours of the air compressor, 3,627 hr/yr
- C₁ = conversion factor, 0.746 kW/hp.

The power used by the air compressor (L) is estimated as the power required to compress the volume of air discharged through a valve (V_p) from atmospheric pressure (P_{atm}) to the compressor discharge pressure (P_d). For choked flow, the volumetric flow (V_p) for the average amount of air supplied to the four drain valves by the air compressor is calculated to be 35.5 acfm. The power used by the air compressor to produce 35.5 acfm of compressed air is estimated to be 7.6 hp. Therefore, the electrical usage saving (EUS) (Eq 6) is:

$$\text{EUS} = L \times H \times C_1$$

$$\text{EUS} = (7.6)(3,627)(0.746)$$

$$\text{EUS} = 20,564 \text{ kWh/yr.}$$

The electrical usage cost savings, EUCS (Eq 7), is found by:

$$\text{EUCS} = \text{EUS} \times (\text{unit cost of electricity})$$

$$\text{EUCS} = (20,564 \text{ kWh/yr})(\$0.065/\text{kWh})$$

$$\text{EUCS} = \$1,337/\text{yr (rounded off).}$$

The electrical demand savings (DS) for using sensor-type drain valves (Eq 8) can be estimated as:

$$\text{DS} = L \times \text{CF} \times C_1$$

Where:

- L = power used by the air compressor, hp

$CF =$ coincidence factor (estimated fraction of demand savings that will affect the peak demand of each month), no units

$C_1 =$ conversion factor, 0.746 kW/hp.

The demand savings for using sensor-type drain valves (DS) is estimated as:

$$DS = (7.6)(1)(0.746)$$

$$DS = 5.67 \text{ kW.}$$

The yearly demand cost savings (YDCS) (Eq 9) is found by:

$$YDCS = DS \times (\text{average demand cost}) \times (\text{number of months per year})$$

$$YDCS = (5.67 \text{ kW})(\$7.00/\text{kW-month})(12 \text{ month/yr})$$

$$YDCS = \$476/\text{yr} \text{ (rounded off).}$$

The total cost savings (TCS_{NonMaint}) (Eq 10) is simply the sum of the electrical usage cost savings, and the yearly demand cost savings as given below:

$$TCS_{\text{NonMaint}} = EUCS + YDCS$$

$$TCS_{\text{NonMaint}} = \$1,337/\text{yr} + \$476/\text{yr}$$

$$TCS_{\text{NonMaint}} = \$1,813/\text{yr.}$$

Implementation Cost

According to a vendor of air compressors and air compressor accessories (Cannon Compressor) the cost for a sensor-type drain valve will be \$600 including taxes. Installation is estimated to be 1 hour per valve at a cost of \$35/hr, for a total installation cost of \$140. The total cost to purchase and install four sensor-type drain valves is estimated to be \$2,540. The total cost saving of \$1,813/yr will pay for the implementation cost of \$2,540 in about 1.4 years.

EEO No. 7 – Install Natural Gas Engine-Driven Air Compressor

Recommended Action

Install and use a natural gas engine-driven air compressor, instead of the existing electric motor-driven compressor, to produce compressed air at your facility. Table 17 lists the estimated savings resulting from installing natural gas engine-driven air compressor.

Table 17. Estimated savings resulting from installing natural gas engine-driven air compressor.

Savings Type	Value / Payback Period
Estimated Electrical Usage Savings	366,036 kWh/yr
Estimated Electrical Demand Savings	100.92 kW
Estimated Natural Gas Usage Increase	37,228 therm/yr
Estimated Electrical Cost Savings	\$32,269/yr
Estimated Natural Gas Cost Increase	\$10,409/yr
Estimated Annual Maintenance Cost	\$4,534/yr
Estimated Total Cost Savings	\$17,326/yr
Estimated Implementation Cost	\$177,925
Simple Payback Period	10.3 years

Background

Compressed air is produced by a 125 hp Gardner-Denver, model EDMQNA rotary-screw air compressor. The compressed air system also includes a 200 hp Ingersoll-Rand, model SSR-EP200 rotary-screw air compressor, and a 150 hp Ingersoll-Rand, model SSR-EP150 rotary-screw air compressor. The two Ingersoll-Rand air compressors serve as back-up units to the main Gardner-Denver unit, and both Ingersoll-Rand compressors are located in a room within Building 209 (Metal Shop). Based on data provided by facility personnel, compressed air is generated during the first shift for 10.5 hours per day, 254 days per year, and is produced during the second shift for 10 hours per day, 96 days per year, for a total of 3,627 hours per year. The air compressors have a discharge pressure of about 101 psig (115.7 psia). A 290-gal air receiver is located in the compressor room outside of Building 210 (Paint Shop), and a 1000-gal receiver is located in the compressor room inside of Building 209 (Metal Shop). The average line pressure is estimated to be 100 psig (114.7 psia).

A natural gas engine driven air compressor rated at 150 bhp could provide the required air for this facility at the present time.

Anticipated Electrical Usage Savings

Cost saving will be realized from the lower cost of gas to provide energy for air compression. The electrical usage savings (EUS_{NG}) due to use of a natural gas engine driven compressor can be calculated as:

$$EUS_{NG} = (HP/EFF_M) \times LF \times H \times UF \times C_1$$

Eq 15

Where:

- HP = horsepower rating of the main air compressor motor, 125 hp
 EFF_M = compressor motor efficiency (from nameplate), 0.924 no units
 LF = load factor, average fraction of rated power at which a compressor operates (measured), 1 no units
 H = annual operating hours of the compressor, 3,627 hr/yr
 UF = utilization factor of the motor, 1 no units
 C₁ = conversion factor, 0.746 kW/hp.

Therefore:

$$EUS = [(125)/(0.924)](1)(3,627)(1)(0.746)$$

$$EUS = 366,036 \text{ kWh/yr.}$$

The annual electrical usage cost savings (EUCS) (Eq 13) from this measure can be estimated as:

$$EUCS = EUS \times (\text{unit electrical usage cost})$$

$$EUCS = (366,036 \text{ kWh/yr})(\$0.065/\text{kWh})$$

$$EUCS = \$23,792/\text{yr (rounded off).}$$

Demand Savings

The estimated demand savings (DS_{NG}) realized by installing a natural gas engine-driven compressor is calculated as:

$$DS_{NG} = [(HP/EFF_M) \times LF \times CF \times C_1] \quad \text{Eq 16}$$

Where:

- HP = horsepower rating of a compressor motor, 125 hp
 EFF_M = compressor motor efficiency, 0.924 (92.4%) no units
 LF = maximum load factor, fraction of rated power at which compressor operates, 1, no units
 CF = coincidence factor, probability of the demand savings affecting the peak demand of the month, 1.0 no units
 C₁ = conversion factor, 0.746 kW/hp,

Thus:

$$DS = [(125)/(0.924)](1.0)(1.0)(0.746)$$

$$DS = 100.92 \text{ kW.}$$

The yearly demand cost savings (YDCS) (Eq 9) can be estimated as:

$$\text{YDCS} = \text{DS} \times (\text{average demand cost}) \times (\text{number of months per year})$$

$$\text{YDCS} = (100.92 \text{ kW})(\$7.00/\text{kW-month})(12 \text{ month/yr})$$

$$\text{YDCS} = \$8,477/\text{yr} \text{ (rounded off).}$$

Natural Gas Usage Increase

By switching from electric motor driven air compressors to a natural gas engine driven air compressor, the plant's annual natural gas consumption will increase. The annual natural gas usage increase (GUI) can be estimated as:

$$\text{GUI} = (\text{EUS} \times \text{EFF}_M \times C_2) / \text{EFF}_E \quad \text{Eq 17}$$

Where:

EUS = electrical usage savings, kWh/yr

EFF_M = compressor motor efficiency, 0.924 no units

C₂ = conversion constant, 0.034122 therm/kWh

EFF_E = energy efficiency of natural gas engine (estimated), 0.31 no units.

Therefore, the annual natural gas usage increase is estimated as:

$$\text{GUI} = [(366,036)(0.924)(0.034122)] / (0.31)$$

$$\text{GUI} = 37,228 \text{ therm/yr.}$$

The gas usage cost increase (GCI) can be estimated as:

$$\text{GCI} = \text{GUI} \times (\text{average gas cost}) \quad \text{Eq 18}$$

$$\text{GCI} = (37,228 \text{ therms/yr})(\$0.2796/\text{therm})$$

$$\text{GCI} = \$10,409/\text{yr.}$$

Annual Maintenance Cost

The proposed natural gas engine will require more annual maintenance than the existing electric motors. The annual maintenance cost (AMC) is estimated as:

$$\text{AMC} = \text{MR} \times \text{HP} \times \text{H} \quad \text{Eq 19}$$

Where:

MR = maintenance cost rate (estimated), \$0.010/hp-hr

HP = rated horsepower of proposed natural gas engine, 125 hp

H = annual operating hours of natural gas-driven compressor, 3,627 hr/yr,

Thus:

$$\text{AMC} = (\$0.010/\text{hp-hr})(125 \text{ hp})(3,627 \text{ hr/yr})$$

$$\text{AMC} = \$4,534/\text{yr}.$$

The total cost savings ($\text{TCS}_{\text{Annual}}$) is thus the annual electrical usage cost savings plus the yearly demand cost savings minus the annual natural gas cost increase and the estimated annual maintenance cost for the natural gas driven compressor as:

$$\text{TCS}_{\text{Annual}} = \text{EUCS} + \text{YDCS} - \text{GCI} - \text{AMC} \quad \text{Eq 20}$$

$$\text{TCS}_{\text{Annual}} = \$23,792/\text{yr} + \$8,477/\text{yr} - \$10,409/\text{yr} - \$4,534/\text{yr}$$

$$\text{TCS}_{\text{Annual}} = \$17,326/\text{yr}.$$

Implementation Cost

The implementation cost will be the cost of a new 150 hp natural gas engine-driven air compressor, taxes, and installation costs. According to a quote from a vendor,* the cost of a gas unit will be about \$150,000. The air compressor will require a new structure to house the unit. It is estimated that 50 ft of 3.5-in. diameter piping will need to be installed to connect the new compressor to the underground compressed air distribution system. According to facility personnel, there is a 2.5-in. diameter natural gas line underground outside of Building 210 and near the proposed location of the engine-driven air compressor. The estimated material costs are listed below. Each includes taxes and installation costs. The cost savings of \$17,326 will pay for the implementation cost of \$177,925 in about 10.3 years. Table 18 lists the estimated materials costs associated with installation of a 150 hp natural gas engine-driven air compressor.

* Accurate Air Engineering, Inc., 2712 North Alameda Street, Compton, CA 90224, (310) 537-1350.

Table 18. Estimated materials costs associated with installation of a 150 hp natural gas engine-driven air compressor.

Materials	Estimated Cost
150 hp natural gas engine-driven air compressor	\$ 150,000
Structure to house air compressor	\$ 10,000
Connection to existing compressed air distribution system	\$ 750
Connection to existing natural gas distribution system	\$ 1,000
Engineering and contracting costs (10% of above costs)	\$ 16,175
Total	\$ 177,925

Notes

1. It is suggested that several vendors for competitive bids be contacted.
2. Implementation of this EEO will eliminate the savings from EEO No. 2.
3. It is suggested that the 125 hp Gardner Denver compressor be kept as a backup unit.

Other Issues Related to Compressed Air

There are other issues related to the compressed air system at SIAD, which have potential for energy saving and performance improvement, but the savings could not be quantified for various reasons, including lack of data. Table 19 lists the savings and costs for other compressed air-related issues.

Table 19. Summary of savings and costs for other compressed air related issues.

EEO Description	Potential Energy Conserved	Demand Savings (kW)	Potential Savings (\$/yr)	Resource Conserved	Implem. Cost (\$)	Simple Payback (years)
Install an Air Cooler in the Back-Up Compressor Room	NA	NA	NA	Electricity	NA	NA
Install an Oil-Free Air Compressor to Produce the Breathing Air	NA	NA	NA	Electricity	\$51,000	NA
Replace Air Powered Tools with Electric Powered Tools	NA	NA	NA	Electricity	NA	NA

Install an Air Cooler in the Back-Up Compressor System

The back-up air compressor in Building 209 does not include an after cooler. An after cooler is used to reduce the temperature of compressed air discharge from a compressor. Reducing the temperature of compressed air also reduces the

amount of moisture in the air. One of the chief complaints of the facility staff is that the back-up compressor system produces compressed air that contains too much water and oil. There is concern that the excessive amounts of water and oil will overwhelm the breathing air purification system (located in Building 210), which may result in hazardous working conditions. The 200 hp Ingersoll-Rand air compressor (AC1) in the back-up compressor system is rated to produce 892 acfm of air at 100 psig. Air produced by this compressor is first passed through a filter before entering a refrigerated dryer (Zeks model 800 NCD). Figure 14 shows a simple drawing of the back-up compressor system.

The air dryer is rated to handle 800 SCFM of air at 100 psig and inlet temperature of 100 °F. It is obvious that the air dryer's rated capacity is less than the air compressor's rated output, which would result in excessive water in the facility's compressed air. However, because the air entering the dryer is much higher than 100 °F, the actual amount of air (in SCFM) that the dryer can process is much less than its rating. According to a manufacturer of compressed air accessories, raising the inlet temperature by 20 °F doubles the amount of moisture in the air stream.

Installing an air-to-air after cooler in between the air compressors and the air filter will reduce the amount of moisture passing on to the air dryer. Reducing the entering air temperature to the dryer to 100 °F will still leave the dryer undersized (800 SCFM vs. 892 SCFM). However, reducing the entering air temperature to the dryer to 80 °F will increase the dryer's capacity by a factor of 1.6 and should reduce the problem of excessive moisture in the compressed air stream.

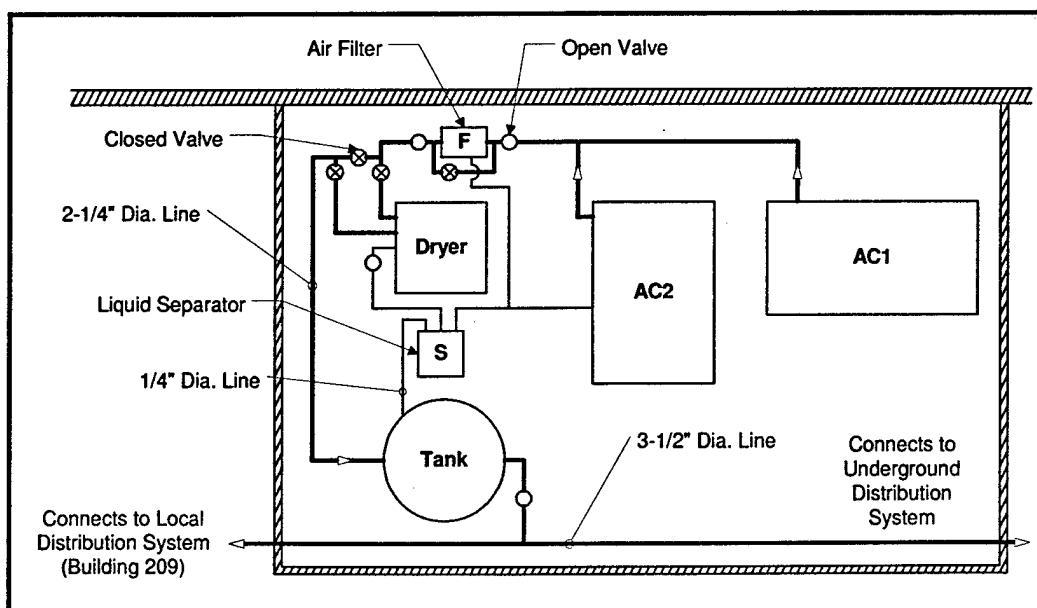


Figure 14. Schematic of back-up compressor room equipment.

An air-to-water after cooler should be capable of cooling the compressed air to 80 °F. These systems tend to be more complex than an air-to-air after cooler, because they include a second heat exchanger, extra piping, and a circulating pump.

Install an Oil-Free Air Compressor To Produce the Breathing Air

Compressed air is produced by a 125 hp Gardner-Denver, model EDMQNA rotary-screw air compressor. In the Paint Shop (Building 210), compressed air is purified by passing through a series of filters so that it can be used as breathing air by shop personnel. The Nomonox Compressed Air Purifier purification system is designed to remove contaminants such as noxious oils, oil aerosols, CO, and water vapor. The system requires 20 to 25 percent of inlet air for regeneration of some of its filters. There are about 10 stations that require breathing air in the Paint Shop, and each breathing air station consumes approximately 15 SCFM of compressed air when in use. At a given time, a maximum of six stations may be in use.

“The Army Respiratory Protection Program” requires that facility engineers “install and maintain breathing air capable of providing Grade D breathing air where required, to include the use of “oil-free” compressors designed for breathing air system (para 3-8)” (section 2.10). Thus, it appears that the SIAD breathing air system is not in compliance with Army regulation concerning the source of compressed air. The solution would be to purchase and install oil-free compressor(s) dedicated to producing air for breathing in Building 210. According to an air compressor representative,* the cost of an oil-less duplex compressor capable of producing 100 acfm of air at 100 psig is about \$40,000. The quoted compressor also includes a 240-gal receiver. The cost for a dryer, pre-filter, and after filter is about \$3,000 with tax. Additional piping and electrical connection costs are estimated to be \$7,000. Thus, the total implementation cost for this recommendation is \$51,000.

Note that, because the proposed air compressor produces air that is “oil-free,” maintenance costs that result from the existing air purification system would be greatly reduced, if not eliminated.

* Ingersoll-Rand Company, 33261 Central Avenue, Union City, CA 94587, (510) 441-5600.

Notes

It is suggested that several vendors for competitive bids be contacted.

Replace Air Powered Tools with Electric Powered Tools

Replace the hand-held compressed air powered tools with electric powered tools. Savings will be realized from the overall higher efficiency of the electric units as compared to the compressed air (pneumatic) units.

Compressed air is supplied to the manufacturing area by means of a 125 hp screw type compressor. Currently, the facility extensively uses hand-held pneumatic tools in both the Metal Shop (Building 209) and the Maintenance Shop (Building 208). Significant energy saving can be realized by replacing the relatively low efficiency pneumatic tools with higher efficiency electric units. The difference in the efficiency of tools of comparable power outputs is due to the power required to produce compressed air versus power required by the small electric motor in the hand held tool.

Electrical energy consumption of an electric motor-powered tool is typically 70 percent of an air-powered tool. Use of electric tools will also reduce the occurrence of air leaks, which is quite common when using air tools. In most cases, the energy cost savings from using a motor-powered tool instead of an air-powered tool will pay for the cost of the motor-powered tool in about 2 years.

Table 20. Summary of savings and costs for other energy issues.

EEO Description	Potential Energy Conserved (kWh/yr)	Demand Savings (kW)	Potential Savings (\$/yr)	Resource Conserved	Implem. Cost (\$)	Simple Payback (years)
Electrical Distribution System for the Industrial Area	NA	NA	NA	NA	NA	NA
Install Occupancy Sensors in the Paint and Shot Blaster Booths	25,139	6.93	2,216	Electricity	360	0.2
Turn-Off Dust Collector Equipment During Non-Operating Hours	32,795	9.04	2,892	Electricity	0	immediate
Use of Natural Gas Heaters	NA	NA	NA	Nat. Gas	NA	NA

Other Energy Issues at the Visited Plants at SIAD

Although the audit team was commissioned to do an energy survey of the compressed air system only, during the compressed air survey some other energy efficiency/performance issues were identified. Table 20 summarizes savings and costs for other energy issues. More engineering analysis and design with respect to these issues may be needed.

Electrical Distribution System for the Industrial Area

The SIAD receives its power from the LMUD at 12 kV. Originally, three 1000-kVA single-phase transformers were used to step down the voltage from 12 kV to 4 kV, which in turn is distributed to various buildings within the SIAD. Recently, another three-phase 3,750 kVA, 12 kV to 4 kV transformer was installed adjacent to those three 1000-kVA single-phase transformers in the substation to supply the power to Buildings 208, 209, 210, and other buildings in the industrial area. Figure 15 shows a simple power system distribution diagram for the industrial area only. The ACSR (Aluminum Cable Steel Re-enforced) cable #4/0 is used in the 4-wire, Y-connected power distribution system. Figure 15 also shows the size, location, and secondary side voltage of transformers that feed Buildings 208, 209, and 210.

Electrical System for Building 210

There are three transformers that provide power to Building 210. One is 225 kVA, 4 kV to 480 V three-phase transformer (No. 6 in Figure 15), which feeds the 125-hp compressor system and the dust collecting system.

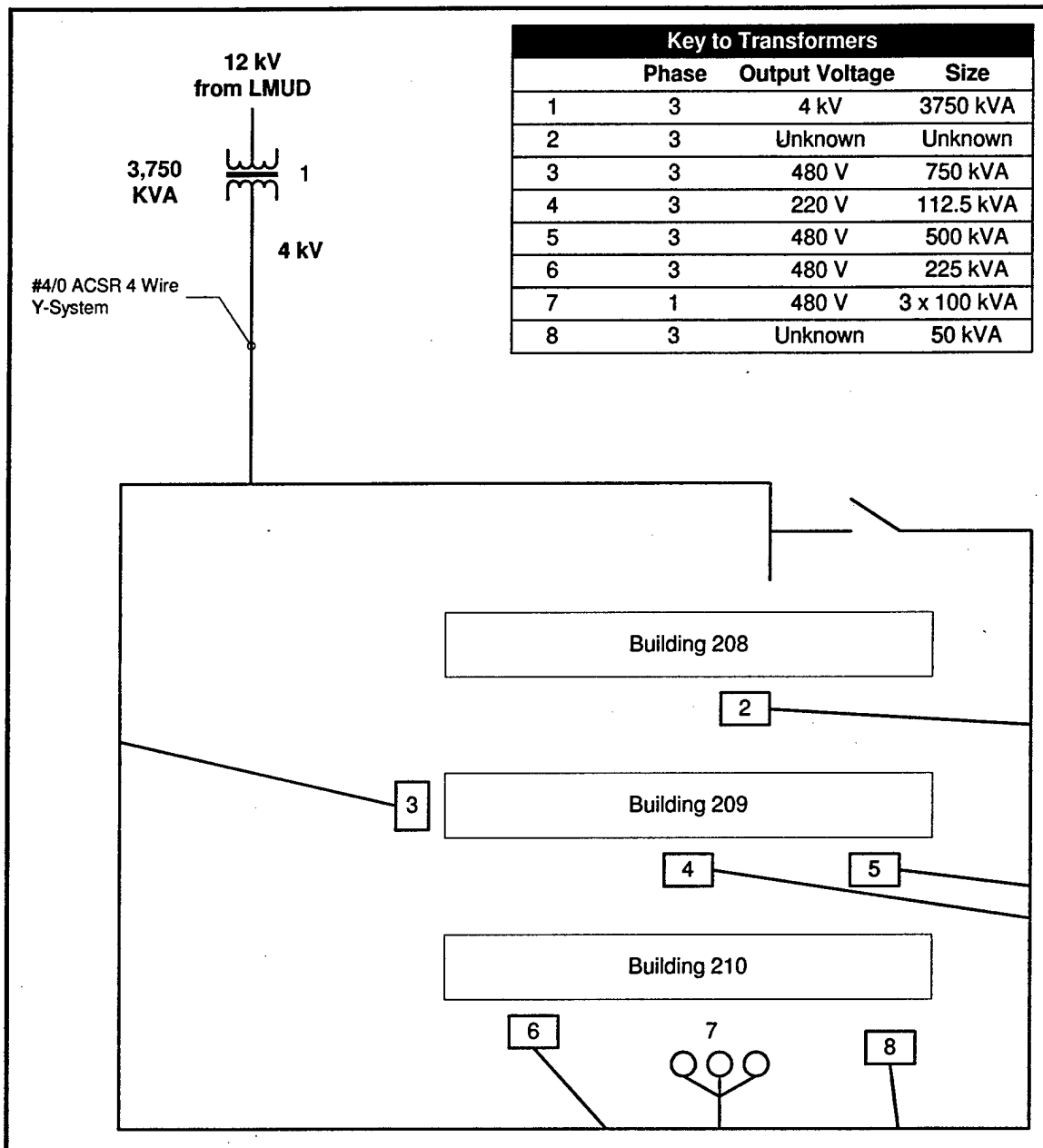


Figure 15. Simple diagram of electrical distribution system.

A 50 kVA three-phase transformer (No. 8 in Figure 15) provides the power for the lighting. (This information was provided by the electrician.) The rest of the industrial load in Building 210 is provided through three 100 kVA, single-phase transformers (No. 7 in Figure 15). Based on all the loads in Building 210, these three transformers should have enough capacity to supply the power to all loads without problem.

Electrical System for Building 209

There are three transformers that feed Building 209: 112.5 kVA, 500 kVA, and 750 kVA. The 750 kVA transformer (No. 3 in Figure 15) is the newest. (It was recently installed.) Currently there is no load connected to this 750 kVA transformer. There is a plan to switch the welding loads and two compressors, 150-hp and 200-hp, to this 750 kVA transformer. The two compressors currently receive power through a 500 kVA transformer (No. 5 in Figure 15). However, because of the breathing air quality requirement, these two compressors are not being used right now. Other significant loads in Building 209 are welding and lighting. Three transformers of the Building 209 have much more capacity than the total connected loads. There should not be any power problems in this building.

Electrical System for Building 208

Based on the survey, there is one transformer (No. 2 in Figure 15) providing power to Building 208. Unfortunately, there was no chance to examine this transformer in detail to find out the rating due to the tight schedule of the electrician. The power usage of Building 208 is small compared to the other two buildings. We believe there should be no power problems for Building 208.

Electrical Problems and Mitigation Scheme for Building 210

Problems

The audit team was told by the people working in Building 210 that there are low voltage problems for the 125-hp compressor and the dust collecting system. Basically, if the compressor stops and starts during the day, it might trip the dust collecting system. Because of this, the compressor is put on the *Continuous Run* mode to avoid the restarting of the compressor. This mode is the least energy efficient compared to other possible operating modes. This issue has been addressed earlier in this report. Also, operators have difficulty in starting the dust collecting system. Once the start button is pressed, the system would sometimes trip immediately. Because of this, operators must hold on to the start button for an extended period of time to start the dust collecting system in the morning.

Cause of the Problem

This problem is caused by the low voltage at the electrical panel of the dust collecting system during the starting of the dust collecting system and starting of the compressor. The dust collecting control panel has a low voltage tripping de-

vice whose function is to provide protection for the blower motor. If the voltage is too low for the blower motor, then the current it draws will be higher. If the motor were not protected properly, then the motor might be damaged due to the higher losses resulting from the higher current. The low voltage tripping device is set to work with nominal system voltage of 480 volts right now. This voltage setting can be easily adjusted to different nominal system voltage if desired.

Current Situation

The audit team measured the voltage at the dust collecting system's electrical panel for both no load and under load. The no load voltage is 479 volts when everything in Building 210 is turned off. When the compressor is running, then the voltage is reduced to 460 volts if the dusting collecting system is not running. The voltage is dropped to about 430 volts momentarily when the START button of the dust collecting motor is pressed and compressor is running. This voltage is low enough to trip the low voltage protecting device inside the dust collecting system's control panel.

If the dust collecting system is running and the compressor is turned off and re-started, the initial current surge of the 125-hp compressor motor will cause the system voltage at the dust collecting system's electrical panel to drop considerably. Then the low voltage protecting device will trip the dust collecting system to protect the blower motor from being damaged. Even though no experiment was conducted to verify this phenomenon, it was evident that the low voltage at the electrical panel causes the system to trip. This is the reason the compressor is always put in the *Continuous Run* mode.

Mitigation Scheme

Change the tap setting of the 225-kVA transformer

The system voltage at the secondary side of the 225 kVA transformer under loaded condition (when both compressor and dust collecting system are running) is about 455 v to 460 v. This is on the low side for a 480-v system. Most modern transformers have a tap setting at its secondary side that can be adjusted with a 2.5 percent per adjustment step. It is suggested that SIAD technicians increase the tap setting at least by one step (i.e., increase the secondary voltage by 2.5 percent). This should solve the low voltage tripping problem of the dust collecting system. If the situation is not improved by the 2.5 percent tap increase, further increase of the tap setting by another step may be warranted (i.e., a total of 5 percent increase). Any more increase of the tap setting is not recommended.

Reduce the low voltage tripping point for the dust collecting system

As mentioned earlier, the dust collecting system has a low voltage tripping protection mechanism. The tripping point is set by selecting the nominal system operating voltage. Currently it is set at 480 volts while the actual system voltage under load is about 455 to 460 volts. Lowering the selected system operating voltage from 480 volts to 460 volts is recommended. With this change, the low voltage tripping point should be low enough so that the momentarily low voltage resulting from starting of either compressor or blower motor (of the dust collecting system) will not trip the dust collecting system. If the transformer tap setting is increased by 2.5 percent already, then it is recommended to adjust the selected system operating voltage to approximately 470 volts. If the transformer tap setting was increased by 5 percent (a 2-step increase), then no change on the selected system voltage should be necessary.

The adjustment of the selected system operating voltage for the dust collecting system is located in the control panel of the dust collecting system. It has four push buttons, four green lights, and four red lights on the front. To adjust it, power has to be turned off first by pulling down the handle on the right side of the panel. The nominal system operating voltage can be changed by using a flat screwdriver to adjust settings in a rectangular electronics box mounted on the left side of the panel. Consultation with the manual located inside the electrical panel is suggested.

Compressor Power Factor

Additionally, the power factor of the compressor was measured over an extended period of time for three different operating modes. The power factor is consistently at 0.9 or better. There is no power factor problem with the Gardner-Denver compressor.

Install Occupancy Sensors in the Paint and Shot Blaster Booths

Recommended Action

Install occupancy sensors in the paint booths and shot blaster booth in Building 210 to reduce lighting energy usage. Table 21 lists the estimated savings that should result from installing occupancy sensors in the paint and shot blaster booths.

Table 21. Estimated savings resulting from installing occupancy sensors in the paint and shot blaster booths.

Savings Type	Value / Payback Period
Estimated electrical usage savings	25,139 kWh/yr
Estimated demand savings	6.93 kW
Estimated electrical usage cost savings	\$1,634/yr
Estimated yearly demand cost savings	\$582/yr
Estimated total cost savings	\$2,216/yr
Estimated implementation cost	\$360
Simple payback period	0.2 years

Background

The audit team observed that the lights are left on all the time in the paint booths and shot blasting booth. Most of these areas have low occupancy throughout their operating hours. By installing occupancy sensors in the paint booths and shot blasting booth, lighting can be eliminated during unoccupied periods. The savings come from turning off the lights during times when people forget to turn off the lights when leaving an area. Savings estimates are based solely on lighting energy savings.

Anticipated Electrical Usage Savings

The electrical usage savings (EUS) for the paint booths and shot blasting booth are calculated as:

$$EUS_{Booths} = N \times LPF \times IW \times H \times CTF / C_1 \quad \text{Eq 21}$$

Where:

- N = number of fixtures in the booths, 76 no units
- LPF = number of lamps per fixture, 4 no units
- IW = input wattage of lamp (including ballast), watts
- H = current operating hours of lamp, hr/yr
- CTF = control factor, fraction of current operating hours the sensors will turn lights off (estimated), 0.60 (60%) no units
- C₁ = conversion constant, 1000 W/kW.

The estimated electrical usage savings (EUS_{Booths}) for installing occupancy sensors for the F34 fluorescent lamps in the paint booths and shot blasting booth (Eq 21) is thus calculated by:

$$EUS_{\text{Booths}} = N \times LPF \times IW \times H \times CTF / C_1$$

$$EUS_{\text{Booths}} = (76)(4)(38)(3,627)(0.60)/(1000)$$

$$EUS_{\text{Booths}} = 25,139 \text{ kWh/yr.}$$

The anticipated annual electrical usage cost savings (EUCS) (Eq 7) due to the installation of occupancy sensors is estimated as:

$$EUCS = EUS \times (\text{unit cost of electricity})$$

$$EUCS = (25,139 \text{ kWh/yr})(\$0.065/\text{kWh})$$

$$EUCS = \$1,634/\text{yr.}$$

Demand Savings

The estimated demand savings (DS_{Booths}) is given by the following relation:

$$DS_{\text{Booths}} = N \times LPF \times IW \times CF / C_1$$

Eq 22

Where:

CF = coincident factor.

and all other variables are the same as for the energy savings calculation.

If occupancy sensors are installed in the paint booths and shot blast booth to reduce lighting energy usage, the demand savings (DS) is:

$$DS = (76)(4)(38)(0.60)/(1,000)$$

$$DS = 6.93 \text{ kW.}$$

The yearly demand cost savings (YDCS) (Eq 9) due to the installation of occupancy sensors is estimated as:

$$YDCS = DS \times (\text{average demand cost}) \times (\text{number of months per year})$$

$$YDCS = (6.93 \text{ kW})(\$7.00/\text{kW-months})(12 \text{ month/yr})$$

$$YDCS = \$582/\text{yr.}$$

The total cost is the sum of electrical usage cost savings and yearly demand cost savings. The total cost savings is estimated to be \$2,216 per year.

Implementation Cost

The cost of implementation is based on a one-time installation of sensors. Estimated cost of each sensor, including labor for installation, is approximately \$120 for reasonably good sensors. The two paint booths and shot blasting booth will require a total of three occupancy sensors, giving a total implementation cost of \$360. The total cost savings of \$2,216/yr would pay for the total estimated implementation cost of \$360 in 0.2 years.

Turn Off Dust Collector Equipment During Nonoperating Hours

Recommended Action

Turn-off the dust collector fan and elevator when the sand blaster is not in use. Table 22 lists the estimated savings that should result from turning off dust collector equipment during nonoperating hours.

Table 22. Estimated savings resulting from turning off dust collector equipment during nonoperating hours.

Savings Type	Value / Payback Period
Estimated Electrical Usage Savings	32,795 kWh/yr
Estimated Demand Savings	9.04 kW
Estimated Electrical Cost Savings	\$2,892/yr
Estimated Implementation Cost	\$0
Simple Payback Period	immediate

Background

While at the facility, the audit team noticed that the dust collector suction fan and elevators were left on when the sand blaster was not being used. According to facility personnel, the dust collector suction fan and elevators operate about 3,627 hours per year. It is estimated that the sand blaster is not used during 40 percent of the dust collection system's operating hours. The suction fan and elevator motors can be turned off when the sand blaster is not being used, resulting in significant energy savings.

Anticipated Savings

Turning off the suction fan and elevator motors when the sand blaster is not being used will reduce your electrical energy usage. The electrical usage savings (EUS_{Motor}) can be estimated as:

$$EUS_{Motor} = N \times (HP/EFF_M) \times LF \times H \times CTF \times UF \times C_1 \quad \text{Eq 23}$$

Where:

- N = number of motors to be turned off, no units
 HP = horsepower of the motor, hp
 EFF_M = efficiency of motors (estimated), no units
 LF = load factor of motors (estimated), 0.75 (75%) no units
 H = current operating hours, 3,627 hr/yr
 CTF = control factor of motors, 0.40 (40%) no units
 UF = utilization factor, 1 no units
 C₁ = conversion constant, 0.746 kW/hp.

There are one 30 hp suction fan motor and two 3 hp elevator motors for the dust collection system. The electrical usage savings (EUS_{Motor2}) for turning off the these motors can be estimated as:

$$EUS_{Motor2} = \{[N \times (HP/EFF_M)]_{30hp} + [N \times (HP/EFF_M)]_{3hp}\} \times LF \times H \times CTF \times UF \times C_1 \quad \text{Eq 24}$$

$$EUS_{Motor2} = \{[(1)(30)/(0.902)] + [(2)(3)/(0.840)]\}(0.75)(3,627)(0.40)(1.0)(0.746)$$

$$EUS_{Motor2} = 32,795 \text{ kWh/yr.}$$

The electrical usage cost savings (EUCS) (Eq 7) for turning off the motors can be estimated as:

$$EUCS = EUS \times (\text{unit cost of electricity})$$

$$EUCS = (32,795 \text{ kWh/yr})(\$0.065/\text{kWh})$$

$$EUCS = \$2,132/\text{yr.}$$

The electrical demand savings (DS_{Motor2}) can be estimated as:

$$DS_{Motor2} = N \times (HP/EFF_M) \times LF \times CTF \times UF \times C_1 \quad \text{Eq 25}$$

Where:

- N = number of motors to be turned off, no units
 HP = horsepower of the motor, hp
 EFF_M = efficiency of motors (estimated), no units
 LF = load factor of motors (estimated), 0.75 (75%) no units
 CTF = control factor of motors, 0.40 (40%) no units
 UF = utilization factor, 1 no units
 C₁ = conversion constant, 0.746 kW/hp.

The electrical demand savings (DS_{MotorOff}) for turning off these motors can be estimated as:

$$DS_{\text{MotorOff}} = \{[N \times (\text{HP}/\text{EFF}_M)]_{30\text{hp}} + [N \times (\text{HP}/\text{EFF}_M)]_{3\text{hp}}\} \times \text{LF} \times \text{CTF} \times \text{UF} \times C_1 \quad \text{Eq 26}$$

$$DS_{\text{MotorOff}} = \{[(1)(30)/(0.902)] + [(2)(3)/(0.840)]\}(0.75)(0.40)(1.0)(0.746)$$

$$DS_{\text{MotorOff}} = 9.04 \text{ kW.}$$

The yearly demand cost savings (YDCS) (Eq 9) realized by the 30 hp suction fan and the two 3 hp elevator motors is estimated as:

$$\text{YDCS} = \text{DS} \times (\text{average demand cost}) \times (\text{number of months per year})$$

$$\text{YDCS} = (9.04 \text{ kW})(\$7.00/\text{kW-month})(12 \text{ months/yr})$$

$$\text{YDCS} = \$760/\text{yr.}$$

The total cost is the sum of electrical usage cost savings and yearly demand cost savings, which is estimated to be \$2,892 per year.

Implementation Cost

The implementation of this EEO will involve training the production workers to turn off the dust collector motors when the sand blaster is not being used. There are no implementation costs associated with this EEO. The estimated cost savings of \$2,892 per year will pay for itself immediately.

Use of Natural Gas Heaters

Currently Buildings 208, 209, and 210 are heated by a high pressure steam system. Steam is produced by a natural gas boiler and distributed to the buildings through insulated lines and a series of overhead fan-coils. The boiler only operates in winter. Use of a high pressure steam system requires maintenance of the boiler, significant use of electricity for boiler pump and fan systems, as well as the potential for energy loss to the ambient air and through the steam traps.

Significant savings will be realized by changing the heating system to natural gas infra-red or convective heaters. This measure will require installation of a natural gas distribution system in the buildings as well as installation of natural gas heaters.

A more economical measure will be to use the present high pressure steam piping system for hot water distribution. The same heaters may be used, but additional units may be needed for heating the buildings. New packaged hot water boilers will be needed for such a system.

7 Conclusion and Recommendations

This study involved a CA system survey conducted from 10 July 2000 through 13 July 2000 at Sierra Army Depot, which included an equipment inventory, inspection and tagging of air leaks, development of CA system drawing, system measurements, a review of data and manuals, and interviews of personnel.

The audit team proposed the following measures, which will yield substantial cost savings in the operation of the compressed air system:

1. Repair compressed air leaks (p 34)
2. Change the air compressor control to low demand mode (p 39)
3. Disconnect the air receiver from the oil/water separator (p 42)
4. Duct outside air into the air compressor room (p 45)
5. Install sensor-type valves on the purifier pre-filters (p 48)
6. Replace timer-type drain valves with sensor-type valves (p 51)
7. Install natural gas engine driven air compressor (p 53)
8. Compressed air- related measures (p 58):
 - a. Install an air cooler in the back-up compressor system
 - b. Install an oil-free air compressor to produce the breathing air
 - c. Replace air powered tools with electric powered tools.

During the audit of the compressed air system, the team also observed other energy conservation measures that could be implemented that have potential for substantial cost savings:

1. Install occupancy sensors in the paint and shot blaster booths (p) 66
2. Turn off dust collector equipment during nonoperating hours (p 69)
3. Use natural gas heaters (p 71).

References

Compressed Air and Gas Institute, *Compressed Air and Gas Handbook*, 5th ed. (Prentice Hall, Englewood, New Jersey, 1989).

Gardner-Denver Industrial Machinery, *Operating and Service Manual – Models 125 – 200 hp*, 13-9/10-643, 3rd ed. (Gardner-Denver Industrial Machinery, 1994).

Zeks Air Dryer Corp., Form: NCD-1097-10M-JRL, “NC Series Non-Cycling Refrigerated Dryers” (Zeks Air Dryer Corp., 1997).

Appendix: Points of Contact

Sierra Army Depot (SIAD), Herlong, CA 96113

Tel. 503-827 — XXXX

DPW: Dan Moore (x-4130)

Walt Zinko (x-5330)

Tom Gordon (x-2595)

OSD-Paint

Art Colgain (x-4560)

OSD-Metal

Joe Stauffer (x-4821)

MPIO

Ray Hillard (x-4584)

Berkeley Applied Science and Engineering (BASE), Inc. San Francisco, CA

Ahmad R. Ganji

Shy-Sheng Liou

Bryan Hackett

Tel. 415-543-1600

US Army Corps of Engineers, Construction Engineering Research Laboratory

Tel. 800-USACERL

POC: Dr. Mike C.J. Lin

CERL Distribution

HQ, Industrial Operation Command
ATTN: HQIOC-IS (2)

Sierra Army Depot
ATTN: SIOSI-DPW (2)

Rock Island Arsenal, Rock Island, IL 61299-7190
ATTN: AMXIS-C

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: HECSA Mailroom (2)
ATTN: CECC-R

Engineer Research and Development Center (Libraries)
ATTN: ERDC, Vicksburg, MS
ATTN: Cold Regions Research, Hanover, NH
ATTN: Topographic Engineering Center, Alexandria, VA

Defense Tech Info Center 22304
ATTN: DTIC-O

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14. ABSTRACT <p>Compressed air (CA) is an indispensable commodity used in manufacturing and maintenance facilities. In most plants/shops, CA is centrally generated and distributed to users through a pipe network. Although a very convenient power source, CA systems are not cheap to operate. The annual cost of electricity needed to run an air compressor is near or more than the initial cost of the compressor. This study conducted complete CA system audits and surveys to reveal these opportunities at the Sierra Army Depot (SIAD). A CA system survey was conducted from 10 July 2000 through 13 July 2000. The site visit included an initial meeting with Depot personnel involved with the CA system operation, a tour of the CA facilities, an equipment inventory, inspection and tagging of air leaks, development of CA system drawing, system measurements, a review of data and manuals, interviews of personnel, and a summary meeting at the end of the visit. The audit team proposed specific measures that will yield substantial cost savings in the operation of the compressed air system. The team also recommended other energy conservation measures with good potential for substantial cost savings.</p>					
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