EXECUTIVE SUMMARY
WIDGET CORPORATION
ERIE, PENNSYLVANNIA

An onsite compressed air system audit was performed at the Widget facility in Erie, Pennsylvania. The audit was conducted by a team from Compressed Air Technologies (CAT Inc.) commencing on March 27th, 2009 through March 31st, 2009. The findings, analysis and recommendations are detailed in this report. Unless otherwise noted, flow is given in Standard Cubic Feet per Minute (SCFM). A summary of the audit and results is provided below:

Overview:

After data collection and analysis, it was estimated that the daily compressed air demand for the air system was approximately 3,805 cfm. The actual air demand when eliminating compressed air inefficiencies is estimated to be 1,924 cfm. Should Widget elect to follow the recommendations contained within this report, savings on the annual compressed air costs of approximately **$302,035.00 per year** would be realized.

Compressed Air Audit Objectives:

The objectives of the Compressed Air Audit were as follows:

1. Identification of compressed air inefficiencies, including quantifying impact on maintenance and energy costs.
2. Provide recommendations/solutions, including estimated costs to eliminate the inefficiencies and assure reliability of the compressed air system.
3. Perform ultrasonic leak detection audit to quantify actual costs of the air leaks. Includes tagging and cataloging of the air leaks found.
4. Determine base line, minimum pressure requirement for the Plant Air system.
6. Perform dewpoint analysis of main air dryers and various areas around the Plant.
7. Determine the cause for increased demand on weekends and develop a strategy to reduce the air consumption.

The table below shows the current operating parameters of the system.

Current vs. Proposed Air System Costs

From Appendix 6	Current Compressed	Proposed
	Air System (106 psig)	Air System (80)
Total Compressors Online	2 - 3	1 - 2
Dryers Online	17	2
Compressor Hp Available	950	950
Total Hp Consumed: Electric	858	544
Average SCFM Consumed	3,805	1,862
Electric Cost (cents/kwh)	$0.119	$0.119
Comp/Dryer Elec Cost/Year	$702,981.58	$445,946.15
Maintenance Cost	$145,000.00	$100,000.00
Total Direct Annual Cost	$847,981.58	$545,946.15
Annual Yearly Savings	**$302,035.43**	
Cost of Compressed Air per Day	$2,323.23	$1,495.74

Note: The above table averages the weekday and weekend compressed air consumption and BHP.

Inefficiencies:

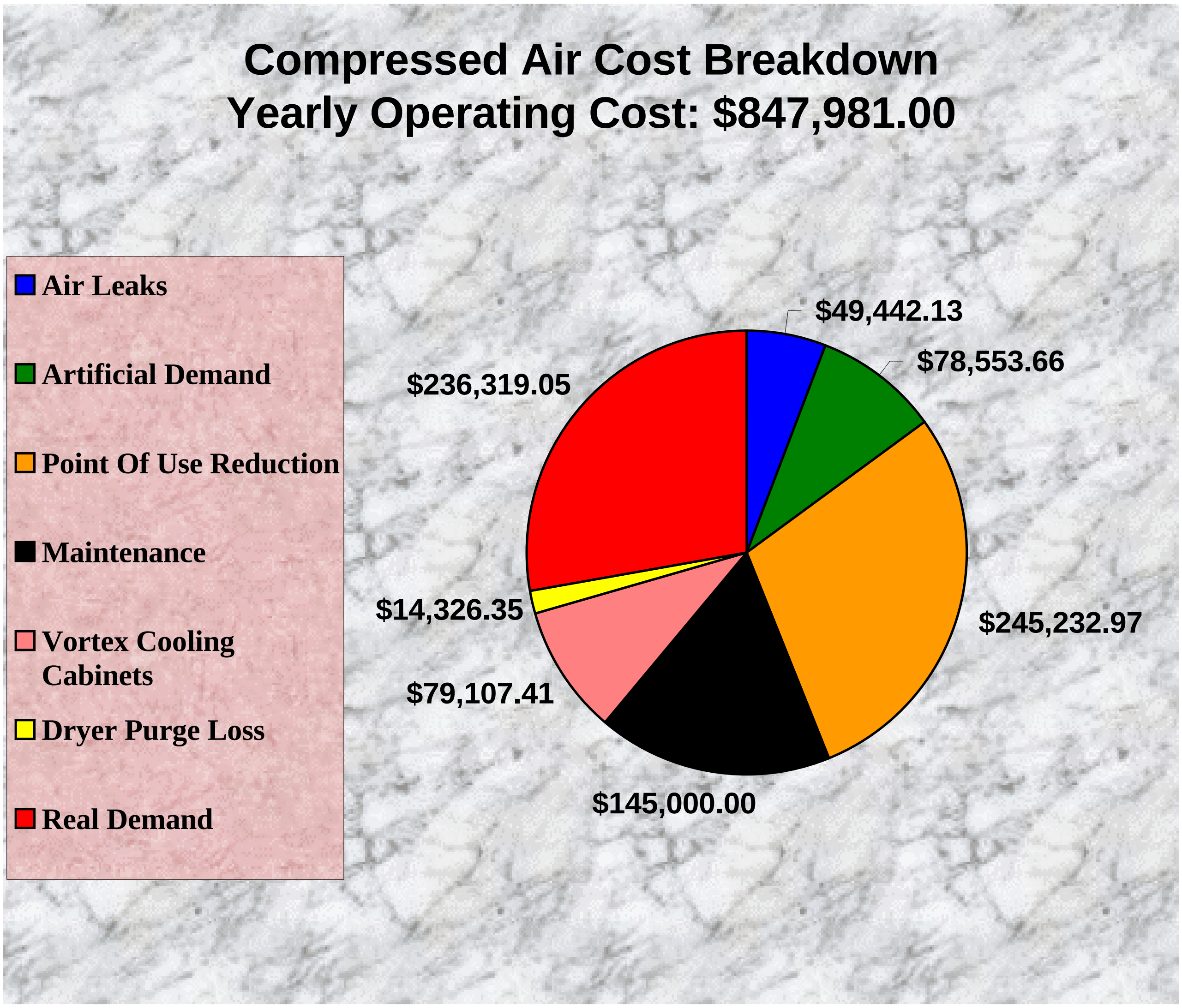
The main inefficiencies as determined by the air audit are as follows:

1. Point of uses applications of compressed air, such as blow-offs and cooling consume the majority of the compressed air produced.
2. Compressed air is left on to production line equipment when not in use.
3. Widget uses compressed air for clean-up operations. This is especially true on weekends. Blow-off guns run on a continuous basis for up to 10 hours on Saturdays.
4. Main header dewpoint was measured at +43F. ISO8573.1 suggest a –40F dewpoint for some of the more specific uses of air at Widget, like control valves and air that may come in contact with product.
5. Air leaks consume approximately 7% of total air produced at the Plant.
6. Artificial demand, whereby the plant air pressure is high then require constitutes approximately 11% of the total compressed air costs.
7. Purge losses from the satellite dryers consume 2% of the compressed air produced.
8. Lack of adequate useful storage in the Plant contributes to pressure fluctuations, which results in an increase in the artificial demand of both the Plant air-lines.

Individual inefficiency costs can be viewed below.

Details of the inefficiencies can be located in the Engineering Report. It should be noted, that by simply repairing one of the inefficiencies, may not necessarily translate into energy savings immediately upon implementation. By simply repairing air leaks for example, without addressing storage and intermediate pressure controls, would have a minimal affect on reducing compressed air demand. The end result would be an increase in the Plant air pressure. This would actually lead to an increase in the bhp consumed by the compressors and increase electrical consumption. The resultant projects, explained below, fully capitalize on the implementation of the cost savings measures.

Compressed Air Costs/Inefficiencies



See Appendix 15 for inefficiency summary

Main Project Summary Chart

The following table contains the scope of supply required to maximize the savings at Widget:

	Widget Corporation - Project/Savings Table Cost Breakdown					
Appendix 14						
		Est. Cost	Est Cost	Total	Pay	Back
Areas	Equipment	Min	Max	Savings	Min	Max
					Yrs	Yrs
150 - 450			PROJECT 1			
	1-3000 cfm Dryer (vac-assist)	$ 55,000.00	$ 65,000.00			
	1 - 3,000 Gallon Air Receivers	$ 12,000.00	$ 15,000.00			
	1 - 3000 cfm Demand Control Valve	$ 18,000.00	$ 24,000.00			
	Installation	$ 100,000.00	$ 125,000.00			
	Engineering/Project Management	$ 18,000.00	$ 25,000.00			
	1 - Air Free Drains	$ 750.00	$ 850.00			
	200 - Hi-E Nozzles	$ 6,000.00	$ 9,000.00			
	150 Hi-E Air guns	$ 10,000.00	$ 14,000.00			
	30 - Air Knives	$ 10,000.00	$ 14,000.00			
	50 - Control Box Fans	$ 4,000.00	$ 6,000.00			
	100 Solenoid Shut-Off Valves	$ 3,000.00	$ 5,000.00			
	2 - 8 HP Vacuums	$ 16,000.00	$ 24,000.00			
	Air Leak Repair	inc	inc			
350 DC						
	1-1500 cfm Dryer (vac-assist)	$ 45,000.00	$ 55,000.00			
	1 - 1500 cfm Demand Control Valve	$ 14,000.00	$ 18,000.00			
	Installation	inc	inc			
	1 - Air Free Drains	$ 750.00	$ 850.00			
	1-8HP Vacuum	$ 17,000.00	$ 19,000.00			
	Estimated Freight	$ 8,000.00	$ 12,000.00			
	Total Cost	$ 337,500.00	$ 431,700.00	$302,035.00	1.12	1.43
Optional	Compressor Controls	$ 25,000.00	$ 35,000.00			
	Add Monitoring Package	$ 25,000.00	$ 50,000.00			

(See Appendix 14)

Note: Above table +/-15% and is based on past experience with similar sized systems and equipment.

By following the recommendations listed in the Engineering Report, Widget can realize the following benefits:

- Elimination of point-of-use dryers.
- Reduction of on-line horsepower.
- Substantial increase in compressed air system quality and reliability.
- Pressure stabilization throughout the entire facility.
- Reduction in maintenance costs for the compressed air system.
- Reduction in air leaks.
- Reduction in overall compressed air demand.
- Increase in storage capacity.
- Increase in compressed air system efficiency will allow Widget to produce air at the lowest cost possible.
- **Compressed air savings of over $302,035.00 per year.**

Summary

The findings presented in this report suggest conclusively, that most of the compressed air costs can be attributed to the point of use blow-off, cooling, clean-up and air leaks. Also contributing to the inefficiencies are compressor inefficiency and satellite regenerative air dryers. A system upgrade project will include the following:

1. Replacement of inefficient dryers.
2. Drying of all compressed air to –40F at primary locations.
3. Addition of a 2 regenerative air dryers (one at 150-450 & 350 DC).
4. Addition of Demand Flow Stabilizer valves.
5. Adding storage at primary compressor areas.
6. Addressing point of use issues (free blowing of compressed air for cooling/clean-up).
7. Reduction of compressed air demand for product blow off on production equipment with air knives and Hi-E nozzles.
8. Reduction in compressed air demand for clean-up in the Plant with Hi-E nozzles.

More description and detail of the above can be located in the Engineering Report.

Based on the facts presented in this report, a compressed air system upgrade project is warranted. Should Widget elect to implement CAT's recommendations, the problems identified in this report will dissipate. The end result will be considerable savings on energy and maintenance costs. Additionally, and most important, compressed **air quality and reliability** will increase dramatically, allowing Widget to operate the air system as efficiently as possible, providing production with a clean and reliable air supply at the proper pressure and lowest cost.

COMPRESSED AIR AUDIT REPORT
WIDGET, ERIE, PENNSYLVANNIA
ENGINEERING REPORT

An onsite compressed air system audit was performed at the Widget facility in Erie, Pennsylvania. The audit was conducted by a team from Compressed Air Technologies (CAT Inc.) commencing on March 27th, 2009 through March 31st, 2009. The findings, analysis and recommendations are detailed in this report. Unless otherwise noted, flow is given in Standard Cubic Feet per Minute (SCFM). A summary of the audit and results is provided below:

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After data collection and analysis, it was estimated that the daily compressed air demand for the air system was approximately 3,805 cfm. The actual air demand when eliminating compressed air inefficiencies is estimated to be 1,924 cfm. Should Widget elect to follow the recommendations contained within this report, savings on the annual compressed air costs of approximately **$302,035.00 per year** would be realized.

Compressed Air Audit Objectives:

The objectives of the Compressed Air Audit were as follows:

1. Identification of compressed air inefficiencies, including quantifying impact on maintenance and energy costs.
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3. Perform ultrasonic leak detection audit to quantify actual costs of the air leaks. Includes tagging and cataloging of the air leaks found.
4. Determine base line, minimum pressure requirement for the Plant Air system.
6. Perform dewpoint analysis of main air dryers and various areas around the Plant.
7. Determine the cause for increased demand on weekends and develop a strategy to reduce the air consumption.

Compressed Air System Descriptions:

There are currently 3 air compressors and 17 air dryers used throughout the Plant. The compressed air production locations and terminology to be used to describe the main systems are as follows:

1. 150 – 450 Area (2 Compressors, 2 Refrigerated Dryers)
2. 350 DC Area (1 Compressor, 1 Refrigerated Dryer)

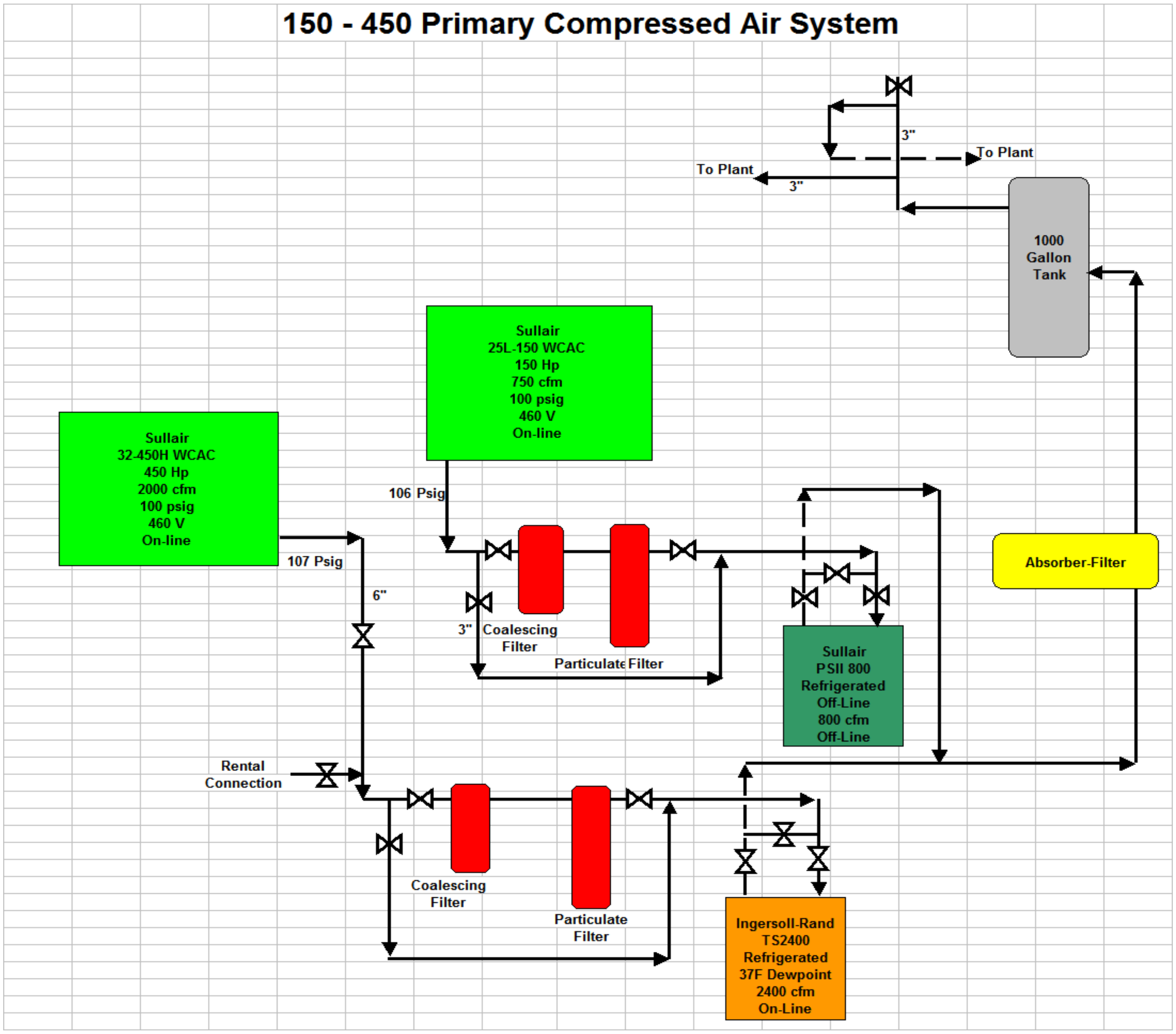
A brief description of the two main air production areas for the Widget facility, are listed as follows:

150 – 450 - Compressed Air Station

At this location, compressed air is produced by two, Sullair, oil-flooded, water-cooled, rotary screw air compressors. Compressor #1 is a Sullair model 32-450H WCAC, rated at a design flow of 2000 Acfm at 115 psig. This unit utilizes a 450 Hp, 460 volt, electric motor. The current discharge pressure from this compressor is 107 psig. After compression, air is sent through a 6” pipe that feed into a coalescing filter. The air then travels into a particulate filter, which leads into an Ingersoll-Rand 2400 cfm refrigerated air dryer, with a dewpoint of 37F. After drying the air is sent through an afterfilter which feeds into a 1000 gallon air receiver. From the air receiver the air feeds into two 3” lines, that supplies the Plant. (See Appendix #3 for locations of dryers and compressors).

The second compressor in this area is a Sullair Model 25L-150 WCAC rated at a published design flow of 750 Acfm at 100 psig. This unit utilizes a 150 Hp, 460 volt, electric motor. The current discharge pressure from this compressor is 106 psig. After compression, air is sent through a 3” pipe that feed into a coalescing filter. The air then travels into a particulate filter, which leads into a Sullair PSII, 800 cfm refrigerated air dryer. This dryer was offline at the time of the audit. The air is then sent into a common header with the first compressor and sent through the afterfilter and into a 1000 gallon air receiver. From the air receiver the air feeds into two 3” lines, that supplies the Plant. (See Appendix #3 for locations of dryers and compressors).

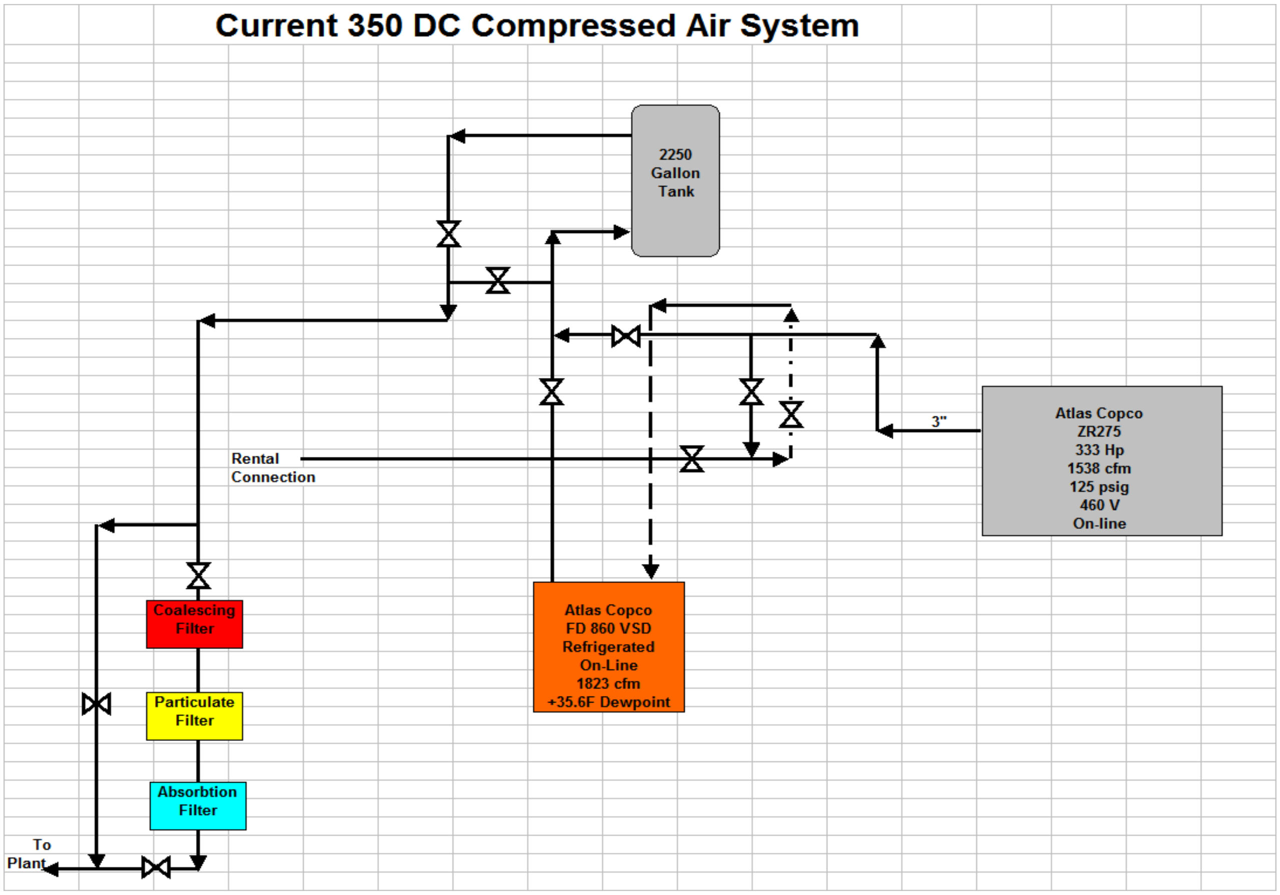
Sketch 1.



350 DC - Compressed Air Station

In this location, compressed air is produced by an Atlas Copco, oil-free, water-cooled, rotary screw air compressor. The compressor is a model ZR275, rated at a design flow of 1538 Acfm at 125 psig. This unit utilizes a 350 Hp (245 kW), 460 volt, electric motor. The current discharge pressure from this compressor is 107 psig. After compression, air is sent through a 3" pipe into an Atlas Copco FD 860 VSP refrigerated air dryer. The dryer has a capacity of 860 cfm and has a dewpoint of 35.6F. After drying the air is sent into a 2250 gallon air receiver. From the receiver air is sent through three filters; a coalescing, particulate and absorption filter. After filtration, compressed air is sent to the 3" Plant Air Header. (See Appendix #3 for locations of dryers and compressors).

Sketch 2.



2.0 Compressed Air Inefficiencies

150 – 450 Compressor Area

A) There is no "Useful Storage" located in this compressor area. Without useful storage the local compressor controls cannot react properly to demand changes in the Plant. Thus large pressure swings can occur. The end result is that various parts of the facility are susceptible to low pressure. The current receivers located in the air system act as transport mechanisms. After the receiver is filled to capacity, the inlet pressure equals the discharge pressure, thus there is no useful storage. Basically the air receiver acts as a pipe, allowing the same amount of air and pressure to pass through, as enters into it. To act as a true storage vessel, air must be stored as close to the compressor design point as possible and released to the Plant at a lower, controlled, pressure. This will create "Useful Storage". Creation of useful storage will in effect, allow compressors to run at optimal levels. Event demands will be satisfied from the stored air in the receiver vessels and dampen the level of pressure fluctuations throughout the Plant. The end result being elimination of low-pressure problems and savings of valuable operating dollars by actually being able to lower pressure to the plant.

B) Lack of compressor controls coupled with the inadequate storage allows each compressor to run independent of one another. Thus the amount of input energy required to run the system is higher as well as the pressure required to satisfy plant air demand. This will result in higher electrical costs, increased maintenance intervals and decrease in compressor longevity.

C) Current artificial demand of the plant is 20 psig. Artificial demand is the difference between the plant minimum air pressure requirement and the actual plant air pressure. The two compressors discharge at 104 psig and the minimum pressure monitored was 84 psig. 104 psig – 84 psig = 20 psig artificial demand. This equates to an additional 10% more input energy required than is necessary to run the plant. This equates to approximately 61.6 BHP or **$48,730.00 per year.**

350 DC Compressor Area

A) As was the case above, there is no "Useful Storage" located anywhere within the compressed air system. Without useful storage the local compressor controls cannot react properly to demand changes in the Plant. Thus large pressure swings can occur. The end result is that various parts of the facility are susceptible to low pressure. The current receivers located in the air system act as transport mechanisms. After the receiver is filled to capacity, the inlet pressure equals the discharge pressure, thus there is no useful storage. Basically the air receiver acts as a pipe, allowing the same amount of air and pressure to pass through, as enters into it. To act as a true storage vessel, air must be stored as close to the compressor design point as possible and released to the Plant at a lower, controlled, pressure. This will create "Useful Storage". Creation of useful storage will in effect, allow compressors to run at optimal levels. Event demands will be satisfied from the stored air in the receiver vessels and dampen the level of pressure fluctuations throughout the Plant. The end result being elimination of low-pressure problems and savings of valuable operating dollars by actually being able to lower pressure to the plant.

B) Current artificial demand of the compressor area plant is 20 psig. Artificial demand is the difference between the plant minimum air pressure requirement and the actual plant air pressure. The two compressors discharge at 104 psig and the minimum pressure monitored was 84 psig. 104 psig – 84 psig = 20 psig artificial demand. This equates to an additional 10% more input energy required than is necessary to run the plant. This equates to approximately 37.7 BHP or **$29,823.00 per year.**

General Plant Inefficiencies

A) It was apparent that there is a substantial amount of air leaks throughout the entire Plant. A conservative estimate puts the total leak loss at approximately 250 cfm This equates to approximately 62.5 Bhp or **$49,442.00 per year in lost energy.**

B) There are several types of blow-off nozzles/cooling devices used in the Plant. They include the following:

1. Air Guns
2. Straight Pipe (½" – ¼")
3. Crimped Pipe
4. Air Lances (straight long pipe)

There are over 100 air guns (ex. #1, below) used throughout the Plant for clean-up and blow-off. The air guns were flow tested and it was found that each gun consumes 50 cfm at line pressure when activated. The straight pipe air lances (ex. #2, below) consume over 100 cfm. In addition when these devices are implemented it will cause the air system pressure to fluctuate do to the relatively small storage volume the pipe system offers and lack of useful storage. The air guns are predominantly used on Saturday, day shifts. During this clean-up period there are approximately 15 guns online at any one time. Thus for 8 hours per week, 750 cfm of compressed air is used consuming 187.5 Bhp. Thus the cost of clean-up based on 416 hours per year equates to $7,043.00 or $17.00 per hour. Though the air guns are used at various times and are not employed on a full time basis, it is conservatively estimated that there are at least two air guns on, at any given time. Thus 100 cfm or 25 Bhp is consumed constantly, equating to **$19,776.00 per year** in lost energy.

1: Air Gun Example

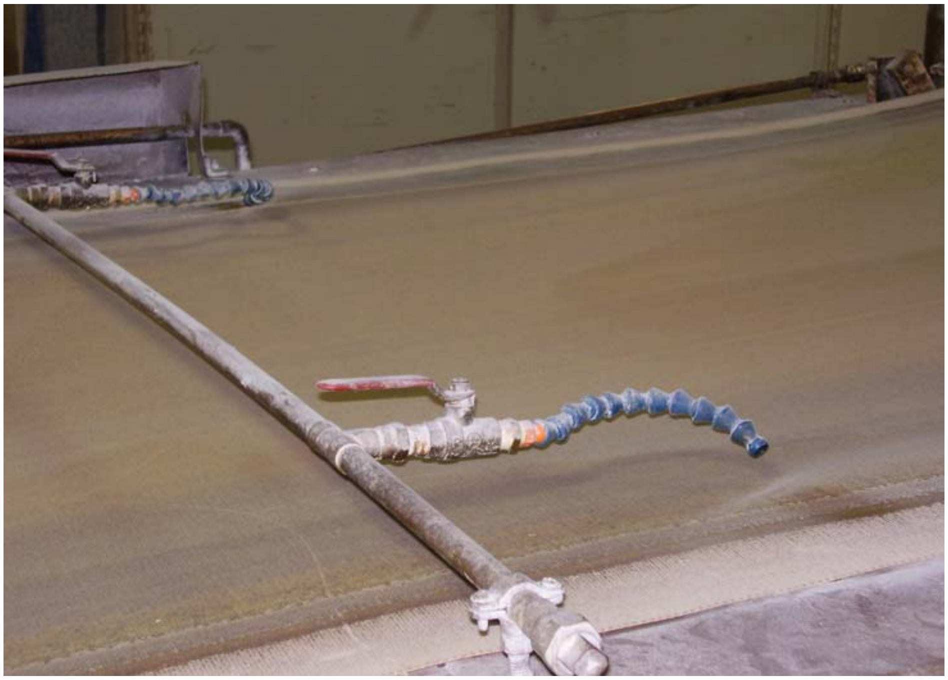
2: Air Lance Example

3: Air Lance Example (2nd Floor Bakery)

It should be noted that open pipes (pic. #2 & #3, above) connected to compressed air lines must have a self relieving mechanism such that if the pipe is pressed against a body, the air will be able to be expelled from the sides. Picture #1, above has this relief, while picture #2 & #3 are an OSHA violation and could be subject to a fine.

E) There are several places within the plant where machinery has the following sign posted on the production lines. The result is that even when there is no production, compressed air remains on-line and is allowed to escape to atmosphere (see item F, below).

F) At the second floor bakery, column I-5 Line uses two ¼” air lines for debris blow-off. This consumes approximately 50 cfm, which equates to 12.5 Bhp or **$9,888.00 per year** in lost energy.



G) At the 2nd floor bakery, near column I-5, two ¼” air-lines with special tips is used for debris blow-off. This consumes approximately 30 cfm, which equates to 7.5 Bhp or **$5,936.00 per year** in lost energy.

H) In the 2^{nd} floor bakery, by the L-5 and K-5 Lines use a perforated pipe for blow-off. The blow-off device has thirty, $1/32^{nd}$ holes, with two sides, for a total of sixty $1/32^{nd}$ holes. The total cfm consumed is 1.3 cfm per hole or 78 cfm total. There are two of these devices. Thus the overall consumption is 156 cfm. This equates to 39 Bhp or **$30,851.00 per year** to operate.

I) Widget - has several dryer/filtration locations. Utilizing satellite compressed air dryers has several distinct disadvantages as follows:

1. Induced pressure drop resulting in lost energy.
2. Elevated overall cost to maintain the system.
3. Operating costs are elevated due to purge losses on the regenerative dryers and power cost to operate refrigerant compressor.

Warehouse Ceiling 1^{st} Floor

First Floor Packaging At Column M-19 Ceiling Duplex-Triplex Filter System

J) Combined, the multiple compressor areas can produce up to **169 gallons of water per day.** Should the dryers be by-passed or taken off-line, the result would be massive quantities of water injected into the compressed air system. As much as 30% – 40% of condensate could be passed into the Plant Air lines. The water could only be removed through use of air within the Plant, air leaks or knock-out tanks, tools or valves.

K) In the 2nd floor bakery, at the H6 Column, there is a 4' pipe stretched across the conveyor. It contains 90, 1/32nd drilled holes use to blow debris or cooling. This apparatus consumes 117 cfm. This equates to 29.25 or **$23,138.00 per year** to operate.

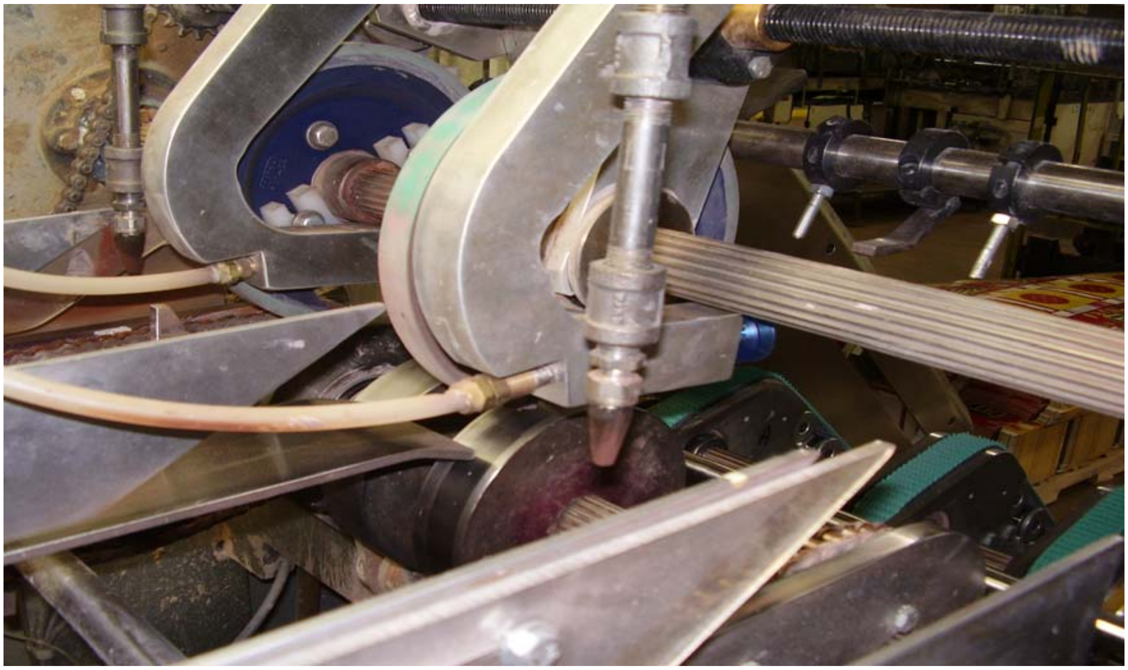
L) On the bakery ovens compressed air is used for cooling/debris blow-off, of the infra-red sensors. They use of ¼” blow-offs regulated to 35 psig. There are a total of eight cameras, thus this process consumes 8 times 45 cfm or 360 cfm. This equates to 90 Bhp or **$44,497.00 per year**.

M) In the 2nd floor bakery at the H6 Column, No.6 oven area, there is are two line blow-offs with ¼” diameter orifice. These devices consume 45 cfm x 2 or 90 cfm total. This equates to 22.5 Bhp or **$18,000.00 per year** to operate.

N) At column F5 in the 2nd floor bakery, a crimped pipe is used for blow-off. The pipe is approximately 3/8” with a 1/8” orifice. This equates to approximately 20 cfm, 5bhp or **$3,955.00 per year** to operate.

O) In the first floor packaging at column J20, Rovena Machines, there is a 1/8" blow-off orifice on 8 of these machines. Each orifice consumes 15 cfm for a total 120 cfm. This totals 30 Bhp or **$23,772.00 per year**.

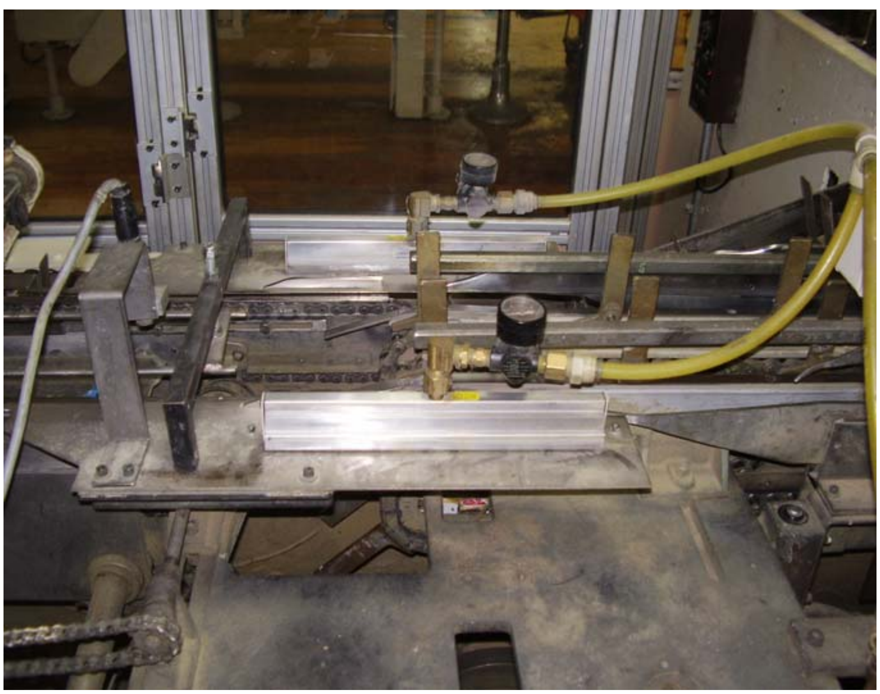
P) In the Packaging are at column K20 there are two ¼" blow-offs consuming approximately 60 cfm. This equates to 15 Bhp or **$11,866.00 per year** to operate.



Q) Bakery cabinets are vortex cooled to keep electrical components from overheating. The smallest vortex cooler offered by Grainger for this task, consumes 8 cfm. This would equate to 2.0 Bhp. There are an estimated 50 of these units scattered around the Plant, thus conservatively Widget is consuming 100 Bhp costing **$79,107.00 per year** in lost energy.

R) In the first floor packaging area, a ¼” line is used to pressurize a tank. The majority of the air was leaking back to atmosphere at a rate of 25 cfm. This equates to 6.25 Bhp or **$4,994.00 per year** to operate.

S) At the first floor packaging area near column K23, there are three machines using a duplex 1/8” orifice, regulated to 20 psig. Thus each unit consumes 14 cfm. Thus the 3 units consume a total of 42 cfm equating to 10.5 Bhp or **$8,306.00 per year**.



T) In the Packaging Area near column K23, there are two ¼” nozzles used for blow-off. Combined they consume 15 cfm, 3.75 Bhp or **$2,966.00 per year.**

U) In the first floor packaging area, a pipe with seven 1/32nd inch holes is used for blow-off. There are two of these devices per unit, with a total of two units. Thus the entire system consumes 30 cfm equating to 7.5 Bhp or **$5,993.00 per year.**

V) Lack of compressor controls does not allow communication between compressors or compressor sites. Thus in times of high or low demand, Widget personnel have to add or remove the appropriate amount of horsepower. Generally, to protect against the instantaneous event demands, more compressors are on-line then required.

W) There are 17 satellite dryers within the air system. The desiccant dryers consume 72 cfm of Air for dryer purge purposes. This equates to 18 Bhp or $7,127.00 per year in lost energy.

3. 0 Compressed Air System Efficiency (CFM Delivered Per BHP Input)

The Widget compressed air system produces a certain amount of compressed air or SCFM for every 1 BHP of input energy. This is commonly called the CFM/BHP ratio. The compressor type and its design discharge pressure, will determine the cfm./ bhp ratio as listed below:

1. Two Stage Oil-Free Rotary Screw Compressors @ 100 psig: 4.0 cfm/bhp (3.8 cfm/Bhp @ 125 Psig)
2. Single Stage Oil Flooded Rotary Screw Compressor @ 100 psig: 4.5 cfm/bhp (4.2 cfm/Bhp @ 125 Psig)
3. Two Stage Oil Flooded Rotary Screw Compressor @ 100 psig: 4.8 cfm/bhp (4.4 cfm/Bhp @ 125 Psig)
4. Three Stage Centrifugal (oil free) Compressor @ 100 psig: 4.5 cfm/bhp (4.2 cfm/Bhp @ 125 Psig)

For rotary screw compressors (oil free & oil flooded), the cfm/bhp ratio is irregardless of the size of the compressors.

Each system has individual characteristics that allow for calculation of the amount of cfm produced per Bhp input or **Cfm/Bhp**. The actual demand was measured using a mass flow insertion probe for the stationary Ingersoll-Rand and Atlas Copco. The remaining compressor's flow was derived using the manufacturer published data, amp draw and over 22 years of performance testing of equivalent compressors.

3.1 450H – 150L Compressors

The two Sullair compressors discharge into a common header. The mass flow probe was placed in this line and measured the total flow from the two compressors.

According to the compressor manufacturer's published data, the 32-450H, oil-flooded rotary screw compressor in this area will produce 2000 cfm at 115 psig, at a full load Bhp of 495. Thus the manufacturers stated Cfm/Bhp ratio is 2000 cfm / 464 Bhp = 4.31 Cfm/Bhp.
The 25L-150, oil-flooded rotary screw compressor in this area will produce 750 cfm at 100 psig, at a full load Bhp of 165. Thus the manufacturers stated Cfm/Bhp ratio is 750 cfm / 165 Bhp = 4.54 Cfm/Bhp. Both ratings are based on **Acfm**. The design inlet conditions are 14.4 psia, inlet pressure, 60% relative humidity and 95F inlet air temperature. Acfm is the amount of **Volume** of air drawn into the compressor. Acfm is used in the design criteria of positive displacement compressors such as reciprocating and rotary screw compressors. **SCFM** is defined as the amount of **Mass** drawn from the compressor based on actual ambient conditions. The standard SCFM conditions, as called for by ASME are 14.4 psia, 68F, 36% RH and is typically used as the basis for rating centrifugal compressors.

Based on the SCFM and Bhp recorded during the audit (see Appendix 5), the compressors, on average, produced 2,418 cfm, consuming 616 Bhp at 106 psig discharge pressure. The amp draws were monitored by, CAT using micro data loggers and converted to Bhp. The resultant Cfm/Bhp ratio is calculated as follows:

2,418 Cfm / 616 Bhp = 3.92 Cfm/Bhp

The above Cfm/Bhp ratio is below satisfactory. The current system should at minimum, achieve a 4.0 cfm/bhp ration. Thus the system is operating at approximately 15% below published industry standard. It is 24.6% less efficient then centrifugals and single stage oil-flooded rotary screw compressors and 29% less efficient than two stage oil-flooded rotary screw compressors.

3.2 – 350 DC Compressor

According to the compressor manufacturer literature, the Atlas Copco compressor, will produce 1,538 cfm at 125 psig, at a full load Bhp of 350. Thus the manufacturers stated Cfm/Bhp ratio is 1,538 cfm/350 Bhp = 4.4 Cfm/Bhp. This rating is based on **Acfm**. According to CAGI/PNEUROP, Acfm is measured at the discharge terminal point of the compressor package. Based on the recorded data obtained by CAT during the audit, the actual average flow of this unit is to 1387 Acfm.

Based on the SCFM and Bhp recorded during the audit (see Appendix 5), the compressors, on average, produced 1,387 cfm, consuming 377 Bhp at 104 psig discharge pressure. The amp draws were monitored by, CAT using micro data loggers and converted to Bhp. The resultant Cfm/Bhp ratio is calculated as follows:

1,387 Cfm / 377 Bhp = 3.7 Cfm/Bhp

The above Cfm/Bhp ratio is below satisfactory. The current system should at minimum, achieve a 4.0 cfm/bhp ration. Thus the system is operating at approximately 20% below nameplate performance. It is 20% less efficient then centrifugals and 25 less efficient than two stage oil-flooded rotary screw compressors.

3.3– Overall Compressed Air System Efficiency

The resultant metered system Cfm/Bhp is 3,805 Cfm /993 bhp = 3.83 Cfm/Bhp.

Based on published data of the compressors currently on-line, the Cfm/Bhp should be 4,128 Cfm / 942 Bhp or 4.38 Cfm/Bhp.

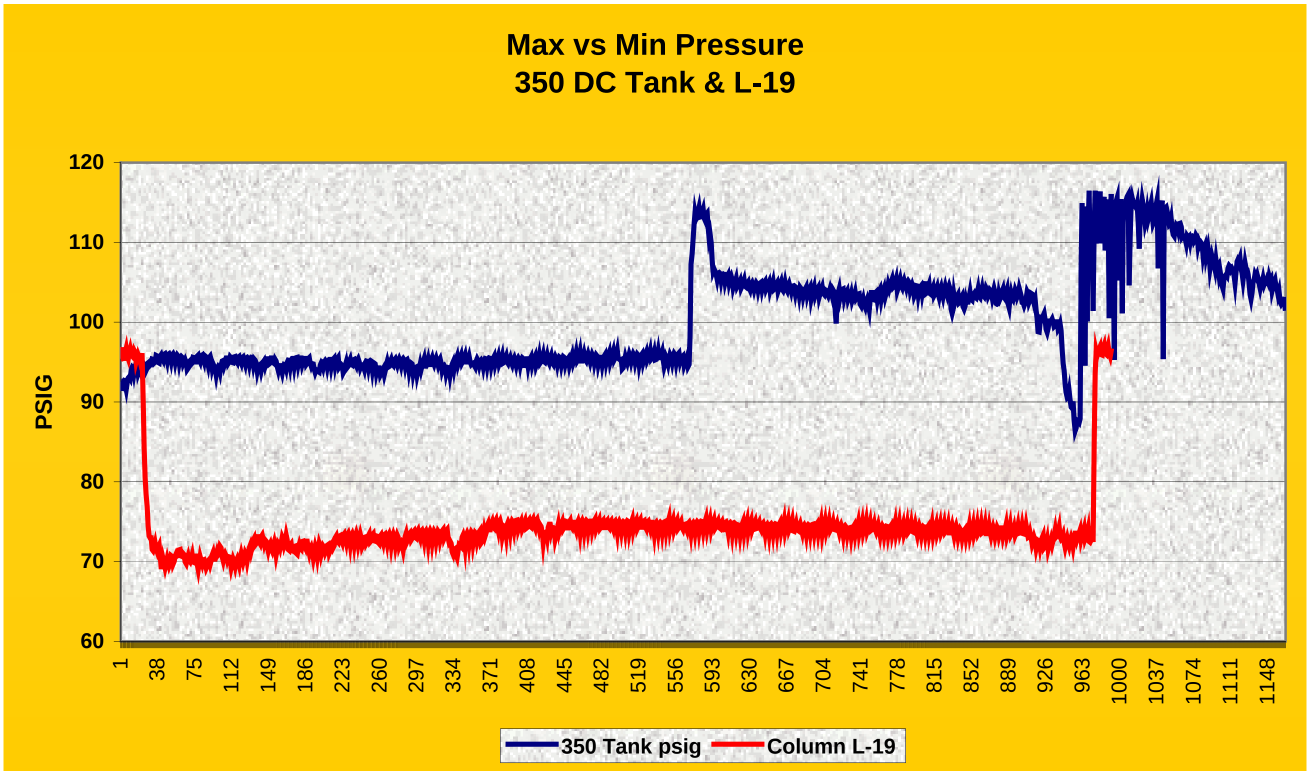
Thus the current system is operating at 3.83/4.38 or 12.6% below current compressor performance design.

4.0 Current Plant & Instrument System Air Pressures

4.1 Plant Air Pressure

The Plant System air pressure fluctuated between 116.9 psig (350 DC Air Receiver) and 69 psig (Column L-19). This excludes the low pressure experienced over the weekend, on Sunday, March 29th at 8:00 am. The only compressor online was the Sullair 25-150L and the pressure dropped to 24 Psig. The large pressure swings occur due to lack of useful storage as described above and frequent event demands such as air gun usage and production lines being brought on-line. Thus the pipe header and air receivers are the sole storage volume, which is not sufficient enough to satisfy the event demands. The Plant pressure recordings from each logged area were charted and tabulated in **Appendix 4** for review. **The average Plant pressure** as determined by the results of the data logging was **87.3 psig.** The following graph depicts the pressure differential.

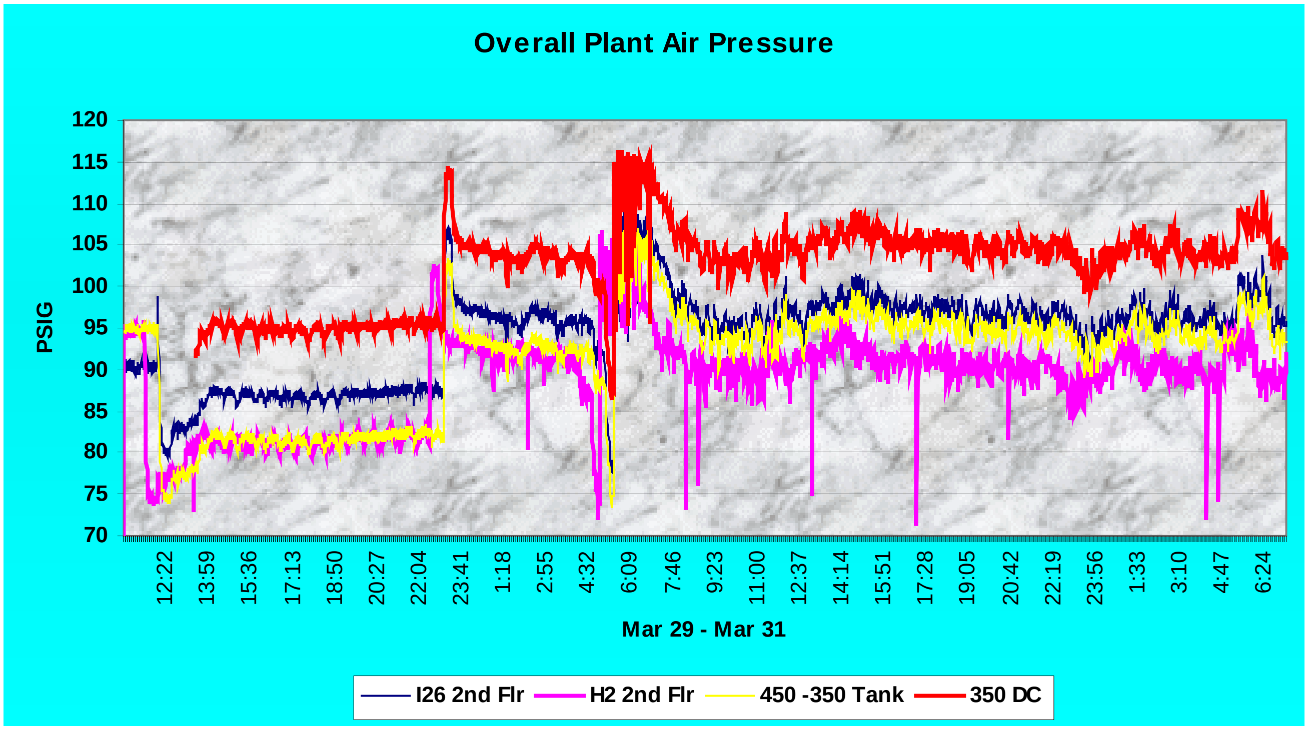
Graph 1:



4.2 Overall Plant Pressure

The following chart represents how the air distribution system is interconnected throughout the plant. The graph clearly shows that without useful storage, event demands or large air use will affect the entire system in a uniform fashion.

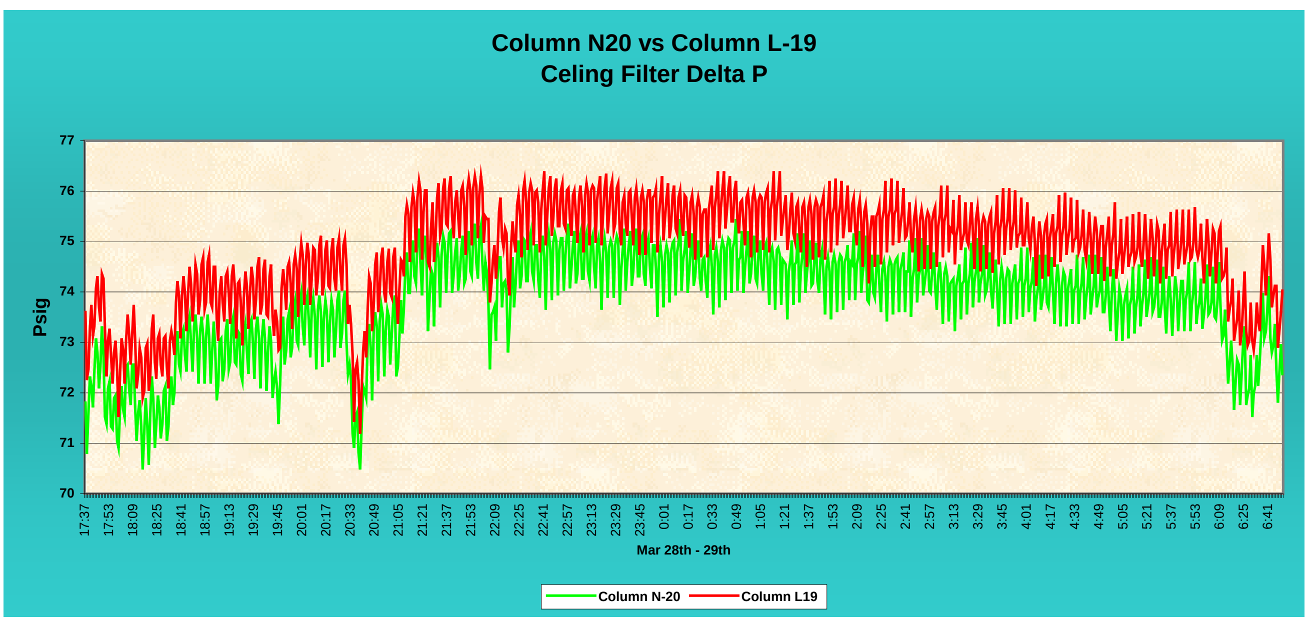
Graph 2:



4.3 Ceiling Filter Delta P

A test to measure the pressure drop across the ceiling filters was undertaken. The results of this test can be viewed in the following chart. The pressure drop across the filters, on average, is approximately 1 psig. These filters have not been changed in some time. Thus the conclusion is that the air is cleaned upstream of these filters and they are not necessary to the operation of the system. Their only purpose is to drain the system of 0.5% energy.

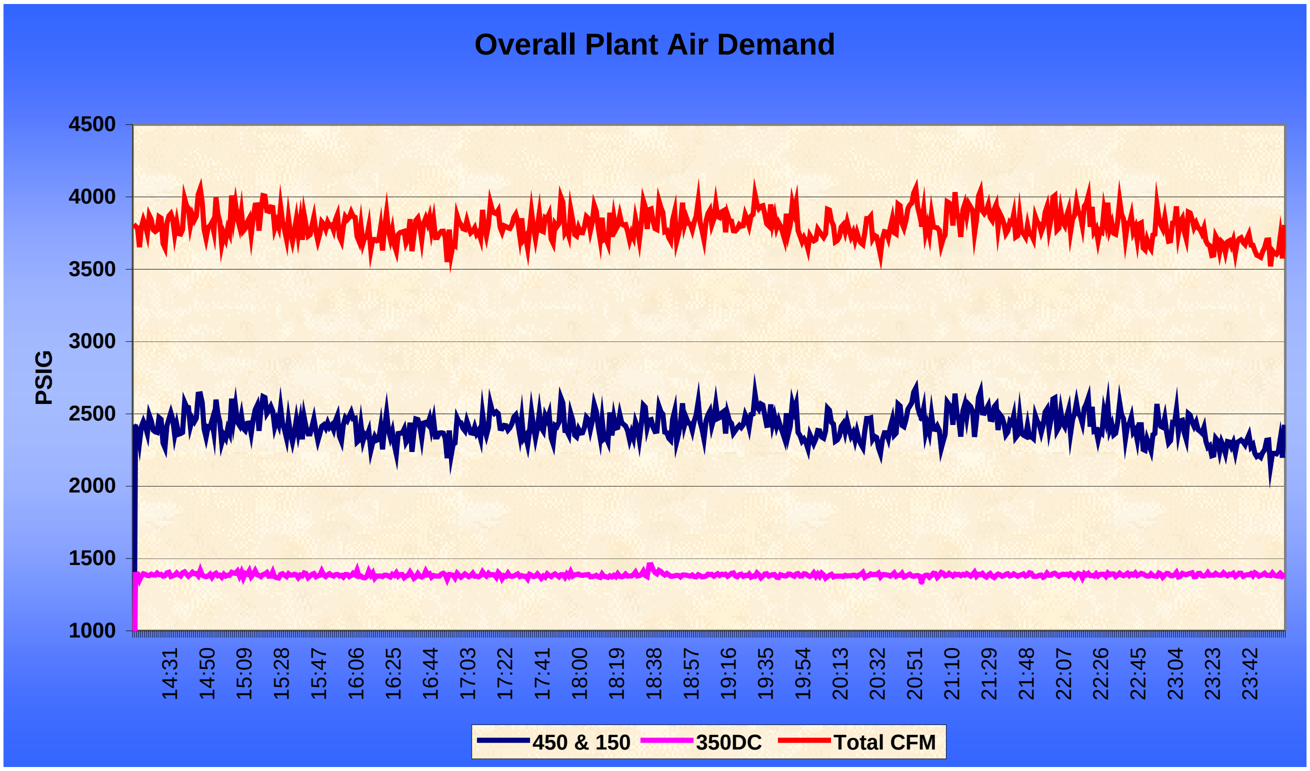
Graph 3:



4.4 Plant Air CFM Demand

The flow was measured at the Widget facility over the course of the audit. The amount of compressors on-line can fluctuate from one to three on-line at any one time. Horsepower and savings calculations were based on approximately 2.5 compressors being online. The demand for weekdays was approximately 3805 cfm and 2400 cfm for weekends. The following graph depicts a typical weekday compressed air demand.

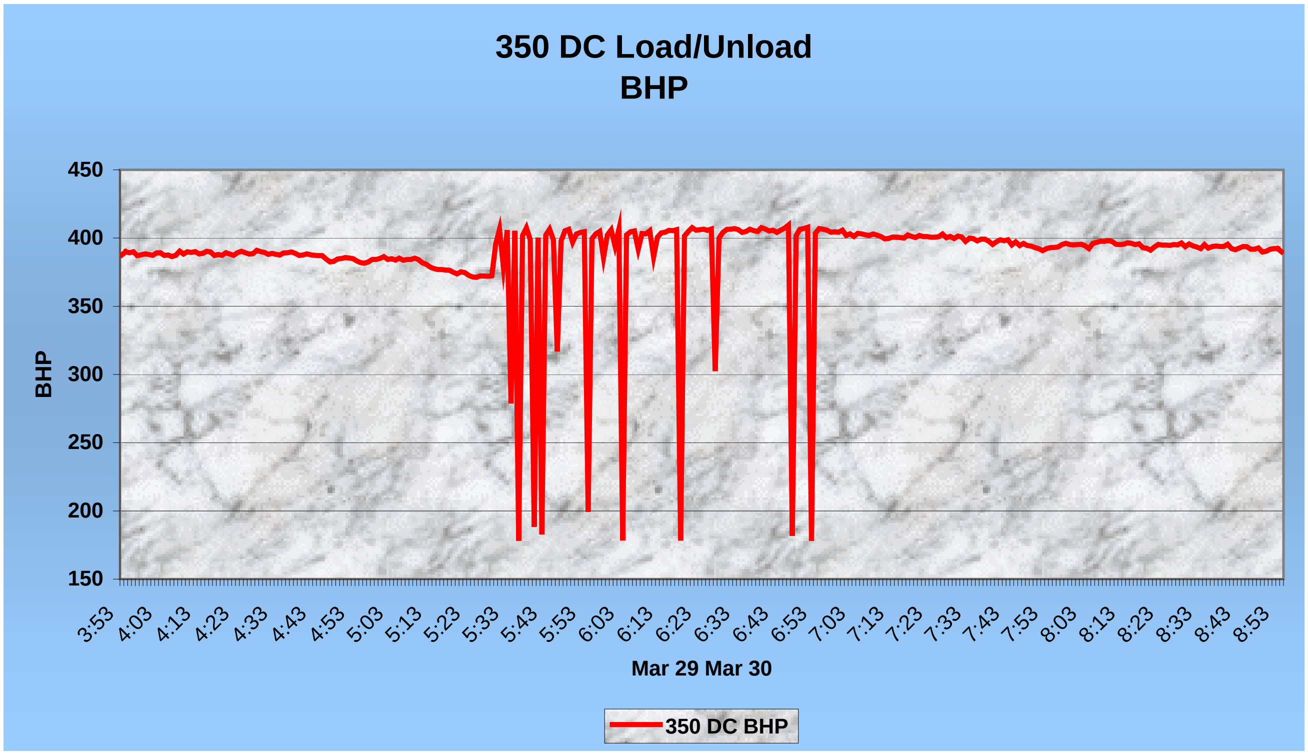
Graph 4.



4.5 Atlas Copco (350 DC) Load/Unload BHP

It should be noted that the Atlas Copco Compressor predominantly runs loaded. At times the unit runs unloaded (see below) the BHP drops to 178 Bhp. Published data predicts approximately 75 Bhp. There may be a malfunction on the discharge check valve, which allows the back-pressure to force the unit to consume more energy.

Graph 5



5.0 Compressor Controls

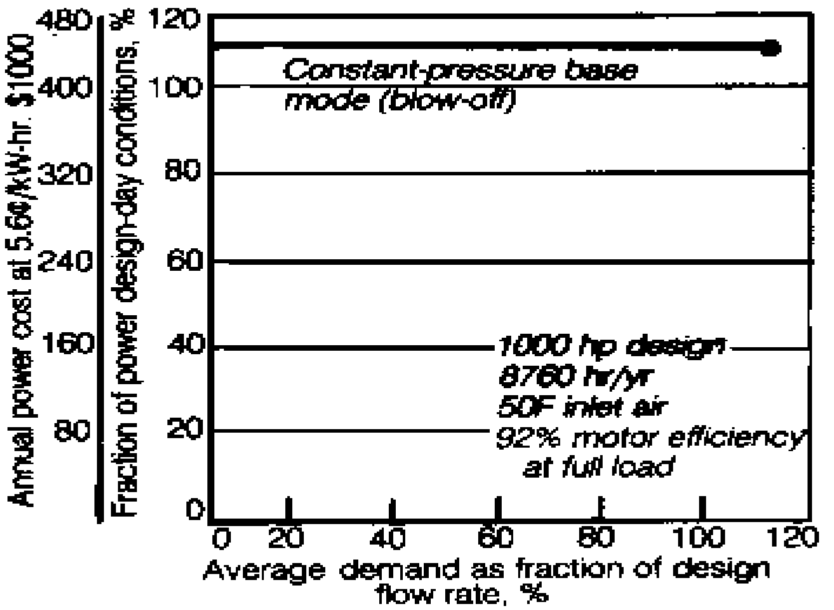
Should Widget elect to replace rotary screw air compressors with centrifugal compressors, the following paragraphs deal with the various types of compressor controls currently on the market with regards to centrifugal compressors. There are several types of controls that are available of which they will be presented below. Once an understanding of the different controls is attained a logical choice can be made as to the type of control that will best fit the application at Widget.

5.1A Constant Pressure Control

Constant pressure control is simply the modulation of an atmospheric blow-off valve on the compressor discharge. This type of system was common a couple of decades ago when power costs were low and not major concern to a company.

The principle of the system was base loading of the air compressor, taking as much air as possible on a continuous basis. Certain types of centrifugal compressors cannot handle swings in Plant air demand and use the atmospheric blow off solely as a safety device. If the compressor operated at its "surge" point the air would actually travel back through the compressor and cause considerable damage to the unit. The atmospheric blow off valve prevents surge by discharging unused air to atmosphere thus keeping the compressor operating above its surge point and keeping the Plant air at a constant.

In actual use the constant pressure control system gives no flexibility for sequencing compressors, demand swings or for outages of other compressors. Specifically in Widget 's case, should all of the inefficiencies listed below be corrected, there would still be no electrical energy savings because the CPC would just divert the air to atmosphere. The motor current draw would remain virtually unchanged.



5.1B Two-Step Control Method (Load/Unload)

The two-step control method with load/unload sequence, operates the compressor at only two steady state conditions. Fully loaded and fully unloaded (throttled) are these two conditions. The measured control variable in this method of control is discharge pressure, relied upon to unload the compressor at a selected maximum pressure and then reload the compressor at a minimum pressure level.

With two step compressor control operation to meet intermediate demand calls for cycling the compressor such that the total time loaded allows sufficient flow of compressed air into the system to meet demand. For example at 50% load the compressor will run loaded 50% of the time and unloaded for 50% of the time. The size of the receiver is critical because it will determine the cycle time. The larger the air receiver the longer the cycle times. Larger air receivers also equate to more energy savings. With ample time to unload, the compressor can achieve it lowest unloaded Bhp which is typically around 12% – 15%. Note it is also important to add power factor correction capacitors to fully realize the electrical savings on the motor. Power factor decreases significantly at low or zero loads and a significant portion of savings can be lost without such protection.

A small air receiver means more frequent cycling and higher power and maintenance cost. If the total receiver capacity is below 20% of the rated compressor capacity in terms of inlet cfm then a load/unload control system will not give satisfactory operation. It is strongly recommended to have a minimum of 1 gallon of storage per cfm of compressor. If possible, 4 gallons per cfm is desired but not always practical.

5.1*C Inlet Throttling Control*

Butterfly Control

Inlet throttling with a butterfly valve on the inlet of the compressor is another way of regulating a compressor's mass flow to meet the varying demand of the Plant air system. This device modulates open or closed to give a constant discharge while making use of both the turndown and the pressure rise to surge of the centrifugal compressor.

Inlet Guide Vanes

Inlet guide vanes as a throttling device on the inlet of a centrifugal compressor stage give capacity modulation and provide power savings. In essence, the inlet guide vanes permit efficient reduction of the extra pressure creating capacity at off design operating conditions. The vanes do this by introducing pre swirl of the air in front of the impeller blade, reducing total momentum (hp/lb of air) imparted to the air during compression. The amount of power reduction available with inlet guide vanes depends on several operating characteristics of the actual compression stage

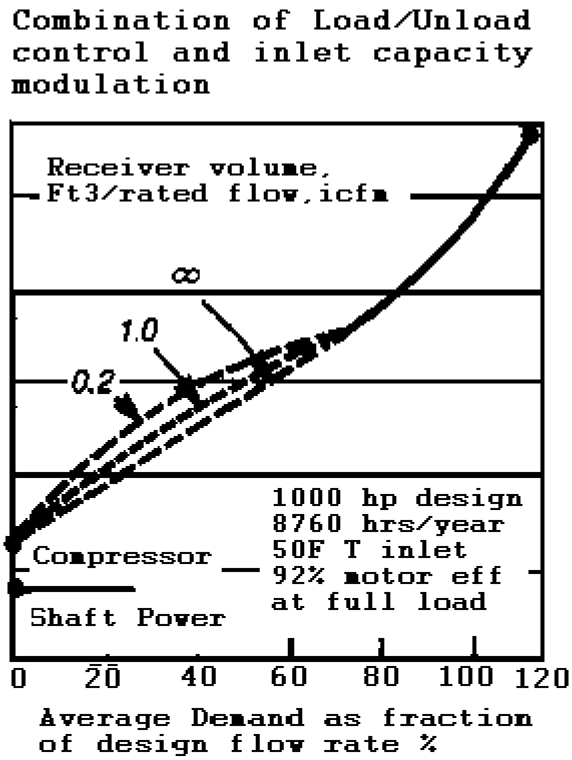
The operational efficiency of either the Butterfly or Inlet guide vanes is limited. All manufacturers tout a 1:1 turndown ratio for up to the first 25%. For example a 1,000 cfm compressor could turn down 25% to 750 cfm and the reduction in BHP would also be 25%. Beyond this turndown of 25% the atmospheric blow-off valve open. In reality the Inlet guide vanes to help but are not as efficient as manufacturers make them out to be. A safe estimate is that the turndown is efficient for the first 10%. After that figure the BHP savings drops of considerably. On some machines it make no difference at all. The turndown is so low it barely affects the amp draw readings.

Another aspect on compressor turndown is the style of the impeller blades themselves. There are basically two types; backward leaning and radial. These two highly different design criteria serve to demonstrate how slight is the variation in power requirement for a given mass flow condition. Although the backward leaning blade machine does give an increase in constant pressure turndown versus the radial impeller, it requires more specific power consumption to get the turndown. Thus the savings is negated.

5.1D Auto Dual Control

Auto dual control with inlet guide vanes is a logical combination of load/unload and capacity modulation control. The curve depicted below illustrates inlet guide vane application for throttling compressor output as demand decreases down to the surge protection control point.

Demand below that point of minimum steady state supply causes the control to switch to load/unload control where demands are met by alternatively operating near minimum turndown or in a totally throttled condition. The load/unload method for low demand conditions operates by unloading the compressor when air demand is below the minimum turndown point. When the system air pressure falls to the minimum, the control reloads the compressor.



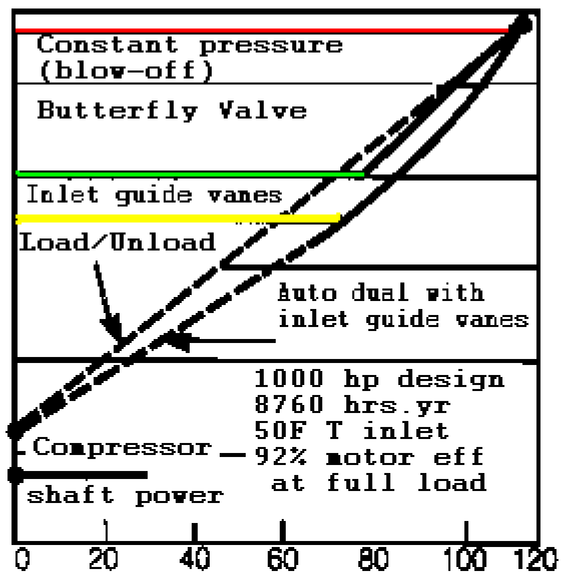
5.1E Controls Comparison

The above, listed out five ways in which Widget can control the centrifugal compressors. The composite plot, below, is representative of the five control methods discussed above. The trends and differentials are fairly accurate in portraying actual performance of the control methods. See composite performance curve below

The constant pressure control system has absolutely no place in control of plant air systems. As the figure makes clear, this approach takes no advantage of centrifugal compressor constant pressure turndown capability and results in the highest possible operating costs for the company with no regard to the actual demand necessary to run the plant. This method of control is comparable to the others only at full load.

What justified this method of control in the past, in multiple compressor installations, was base-loading of one compressor equipped with the control and taking of all load swings on other compressors. That method of operation is, however, inferior to more systematic control of multiple compressor installations.

Composite plot of five control methods



It may be said with similar conviction that an inlet butterfly valve should never get consideration for capacity throttling of a Plant air compressor. The savings in operating power costs from inlet guide vanes rather than a butterfly valve will always outweigh any amortized capital cost associated with the purchase of inlet guide vanes.

Capacity modulation with inlet guide vanes plus atmospheric blow off below minimum turndown flow does have an application where pressure control in the air system is very tight (1 or 2 psi differential) or where mass flow must be kept nearly constant and the surge blow off control is merely a protective device. Neither of these considerations is normal, however, for a plant air system, so that from an operating-power-cost consideration there are better control methods.

In the past, the load/unload control method has been popular for control of both positive displacement (reciprocating and rotary screw) and centrifugal compressors. Unfortunately it does not realize the power savings that are available in a centrifugal compressor’s constant pressure turndown capability.
The auto dual control system can take advantage of the constant pressure turndown and inlet guide vanes to save operating power costs. The above diagram illustrates this advantage by presenting power costs for the auto dual control system that are lower than those for the load/unload control at any intermediate demand between zero and full output.

6.0 Widget Compressed Air System Operating Cost Profile:

6.1 Plant Compressed Air System Operating Cost:

Compressor & Dryer Electric Cost (0.119 $/kwh):	$ 702,981.58
Maintenance Cost:	$ 145,000.00

Total Widget , Erie Energy, Rental and Maintenance Costs = $847,981.58 per year
(See Appendix 6 for details)

7.0 Estimated Required System Pressures & Compressed Air Demand

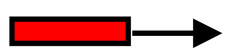
7.1 Weekday Plant Air System Estimated Pressure & Flow Requirements

7.1A Plant Pressure Requirement

As the pressure data logs depict (see section 4.1 above), at various times throughout the day, the air system pressure fluctuated between 116.9 psig (350 DC Air Receiver) and 69 psig (Column L-19). This excludes the low pressure experienced over the weekend, on Sunday, March 29th at 8:00 am. Compressed air is supplied to the plant from the compressors at 100 psig. Based on many years of experience in numerous plants, it is highly conceivable that the Plant Air System could operate properly at a pressure of approximately **70-80 psig** with small point of use pressure boosters used on equipment needing a slightly higher pressure. The lower the pressure to the Plant, the more energy savings can be attained. It will also create useful storage in the primary air receivers.
By lowering the pressure to the Plant, will also reduce the amount of cfm consumed. An example would be to view the Plant as an open orifice. Thus the total amount of air consumed at 100 psig, which is the compressor discharge pressure, can be compared to that consumed at 80 psig as follows:

Diagram 1: 100 psig

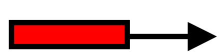
1” diameter nozzle with
Inlet pressure
of 100 psig



Yields
1661 cfm output

Diagram 2: 80 psig

1” diameter nozzle with
Inlet pressure
of 80 psig



Yields
1371 cfm output

Where as diagram 1 shows a flow of 1661 cfm at 100 psig, diagram 2 shows a flow of 1371 cfm at 80 psig using the same size nozzle. When the pressure is reduced from 100 psig to 80 psig the overall cfm consumption drops by 17.5%. That is every piece of equipment in the facility would consume 17.5% less compressed air. As a rule of thumb, *for every 10 psig drop in consumption pressure equates to a 5% savings in energy to produce compressed air.*

7.1B Compressed Air Demand Requirement

The above examples shows that by lowering pressure to the Plant after the dryers (regulation), air consumption will also decrease. This will affect the operation/performance of the air compressors. Dealing with Mass Flow, a computation can be performed to show the positive effect reducing pressure to the Plant can have on the required compressor cfm input. In addition the current compressors in use are designed for 100 psig. Should the air system operate properly at the estimated 3,805 cfm @ 80 psig (before removal of inefficiencies), the compressor's input cfm demand drops to 3,141 cfm @ 100 psig. The following computation depicts the savings in mass flow input cfm.

Weight of Air @ 100 psig = 0.585 lb/cu.ft. @ 70F
Weight of Air @ 80 psig = 0.483 lb/cu.ft. @ 70F
CFM @ 100 psig = "X" cfm
CFM @ 80 psig = 3,805 cfm (estimated demand)

Thus: "X" cfm x 0.585 lb/cu.ft. = 3,805 cfm x 0.483 lb/cu.ft.

Thus Solving for "X" = 3,141 cfm @ 100 psig is required to produce 3,805 cfm at 80 psig

Combining the pressure reduction with the reduction in point of use inefficiency will yield tremendous operating and maintenance cost savings.

7.2 Weekend Air System Estimated Pressure & Flow Requirements

7.2A Plant Pressure Requirement

On the weekends where typical production is not on-line and compressed air is mainly used as clean-up, the pressure and demand of the system could be reduced dramatically. The lower the pressure to the Plant, the more energy savings can be attained. It will also create useful storage in the primary air receivers.

7.2B Weekend Air Demand Requirement to 40 Psig

The calculation performed in 7.1B can also be applied in this case:

The current weekend Plant Air demand is 2,400 cfm at 100 psig. Based on a pressure requirement of 40 psig the mass flow equivalent is calculated below.

Weight of Air @ 100 psig = 0.585 lb/cu.ft. @ 70F
Weight of Air @ 40 psig = 0.279 lb/cu.ft. @ 70F
CFM @ 90 psig = "X" cfm
CFM @ 70 psig = 2,400 cfm (estimated demand)

Thus: "X" cfm x 0.5085 lb/cu.ft. = 2,400 cfm x 0.279 lb/cu.ft

Thus Solving for "X" = 1,144 cfm @ 100 psig is required to produce 2,400 cfm at 40 psig

7.3 Proposed Flow and Pressure Requirements

Air	**Current**	**Current**	**Proposed**	**Proposed**
System	**Flow**	**Pressure**	**Flow (100 Psig)**	**Pressure**
	SCFM	**PSIG (max)**	**SCFM**	**PSIG**
Weekday	3,805	100.00	3,141	80.00
Weekend	2,400	85.00	1,144	40.00

Note: Computations do not take into account Inefficiency removal.

8.0 Leak Management

There were 77 air leaks found at the Widget facility. This equated to conservatively, 250 cfm. See Appendix 7 for the complete table.

The following information may be useful to Widget in the future in determining leak rates:

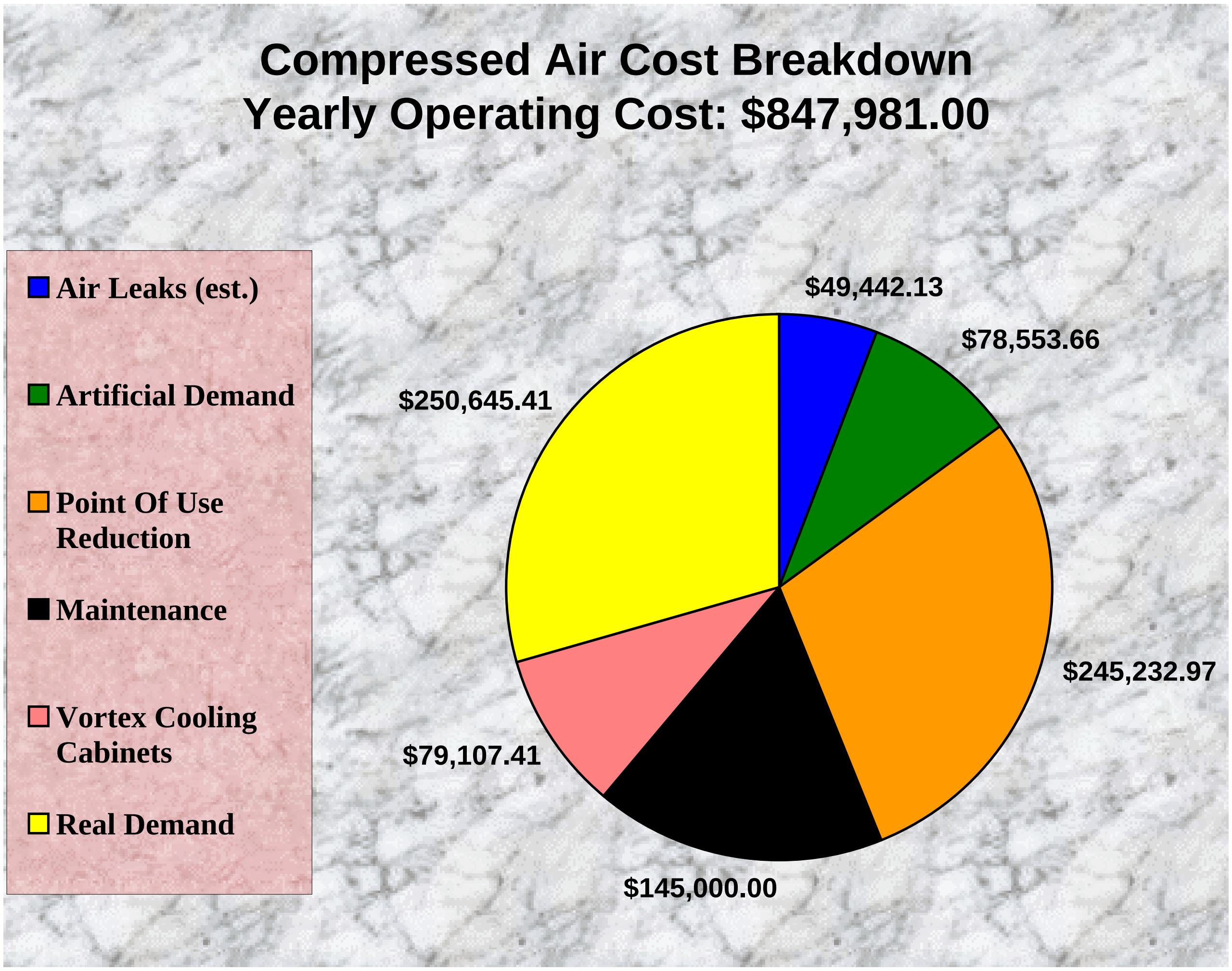
* Hear and feel a leak: it's over 5 scfm.
* Felt but not heard: Its leaking 2 - 5 scfm.
* Can't be detected by human senses: It still can leak 1 - 2 scfm.

Leaks represent a real demand that must be satisfied or production will suffer. Large leaks tend to get fixed, but small leaks do not. Short of implementing a full program, leak losses can be mitigated by feeding them at the lowest possible pressure. The air consumption savings approximate 1% per psig. For every 10-psig reduction in the supply pressure, results in 10% savings in the air consumed, by a leak. Addressing point of use issues by applying pressure regulation will also lower leak losses since most of the small insidious leaks are associated with the work stations located downstream of the main piping header.

9.0 Air Usage Breakdown, Inefficiency Costs

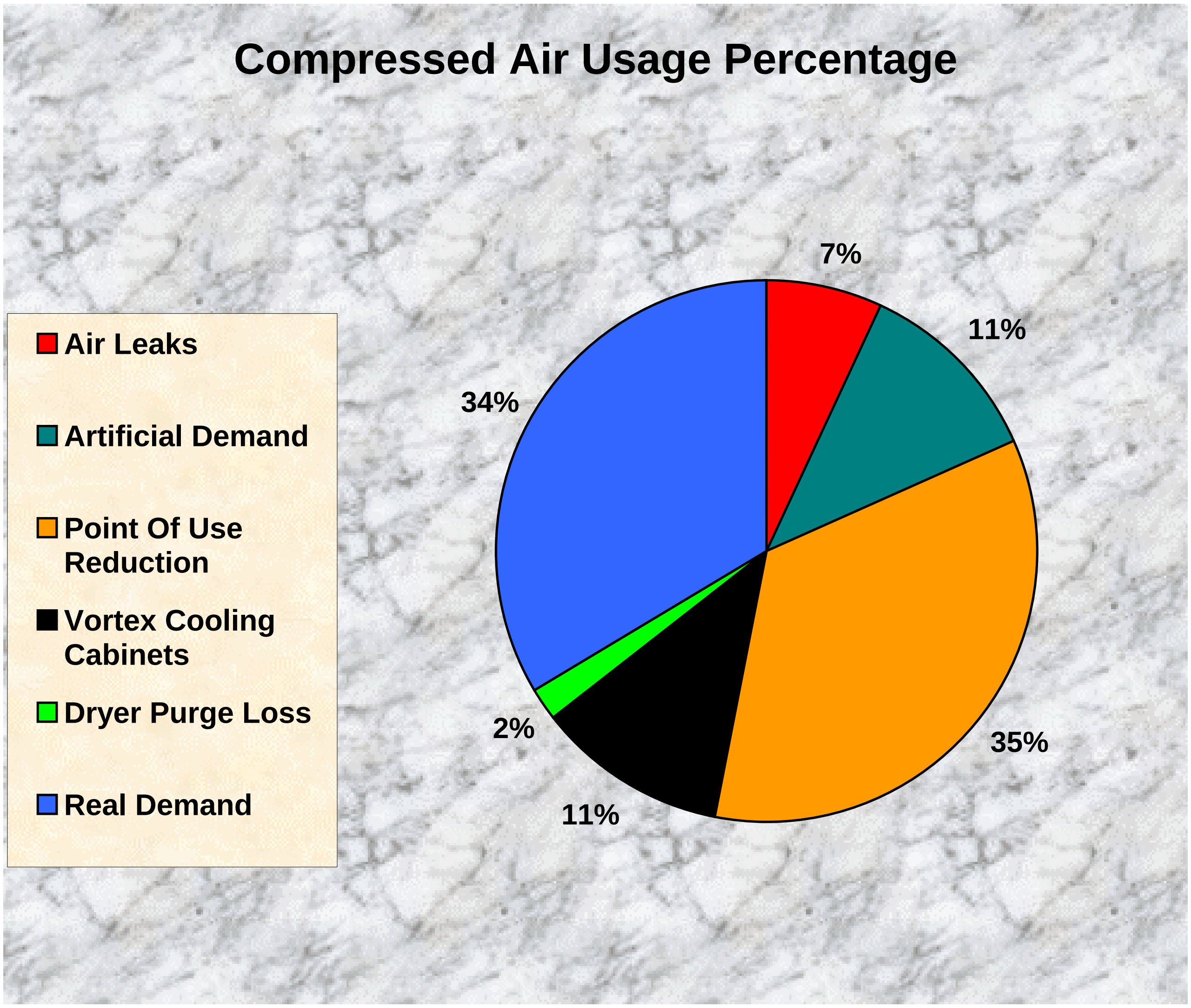
When factoring in all the costs associated with the compressed air system, the breakdown of each cost, is depicted showing the maximum savings in the following Chart:

Chart 1



When factoring in all the inefficiencies of the compressed air system (less maintenance costs) at Widget, the actual air use percentage breakdown based on maximum savings of the system is as follows:

Chart 2



Widget efficiently utilizes only 34% of the total compressed air cost for actual production. The other 66% is used inefficiently.

The recommendations listed in section #11, will help reduce or eliminate the inefficiency within the system.

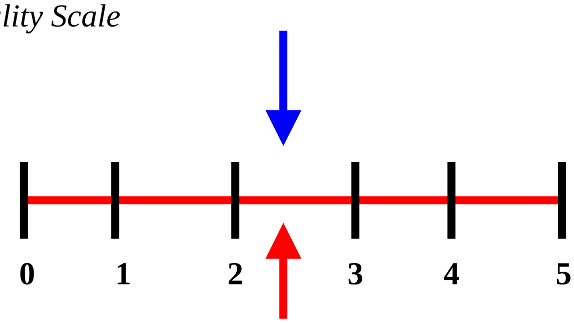
10.0 Compressed Air System Reliability/Air Quality Scale/Dewpoint Analysis

The air system scale (see below) is based on a scale from 0 to 5. Zero means no reliability and poor air quality and five meaning excellent.

A review of the components used in compressed air production at Widget places the reliability and air quality factors at the following levels.

10.1 Widget – Erie

Reliability/Air Quality Scale



- Compressed Air Quality Scale Instrument Air

- Component Reliability

10.1A Plant Air Quality

The level of 2.5 selected for the plant air quality interprets as fair. All of the dewpoints are below ISO8573.1 standards. Overall the average dewpoint of the Plant Air was +43.1F. This included the regenerative dryer we tested. The industry norm for compressed air used in food processing or for control air is –25F or bettor. This is to protect the product, valves and actuators from particles, oil and moisture, such that the reliability of these devices is at its peak. Below -25F, valve life and reliability decreases and could affect production in a relatively short time span. There are several point of use dryers which do not have access points to check the dewpoint. The complete dewpoint recording table can be found in Appendix 9. The reason for the high dewpoint is the fact that the Widget has elected to use refrigerated air dryers. Refrigerated dryers have a design dewpoint of +38F. Widget uses three filters (coalescing, particulate and absorber) to remove oil, water and particulate. Thus the air quality may be acceptable. A potential problem to this method is that should the compressed air piping come in contact with ambient temperatures below the average +43.1F, condensate would drop out in the lines and possibly contaminate valves or product.

In addition, higher dewpoints allow for a certain amount of water to be introduced into the air system from Hysteresis. Hysteresis is the occurrence of moisture actually entering into a compressed air system through an air leak. Specifics about Hysteresis are discussed in the following diagrams.

Diagram 1

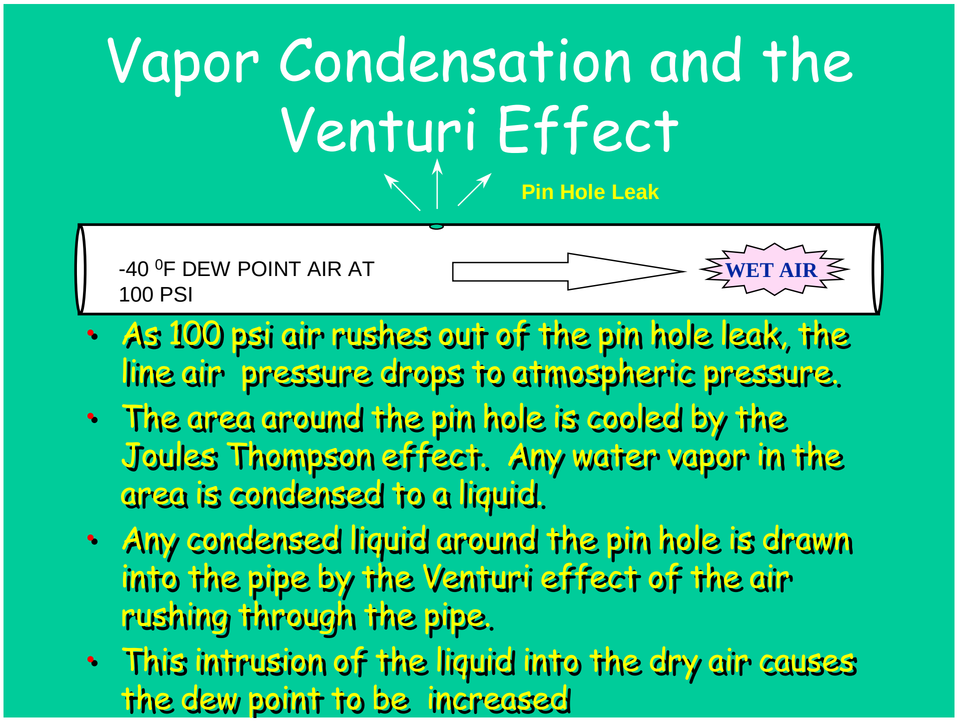


Diagram 2: Cooling Affect

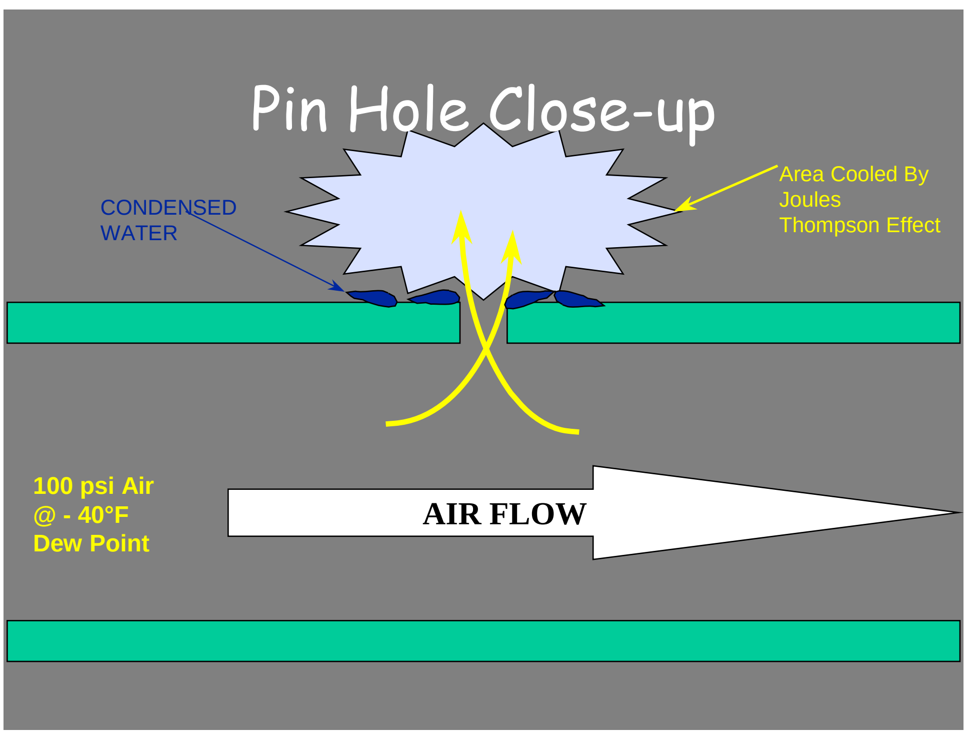
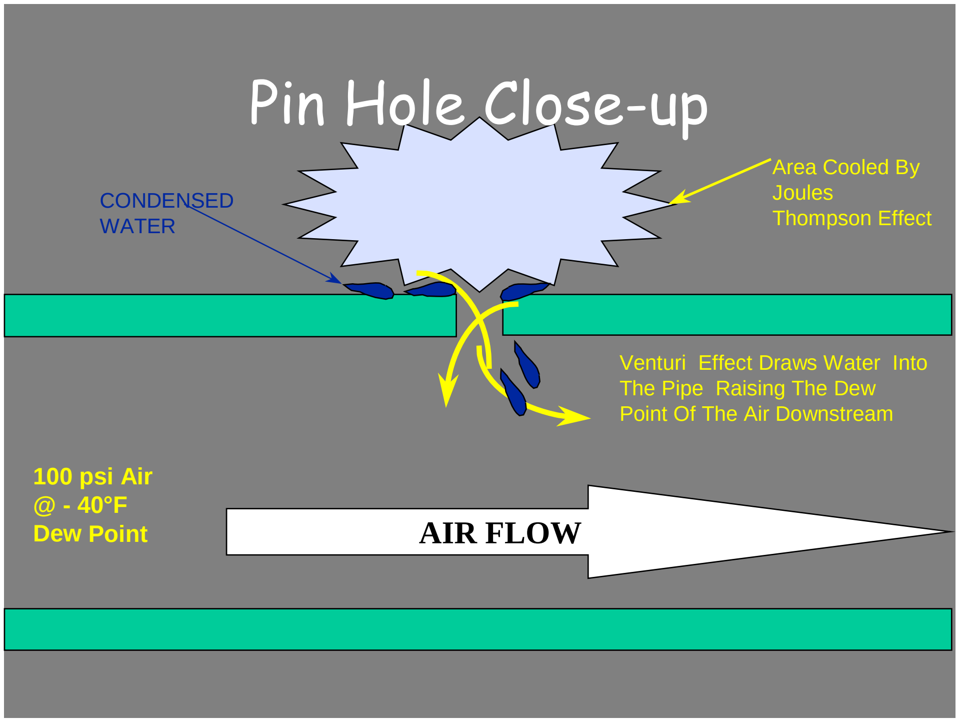


Diagram 3 Venturi Affect



Should water from this phenomenon be introduced into the system the lower dewpoint would absorb the water and change the dewpoint only slightly. The above diagrams show that proper leak maintenance is vital to assuring a minimal amount of moisture is introduced into the compressed air system.

Following the guidelines as set forth by ISO 8573.1 (see table below), for moisture, the Plant Air system was rated at a Grade 4 – Grade 5 at the time the audit took place. The table also lists out the grade required for compressed air usages.

Air Quality Classifications ISO 8573.1

QUALITY CLASS	DIRT Particle size in micron	WATER Pressure Dewpoint °C at 7 barg	OIL (including vapour) mg/m³
1	0.1	-70	0.01
2	1	-40	0.1
3	5	-20	1
4	40	+3	5
5	-	+7	25
6	-	+10	-

Pneurop Recommended Standards

Application Classes	Typical Quality Classes		
	Oil	**Dirt**	**Water**
Air agitation	3	5	3
Air bearings	2	2	3
Air gauging	2	3	3
Air motors	4	4-1	5
Brick & glass machines	4	4	5
Cleaning of machine parts	4	4	4
Construction	4	5	5
Conveying, granular products	3	4	3
Conveying, powder products	2	3	2
Fluidics, power circuits	4	4	4
Fluidics, sensors	2	2-1	2
Foundry machines	4	4	5
Food and beverages	2	3	1
Hand operated air tools	4	5-4	5-4
Machine tools	4	3	5
Mining	4	5	5
Micro-electronics manufacture	1	1	1
Packaging and textile machines	4	3	3
Photographic film processing	1	1	1
Pneumatic cylinders	4	4	4
Pneumatic tools	4	4	4
Process control instruments	2	2	3
Paint spraying	3	3	3
Sand blasting	-	3	3
Welding machines	4	4	5
General workshop air	4	4	5

10.1B Plant Component Reliability

The reliability of the current air components is rated at 2.5. This indicates that an action plan should be developed to upgrade the current system. This would include, upgrade or replacement of the compressors and ancillary equipment (storage), dryers, point of use retrofits and condensate removal. Should one compressor go off-line, a rental compressor would need to be brought in to maintain pressure during full production. The compressed air system does not have a central controller to ensure the proper number of compressors are on line, minimizing Bhp, to satisfy Plant air demand. In addition, the Sullair compressors are antiquated and do not possess the latest capacity controls or high efficiency airends. The Atlas Copco is inherently inefficient as section 3 above clearly shows. There is also insufficient storage capacity to adequately supply the system with compressed air, such that pressure fluctuations can be kept to a minimum and artificial demand can be reduced. This lack of storage is most evident when a production line is brought on-line, where-by plant air pressure throughout the entire Plant collapses and forces Widget to have more compressors on-line than necessary. The extra compressors are on-line as a precautionary measure to prevent the pressure drop should an event demand occur (i.e. four or more air hoses being turned on at once). Based on these facts and the age and efficiency of the equipment and advances in new compressor and dryer technology, the reliability of 2.5 was selected.

11.0 Recommendations

11.1. Reduce Compressed Air Drying Locations

It is recommended to consolidating air production (compressors, primary air receivers, filters and dryers) to the following areas:

a. 150 – 450 Compressor Area
b. 350 DC Compressor Area

Both of theses areas have power, cooling water, space for ease of maintenance repairs and good ventilation. Both areas are currently the main air production areas. Consolidating compressed air operations in these areas will have several benefits, as listed below:

1. Increase the efficiency and reliability of the system.
2. Reduce maintenance time and cost.
3. Increase in the control of the air quality.
4. Increase in the control of pressure distributed to the facility.
5. Reduction or elimination of satellite air dryers and purge air losses.
6. Elimination of in-plant filter pressure drop.
7. Reduction in on-line hp/operating costs.
8. Increase in useful storage.

The remaining satellite dryers around the Plant, can be shut off and by-passed to act as back up to the primary compressor areas.

11.2 Add New Centrifugal or Two Stage Rotary Screw Compressor (150 – 450 Area)

Future planning should include replacement of the two Sullair compressors in the 150 – 450 compressor area. Replacement with state of the art compressors and controls will increase efficiency by 16% at full loads and at minimum 25% at part load demand. It is recommended to install either two 300 Hp centrifugals or two 300 Hp, two stage oil flooded rotary screw compressors (with VFD control). A provision to move one of the compressors to the DC350 Area for back-up should also be considered. This would eliminate any need for rental compressors should one of the primary compressors go off-line.

11.3 Replace Current Satellite Regenerative & Refrigerated Dryers With One Regenerative Dryer at Each Compressor Production Area

Should Widget elect to reduce satellite air dryers, as suggested above, it is also recommended to install one new air dryer at each of the two compressed air stations. The 150 – 450 area dryer should be sized to handle 3,000 cfm and 1,500 cfm at the 350 DC area. If the dryers needed to be taken off-line for maintenance or failure, the current satellite air dryers could be used as back up to the primary. Otherwise all the current dryers would remain by-passed. The new dryers should be vac-assist type. The vac-assist will use an external vacuum pump to assist in the dryer purge. The dryer will act like a standard pressure swing dryer but it will not use the 15% purge air required by standard regenerative dryers. The vacuum will reduce the purge rate down to 2% – 3%. Utilizing the vacuum pump will use considerably less energy than either a standard regenerative or blower/heated dryer currently offered on the market. The vacuum would be an oil-less rotary vane.

11.4 Install Air Free Drains on all Condensate Drain Lines to Replace Time Drains

On all open or timed condensate drain lines, recommend installing an upgraded air free drain. This will remove the condensate without wasting compressed air. In addition the moving parts are not exposed to the condensate and thus eliminates valve malfunction. The drains should have a signal that can be sent to the DCS system to warn if there is a problem with the drain operation. In addition the drain should have a local annunciation to alert maintenance that will be performing daily inspections on the compressors and dryers.

11.5 Addition of Demand Flow Stabilizers to Eliminate Plant Wide Pressure Fluctuations

The Demand Flow Stabilizer (DFS) will regulate the air to the plant air system and works in conjunction with the air receivers. The air will be produced by the air compressors at approximately 100 psig and stored in the air receivers. The last receiver in the storage battery will have two outlet connections. The outlet connections will have a (DFS) dedicated to the Plant and Instrument air system and should be set at 80 psig for Plant Air. The locations for these valves will be at each compressor location; 150 – 450 and 350 DC Area. The control valve to be put in place should have a multi-valve design that will ensure proper flow distribution to the entire facility. The multi-valve design will respond much quicker than the single valve currently in place. The following sections will give a more detailed explanation of the different control valves.

11.6 & 11.6B Addition of the DFS will have two key effects on the entire air system.

11.6A It will stabilize plant air pressure and maintain it within 2-3 psig throughout the entire plant. The DFS's separate the compressors from the plant. They only need to respond to changes in pressure at the air receiver, not changes in the plant, while the DFS will respond to the changes in the plant pressure instantaneously. The reason for this pressure stabilization is due to the fact that storing air at a higher pressure allows potential energy to be stored in the receiver. When air is required, it is already stored and available for immediate use. The response time to air demand changes would be much faster than the current system, where changes in plant pressure cannot be responded to as quickly by the compressors, resulting in pressure fluctuations.

11.6B Air will be stored at 100 psig and distributed at approximately 80 psig. Installation of the DFS has the potential for reducing output of the compressors to less than 1,497 cfm @ 100 psig, which includes removal of inefficiencies.

11.6C Demand Flow Stabilizers (DFS) vs. Regulators

The most frequently asked question concerning the application of demand flow stabilizers is "why can't a regulator be used?" An understanding of the performance required of a demand flow stabilizer and the capabilities of a standard pressure regulator would provide the answer.

Any device that imposes a differential pressure across a vessel will create storage. Applied in this manner, a regulator can be used to create storage in a receiver tank. But creating storage is not the same as utilizing storage. It is the utilization of storage that is critical to keeping the air system under control.

There are two important goals:

1. Provide production with a stable, consistent, reliable supply of compressed air at all times.
2. Satisfy all load demands with the minimum amount of expended energy.

To achieve these goals, the air system must be configured using a demand flow stabilizer to fully utilize all available storage while maintaining a constant balance point pressure. A typical regulator can not accomplish this task.

Regulators control by changing the differential pressure across the valve to maintain a set outlet pressure. Flow becomes a consequence of the changing differential. The force required to control the differential adds to the total pressure drop and subtracts from usable storage. The demand flow stabilizer maintains the set outlet pressure by changing flow. Differential pressure is a consequence of the change in flow and can be designed to a minimum, even to the point of approaching a zero pressure drop.

Standard regulators are designed using what is called the "53 Rule". The "53 Rule" design criteria defines the optimum operating point for a regulator as 53% of the inlet pressure. For example, with a 100-psig inlet pressure, a regulator is designed to control best at 53 psig out. Since the regulator spring balance is non-linear, the further the actual outlet pressure is from the designed 53%, the poorer the regulator will perform. The 53% design criteria is fine for instrument air and applications such as point of use, where the air is being expanded to atmosphere. At the intermediate point of an air system, however, the controlled outlet pressure is usually 60-80% of inlet. The "53 Rule" severely limits the overall performance of a standard regulator when applied as a demand flow stabilizer.

Regulators typically require a force load pressure of 12 - 18 psi to move the internal spring before they can even begin to control. This counterbalance force pressure is unavailable for controlling the outlet pressure and is lost energy. While it will create a differential pressure and add air to storage, the reserve energy created by the force pressure is unusable. The highest initial controlled outlet pressure of the regulator is equal to the inlet pressure less the force pressure. For example: If the inlet pressure from storage is 100 psig and the regulator requires 15 psi differential force pressure to operate, it can only “begin” to control at a pressure of 85 psig. The storage resulting from the 15-psi differential must always remain in the receiver or the system pressure will collapse.

The word “begin” must be emphasized because as demand calls for air to be released from the storage, a pressure differential due to flow impacts on the outlet pressure. It also subtracts from the inlet pressure. As flow from storage increases, the total pressure drop across the regulator becomes higher. With a typical regulator, as much as a 20-30 psi differential is required before a stable balance point can be established through utilization of storage.

It is important to understand what is actually occurring with the pressure and flow at the intermediate point of the air system. The demand flow stabilizer impedes flow and the resulting differential creates what is termed "primary storage" upstream. The air released from the primary storage continuously satisfies the instantaneous cumulative demand of the entire system.

The downstream side of the demand flow stabilizer is connected to a lengthy piping distribution system, which in reality, is a fixed volume vessel. At the other end of the piping distribution system are the points of use where the air is expanded from a fixed pressure to atmosphere to produce work. The differential pressure between the outlet of the demand flow stabilizer and the end pressure prior to doing work creates system storage in the connecting piping distribution system. This is termed "secondary" storage and is used to stabilize the pressure at the production points of use. Note also the addition of a storage tank at or near the point of use is also included as secondary storage.

In a properly configured system, air used by production first cascades from primary storage into secondary storage in a manner directed by the demand flow stabilizer. Secondary storage must be adequately replenished under all conditions to assure production will always have available a constant, stable source of compressed air and the system will not draw down and collapse. The demand flow stabilizer must be very responsive to the dynamic changes in flow while holding a steady balance point pressure.

Standard pressure regulators cannot address secondary storage adequately because they have a characteristic known as droop. Droop is the term used to quantify the degree the controlled outlet pressure will fall off as the flow through the regulator increases. A regulator set to control at a fixed pressure will control at an ever decreasing outlet pressure as the flow increases. A regulator set at 100 psig at low flow condition might droop to a critical point pressure of 85 psig at its full flow condition. Depending upon the characteristics of the specific valve and the design criteria used in its selection, droop can range from 10% - 45%.

Flow at the intermediate point in the system will vary as a function of demand. When the load surges, the demand flow stabilizer must open quickly to increase the flow to satisfy the demand. If the surge occurs at the same time as a secondary storage is depleted, the total flow peaks even higher as the demand flow stabilizer must replenish secondary storage at the same time it satisfies the load surge. In a large system with long runs of big diameter header pipe, the replenishment of secondary storage can actually exceed demand flow by double and more. The demand flow stabilizer must be capable of handling this flow or the system pressure will collapse. The outlet pressure of a regulator selected to handle the full range of flows will wander as it droops when it has to satisfy the peak flow and then creeps back up during steady flow conditions. The intermediate point is the aorta of the air system. Relying on a single control valve jeopardizes the entire production facility in the event it fails or become erratic in its operation. Multiple regulators installed in parallel will interfere with one another resulting in a lead-lag operation.

In summary, a demand flow stabilizer offers the following advantages to a standard regulator. Requires less than 3 psi differential force load pressure to operate, uses a mechanically amplified bias signal to eliminate droop, will operate in parallel with other demand flow stabilizers and allows for responsive control at both high and low flow conditions.
A flow control valve or Demand Flow Stabilizers (DFS) should be added to the air system. This valve will be used to eliminate or reduce the current artificial demand of the plant as described above. The DFS is placed after the air receivers. The air will be stored in the receivers at 100 psig and released to the plant via the DFS at 80 psig. The DFS will respond quicker, more efficiently to plant air demands, than the current compressors. It will also maintain a stable plant air pressure, eliminating unacceptable pressure fluctuations and stabilize plant air pressure in all parts of plant. As an added benefit, the Demand Flow Stabilizer will eliminate artificial demand, reduce operating costs and create “Useful Storage” correctly utilizing air receivers.

11.7A Add 3,000 gallons (401 Cu. Ft) Storage At The 150 - 450 Compressor Area

The addition of 3,000 gallons of storage at the 150 – 450 Area is to ensure there is ample, "useful storage". Useful storage is defined as the differential pressure between stored pressure and working pressure. This would be in addition to the 1000 gallon tank currently in place. In this case, if a Plant Air demand of 80 psig is used, the useful storage is 100 psig - 80 psig = 20 psi differential. Equating this to stored air is as follows: (20 psi/14.7) * (4,000 gal / 7.48) = 727 cu. ft. of useful storage.

11.7B Convert 2250 Gallon (300 Cu.Ft.) at 350 DC To Useful Storage

The conversion of the 2,250 gallon tank at the 350 DC Area will increase "useful storage". As in the above case, if a Plant Air demand of 80 psig is used as above, the useful storage is 100 psig - 80 psig = 20 psi differential. Equating this to stored air is as follows: (20 psi/14.7) * (2,250 gal / 7.48) = 409 cu. ft. of useful storage.

To simplify, a good rule of thumb is to have at least 3 gallons of storage for every scfm of demand. This will ensure that if there is an instantaneous demand of up to 1136 cu.ft (727 cu.ft + 409 cu.ft.) for air in the Plant, the air receivers will be able to handle the load in lieu of starting another air compressor to keep the plant air pressure from falling.

11.8 Compressor Controls

Recommend installing a master control for all the air compressors, dryers and DFS valves for the two recommended compressor locations. The master controller would automatically bring online or off-line the compressors and dryers as needed to ensure the minimum amount of horsepower would be on-line to supply the facility. A compressor controller would ensure that if the demand fell, a compressor would automatically shut down. The controller would also rotate equipment to ensure even runtime among the compressors and dryers. The master controller should also be connected to allow maintenance to remote monitor the compressor functions from a desktop. Consolidating compressors will accomplish the following:

a. Overall benefits
   1. Elimination of satellite compressors & dryers.
   2. Reduction in maintenance time/cost
   3. Reduction in electrical consumption

4. Constant dewpoint (-25F minimum)
5. Reduction of online horsepower

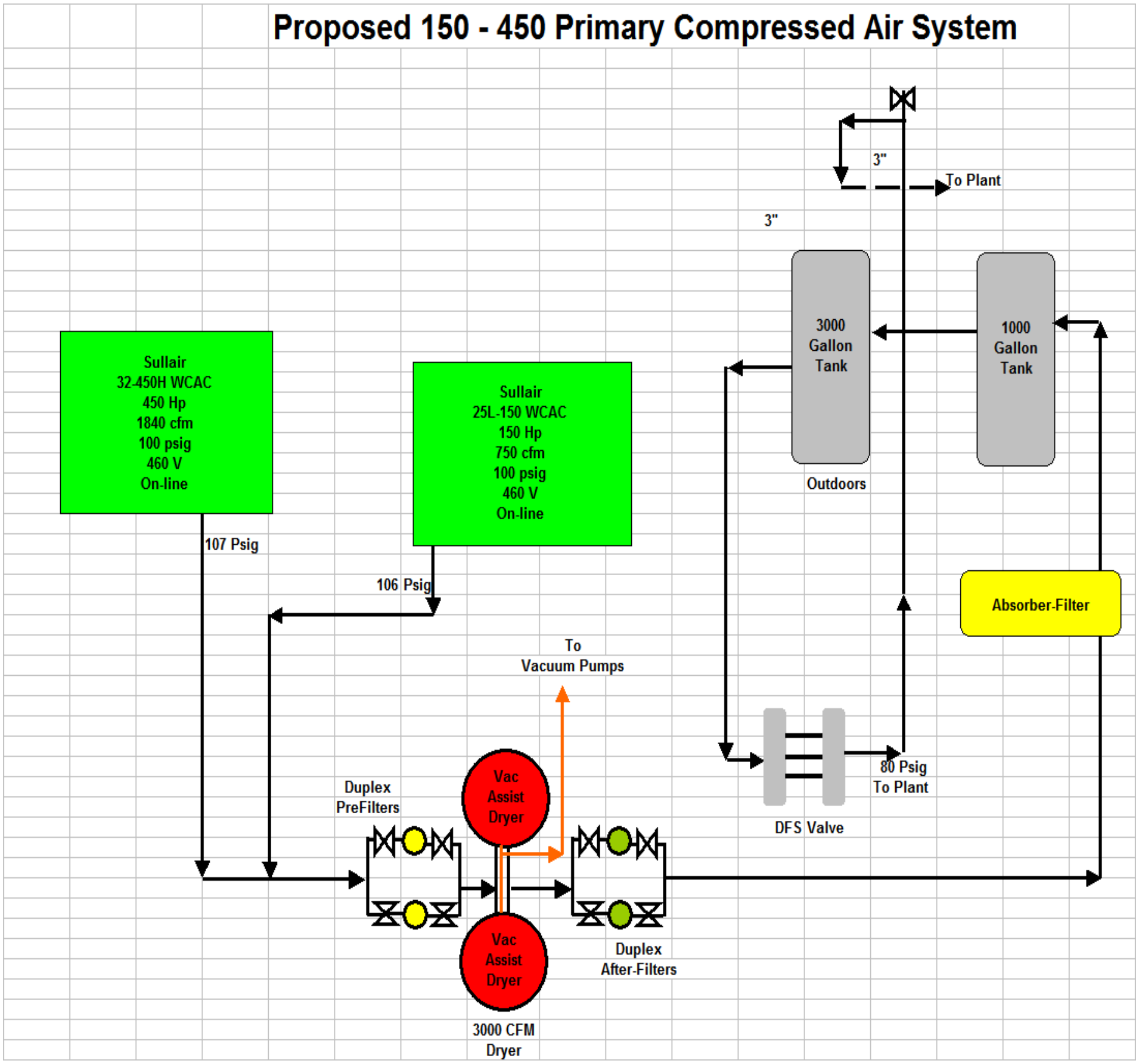
b. Compressor Control
   1. Automatically control compressors and dryers
   2. Automatically turn compressor and dryers on or off depending on system air demand
   3. Automatically rotate compressors and dryers for even wear
   4. Control system discharge pressure to the plant

c. Reliability/Backup
   1. Reliability will increase.
   2. Compressed air system will have 100% redundancy with automatic change over should a compressor fail.
   3. Satellite dryers and compressors will be eliminated reducing maintenance and increasing reliability and quality of the air released to the plant.

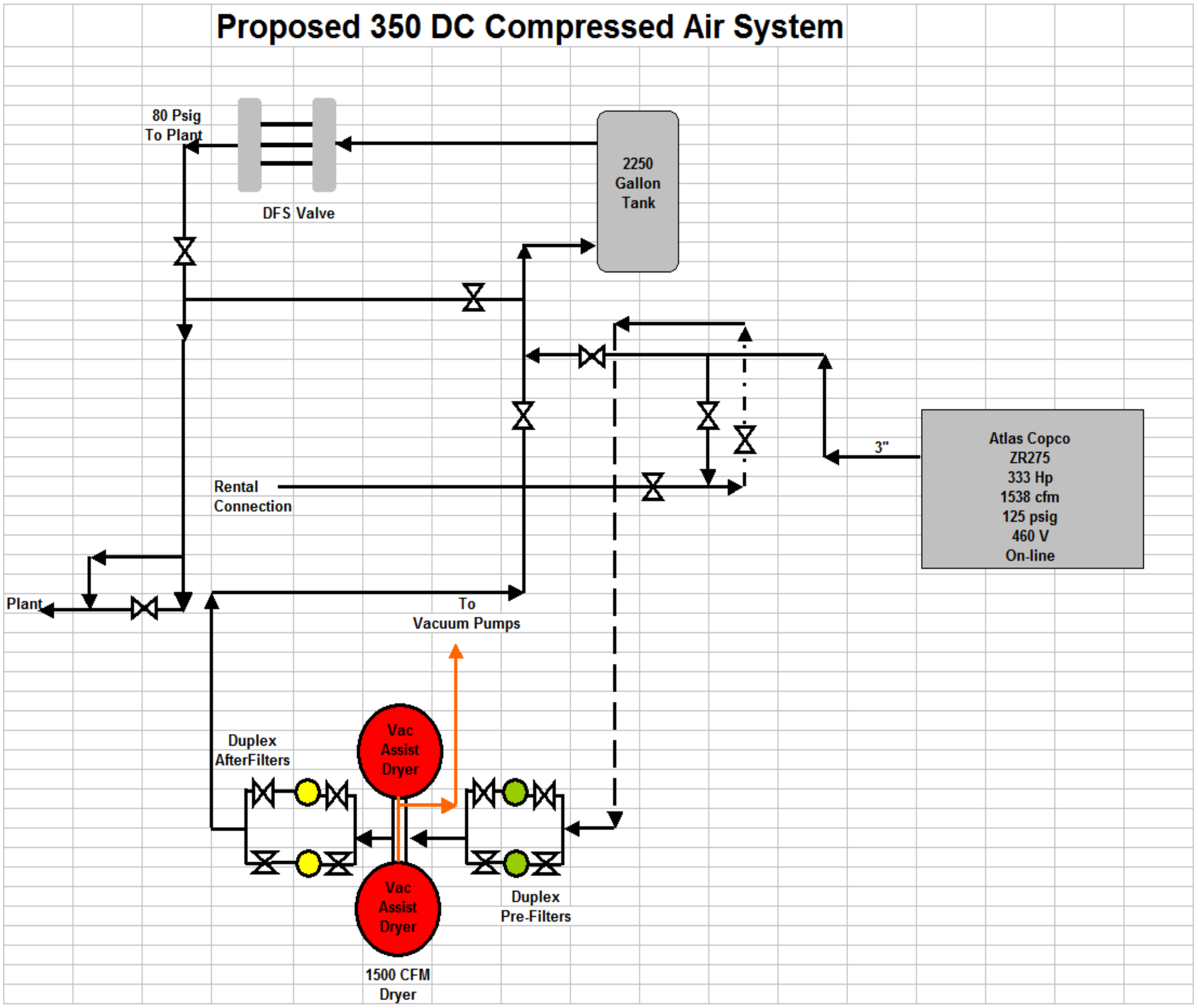
d. Remote Monitoring
   1. Plant CFM demand
   2. Plant Air Pressure
   3. Compressor maintenance items (optional)
   4. Dryer dewpoint (optional)

In other words, there will be single source reliability for the compressed air system as depicted below.

150 – 450 Compressor Area



350 DC Area



11.9 Repair Plant Air Leaks

Using the leak audit table in Appendix 7, Widget should institute a program to repair all the leaks listed in the table.

11.10 Air Leak Management

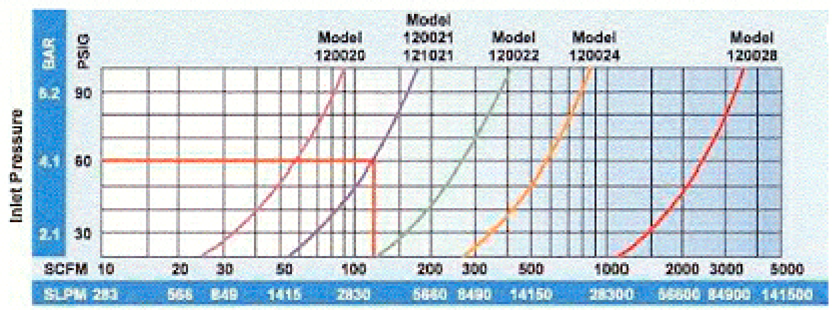
After repairing air leaks it is recommended that Widget continue to institute an air leak program whereby a leak audit is performed no less than once per year.

11.11 Cooling Air/ Blow-Off / Clean-Up Wands

Widget uses, open jets or crimped pipe for cleanup, cooling or blowing off debris. By replacing the current nozzles with a high efficiency type nozzle, flow requirements can be drastically reduced. There are numerous manufacturers of these devices. The chart below depicts the savings in cfm that can be attained by incorporating said device.

Super Air Amplifier Performance at 80 PSIG (5.5 Bar)

	Air Consumption		Amplification	Air Volume at outlet		Air Volume at 6" (15cm)		Sound Level
Model	SCFM	SLPM	Ratio	SCFM	SLPM	SCFM	SLPM	dBA
120020	6.1	173	12	73	2066	219	6198	69
120021	8.1	229	18	146	4132	436	12,339	72
120022	15.5	439	22	341	9650	1023	28,951	72
120024	29.2	826	25	730	20,659	2190	61,977	73
120028	120	3396	25	3000	84,900	9000	254,700	88



Total Output Flow with .003" (.08mm) thick shim installed. Excludes downstream entrainment.

For example, assume Widget needs approximately 50 cfm per open jet. According to this chart an input of 6.1 scfm at 80 psig will deliver 73 cfm. This is a savings of 44 scfm per nozzle. Thus the cooling of any device can be done at a fraction of the cost. In addition to cfm savings, these types of devices also reduce the noise associated with open-air jets. In most cases the Dba drops to the low 70's range.

11.12 Replace Blow-Off Pipes With Air Knives

In order to eliminate the pressure decay and high energy cost in debris blow-off on production equipment, it is recommended to implement the following recommendation.

Retrofit the current blow off pipes with air-knives. Air knives have an amplification factor of 40:1. As the chart below shows the cfm consumption of an air knife to holes drilled in a pipe.

Air Knife Performance with .002" (.05mm) thick shim installed

Pressure Supply		Air Consumption per Inch (25mm)		Velocity @ 6" (152mm) from target		Sound level @ 3' (914mm)	Force per Inch (25mm) @ 6" (152mm) from target	
PSIG	Bar	SCFM	SLPM	FPM	M/S	dBA	Ounces	Grams
20	1.4	1.1	31	5000	25.4	57	0.6	17
40	2.8	1.7	48	7000	35.6	61	1.1	31
60	**4.1**	**2.3**	**65**	**9600**	**48.8**	**65**	**1.8**	**51**
80	5.5	2.9	82	11,800	59.9	69	2.5	71
100	6.9	3.5	99	13,500	68.5	72	3.2	91

Holes Drilled in Pipe

Pressure Supply		Air Consumption 1/16" (1.59mm) dia. hole		Air Consumption 3/32" (2.38mm) dia. hole		Air Consumption 1/8" (3.18mm) dia. hole		Air Consumption 3/16" (4.76mm) dia.hole		Air Consumption 1/4" (6.35mm) dia.hole	
PSIG	Bar	SCFM	SLPM	SCFM	SLPM	SCFM	SLPM	SCFM	SLPM	SCFM	SLPM
20	1.4	1.4	40	3.5	99	6.4	181	14.5	410	25	710
40	2.8	2.2	62	5.4	153	10.2	289	22.9	648	40	1132
60	4.1	3.0	85	7.4	209	14	396	31	877	54	1528
80	5.5	3.8	108	9.4	266	17.5	495	39.5	1118	69	1953
100	6.9	4.6	130	11.5	326	21.5	609	47.5	1344	84	2363

This will greatly reduce the air consumption of this process and should be investigated further to ascertain the feasibility of using these devices. There are numerous name brands on the market.

11.13 Compressed Air Responsibility

There should be one team that handles all compressed air problems and changes to the system. It should be made mandatory that prior to placing into service, any equipment that will consume compressed air, be cleared through the “AIR TEAM”. In response, the “AIR TEAM” can then plan on placing into service, the appropriate amount of air compressors to satisfy the new additional demand. This will avoid the decay in system pressure that will ensue upon start-up of these devices. In this manner the “AIR TEAM” can be proactive and avoid pressure problems. As of today, the Plant has to react to problems. In many cases it cannot respond quick enough and parts of the system experience low pressure. When the Air Team is notified "PROPER" solutions can be instituted and system pressure decay and unnecessary accidents can be avoided. Simple changes in Scfm usage or pressure increases can and will affect other areas of the Facility. The air team will be able to anticipate problems before they happen.

11.14 Install Auto Compressed Air Shut-Off Valves

It should be investigated as to whether automatic, air shut-off valves can be installed on production equipment. Even when not in use, the air remains on to most of the units. It should be designed so that when the main equipment is de-energized, the valves would automatically close to prevent air from feeding the idle equipment and bleeding compressed air to the atmosphere. When the production equipment is re-energized, the valves would open to allow compressed air to supply the equipment.

11.15 Maintenance Area

Maintenance areas may require a higher supply pressure. In lieu of maintaining elevated Plant Air pressure to accommodate the maintenance shops, it may be more cost effective to supply these areas with either their own supply air compressor or a booster compressor. There is already a duplex 10 Hp 150 psig compressor located on the Mezzanine just above the shop. The units rarely come on-line. In addition, there is actually a connection, which is located adjacent to the maintenance area on the first floor that could service this area. This would allow Widget to operate the Plant at the lowest pressure and save operating dollars.

11.16 Retrofit Infra-Red Sensor Blow-Off

It is recommended to retrofit the infra-red sensors with either Hi-“E” nozzles. This will reduce the amount of compressed air used from 45 cfm to 6 cfm. A second option would be to put a simplex blower unit on each machine.

11.17 Retrofit Control Cabinets With Fans

In lieu of using the vortex coolers to maintain temperature in control boxes, it is proposed to replace the vortex coolers with box fans. These units would most likely perform satisfactorily on all the boxes except those between the two ovens. In this region, ambient temperature may be too great to keep the boxes from overheating using just a fan. In all cases, air to the vortex coolers was still on, even when production equipment was off-line.

12.0 Equipment Required/Costs/Payback:

12.1 Project 1: Compressed Air Upgrade Project

<u>Project I</u>

Project description:

This project will entail the installation of storage, vac-assist dryers, air free drains, demand flow stabilizers, compressor controls (optional) and monitoring equipment (optional). It includes retrofit of the production equipment air cooling or blow-off mechanisms, nozzles and air lances with High “E” devices and regulators. Retrofitting of equipment with air knives and, air shut-off valves. It also includes air leak repair.

End Result:

The end result of the project will be the reduction in compressors on-line. It will also reduce compressed air demand and stabilize plant air pressure. It includes a reduction in satellite air dryers and increase in efficiency/reliability of compressed air production. It will also lead to a reduction in maintenance costs, creation of back-up compressors and dryers.

12.2 Project Summary Table

	Widget Corporation - Project/Savings Table Cost Breakdown					
Appendix 14						
		Est. Cost	Est Cost	Total	Pay Back	
Areas	Equipment	Min	Max	Savings	Min	Max
					Yrs	Yrs
150 - 450			PROJECT 1			
	1-3000 cfm Dryer (vac-assist)	$ 55,000.00	$ 65,000.00			
	1 - 3,000 Gallon Air Receivers	$ 12,000.00	$ 15,000.00			
	1 - 3000 cfm Demand Control Valve	$ 18,000.00	$ 24,000.00			
	Installation	$ 100,000.00	$ 125,000.00			
	Engineering/Project Management	$ 18,000.00	$ 25,000.00			
	1 - Air Free Drains	$ 750.00	$ 850.00			
	200 - Hi-E Nozzles	$ 6,000.00	$ 9,000.00			
	150 Hi-E Air guns	$ 10,000.00	$ 14,000.00			
	30 - Air Knives	$ 10,000.00	$ 14,000.00			
	50 - Control Box Fans	$ 4,000.00	$ 6,000.00			
	100 Solenoid Shut-Off Valves	$ 3,000.00	$ 5,000.00			
	2 - 8 HP Vacuums	$ 16,000.00	$ 24,000.00			
	Air Leak Repair	inc	inc			
350 DC						
	1-1500 cfm Dryer (vac-assist)	$ 45,000.00	$ 55,000.00			
	1 - 1500 cfm Demand Control Valve	$ 14,000.00	$ 18,000.00			
	Installation	inc	inc			
	1 - Air Free Drains	$ 750.00	$ 850.00			
	1-8HP Vacuum	$ 17,000.00	$ 19,000.00			
	Estimated Freight	$ 8,000.00	$ 12,000.00			
	Total Cost	$ 337,500.00	$ 431,700.00	$302,035.00	1.12	1.43
Optional	Compressor Controls	$ 25,000.00	$ 35,000.00			
	Add Monitoring Package	$ 25,000.00	$ 50,000.00			

12.3 CAT Services Included With Above

<u>**SCHEDULE:**</u>

Compressed Air Technologies will work with Quaker and the Widget Foods staff (the design team) to provide the documents, as outlined below, with the following milestone schedule:

- Schematic Design
- Equipment Pre-Purchase Bid package
- Bid Evaluation
- Design Development
- Submit phase one and phase two Construction Documents for Bid
- Procure Equipment
- Project Coordination & Management
- Start-Up Services
- Widget Personnel Training

If the above schedule does not concur with your expectations, please contact us.

<u>OUR SCOPE OF SERVICES FOR THIS PROJECT WILL BE AS FOLLOWS:</u>

<u>Schematic Design:</u>

This phase will include major component selections and conclusions of all system types and locations, electrical requirements, service locations and other required physical space requirements and support spaces. At the completion of this phase, based on a specific final scope, a revised/specific cost estimate will be generated. At the completion of this phase, the equipment bid package will be submitted for bid.

<u>Design Development Phase:</u>

This phase will include more detailed design information. Weights and sizes of equipment will be provided to structural disciplines. Room level details will begin to be identified. General specifications will be available at the completion of this phase, if required, for submittal. The probable cost estimate will be reviewed comparing the schematic cost estimated to include any additional work identified as part of the detailing of the work, to the scope outline.

<u>Bidding Phase:</u>

Compressed Air Technologies will provide bidding support services for required clarifications associated with the presentation of their disciplines work on the contract documents. Required addendum will be issued.

<u>Construction Services:</u>

Compressed Air Technologies have included construction services in the design cost listed above. Construction Services will be limited to meeting attendance, system installation review for installation compliance to project specifications and offsite factory performance testing including compliance sign off. These services will be provided to the Widget to facilitate the construction process. They also include construction management services such as day-to-day scheduling, phasing and/or mediation between contractors. Onsite time capped at 10 days.

<u>SERVICES PROVIDED BY THE WIDGET</u>:

A. Electrical wiring of dryers, vacuum pumps, drains, DFS valves.

B. Retrofit of air nozzles, guns, knives and control box fans.

<u>PAYMENT/TERMS:</u>

CAT Inc. will invoice against the completion of the project net thirty (30) days of the date of our invoice.

14.0 Conclusion

14.1 Action Plan

Widget must first decide if a compressed air project is feasible. Given the facts as presented in this report, a compressed air project will elevate the systems reliability, air quality and reduce operating costs with respect to maintenance and electric cost. In order to achieve these goals, the system should be treated as a whole to attain the highest results. Should it be decided that the compressed air project is viable, the following *preliminary* action items must be implemented:

14.2 Compressed Air Upgrade Project

1. Finalize project components, locations for compressor, dryers and ancillary equipment
2. Begin Engineering phase of the projects
   Includes:
   a. Determine equipment layout and pipe tie-ins
   b. Check availability of utility connections (electric, water, sewer)
   c. Engineering of Equipment/Piping
   d. Equipment Specification Write-Up
   e. Installation Specification Write-Up
   f. Specification Issuance to Vendors
   g. Bid Evaluation
   h. Equipment Selection
   i. Release of PO
   j. Drawings (Compressor Area Layout)
3. Repair air leaks.
4. Replace blow off nozzles with high efficiency nozzles air knives and amplifiers (by Widget).
5. Install new equipment and controls at primary compressor area.
6. Perform new system Start-Up.
7. Turn off all satellite compressors.
8. By-Pass all satellite dryers.
9. Set discharge pressure on the compressors to 100 psig.
10. Set the discharge pressure on DFS controller to 90 psig.

14.3 Sequence Order of Events/Operating Strategy

After completion of the items listed above, the following operating strategy should be implemented: First, Widget's base set point pressure for the demand flow control valve should be set at a approximately 90 psig for release to the Plant. This is currently the approximate supply pressure to the Plant Air System. Every two days, the base pressure should be lowered by 2 psig. This turn down period will allow a gradual decrease in system air pressure and allow equipment that may require higher pressure to be identified. For example, the requirements for impact wrenches, which are designed for 450 ft lbs., torque at 90 psig. As the Plant air pressure is decreased, these tools would be the first to drop out. At that point a decision can be made to hold the base pressure at a slightly higher pressure to accommodate the impact wrenches, add special booster compressors or use the high pressure air from the compressors located on the Mezzanine. If this course of action is chosen, then the base pressure can be further reduced. If another piece of equipment drops out, follow the same process. This process should be repeated until a minimum base pressure is reached that satisfies the requirements for the entire plant. **The lower the pressure, the higher the savings, that can be realized**.

14.4 Final Summary

An effective approach necessitates that the supply and demand side issues, as well as point of use practices be reviewed in terms of a complete system. The audit process performed at Widget deals with the Plant Compressed Air System as a whole and this report provides a guide for developing a long term operating plan for achieving the goal of delivering reliable, quality compressed air to production at the least possible cost.

The success of the audit is due to the people at Widget who assisted in the process. Their help was essential in understanding and resolving the many complex issues. Please extend our thanks to everyone involved. Any questions concerning the findings or subsequent recommendations should be addressed to Mark J. Marino. Please feel free to call anytime.

Sincerely,

Mark J. Marino
Compressed Air Systems Specialist