

AR No. 1 - Repair Compressed Air Leaks

Estimated Electric Energy Savings = 30,100 kWh/yr
Estimated Electric Energy Cost Savings = \$1,060/yr
Estimated Peak Electric Demand Savings = 46 kW-mo./yr
Estimated Peak Electric Demand Cost Savings = \$610/yr
Estimated Total Cost Savings = \$1,670/yr
Estimated Implementation Cost = \$280
Simple Payback = 0.2 year

Recommended Action

Leaks in compressed air lines should be repaired and regular maintenance should be implemented on the compressed air system. Savings will result from reduced electric energy consumption and peak demand charges since less power will be required to operate the compressed air system.

Air Compressors

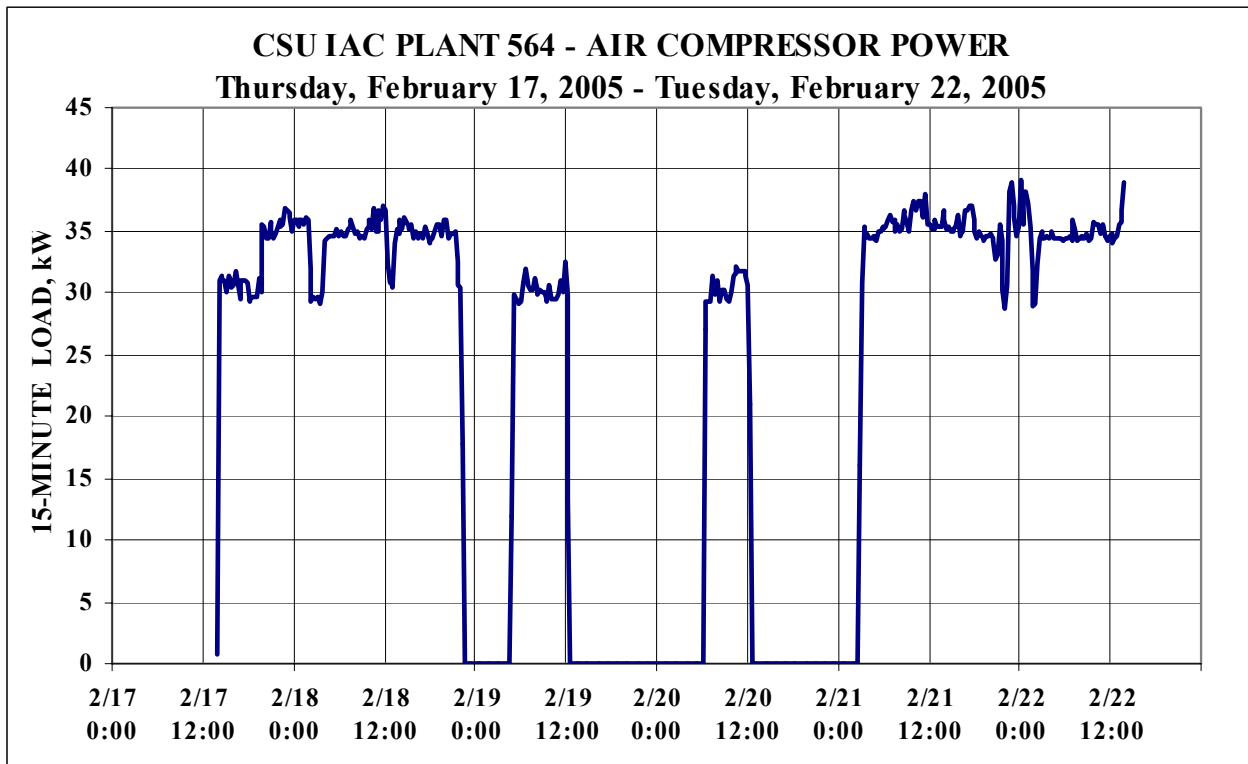
The compressed air system at this facility consists of a main rotary screw compressor, and a backup reciprocating compressor that operate at 100 psig system pressure. Information about the compressed air equipment is as follows:

- One 60 hp Kaeser rotary screw compressor model CS76 (S/N 6100585). The rated capacity at the maximum operating pressure of 100 psi is 291 actual cubic feet per minute (acfm) at inlet conditions. From the motor nameplate, the motor is rated at 460V, 83 amps full load, and 1,770 rpm, and the motor efficiency is 93.6%. At full load, the compressor power is $60 \text{ hp} \times 0.746 \text{ kW/hp} \div 93.6\% = 47.8 \text{ kW}$.
- One 20 hp Ingersoll-Rand reciprocating compressor model EP20-ESP (S/N AN3417U98293). The rated capacity at the maximum operating pressure of 125 psi is 72 acfm at inlet conditions. From the motor nameplate, the motor efficiency is 87.5%. At full load, the compressor power is $20 \text{ hp} \times 0.746 \text{ kW/hp} \div 87.5\% = 17.1 \text{ kW}$.
- One Kaeser refrigerated air dryer model KRD300 (S/N 0362-2T-9701-1K) rated at 300 standard cubic feet per minute (scfm) at 100 psig and 100°F. The maximum air inlet conditions are 200 psig and 120°F. The total dryer package is rated at 460V and 3.9 amps full load.

At the time of the site visit, the 60 hp Kaeser rotary compressor was in operation. Based on discussions with plant personnel, the compressed air system operates from 6:30 a.m. on Mondays through 3:00 p.m. on Saturdays or $152.5 \text{ h/wk} \times 52 \text{ weeks/yr} = 7,920 \text{ h/yr}$ to supply 100 psig of air pressure to the plant. The 20 hp Ingersoll-Rand reciprocating compressor is for backup purposes only. The supply lines had several leaks in the fittings, joints, regulators, and other pneumatic equipment. These leaks are analyzed below to find potential energy and cost savings resulting from fixing the leaks.

During the site visit, the operating 60 hp compressor was outfitted with an Architectural Energy MicroDataLogger to record the energy consumption for the period from 1:00 p.m. on Thursday, February 17, 2005 through 1:45 p.m. on Tuesday, February 22, 2005. The sample interval was set to 15 minutes. The unit was configured to generate pulses that were counted by the data logger. Each pulse represents a watt-hour of energy. The energy consumption per sample interval was then divided by 0.25 hours to convert the energy consumption into kW, so the

recorded readings represent the **average** power draw during the 15 minute sample interval. These readings reflect the demand loads that would actually be seen by the utility electric meter. The 15-minute load data are presented in the graph below:



For reference, the average load measured when the compressor was operating during this period was 22.8 kW, or about $22.8/47.8 \times 100\% = 48\%$ of full load. Under the average measured load, the total energy usage to operate this compressor is $22.8 \text{ kW} \times 7,920 \text{ h/yr} = 180,600 \text{ kWh/yr}$, with a corresponding energy cost of \$6,360/yr. The total peak demand to operate the compressor $22.8 \text{ kW} \times 12 \text{ mo./yr} = 274 \text{ kW-mo./yr}$, with a corresponding demand cost of \$3,610/yr. Thus, the total electric operating costs are $\$6,360/\text{yr} + \$3,610/\text{yr} = \$9,970/\text{yr}$. This is about 9% of the total electric energy costs for this facility.

It is recommended that maintenance personnel implement a preventive maintenance program to check for and repair air leaks on a regular basis. The cost of such a program will subtract from the potential savings. Parts and labor costs required to repair the leaks will occur after each periodic survey, but only the initial repairs to the leaks discovered during the site visit are considered in this analysis.

Anticipated Savings

The amount of lost air depends on several factors: the line pressure, the compressed air temperature at the point of the leak, the air temperature at the compressor inlet, and the estimated leak area. The area of the leaks is estimated by listening and feeling the airflow from the leak. It is usually recorded as an equivalent circle diameter (in inches) according to the following scale: 1/64, very small hole; 1/32, small hole; 1/16, medium sized hole; 1/8, large hole; and 1/4, enormous hole. Because of long equipment runs, the compressed air temperature is estimated to be the same as room temperature. The operating pressure at the time of the site visit was 125 psig. The pressure at the leak is assessed by using an ultrasonic leak detector. Values for all factors affecting the cost of compressed air leaks were determined during the site visit, and are listed in the table below.

Condition of Compressed Air System at Time of Site Visit

Variable	Kaeser	Ingersoll-Rand
Air temperature at compressor inlet, F	75	75
Atmospheric pressure, psia	12.363	12.363
Compressor operating pressure, psig	100	125
Air temperature at the leak, F	72	72
Line pressure at the leaks, psig	100	125
Compressor motor size, hp	60	20
Compressor motor efficiency	93.6%	87.5%
Compressor type	Rotary Screw	Reciprocating
Number of stages	1	1
Compressor operating hours, per year	7,920	0
Peak demand months, per year	12	0

The volumetric flow rate of free air exiting the hole is dependent upon whether the flow is choked. When the ratio of atmospheric pressure to line pressure is less than 0.5283, the flow is said to be choked (i.e., traveling at the speed of sound). The ratio of 12.363 psia atmospheric pressure to 125 psia line pressure is 0.099. Thus, the flow is choked. The volumetric flow rate of free air, V_f , exiting the leak under choked flow conditions is calculated as follows:

$$V_f = \frac{NL \times (T_i + 460) \times \frac{P_l}{P_i} \times C_1 \times C_2 \times C_d \times \frac{\pi D^2}{4}}{C_3 \times \sqrt{T_i + 460}}$$

where

- V_f = volumetric flow rate of free air, cubic feet per minute
- NL = number of air leaks, no units
- T_i = temperature of the air at the compressor inlet (yearly average), °F
- P_l = line pressure at leak in question, psia
- P_i = inlet (atmospheric) pressure, psia
- C_1 = isentropic sonic volumetric flow constant, 28.37 ft/sec-°R^{0.5}
- C_2 = conversion constant, 60 sec/min

- C_d = coefficient of discharge for square edged orifice¹, 0.8 no units
 π = Pythagorean constant, 3.1416
 D = leak diameter, inches (estimated from observations)
 C_3 = conversion constant, 144 in²/ft²
 T_l = average line temperature, °F (assumed to be the same as temp at the leak)

For example, the flow of free air through a 1/16" diameter hole for a 125 psig leak and the conditions at this plant listed above is calculated as follows:

$$V_{f,1/16"} = \frac{(1)(72 + 460) \times \frac{(100 + 12.363)}{(12.363)} \times (28.37)(60)(0.8) \times \frac{\pi(1/16)^2}{4}}{(144)\sqrt{72 + 460}} = 6.1 \text{ cfm}$$

The power loss from leaks is estimated as the power required to compress the volume of air lost from atmospheric pressure, P_i , to the compressor discharge pressure, P_o , as follows²:

$$L = \frac{P_i \times C_3 \times V_f \times \frac{k}{k-1} \times N \times C_4 \times \left[\left(\frac{P_o}{P_i} \right)^{\frac{k-1}{k \times N}} - 1 \right]}{E_a \times E_m}$$

where

- L = power loss due to air leak, hp
 k = specific heat ratio of air, 1.4, no units
 N = number of stages, no units
 C_4 = conversion constant, 3.03×10^{-5} hp-min/ft-lb
 P_o = compressor operating pressure, psia
 E_a = air compressor isentropic (adiabatic) efficiency, no units
 $E_a = 0.82$ for rotary screw compressors³
 E_m = compressor motor efficiency, no units

Again using the example above for plant conditions, the power loss due to a 1/16" diameter air leak at 125 psig is calculated as follows:

¹ A.H. Shapiro, **The Dynamics and Thermodynamics of Compressible Fluid Flow**, Vol 1, Ronald Press, N.Y. 1953, p. 100.

² Chapters 10 and 11, **Compressed Air and Gas Handbook, Fifth Edition**, Compressed Air and Gas Institute, New Jersey, 1989.

³ From Table 1, p. 49, **Pneumatic Handbook, 7th ed.**, Anthony Barber, Trade and Technical Press, 1989.

$$L_{1/16''} = \frac{(12.363)(144)(6.1) \times \frac{(1.4)}{(1.4-1)} \times (1)(3.03 \times 10^{-5}) \times \left[\left(\frac{(100 + 12.363)}{12.363} \right)^{\frac{(1.4-1)}{(1.4)(1)}} - 1 \right]}{(0.82)(0.936)} = 1.3 \text{ hp}$$

The annual energy savings, ES , and energy cost savings, ECS , are estimated as follows:

$$ES = L \times H \times C_5$$

$$ECS = ES \times \text{avoided cost of electric energy}$$

where

H = annual time during which leak occurs, h/yr

C_5 = conversion factor, 0.746 kW/hp

For a 1/16" diameter hole at plant conditions, the energy savings are calculated as follows:

$$ES_{1/16''} = (1.3)(7,920)(0.746) = 7,681 \text{ kWh/yr}$$

$$ECS_{1/16''} = (7,681 \text{ kWh/yr})(\$0.03522/\text{kWh}) = \$271/\text{yr}$$

The peak electric demand savings, DS , and the savings, DCS , can be estimated as follows:

$$DS = L \times DM \times C_5$$

$$DCS = DS \times \text{avoided cost of peak electric demand}$$

where

DM = demand months – annual number of months per year that the air compressor is assumed to contribute to the peak demand, 12 months/yr

For a 1/16" diameter hole at plant conditions, the peak electric demand and cost savings are calculated as follows:

$$DS_{1/16''} = (1.3)(12)(0.746) = 11.6 \text{ kW-mo./yr}$$

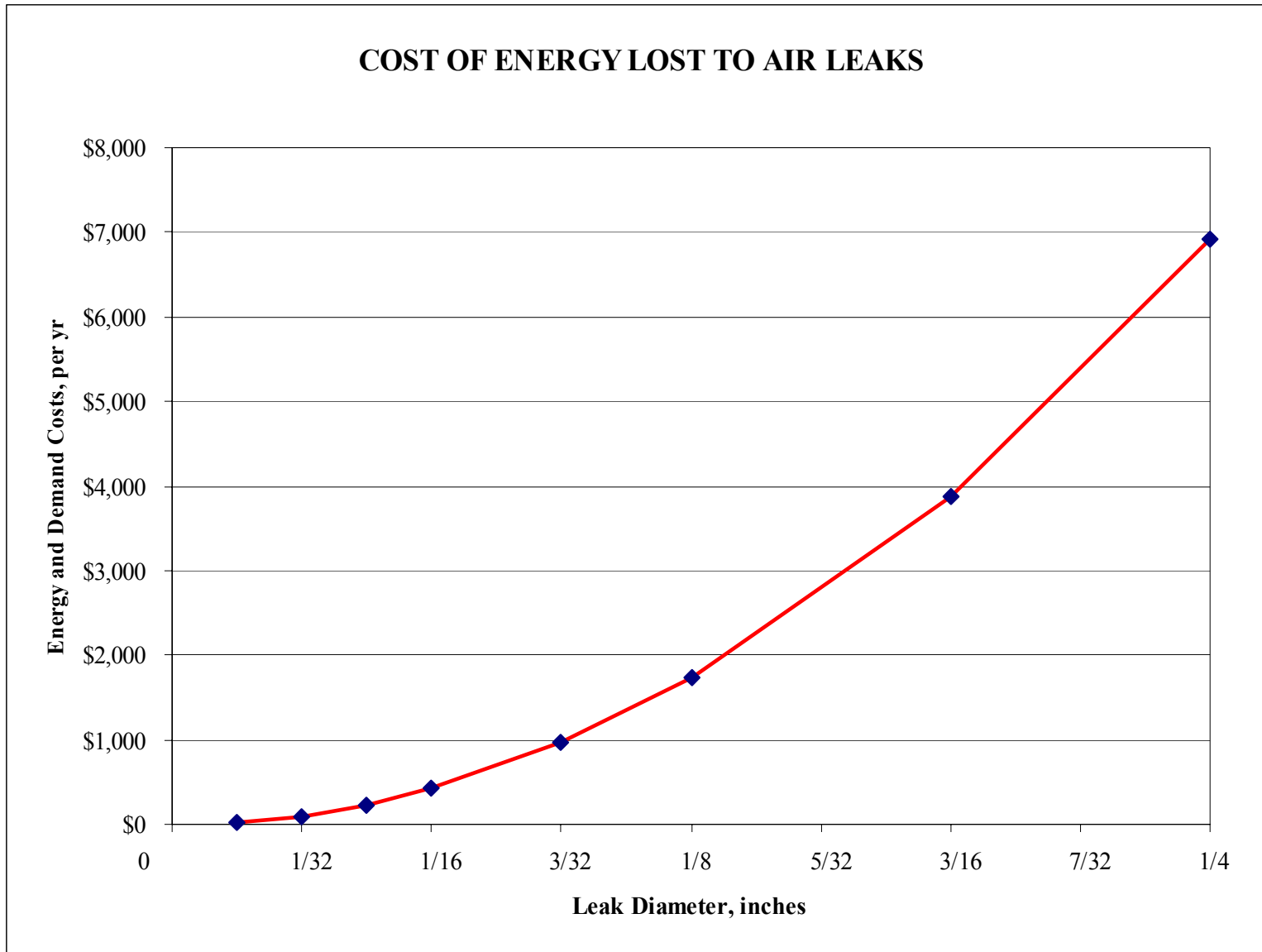
$$DCS_{1/16''} = (11.6 \text{ kW-mo./yr})(\$13.19/\text{kW-mo.}) = \$153/\text{yr}$$

Using the conditions at this plant, the volumetric flow rate, power lost due to leaks, energy lost and cost for leaks of various sizes were calculated specifically for the conditions at this plant. Detailed equations for these calculations have been listed above. The results are shown in the table below.

Potential Cost of Compressed Air Leaks At Line Pressure (100 psig) At This Site

Leak Diameter	Flow Rate <i>cfm</i>	Power Loss <i>hp</i>	Energy Lost <i>kWh/yr</i>	Energy Cost Savings <i>per year</i>	Peak Demand Savings <i>kW-mo/yr</i>	Peak Cost Savings <i>per year</i>	Total Cost Savings <i>per year</i>
1/64	0.4	0.1	591	\$21	0.9	\$12	\$33
1/32	1.5	0.3	1,772	\$62	2.7	\$36	\$98
3/64	3.4	0.7	4,136	\$146	6.3	\$83	\$229
1/16	6.1	1.3	7,681	\$271	11.6	\$153	\$424
3/32	13.8	3.0	17,725	\$624	26.9	\$355	\$979
1/8	24.5	5.3	31,314	\$1,103	47.4	\$625	\$1,728
3/16	55.0	11.9	70,309	\$2,476	106.5	\$1,405	\$3,881
1/4	97.9	21.2	125,256	\$4,412	189.8	\$2,503	\$6,915

As the table shows, the cost of compressed air leaks increases exponentially as the size of the leak increases. This can be seen even more clearly in the graph below. As part of a continuing program to find and repair compressed air leaks, the table or graph on the next page can be referenced to estimate the cost of any leaks that might be found.



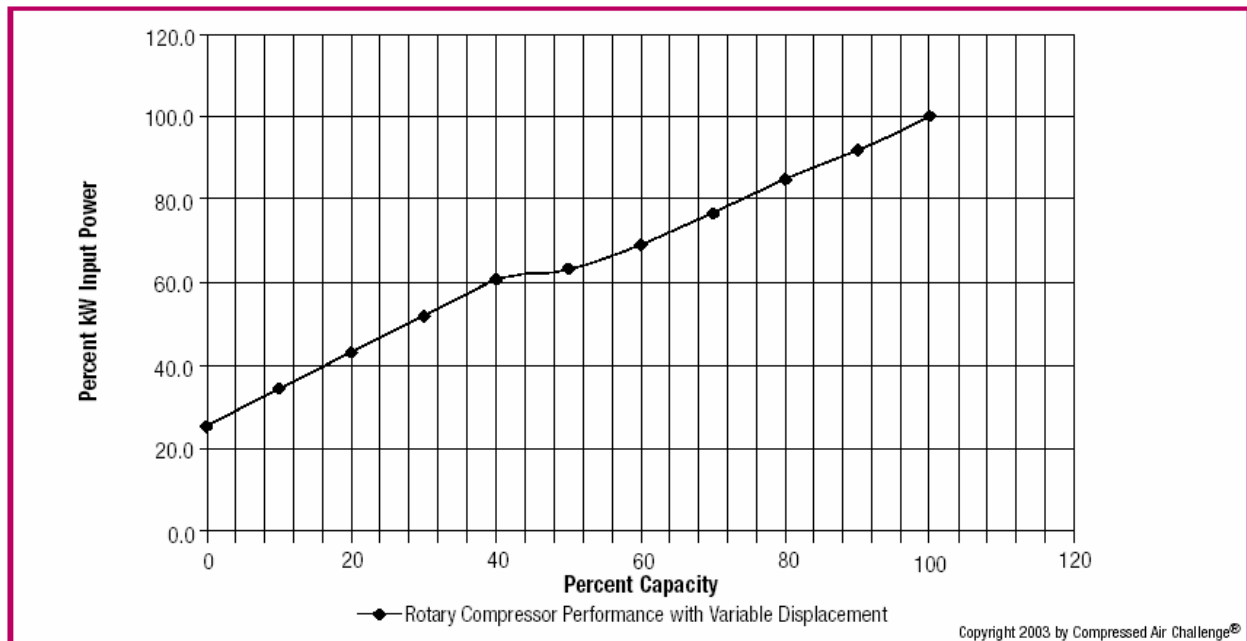
The estimated energy, peak demand, and cost savings for the specific air leaks found during the site visit are listed in the table below

Summary of Savings

Location			Leak Diam.	Pressure at Leak	Flow Rate	Power Loss	Energy Savings	Energy Cost Savings	Peak Demand Savings	Demand Cost Savings	Total Cost Savings
Area	Location	Source	<i>inches</i>	<i>psig</i>	<i>cfm</i>	<i>hp</i>	<i>kWh/yr</i>	<i>per year</i>	<i>kW-mo/yr</i>	<i>per year</i>	<i>per year</i>
Welding Area	Near pillar labeled: "1997, July"	ball valve	1/64	100	0.4	0.1	591	\$21	0.9	\$12	\$33
Main Room	Crane, Serial No: 97060210	ball valve	1/32	100	1.5	0.3	1,772	\$62	2.7	\$36	\$98
Main Room	Crane, Serial No: 97060211	t-valve	1/32	100	1.5	0.3	1,772	\$62	2.7	\$36	\$98
Main Room	Weld Storage Area	coupling	1/64	100	0.4	0.1	591	\$21	0.9	\$12	\$33
Welding Area	Above Milling Machine	t-valve	1/64	100	0.4	0.1	591	\$21	0.9	\$12	\$33
Welding Area	Above Milling Machine	t-valve	1/32	100	1.5	0.3	1,772	\$62	2.7	\$36	\$98
Main Room	In between BN-25A and 115013	air gun	1/64	100	0.4	0.1	591	\$21	0.9	\$12	\$33
New Line Testing	SW Corner by new machinery	air gun	1/32	100	1.5	0.3	1,772	\$62	2.7	\$36	\$98
New Line Testing	Near markerboard, above door	coupling	1/64	100	0.4	0.1	591	\$21	0.9	\$12	\$33
New Line Testing	In corner, by heater	ball valve	3/32	100	13.8	3.0	17,725	\$624	26.9	\$355	\$979
New Line Testing	CO monitor, by paint area	t-valve	1/32	100	1.5	0.3	1,772	\$62	2.7	\$36	\$98
Receiving	Crane, Serial No: 253525	coupling	1/64	100	0.4	0.1	591	\$21	0.9	\$12	\$33
TOTALS					23.7	5.1	30,131	\$1,060	45.8	\$607	\$1,667

From the table, the total power loss is about 5.1 hp or about 8.5% of the 60 hp maximum total operating compressor load for the two main compressors. This is a reasonable result since a good rule of thumb is that the total power loss due to air leaks could be as high as 20% of the total compressor power (20% of the maximum total operating pipe plant compressor power is $20\% \times 60 \text{ hp} = 12 \text{ hp}$). As the table indicates, the total estimated energy savings are about 30,100 kWh/yr and the corresponding energy cost savings are about \$1,060/yr. The peak demand savings are about 46 kW-mo./yr, which corresponds to annual peak demand cost savings of about \$610/yr. Thus, the total savings are about \$1,670/yr.

Note that from the table, the total compressed air flow lost through leaks is about 24 cfm. A good rule of thumb is that the total compressed air flow through air leaks could be as high as 20-30% of the total compressor output. Based on manufacturer's performance data, the capacity of this compressor is about 291 acfm at full load operating pressure and power. However, from the datalogger, the compressor is operating at about 50% of the full load power. The graph at the top of the following page shows the relationship between power and capacity for a typical air compressor with variable displacement control⁴ (such as that employed by this compressor).



As the graph shows, the capacity of a variable displacement compressor at 50% power is about 27% of full rated flow or about $291 \text{ acfm} \times 27\% \approx 79 \text{ acfm}$. Thus, the fraction of actual capacity lost to air leaks at this facility is $24 \text{ acfm} \div 79 \text{ acfm} = 30\%$.

Implementation Cost

In general, implementation involves any or all of the following: 1) replacement of couplings, fittings, gauges, and/or hoses; 2) replacement of seals around filters; and 3) repairing breaks in lines, etc. Estimates of the specific repairs and costs needed for the leaks found during the site visit are

⁴ From "Improving Compressed Air System Performance: A Sourcebook for Industry", page 44, U. S. Department of Energy, DOE/GO-102003-1822, November 2003, available online at http://www.compressedairchallenge.org/loc/location_library.cfm.

given in the table below. These estimates are based on the preliminary analysis of the leaks made by IAC personnel. Prices for replacement products were obtained from the Grainger 2004-2005 Catalog No. 395, as follows:

Costs for Replacement Parts

Description	Grainger List	Est. Discount	Est. Cost	Est. Labor	Total Cost	Item No.
1/4" Tee	\$8.79	10%	\$8	\$15	\$23	6JM16
1/4" Coupling	\$1.48	10%	\$1	\$15	\$16	6JL97
1/4" Ball Valve	\$4.96	10%	\$4	\$15	\$19	6GD1
1/4" Air Gun	\$13.99	10%	\$13	\$30	\$43	BG45

Maintenance personnel should perform a thorough examination to obtain a more accurate cost assessment. In some cases, the repair cost has been estimated high in order to provide the worst-case scenario.

Implementation Costs

Location			Repair Needed	Parts	Labor	Total Cost
Area	Specific	Leak Source				
Welding Area	Near pillar labeled: "1997, July"	ball valve	replace fitting	\$4	\$15	\$19
Main Room	Crane, Serial No: 97060210	ball valve	replace fitting	\$4	\$15	\$19
Main Room	Crane, Serial No: 97060211	t-valve	replace fitting	\$8	\$15	\$23
Main Room	Weld Storage Area	coupling	replace fitting	\$1	\$15	\$16
Welding Area	Above Milling Machine	t-valve	replace fitting	\$8	\$15	\$23
Welding Area	Above Milling Machine	t-valve	replace fitting	\$8	\$15	\$23
Main Room	In between BN-25A and 115013	air gun	replace fitting	\$13	\$30	\$43
New Line Testing	SW Corner by new machinery	air gun	replace fitting	\$13	\$30	\$43
New Line Testing	Near markerboard, above door	coupling	replace fitting	\$1	\$15	\$16
New Line Testing	In corner, by heater	ball valve	replace fitting	\$4	\$15	\$19
New Line Testing	CO monitor, by paint area	t-valve	replace fitting	\$8	\$15	\$23
Receiving	Crane, Serial No: 253525	coupling	replace fitting	\$1	\$15	\$16
TOTALS				\$73	\$210	\$283

Assuming that facility maintenance personnel can do this work, these leaks can be eliminated for about \$280. The cost savings of \$1,670/yr would pay for the implementation cost in about 2 months (about 0.2 year).

Recommended Preventive Maintenance Program

Maintenance personnel should also consider implementing a preventive maintenance program to continuously check for and repair air leaks. A preventive maintenance program could be implemented by having someone spend approximately one hour per week each month checking for and repairing air leaks. Based on figures estimated by IAC staff, the cost of maintenance labor is \$30/h. Thus, the annual maintenance labor costs would be $1 \text{ h/wk} \times 52 \text{ weeks/yr} \times \$30/\text{h} = \$1,560/\text{yr}$.

Our customers often ask about the ultrasonic leak detector that we use at the CSU IAC. We use a Model FS170MUS/SDT 170 Multifunctional kit available from SDT-North America. We purchased this unit with a flexible sensor, parabolic dish, and an aluminum case for about \$6,500 in August 2001. The SDT sales office in California can be reached at (210) 697 0335 or through email at sonatest@sbcglobal.net or on the Internet at <http://www.sonatest-plc.com>