Reducing Energy Use and Oil Mist Generation

MnTAP Intern Project Report
Roberts Automatic Products, Chanhassen

Chris Iacono
2009

The Minnesota Technical Assistance Program (MnTAP), University of Minnesota, provided a student intern and staff assistance free of charge to identify useful changes that reduce waste, emissions, and/or hazards, to increase efficiency at the company. However, the company decides whether to implement suggestions based, among other things, on its own evaluations of the project, including its own evaluation of the work performed by the intern under the company's supervision. THE COMPANY ACCEPTED THE SERVICES "AS IS" AND WITHOUT WARRANTY, INCLUDING EXPRESSLY WITHOUT WARRANT OF MERCHANTABILITY OR WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE.

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Preface

The work described in this report is a service of the Minnesota Technical Assistance Program (MnTAP), University of Minnesota, School of Public Health, Division of Environmental Health Sciences. MnTAP is funded primarily by the Minnesota Pollution Control Agency's Prevention and Assistance division.

MnTAP helps Minnesota businesses implement industry-tailored solutions that maximize resource efficiency, increase energy efficiency, prevent pollution, and reduce costs to improve public health and the environment.

As outlined in the MnTAP Intern Project Agreement, MnTAP staff will contact key facility personnel for up to two years following completion of the intern's work to collect information on which, if any, of the recommendations have been implemented.

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Contact information for environmental, health and safety regulations can be found on MnTAP's Web site <mntap.umn.edu/resources/regresources.htm>.

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August 25, 2009

Summary

Problem/opportunity:

Roberts Automatic spends a significant portion of overhead costs on utility payment for energy usage. There was desire to assess overall process energy efficiency and reduce unnecessary uses. The company was also interested in studying oil mist levels in the facility and researching methods for improvement. Energy efficiency also tied into oil mist reduction, since some equipment in the building was tasked with improving air quality. Also, since some facility equipment was getting old, there was interest to identify any potential upgrades that may lead to increased efficiency.

Solution:

I propose that COMPANY implement the options below:

1) Use the 7 ½ HP compressor for the "lights out shift"
2) Use a leak tag system to reduce leaks by 50%
3) Provide better mist collection at high-source locations identified
4) Use optimal Davenport door positions when machining
5) Purchase a VSD compressor when the existing 50 HP fails

Justification

These solutions provided the highest likelihood for improved energy efficiency and reduced oil mist generation. In total, these options have the potential to reduce energy consumption by 140,000 kWh/yr, or $5,600/yr. Oil mist level exposure will be reduced significantly at the source, as well as an estimated 10 grams of oil per hour being prevented from entering the shop air.

Key Staff

Chris Iacono, Minnesota Technical Assistance Program, University of Minnesota, summer intern, 2009

Bill Roberts, Senior Process Engineer, 952-567-2866

Table 1. Summary of Reduction Options

Waste reduction option	Change Type	Energy/oil mist reduced	Implementation cost	Cost savings (per year)	Payback period	Status
Use the 7 ½ HP compressor for "lights out" shift	Equipment change	50,000 kWh/yr	$1,000	$2,000	6 months	Partially Implemented
Use a leak tag system to reduce leaks by 50%	Procedure change	10,000-15,000 kWh/yr	Unknown*	$400-600/yr	Unknown*	Recommended
Run the 75 HP compressor instead of the 50 HP	Procedure change	-(7,500) kWh/yr	$0	-($300)	N/A	Not recommended
Purchase a VSD compressor when the existing 50 HP fails	Equipment change	50,000-75,000 kWh/yr	$19,000-22,000	$1,900-$2,700/yr	7-12 years	Recommended if air demand stays at current low levels
Provide better mist collection at high-source locations identified	Equipment change	10 grams/hour	None	N/A	N/A	Recommended
Use optimal Davenport door positioning when machining	Procedure change	Mist exposure magnitudes reduced 50% or more	None	N/A	N/A	Recommended
Modify building ventilation	Equipment change	47, 800 kWh in cooling costs Oil mist level affects unknown	Unknown	$1,900	Unknown	Not enough information for recommendation
Replace gas-fired evaporator with natural atmospheric evaporator	Equipment change	960 therms/yr	$7,700	$600/yr	13 yrs	Not recommended

*Leak costs will depend on the quantity of leaks in the building and the average costs per leak. It is possible that leak repair costs may eventually exceed the potential savings, so it is recommended that repair costs be recorded and monitored regularly.

The economic benefits of each waste reduction option are listed above are for each change individually. Because the savings are not necessarily additive, the overall savings may be less if multiple waste reduction options are implemented. For example, if the 7 ½ HP compressor is used for weekend shifts, leaks will not occur during this time and total leak savings will be reduced.

Background

Company Description

Address:	880 Lake Drive Chanhassen, Minnesota 55317
Telephone:	952-949-1000
Fax:	952-949-9240
Principal Products:	[Precision machined metal parts]
SIC code:	3451
NAICS code:	332710

Incentives for Change

Resource efficiency is an important goal for all companies. A resource that has received additional attention by many today is energy. Across many industries, there is a strong desire to reduce energy consumption where there is a cost benefit. Roberts Automatic has similarly been motivated by the potential to save on the overhead costs of electricity and natural gas consumption. By reducing monthly utility payments, Roberts Automatic can increase profitability without a change in production. Business has slowed during recent months as well which has added additional incentive for energy efficiency improvements.

Roberts Automatic utilizes large amounts of metal-working fluids, or MWF's, for use as cutting oils, coolants, and lubricants. As MWF's are sprayed onto moving parts during machining, a fine mist regularly develops around the work area. Since exposure to high levels of oil mist can cause many forms of irritation and discomfort to employees, there standards for acceptable concentrations. Roberts Automatic has not had any problems meeting regulatory standards for oil misting, however there is desire to improve indoor air quality whenever possible. Reducing employee exposure to any levels of contaminants is a priority to Roberts Automatic and a cleaner workplace is always more comfortable to work in. Additionally, facility cleanliness increases the level of professionalism perceived by current customers and potential clients.

Several processes in the facility generate significant amounts of heat. Roberts Automatic currently has some waste heat capture equipment in place on their chiller and air compressors. Even with this equipment, excess heat from these processes and others is still regularly leaving the building. This heat represents energy already spent, and finding appropriate uses for it may allow for reduced energy costs in other areas of the facility.

With their machining business dating back several decades, the Roberts Automatic facility contains a mixture of new and old equipment. Though the more dated equipment has been maintained and operates regularly, there is interest in upgrading or refurbishing when efficiency benefits present good paybacks. A long-term replacement guide for facility equipment could provide the needed justification for more efficient options when decision time comes. Major purchases may not be required presently, but this type of guidance was appealing to Roberts Automatic and became a consideration when evaluating building efficiency.

Process Description

Roberts Automatic has a versatile line of automatic machining equipment that allows them to manufacture parts in large quantities at high precision. Various screw machines and CNCs make up the core of their operations, however, various secondary operation equipment is utilized as well.

The facility has several processes through which machining equipment is able to operate most efficiently. These processes include the production of compressed air, chilled water and hot water. Additional equipment in the shop conditions the working environment to provide temperature and humidity control, adequate lighting, ventilation and air quality. These support processes were the focus of the study on how to reduce energy consumption and mist generation.

Compressed air provides the pneumatic power needed to operate machining equipment. Components within the screw machines and CNCs require pressurized air to perform their machining operations. Two industrial air compressors supply this demand through a shop-wide distribution system.

Chilled water and hot water are created using a custom-designed chiller system that allows heat removed from the cold water to be utilized for creating hot water. Continuous hot and cold water streams are required to run a vapor degreaser for cleaning machined parts. Chilled water is additionally used for cooling cutting oils in the machining equipment.

The shop air is conditioned by multiple rooftop units (RTUs) to provide cooling during the summer. They also bring in fresh air depending on daily weather conditions. Infrared heaters near the shop ceiling provide heating during the winter months. Dedicated RTUs serve office areas in the facility, meeting both heating and cooling demands throughout the year.

Several types of air filtration equipment reduce oil misting at the source and also filter ambient air. There are multiple methods employed, including media filtration, electrostatic precipitation and centrifugal impaction.

Figure 1 below is a normalized distribution showing electricity usage in the described processes, and excludes other smaller areas in the building that may be consuming electricity. The eight areas shown were found to represent 81% of the 2008 total electric costs as seen in past bills, with 2008 equipment operation estimated to best of ability. Approximations intentionally undershoot the annual total, acknowledging it would be unrealistic to catalog every electricity-consuming device. It is likely that there is error in some equipment run time and power estimations, since they are influenced by many factors such as production levels, weather conditions and operator's preferences. Raw data from electricity consumption estimating can be seen in Appendix B.

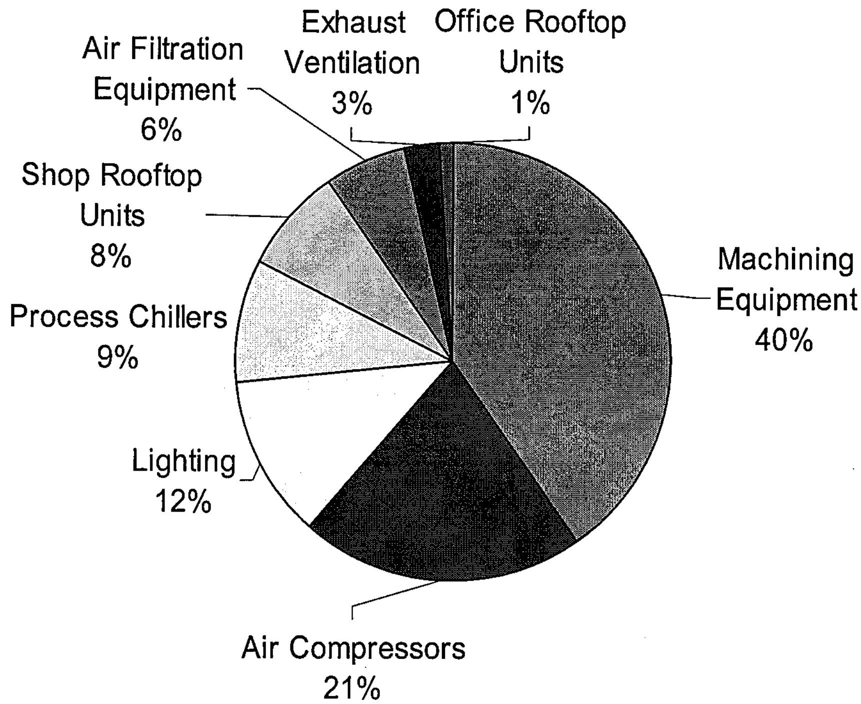


Figure 1 – Annual Electricity Consumption (% kWh/year)

As seen in Figure 1, the support processes described make up a large portion of the annual electricity use at the facility. Note that machining equipment is also included and is the largest single area. Electrical consumption was estimated using nameplate information from equipment and/or datalogging, with assumptions made about run times. Individual sections in this report will further detail how energy estimates were made.

The plot in Figure 1 provided insight to where efforts should be placed when looking for conservation opportunities. Though machining equipment was the largest portion of electricity use, there was little opportunity to reduce consumption being that they were tied to machine hours and part production. Lighting had been recently upgraded to an efficient fluorescent system, leaving only small savings opportunities if automated controls were desirable. From the remaining facility areas, air compressors and process chillers appeared to be a good starting point for looking at energy savings potential. Air filtration equipment, rooftop units and exhaust ventilation would also be analyzed for any opportunities.

Gas consumption was also analyzed, however, annual gas costs made up only a small portion of total energy costs as illustrated by Figure 2 below. Though more time was spent documenting electricity, natural gas use was of some importance considering that any use for waste heat from other processes might eliminate some need for natural gas.

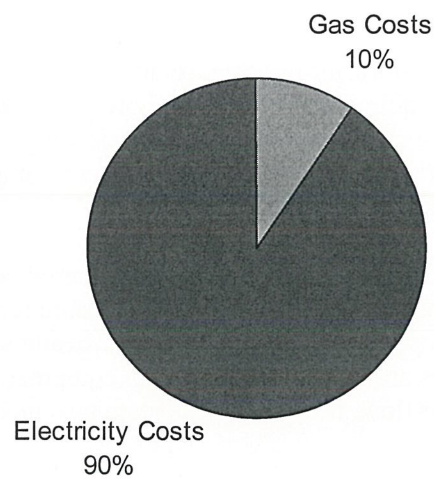


Figure 2 – 2008 Annual Energy Costs

Figure 3 below shows the three primary processes which consume natural gas. A gas-fired wastewater evaporator allows spent mopwater to be processed by boiling off the water and exhausting it out of the building. A gas-fired hot water heater provides hot water for domestic use. During the winter, gas is used to heat the shop using overhead infrared radiant heaters and in RTUs serving the office areas.

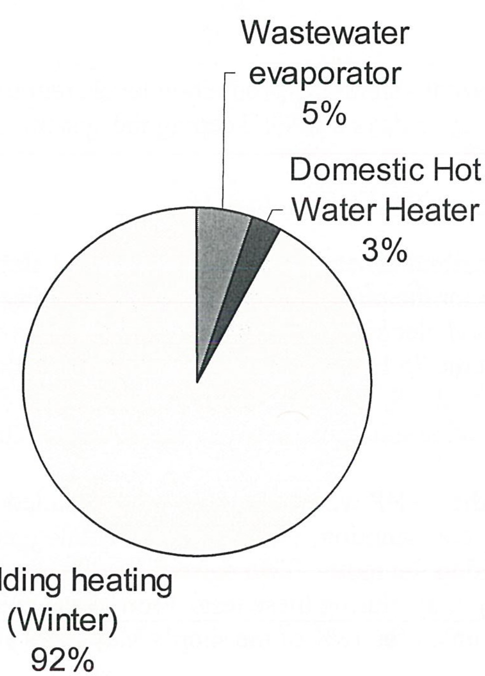


Figure 3 – Annual Gas Consumption (% Therms/yr)

Issue 1: Air compressor system inefficiencies

Management Method

Compressed air is created using two Quincy, lubricant-injected, rotary screw compressors, a 75 HP and a 50 HP, which work together to provide the required air volumes and pressure. The air is primarily used to run shop machines, however, air-powered hand tools are also used for cleaning oil off machines and parts. Shop demand for compressed air directly influences the work load at the air compressor units such that higher electrical power is needed during peak work hours.

Once discharged from the air compressors, compressed air is dried and filtered before being routed to the 1,000 gallon storage tank, or receiver. Downstream of the receiver, a pressure regulator drops the line pressure to a specified level before being supplied to the shop. Two-inch headers serve as the distribution system for the facility, from which drop lines are tapped off and fed to equipment. Figure 4 below provides an illustration of the compressed air flow. Note that the system also includes a regulator bypass for higher pressure needs.

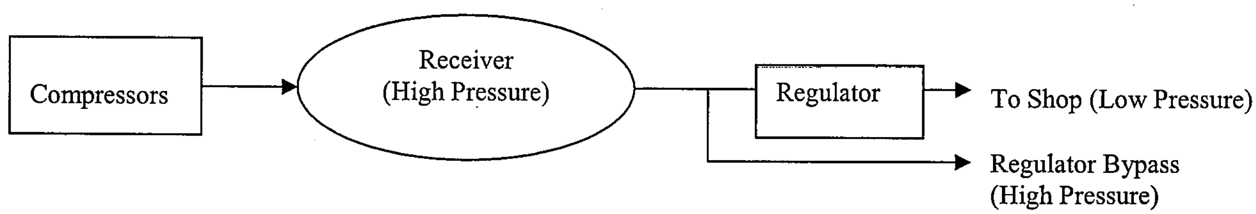


Figure 4– Compressed air flow diagram

At the time of this study, the current machining production levels required only the 50 HP compressor to run. The 50 HP ran 24 hours a day, 7 days a week, keeping the system pressurized at all times.

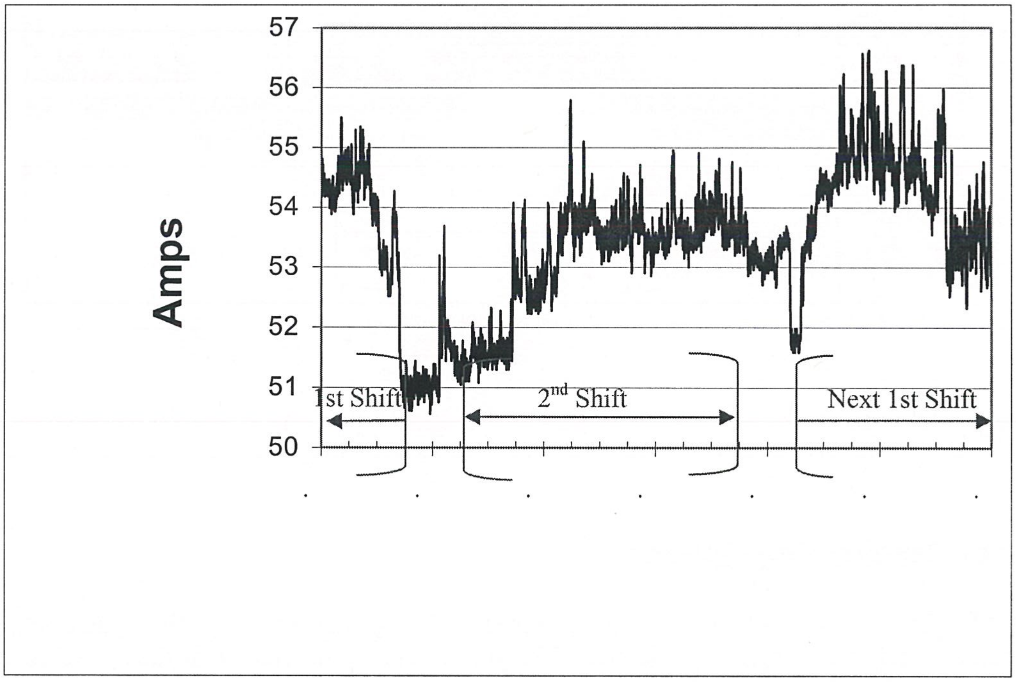
Energy Profile

The electricity consumption distribution seen previously in Figure 1 stating 21% annual electric consumption was an estimation for the previous year, 2008, since utility electric bills allowed for comparison to documented annual electricity consumption. Based on conversations with maintenance, business levels were higher and the 75 HP compressor operated the majority of the time during 2008. To approximate the energy usage for 2008, the observed 2009 compressor flow rates were prorated based on the difference in documented production hours between the 2008 and 2009 years.

For 2009 business levels, only the 50 HP was running, so more detailed analysis was conducted to determine its percent electricity consumption. The 50 HP was datalogged during weekday and weekend shifts to measure amps delivered to the motor. Two current transducers placed on the load side of the motor starter monitored the amp draw during these tests. From these measurements, it was estimated that the compressed air system accounted for 18% of the shop's May 2009 electricity consumption.

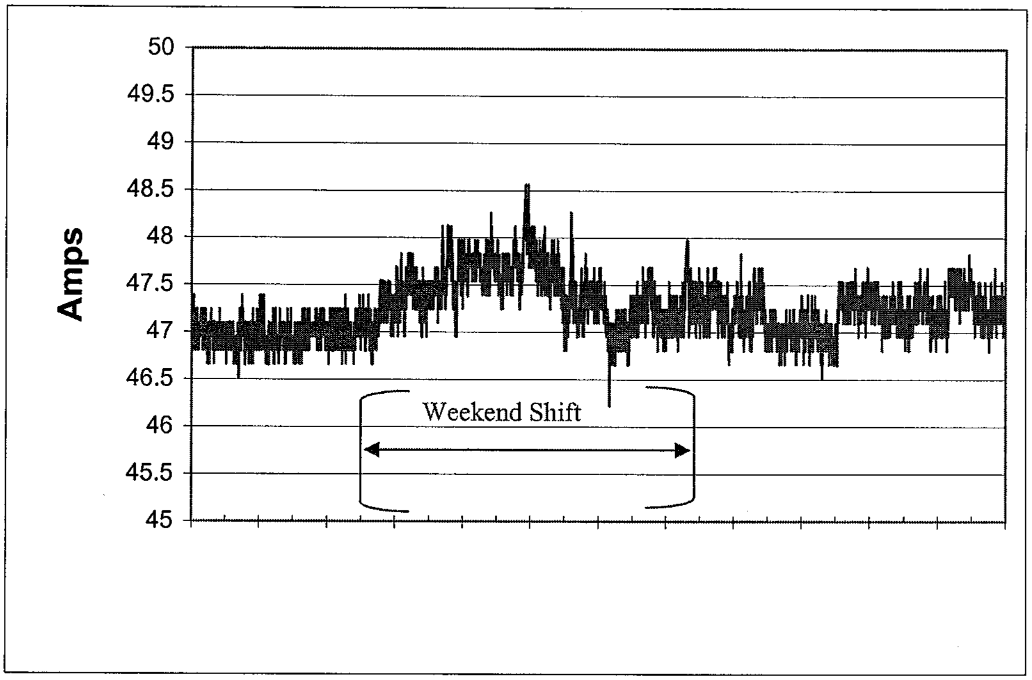
Figure 5 below shows the amp loads on the 50 HP compressor during a typical weekday shift. The amps delivered to the compressor were monitored over a 24-hour period using a current transducer attached to the load side of the motor starter. The red brackets identify first and second shifts. The observed amp loads follow the trend that would be expected, rising during the beginning of a shift and falling towards the end of the shift. The average amp level for this 24-hour period was 53 amps. With nameplate full-load amps at 57.3 amps and a 10% service factor, this was estimated to be 85% full-load power. Note that amp levels fluctuate rapidly and irregularly, a tell-tale sign that the system is responding to changes in demand instaneously due to its inlet modulation controls.

Figure 5– 50 HP compressor amp loads, June 1– June 2, 2009



Compressor power requirements for a typical weekend shift (Friday – Sunday) can be seen in Figure 6 below, with red brackets again identifying when the shift begins and ends. There is a rise during the shift, but the observed amp level is lower, averaging about 47 amps or 75% full-load power over the 24-hour period. Note that most of the compressors run time occurs outside the weekend shift period, when nobody is in the building. The compressor was left on for the "lights out", during which one Gildemeister machine continues to run independently.

Figure 6 – 50 HP compressor amp loads, Saturday, July 20, 2009



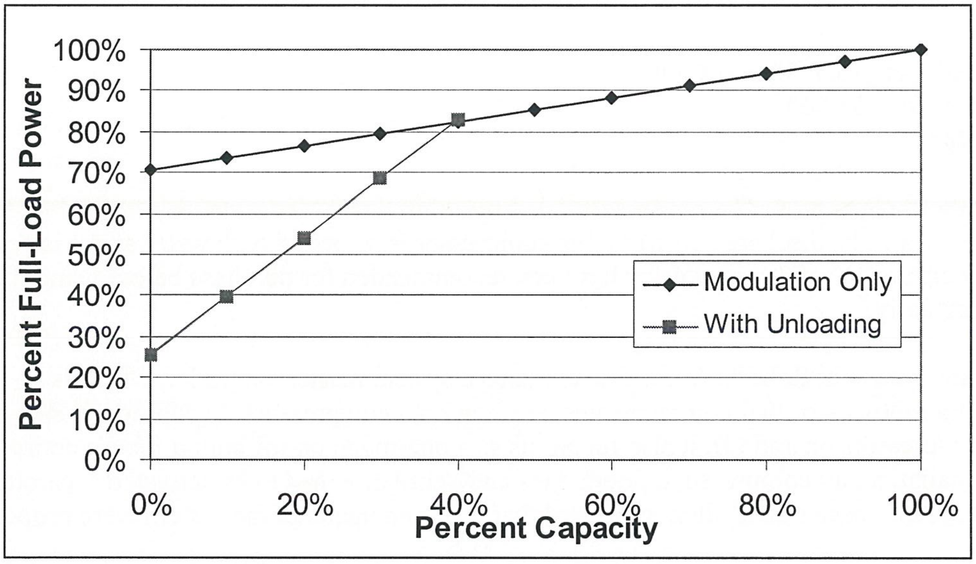
Reasons for Researching Options

As illustrated by previous discussions about air compressor energy consumption, this system represented a large portion of electricity usage in the facility. The graphs shown indicated that the 50 HP compressor never drops below 75% of its full-load power, even during times of very small or zero air demand. Determining why this was occurring and if there were better alternatives would have a noticeable impact on electricity costs. Control settings and air leaks were initially suspected to play some role in this behavior.

The 50 HP compressor and the 75 HP compressor are both lubricant-injected rotary screw compressors, however they contain different controls. Both control mechanisms are attempting to accomplish the same task—to reduce the volume of air produced to satisfy demand. More specifically, the compressor is responding to changes in system pressure to reduce its percent capacity, and subsequently, its electrical input power.

The 50 HP uses a control mechanism called inlet modulation, a method that is often considered inefficient (Kemp, 2006). Reduced capacity is achieved by modulating the size of the inlet such that a smaller volume of air enters the compressor intake. When a compressor is reduced to a certain capacity, it may have the ability to unload. Unloading will let the motor to run without compressing air, allowing storage in the facility to supply air. By unloading, the motor can run at a reduced power level and be ready to load up again quickly when needed. Figure 7 below shows the relationship between percent capacity and percent power for a typical screw compressor with inlet modulation controls. Depending on how the compressor is set up on site, unloading may or may not be allowed. From the datalogged amp levels shown in the previous section, the 50 HP compressor was not unloading.

Figure 7 –S crew Compressor, Inlet Valve Modulation ("Compressed Air Storage", 2003)



Notice that without unloading, the compressor can only operate down to 70% of the full-load power. If unloading is enabled, the compressor will unload around 40% capacity and operate at approximately 25% of its full-load power.

The 75 HP compressor contains a more sophisticated control mechanism. Using four staggered lift valves located directly in the air-end housing, the compressor can vary its displacement to allow a steeper power turn-down as capacity decreases. As shop demand decreases, each valve incrementally lowers the capacity by 12.5%. Thus, with all four valves open, the compressor runs at 50% capacity. If demand continues to drop below 50% capacity, the compressor will unload. The compressor includes a digital interface, which can be used to quickly adjust the load/unload setpoints and other settings.

An independent system master controller communicates with both compressors to determine which should run. This programmed logic controller (PLC) uses a single pressure transducer to monitor supply pressure and also monitors the 75 HP compressor's variable displacement. The logic is set so that at start up, if a low enough pressure is detected, the 75 HP will turn on and begin supplying air to the shop. If shop demand is low enough, the lift valves described previously will begin to open one by one. After the third lift valve is open, the master controller starts the 50 HP and disables the 75 HP. With this logic, the 50 HP is tasked with supplying low air demands in the shop. If demand is high, the controller is capable of activating both compressors to supply maximum airflow. As an additional feature, the controller acts as a one-button power switch, ensuring all compressors, dryers, aftercoolers and ventilation are set up correctly.

In summary, options for the compressed air system were researched because it appeared there would be several opportunities to reduce power in the system. The controls on the 50 HP compressor were outdated and inefficient, and seemed to be consuming high power even at unnecessary times since it was not unloading. Furthermore, there was a sophisticated unit that appeared to be playing more of a back-up role for low levels of demand. An independent master controller allowed for convenient activation, but perhaps not the most energy-efficient logic. Between all the questions regarding controls, there was also the opportunity to quantify leaks and their added costs.

Reduction Option [1.1]: Use 7 ½ HP compressor for "light out" shift

Summary
Energy reduced (per year): 50,000 kWh
Implementation cost: $1,000
Cost savings (per year): $2,000
Payback period: 6 months
Status: Partially Implemented. The power line has dropped in the Gildemeister department to power to the 7 ½ HP compressor. The discharge air from this compressor is saturated with water and it is desirable to remove this moisture. A refrigerated dryer has been recommended for purchase before using the compressor regularly.

The compressor system at Roberts Automatic contains a system master controller, which is an independent microprocessor that communicates between both compressors. In addition to sequencing each of the compressors on and off, it also functions as a one-touch on/off button for the entire system. Prior to its installation, all compressors, driers, fans and ventilation had to be activated separately. By installing the system master controller, it ensured that all components of the system were properly set up.

Currently the compressor system is never shut off, however this was not always the case. Several years ago, the entire shop was shut down during the week from 3 AM to 5 AM between shifts. Also, no one worked on the weekends and the system remained off then as well. With the addition of a weekend shift and automated lights out equipment, the compressor was needed more often and was no longer shut down. Lights out machines can run while no one is in the shop, since they are equipped with automatic bar loaders and fire suppression equipment.

During the course of this study, only one screw machine, a Gildemeister, was running on a "lights out" shift. The machine ran from 5 PM to 5 AM, Friday through Sunday, when no one was in the shop. Though these machines require compressed air to operate, they demand much less air than most equipment in the shop. Flow meter tests suggested air consumption as low as 10 CFM, and minimum pressure is estimated in the 60-70 psi range. The 50 HP compressor, with its inefficient partial capacity controls, is an inefficient system for meeting these air demands. Furthermore, air is continually being lost due to leaks during these hours. It is estimated that 57,500 kWh per year, or roughly $2,300, is spent on making compressed air during the lights out shifts.

There is a stand-alone air compressor at the facility that is capable of meeting the demands of the Gildemeisters. The compressor is a 7.5 HP, 2-stage reciprocating compressor with an 80-gallon storage tank. The compressor fills the tank at 175 psi and is rated for an output of 27 CFM at 90 psi. This small compressor consumes 90% less power to provide the air requirements for one Gildemeister machine. If the main system can be shut down on weekends and lights out equipment demands met with the stand-alone compressor, expected savings are estimated at $2,000/yr. The compressor would supply the air directly to the Gildemeister, rather than through the main distribution system.

The 7 ½ HP compressor was tested to confirm its ability to meet the required pressure and flow for a Gildemeister. Table 2 below was created by open-blowing the compressor while simultaneously measuring pressure and flow. A ball valve was used to choke off the air down to different flow rates, noting the pressure at that flow rate.

Table 2 – 7 ½ HP measured pressure at various flows

Air flow (CFM)	Pressure (psi)
0	107
15	98
20	94
25	88
30	84
35	83
40	75
60	25

Gildemeister air needs were investigated to ensure minimum requirements were met for proper operation. A flow meter was used to measure the air flow rate entering a Gildemeister while running. The gauge pulsed between 7 and 9 CFM, never exceeding 10 CFM.

Minimum pressure requirements could not be tested without endangering the machine, so points of air use in the machine were identified and researched. The machine operator said air was used in the spindle pick off which removes the finished part, and the automatic bar loader which reloads bar stock as needed. Depending on the job, an air-driven thread-rolling tool may also be required. The Gildemeister operating manual stated an operating pressure range of 4-6 bar, or about 60-90 psi. Documentation for the automatic bar loading system suggested an operating pressure of 90 psi.

The operator felt that the bar loader used very little air was surprised by this requirement. He showed me the two small air cylinders he knew of. Also, shop pressure is supplied at 90 psi and the machine ran fin despit readings in the high 80's at nearby pressure taps. I spoke with a technician at IEMCA, the company that makes the bar loaders and asked about this requirement. He said that this number was a rule of the thumb, not a requirement, used for all of the company's bar loaders. For the particular model at Roberts Automatic, most functions are hydraulic and require very little air. Air is only used for a couple minor functions, including opening a small door. He suggested minimum pressure was likely below 80 psi, but didn't have a specific figure.

Documentation was not found for the pneumatic thread-rolling tool, however, operators believed it worked best in the 85-90 psi range. However, the job currently running in the Gildemeister department did not require thread-rolling. The department lead also indicated it was unlikely that a thread-rolling job would run "lights out." The 7 ½ HP compressors rated output indicated one Gildemeister could easily be supplied, and the data in Table 1 suggested it might handle all three Gildemeisters, assuming no thread-rolling tools are used. Flow rates for the thread-rolling tools are unknown, and may drop pressure too low. There is a large buffer in the high-pressure storage tank that might make thread-rolling a possibility, but it was not testable at the time.

The 7 ½ HP compressor was tested on the current Gildemeister job during a normal day shift and it successfully kept the machine operating. Before moving to implementation, the 7 ½ HP compressor system does need some modifications. The operator noticed moisture in the lines during the test while operating a hand tool. Since there is no air dryer, the discharged air is saturated with water. This moisture can condense inside the Gildemeister and eventually cause maintenance issues. It is recommended that a refrigerated air dryer be purchased to remove this moisture. Also, since the 7 ½ HP compressor has not been closely maintained over the past few years, it could use some basic maintenance. The filter set may need to be replaced to ensure clean air. It is believed that the oil in the unit has never been change either.

Once a dryer has been purchased and some basic maintenance completed, the system should be ready to run during the "lights out" shifts. Before leaving at the end of the day, the operator will need to plug in the compressor and direct the airflow to the machine. The operator will need to close the valve to main supply so the 7.5 HP compressor does not backfeed into the main distribution system. Once the "lights out" machine is isolated, the main compressor system can be shut down by pressing the master switch on the system master controller. The next morning, an operator will need to turn on the main system again and disconnect the 7.5 HP compressor.

If manually activating the small compressor and re-routing the air lines becomes too tedious for employees, automation could be added to make it simpler. A 3-way solenoid valve could be activated by a pressure switch that monitors the main system pressure. At the end of the shift, the operator would simply enter the compressor and turn off the main system with existing master switch. A schematic of this system, and how it could be tied into some of the existing piping, can be found in the Appendix.

This system has potential for expansion to other departments that might need to run a "light out" shift. The Swiss machines were identified as one department that might someday run. The existing 7 ½ HP compressor could be moved to this department, or a second smaller compressor could be purchased. Additional investigation would be needed to ensure that the compressor size could meet the pressure and flow needs.

Benefits
This option is a promising reduction idea due to its simplicity for implementation and quick payback. Savings will be seen immediately as long as long as the procedure is followed by employees every weekend, Friday through Sunday. Shutting down the main compressor system was a regular procedure in the past and those in charge at the shop should know how to do it. If re-routing air to draw from the smaller compressor becomes to tedious, there is potential for automating to be as easy as pressing one button.

Economic Analysis
The capital investment for this option goes towards purchasing an air dryer to remove moisture. Refrigerated dryers rated for 30 CFM are sold for around $1,000 but a used one may be found for lower prices. Maintenance costs on the 7 ½ HP compressor may be more regular to ensure the "lights out" machines keep running well.

Implementation Status
The status of this suggestion is: Partially implemented. A 220 V single phase power line has been dropped in the Gildemeister department. The 7 ½ HP compressor was moved from storage and placed in a convenient spot near the Gildemeister that is currently running. Once an air dryer is purchased to remove moisture from the 7 ½ HP compressor's discharge air, the system will be able to start powering the Gildemeister currently running "lights out."

Reduction Option [1.2]: Use a leak tag system to reduce leaks by 50%

Summary [Should match information in Table 1.]
Energy reduced (per year): 10,000-15,000 kWh
Implementation cost: $20/leak (Estimated)
Cost savings (per year): $400-600
Payback period: Unknown
Status: Recommended

There is no current procedure for finding and documenting leaks within the building. Any leak repairs typically only happen if they are causing noticeable interference with facility operations. Maintenance staff acknowledges that there likely are many leaks in the building, but no efforts had been made to quantify the costs of them.

A test was conducted to determine the leak rate in the compressed air distribution system. The test was conducted during a time when no equipment was running. The time it took for the demand-side pressure to drop to half its original value was note. This time was used to estimated the leak rate using the equation found in Appendix D. The leak rate was found to be approximately 40 CFM, which is 17% of the 50 HP compressor capacity or 11% of the 75 HP.

The cost of these leaks was assessed by using the capacity versus power plots to determine the change in power seen from reducing flow rate. If enough leaks are fixed to reduce the leak rate to 20 CFM, the 50 HP compressor will see about $400/yr in savings. When the 75 HP compressor is running the savings will be slightly larger—around $600/yr. Although the 75 HP is much more efficient at reducing power, the difference is small between the two compressors because the leak rate is a smaller percentage of total capacity for the 75 HP. To maximize savings from leak reduction, a new compressor with a variable speed drive (VSD) would be most effective, capturing $1,200/yr in savings. For additional discussion on VSDs, refer to section 1.4.

My recommendation to Roberts Automatic is to establish a more specific procedure for locating and repairing air leaks. The motivation for fixing leaks should not be limited to successful end use operation, but should also include the desire to reduce any unnecessary costs at the air compressors. Also, the number of new leaks and size of existing leaks may increase if gone unchecked. A leak tag system would allow for better management of leak repairs and could help establish a regular repair schedule. In this leak tag system, a specific number of leaks could be identified and tagged for later repair. The location could be recorded in a master list, which maintenance would use to track the leaks, prioritize repairs and keep records of repair costs. By identifying leaks with a tag, it would act as physical reminder to repair it as well. Ideally, the search would occur when all equipment is off, to assist in finding the loudest leaks and to get a sense of how many are still out there.

The goal of this system would be to keep a manageable number of leaks on the monthly repair schedule so that maintenance could get into a routine. For example, setting the number of leaks at 20 per month would assume that roughly one leak was repaired each day.

It was difficult to estimate the number of leaks in the building, however, when its quiet, many leaks can be heard on a brief walk through the shop. If the average leak is between 0.5 and 1.0 CFM, as many as 40-80 leaks may exist. Thus, a goal to reduce half the leaks means fixing 20-40 of them. The cost of fixing a leak may be a small or large depending on the component that is leaking. If components are replaced at each leak, a $20/yr cost may be a reasonable estimate. It is easy to see that, according to these figures, the cost to fix half the leaks may approach the energy savings received. It would be important to monitor the costs spent to fix leaks to make sure continued efforts were worthwhile.

Roberts Automatic may also find it beneficial to track the improvements from the leak reduction program to evaluate how effective it is. This could be done very easily by conducting an analysis similar to mine, using Equation 1 in Appendix D. Every month when new leaks are located and tagged, the compressor system could be shutdown and the time to reach half the operating pressure would be recorded. Monthly monitoring would offer insight to how greatly leaks have been reduced.

Benefits

By establishing a procedural leak reduction program, the compressor will see lower loads and require lower electrical power. Being that leaks will be fixed on a regular basis, the shop may see fewer pressure drops and there will be lower risk for interference at point of use equipment.

Economic Analysis

The capital investment will depend on the components that need to be replaced. An average cost of $20/leak was estimated, however, the cost while fixing leaks should be monitored.

Implementation Status

The status of this suggestion is: Recommended. There are potential savings at the air compressor that may be seen if leaks are significantly reduced. Leaks will continue to increase if gone unchecked and it is worthwhile to get into a routine of tracking and fixing them. I advise that attention be given to the costs spent, recognizing that that the savings realized by the existing compressors may limit how many leaks are fixed.

Reduction Option [1.3]: Run the 75 HP compressor instead of the 50 HP

Summary

Energy reduced (per year): -(7500) kWh
Implementation cost: $0
Cost savings (per year): -($300)
Payback period: N/A
Status: Not recommended

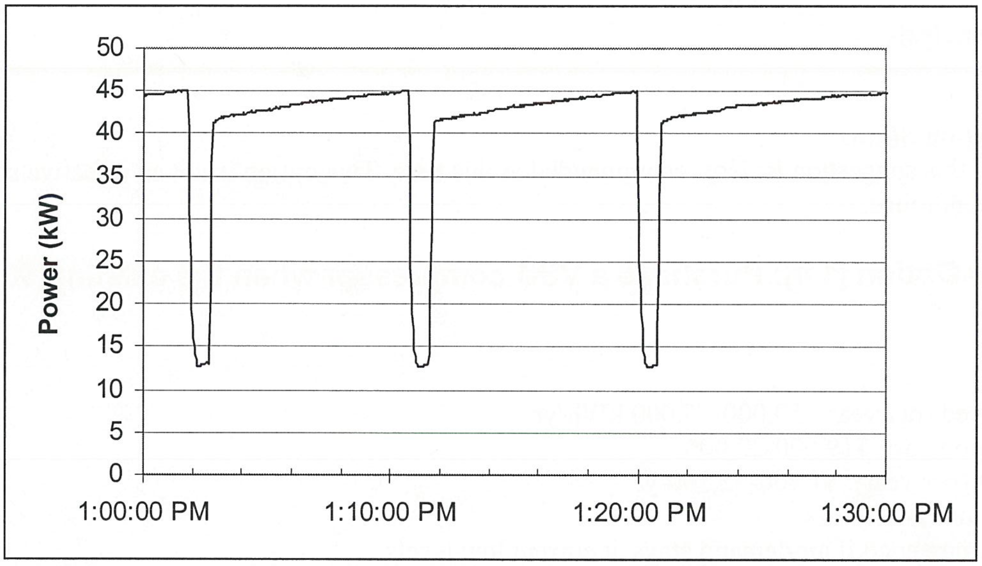
As discussed in the Reasons for Researching Options section, the 50 HP compressor was operating using inlet modulation controls and it datalogger results indicated it was not unloading. A compressed air consultant at John Henry Foster assisted in determining why the 50 HP compressor wasn't unloading and if there a more efficient way to meet the low air demands in shop.

The 75 HP compressors variable displacement controls, as discussed in the Reasons for Researching Options section, allowed this compressor to more drastically reduce its power as capacity decreased. Despite the larger motor, early estimations suggested that the 75 HP may be able to utilize its variable displacement and unloading capabilities to meet current shop demands at a lower energy cost.

By turning off the system master controller (PLC), I was able to manually activate the 75 HP compressor and deactivate the 50 HP. Using a power logger rented from John Henry Foster, precise true power readings were collected and used to compare the 50 HP and the 75 HP compressors. The tests were conducted for a weekday shift and a weekend shift, since the level of demand influenced the length of time that the compressor could stay unloaded. Thus, during the weekends when there was less equipment running, the 75 HP compressor could stay unloaded longer and could run at a lower average power.

Figure 8 below shows the 75 HP operation while running load/unload on a weekday. Load and unload setpoints can be set using the digital interface, and for the test were set at 99-114 psi to maximize unload time. Note that when unloaded, the power is approximately 25% of the loaded power.

Figure 8 – 75 HP Compressor True Power, August 5, 2009



Average power for the 75 HP compressor when operating in this sequence was calculated for a weekday and a weekend shift. Table 3 shows the results when compared to the 50 HP average power. Logging for each compressor occurred on the same day, shortly after one another to make the comparison as direct as possible.

Table 3 – Average power comparisons, 50 HP compressor vs. 50 HP compressor

	Weekday Avg. Power (kW)	Weekend Avg. Power (kW)	Approx. Annual Cost
75 HP	38	31	$12, 260
50 HP	35	33	$11, 960
Savings	3	-(2)	-($300)

The 75 HP compressor is slightly cheaper to run on weekends, however the 50 HP compressor is slightly cheaper to run on weekdays. The savings nearly offset themselves, with an annual $300 penalty for running the 75 HP compressor.

If demand air decreases, because of slower production or because of leak repairs, the 75 HP compressor will be able to unload for a longer period of time. It is possible for there to be a time when the 75 HP compressor is always more efficient, however, the current conditions are not the right time.

There was some investigation into whether the 50 HP compressor could bypass modulation and run load/unload. After speaking with a service technician from John Henry Foster, it is possible to adjust the compressor to do so. However, the technician believed that the compressor was purposely set up to stay loaded and modulated instead. Because the compressor is much older, the rapid load/unload cycles would likely be harder on the unit and increase maintenance costs. It seems that the unit has never run in such a way in its lifetime, so I am hesitant to suggest such a change. The compressed air consultant from John Henry Foster acknowledged the technician's opinion. He also pointed out that the 50 HP's unloaded power is probably higher than the 75 HP's unloaded power, since the 75 HP has such a low unloaded sump pressure. It is very possible that the 75 HP in load/unload will operate more efficiently than the 50 HP in load/unload.

Benefits
N/A

Economic Analysis
N/A

Implementation Status
The status of this suggestion is: Not recommended at this time. This option is not an effective solution for the current conditions.

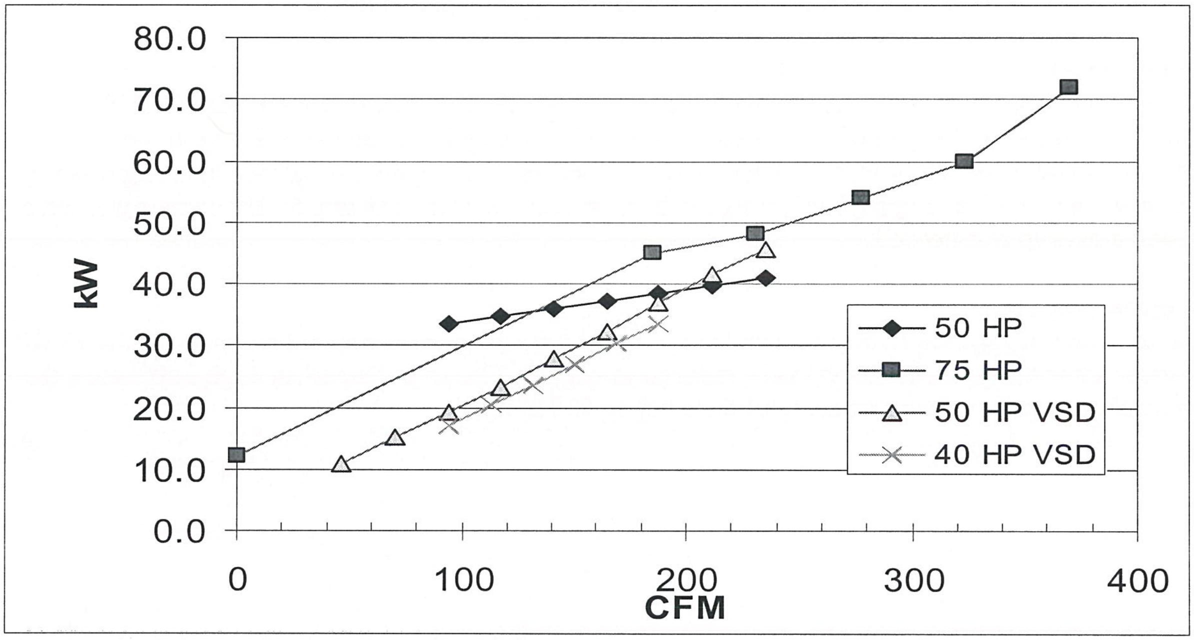
Reduction Option [1.4]: Purchase a VSD compressor when the existing 50 HP fails

Summary
Energy reduced (per year): 50,000-75,000 kWh/yr
Implementation cost: $19,000-22,000
Cost savings (per year): $1,900-$2,700/yr
Payback period: 7-12 years
Status: Recommended if air demand stays at current low levels.

The 50 HP compressor is older than the current Roberts Automatic facility, and will likely be replaced sometime in the future. A variable speed drive (VSD) compressor would be the most efficient technology to operate the lowest costs, especially for the current levels of air demand.

Figure 9 shows the existing compressors in the facility, their operating conditions and two potential VSD replacement options for the existing 50 HP. The energy savings can be seen by the reduced power level that the VSD compressors operate at for most flow rates. If demand for air during the weekday increases back up to the 75 HP capacity, such as the 2008 operating levels, the VSD will not be as beneficial. Energy savings might only be seen on weekend shifts when demand drops back down to the smaller flow rates. Alternately, if demand exceeds the 75 HP compressor capacity, the VSD will allow operate as a trimming device and will be an effective means for reducing power.

Figure 9 – Recommended VSD compressors and operating conditions



John Henry Foster assisted in identifying these two VSD compressor options. The 50 HP VSD is a rotary screw compressor, the same style as the existing compressors in the facility. To go down to a smaller compressor, a 40 HP VSD rotary vane compressor would be the next option. Based on average power estimates, the 40 HP rotary vane initially appears be a little more efficient, and there is less overlap between it and the 75 HP. On the other hand, the 50 HP VSD is capable of reducing capacity down to lower levels before unloading. John Henry Foster also mentioned that is sometimes desirable to maintain the same type of compressor at a facility. Either option appears to be an efficient choice since both contain VSD controls, however more in-depth discussion should take place with John Henry Foster before deciding which choice is best for Roberts Automatic.

Table 4 shows the savings that would be seen immediately if a variable speed drive compressor was installed. As mentioned, a significant increase in air demand during weekdays may reduce savings if the VSD can only operate on weekends.

Table 4 – Variable Speed Drive compressor savings

		50 HP VSD	40 HP VSD
Runs all shifts	Purchase Cost	$22,900	$19,200
	$/yr saved	$1,916	$2,729
	Payback	12	7
Runs weekends only	Purchase Cost	$22,900	$19,200
	$/yr saved	$618	$990
	Payback	37	19

As an added benefit, the VSD controls will also allow for better realization of repaired leak savings. If the leak rate is reduced by 50%, $1,200/yr will be saved.

Benefits

Low levels of air demand will be met by the most efficient technology available, allowing for reduced operating costs. Between the VSD controls on a new compressor and the existing variable displacement controls on the 75 HP compressor, the facility will operate at high efficiency across all possible levels of air demand. Also, the controls will allow for higher savings from repaired leaks.

Economic Analysis

This recommendation would require the purchase of a brand new compressor with the desired VSD controls. Depending on the type of compressor, the initial cost may be as high as $22,900. If the compressor operates for all shifts, a payback of 12 years or less may be possible. Since the compressor is a large investment with a long payback, it would be most realistic if the existing 50 HP compressor were to fail and a backup was needed.

Implementation Status

The status of this suggestion is: Recommended if air demand continues to stay at low levels. If the 75 HP compressor starts taking some of the loads, reduced savings will be seen. Due to the high initial cost, the recommendation may not be practical until the existing 50 HP fails.

Issue 2: Methods for reducing oil misting

Management Method

As previously discussed, the MWFs used in machining operations produce oil mist in machine enclosures which often escapes into the shop air. High employee exposure to mist and the physical presence of the mist is undesirable, so mist levels are attempted to be reduced using various equipment. Mist collectors deal with oil mist directly by pulling contaminated air out of machine enclosure and using centrifugal forces and media filters to separate the oil. The filtered air is then discharged into the shop and mixes with the ambient air.

There are several types and sizes of mist collectors in the shop, and the set up varies between each machine. Some machines share the same collection unit using multiple hoses, while others machines have dedicated units. The mist collectors are turned on at the operator's discretion. A list of all of the major machining equipment in the building, and their respective mist collectors, has been compiled and can be found in the Appendix E. Not all machines currently have mist collectors, however, many of these machines are not currently operated regularly.

A second stage of filtration occurs at the 14 air cleaners scattered around the shop. As of August 2009, 13 of the 14 air cleaners are operational. Hung from the ceiling, the air cleaners use media filtration and/or electronic filtration to remove additional oil from the air. Five of these air cleaners are new models, but the others are much older and less maintained. Figure 10 is a diagram showing the air cleaner layout in the shop. As the red arrows show, air circulation is created due to the orientation of the units. The air cleaners typically remain on throughout the shifts.

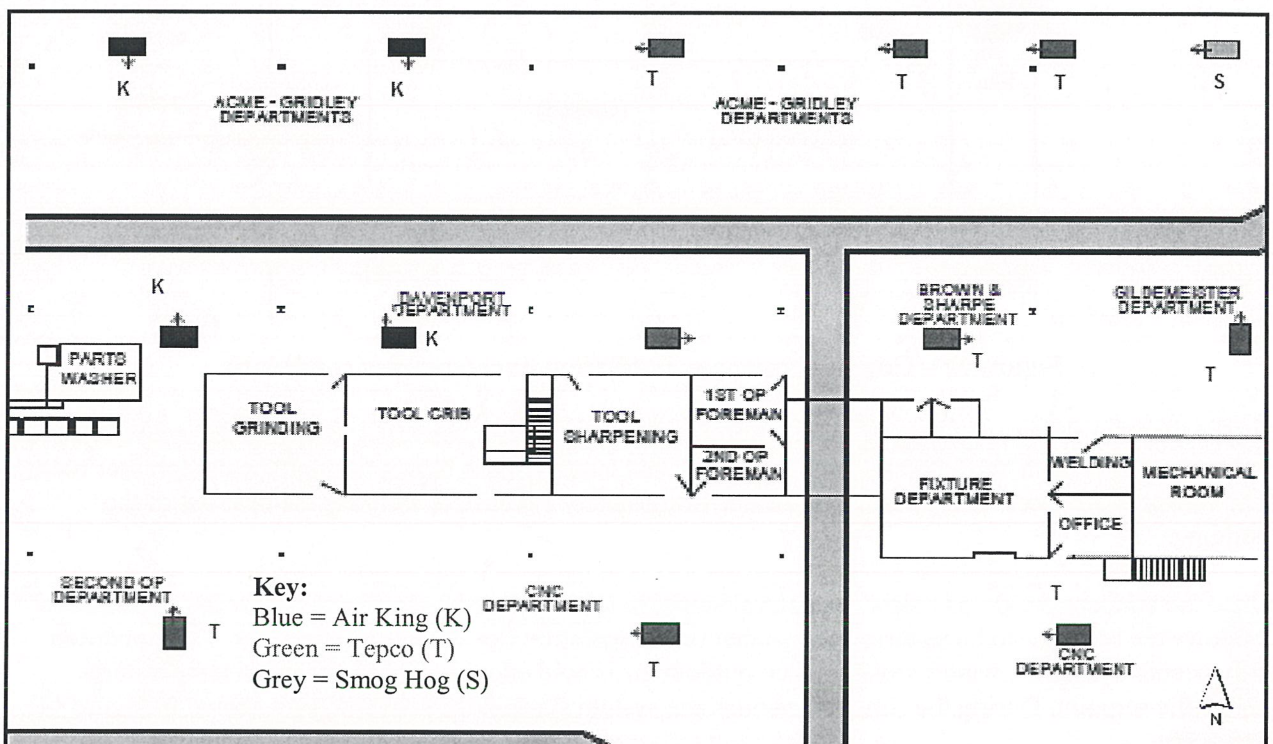


Figure 10 – Ceiling-mounted air cleaner layout

Intake and exhaust streams also contribute to air quality in the shop, since these rates determine the number of fresh air changes the building gets. During the summer, outdoor air is primarily brought into the building through rooftop units, which provide temperature conditioning as well. Depending on the weather conditions, varying levels of outdoor air are brought into the building. An economizer controller on each unit determines the most efficient mix of outdoor air and return air to provide the required cooling. Thus, on milder summer days, up to 100% outdoor air might be used to cool the building, with the added benefit of increased ventilation since the existing shop air is exhausted. On the hottest summer days, the minimum outdoor air damper position dictates the amount of outdoor air brought in, with cooling provided by the unit's compressors. At the beginning of this study, maintenance staff and a service technician believed the minimum position was set at 10% for each unit. It was later determined that only one unit, RTUS5, was set to 10% outdoor air, with the others at 0% outdoor air. During the winter season, the shop rooftop units are manually turned off since they do not have heating capabilities.

Air can also enter the building through a separate air stream which uses outdoor air to cool the compressor room. The air compressor motors release a large heat load into the room, which if not removed, can lead to extreme temperatures and potentially equipment failure. A ventilation system independent of the rest of the shop allows the room to stay at an acceptable temperature without placing this heat load on the roof-top units. Servo-controlled louvers automatically control airflow depending on the compressor room temperature. A schematic for the system can be seen in Figure 11.

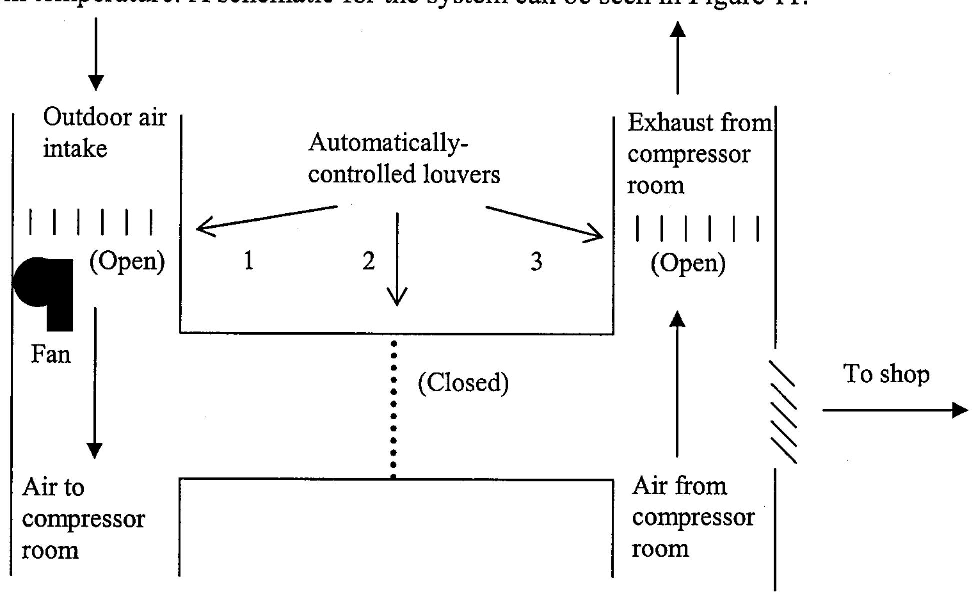


Figure 11 – Compressor room ventilation duct (summer condition)

As the diagram shows, when the compressor room calls for cooling, louvers 1 and 3 on the intake and exhaust streams open up. Louver 2 stays closed so that outdoor air is blown through the compressor room. The outdoor air passes through the room and is immediately exhausted, carrying the heat out of the building.

Once the temperature drops below the control setpoint, louvers 1 and 3 close, and louver 2 opens. Louver 2 allows the room air to be re-circulated so that the temperature rise occurs more slowly. This condition only occurs during the winter season, when outdoor air is cold enough to push the room temperature below the setpoint. During the summer months, the system stays in the configuration shown in Figure 11.

As previously mentioned, this system provides an additional air stream into shop, due to manual louvers on the exhaust side of the duct. A portion of the exhaust air is recovered and directed into the shop. This air stream provides additional ventilation and functions as a heat recovery device. During the summer season, additional heat load in the building is undesirable. During the winter, this heat recovery may be more desirable and might slightly reduce heating costs.

Also contributing to ventilation, there are multiple exhaust fans that remove air from the building. Exhaust fans that run continuously include the air-cooled condenser exhaust, tool grinding room exhaust and the shop bathroom exhaust. The air-cooled condenser, located on the mezzanine, directly removes shop air from the building. The tool grinding room and shop bathroom are enclosed rooms that receive supply air from different rooftop units than the general shop air does. However, the negative pressure in this room causes general exhaust air to enter from beneath the door. Thus, the tool grinding room and shop bathroom are additional exhaust sources.

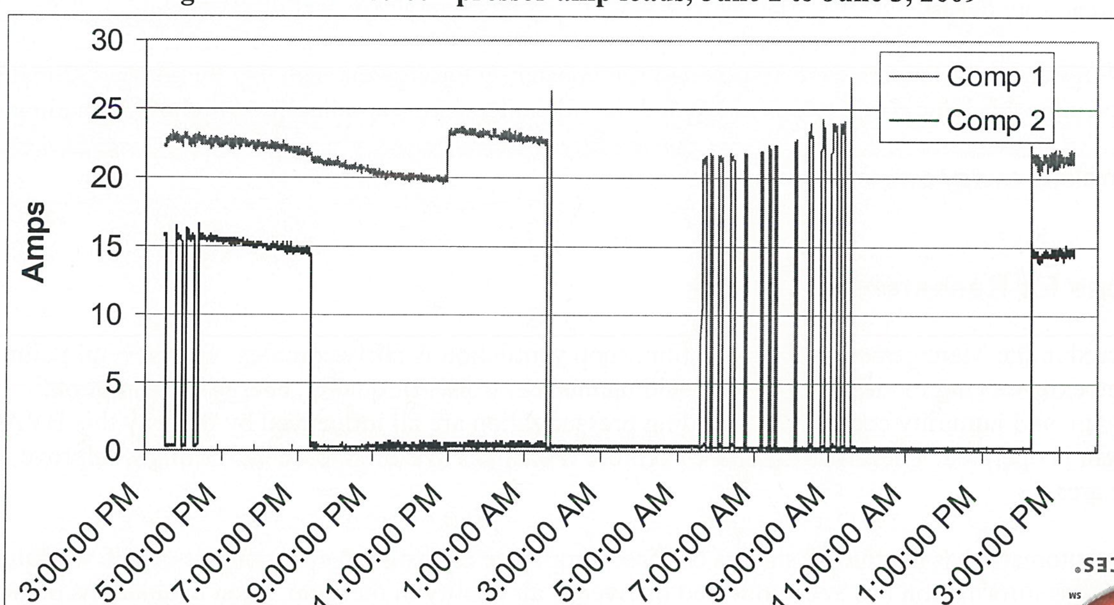
Energy Profile

Electricity is consumed at all shop equipment that conditions the air, a category made up of rooftop units, exhaust fans, mist collectors and air cleaners. Altogether, these devices make up about 18% of total building electricity consumption, as seen previously in Figure 1.

These figures were determined by observing equipment operation and investigating energy use at each unit. For the rooftop units, both monitored data and specified product data was used in this process. Maintenance indicated that RTUS5 ran the most frequently, so dataloggers were placed on the unit's air-conditioning compressors to observe how often mechanical cooling was occurring. Data was collected for several days and during different weather conditions to evaluate how cooling loads varied. A typical mechanical cooling day was identified based off the collected data.

Figure 12 below shows the amp loads at the roof-top unit compressors for a typical 24-hour period. During this time, compressor 1 ran for approximately 12.5 hours and compressor 2 for about 4.5 hours. For this unit, compressor 1 is the primary and compressor 2 provides additional secondary mechanical cooling. According to the product manual, these compressors also have multiple capacity steps and thus can vary their power consumption as cooling loads change. This may be evident on the graph, as compressor 2 amps are significantly lower, and compressor 1 amps step up at one point during the day.

Figure 12 – RTUS5 compressor amp loads, June 2 to June 3, 2009



The trends shown in Figure 12 are not always intuitive—the compressors aren't always on or off when one might expect. For example, compressor 1 doesn't turn off until 2 AM, even though nights in June are typically cooler and potentially good economizer hours. This can best be explained by the complexities behind what determines mechanical cooling at a facility like Roberts Automatic. Heat is generated by machines in the facility, outdoor temperature and humidity is always changing and this particular unit only serves a small portion of the building. With this data alone we are not able to see the entire picture, so the rooftop unit behavior appears erratic.

One more observation is the rapid cycling of the unit's compressors. There is an Xcel Energy switch that is tied to one or both of the compressor that allows Xcel Energy to cycle them on and off for reduced energy demand during peak hours. However, compressor 1 cycles on from 6AM to 10AM, a time that wouldn't be considered peak hours. It is possible that the unit might have been cycling at its own will to meet a small cooling demand at this time. Again, not enough data has been collected to narrow in on all of the unit's trends.

The four remaining shop rooftop units were not datalogged, however, run times were proportioned based on maintenance's knowledge of their operation relative to RTUS5. Because they do not operate during the winter months, it was assumed that the units run for 5 months of the year. Cooling loads are lower during the spring and fall months, so a typical economizer operating conditions were estimated and built into the calculation. The economizer operation estimate assumed that only the fans operated for 1/3 of the 5 month cooling period. During economizer operation, heat loads are removed by using a percentage of cool outdoor air, up to 100%, rather than mechanical cooling.

Any significant exhaust fans in the building ran continuously, so most energy estimates were made solely on the fan brake horsepower. The tool grinding room exhaust fan was datalogged to observe how its variable frequency drive came into play. The VFD is controlled by a manual dial, which is set at 40% and is never turned off. Despite the 40% dial setting, the fan only operated around 12% of its full-load power.

Mist collectors, attached to most of the screw machines and a few CNC machines, ideally operate when their respective machining equipment is running. Therefore, run times for the mist collectors were estimated based on machining production hours. This method makes the assumption that operators consistently turn the mist collectors on and off as they are working. The mist collectors were powered by electric motors, ranging from 1 HP to 3 HP depending on the type of collector, from which energy magnitudes were based.

The ceiling-hung air cleaners were assumed to run constantly throughout each day for energy estimating purposes, although later observations suggested that the units were sporadically turned off depending on the operator's preferences. The units were powered by electric motors, ranging 1 to 2 HP, which were also in making energy estimates.

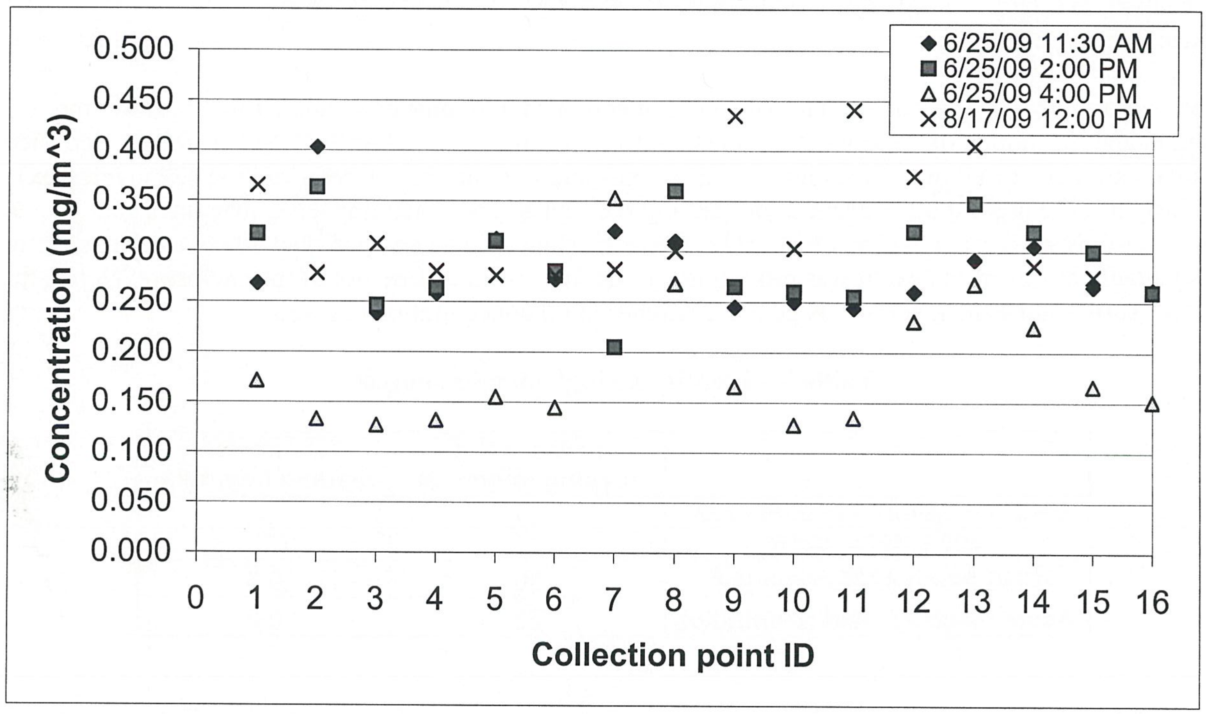
Reasons for Researching Options

As covered in the Management Method section, shop ventilation is fairly complex, with several points of entry and exit, varying modes of operation, and manual controls. Air quality, energy consumption, temperature and humidity control, and building pressurization are all influenced by the way this HVAC equipment is operated. There was interest to explore if changes to current procedures might improve some of these areas.

Roberts Automatic has conducted studies on direct employee exposure to contaminants while working, although less information has been collected on overall air quality in the shop. Most evaluations of air quality have been qualitative, such as haziness near the ceiling, odor, or slippery floors. There was desire to evaluate the current air quality in the shop and to identify the effectiveness of each component. By identifying ineffective equipment, improvements can be made. Alternately, if modifications can be made to the current modes of operation without sacrificing air quality, there may be opportunity to reduce these energy costs.

Physical observations alone did not provide a good measure of oil mist level severity. Therefore, data was collected to provide quantitative reasons to research air quality improvement options. Oil mist concentrations, in mg/m^3, were recorded using a DustTrak Aerosol Monitor, a device that uses light scattering to determine the mass of particles in the air. Sixteen data collection locations were established around the shop, and data was taken sporadically over the course of a few weeks. Figure 13 below shows findings at these locations on a given day.

Figure 13– Shop air quality sampling, June 25, 2009



Additional data from these 16 locations can be seen in the Appendix E, as well as the locations of each data collection point. Continuous datalogging was also utilized, and results and discussion can also be found in Appendix F. Figure 13 above shows representative behavior of oil mist trends in the shop. For most of the collected data, maximum concentrations peaked near 0.40 mg/ m^3, while average levels were in the 0.20-0.25 mg/m^3 range. Also, concentrations were consistently lower between 4 PM and 6 PM, where there was often machining downtime between the first and second workshifts.

The Occupational Safety and Health Administration (OSHA) has a permissible exposure limit (PEL) of of 5.0 mg/m^3 for mineral oil mist as an 8-hour time-weighted average. The National Institute for Occupational Safety and Health's (NIOSH) has a recommended exposure limit (REL) that is specific to MWF's commonly found in machine shops. The NIOSH REL of 0.4 mg/m^3 as a 10-hour time-weighted average, is considered a health-based best practice but is not a regulatory compliance limit. NIOSH does cite concern for several health effects from mist exposure, including respiratory conditions, work-related asthma and skin irritation. ("Metal Working Fluids", 2003)

The collected data as compared to the NIOSH standards indicated that ambient air in the building was fairly clean. The REL appeared to be a realistic goal for Roberts Automatic to continue to achieve. There were times when the REL was exceeded, so it may be preferable to keep readings lower to act as a buffer for when machining production increases again. are likely areas near machines which are regularly higher. Improving mist collection at the source, as well as filtration and ventilation, would have a positive effect in both the short term and long term.

Reduction Option 2.1: Provide better mist collection at high-source locations identified

Summary
Oil mist reduced: 10 grams/hour
Implementation cost: None
Cost savings (per year): N/A
Payback period: N/A
Status: Recommended

There were some machines being run that were not equipped with mist collectors. Table 5 shows the location and magnitude of these worst oil mist contributors in the shop. For the CNC machines identified, oil mist natural diffused out of the chip conveyor exits and into the shop. CNC machine 4225 (Integrex) regularly had the highest oil concentrations among the CNCs. The remaining CNC machines had concentrations similar to CNC machine 4222. Acme machine 16 had an open duct where a mist collector could attach, however, instead it was providing an exit for mist to diffuse out of the enclosure. Notice that the area surrounding the machines is generally higher in oil concentrations as well.

Table 5 – Identifying high oil mist sources

	Primary exit reading (mg/m^3)	Perimeter reading (mg/m^3)
CNC conveyors - machs 4222, 4223, 4224, 4215	14	N/A
CNC mach 4225 conveyor	30	0.6
Acme mach 16 duct (8-spindle)	23	0.9

Much of the remaining machining equipment is currently equipped with mist collectors and a complete list can be seen in Appendix E. Data was collected to judge how clean the discharge air was and assess the collection effectiveness. Readings were taken from the mist collector exhaust with the collector on and with it off, noting the improvement in air quality. From the results in Table 6 , it is seen that mist collectors are generally making cleaner air.

Table 6 – Mist collector readings

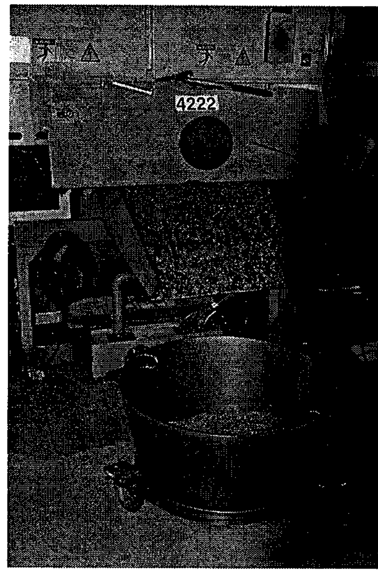
	Collector Type	Exhaust, Collector ON	Exhaust, Collector OFF	Percent Improved
Davenport mach 29	Aercology	0.089	0.34	74%
Davenport mach 28	Royal Filtermist	0.103	0.297	65%
Davenport mach 28	Royal Filtermist	0.095	0.297	68%
Acme mach 1 (High pressure)	Aercology	1.7	5.15	67%
Gildemeister mach 1503	Aercology	Would not start	0.3	N/A
Davenport 24 (High Pressure)	Donaldson HEPA	0	0.06 (2.7 inside)	100%

Notice that for Acme machine 1, while the air is significantly cleaner, the magnitude is still high. It is possible that the mist collector cannot keep up with the level of mist in this high pressure coolant machine. It may also be that the mist collector needs maintenance—there are filter pads inside the mist collector that eventually need to be replaced. In the opposite case, the Davenport machine 24 with high pressure coolant eliminated all traces of oil. With the HEPA filter on this collector, the oil mist wasn't able to penetrate through the duct when it was turned off and a reading had to be taken from inside the machine instead.

Since data indicates that mist collectors are having a positive impact, it is recommended that Roberts Automatic install mist collectors on the high sources identified in Table 6. Acme machine 16 and CNC machine 4225 have existing ports by which mist collectors can easily be connected. There are power supplies nearby that could run the mist collectors if they were hung above the machines.
The remaining CNCs in the facility would require some retrofitting, which may prove difficult for machines with automatic loaders since there is less clearance for ducting. Also, a power supply isn't currently located above many of these machines. However, finding a way to install mist collectors could significantly boost air quality in the CNC department, which has been seen to be the dirtier side of the shop since the screw machine department is not running many jobs. Additionally, by preventing buildup inside the machine, it would reduce personal exposure when the operators are opening the enclosure doors.

A specific retrofit method was not identified during this study, however, some options were discussed. There may be enough clearance on some of the CNCs to cut a hole in the top of the machine for a collector duct. However, for the machines with automatic loaders, this duct would interfere with robotic arm movement. Alternately, a collector could be ducted to the cover on the chip conveyor shown in Figure 14—the red circle identifying where the duct might sit. Since the opening wouldn't be directed into the enclosure, it would not create suction inside the machine and would require another force to push the mist out towards the conveyor exit.

Figure 14 – CNC chip conveyor exit, potential duct placement



Potential mist collector duct placement

Table 7 shows unused mist collectors that were found in the building, and suggestions on where to place some of them. There are filter pads for both the Filtermist and Aercology in the south mezzanine storage room. It is recommended that the mist collectors be inspected and filter replaced if needed before making re-equipping them.

Table 7– Unused mist collector list

	Collector Current Location	Suggested Location
Small Filtermist with HEPA	Outside maintenance office	CNC mach 4225
Filtermist with HEPA	South storage mezzanine	Acme mach 16
Filtermist with HEPA	Hanging in screw mach dept	Future retrofit CNC
Filtermist	Hanging in screw mach dept	Future retrofit CNC
Aercology	South storage mezzanine	Future retrofit CNC

Benefits
This option eliminates several high sources of oil misting in the facility by equipping mist collectors that are already on site. Maintaining existing mist collectors by replacing filter pads, strategically moving them as jobs change and retrofitting them to CNCs that output high oil levels will result in reduced personal exposure and improved air quality.

Economic Analysis
The capital investment is negligible since existing collectors can be used to eliminate current high sources and there are some boxes of filter pads already in storage that can be used for maintenance.

Implementation Status
The status of this suggestion is: Recommended. The suggestion has been discussed with shop personnel and there is interest to handle the easier installments on CNC machine 4225 and Acme machine 16 in the near future. Retrofits will require further discussion amongst department leads to ensure the modifications won't interfere with machining operations.

Reduction Option 2.2: Use optimal Davenport door position when machining

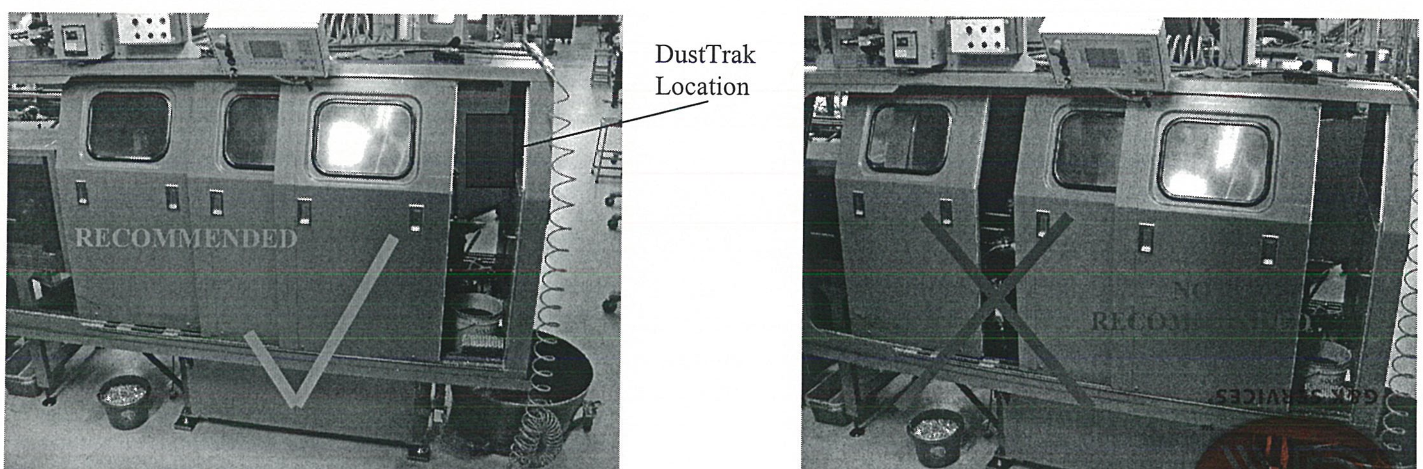
Summary [Should match information in Table 1.]
Mist exposure reduced: Mist exposure magnitudes reduced 50% or more
Implementation cost: None
Cost savings (per year): N/A
Payback period: N/A
Status: Recommended

During walks through the shop, it was noticed that the Davenport screw machines are operated with their doors partially open and sometimes fully open. Since all other screw machines have full enclosures that remain closed during machining, an investigation was done to determine why this department was different.

After talking to operators, the doors are primarily intended for sound-proofing and aren't meant to seal up the machine. Each operator has different habits, but they usually prefer to keep the door at least partially open so the operator can see and hear what is happening at the machine without having to be right next to it.

Using the Dust Trak to measure mist levels in the area where the operator most often worked, as identified by the blue rectangle in Figure 15, I was able to identify door positions that minimized oil concentrations. As the picture indicates, having the right-most doors partially cracked open creates the best scenario. This is due to the airflow path that is created by mist collector's suction. The mist collector intake is located on the left-most side of the enclosure, so by pulling air from the opposite end of the machine, the maximum amount of air flow is directed down the length of the machine. This sweeping airflow path results for maximum mist removal, since mist is generated in the middle of the machine.

Figure 15– Davenport doors, optimal position



Closing the door completely actually results in higher mist levels, since air is instead primarily drawn from a hole in the machine housing where the motor sits, on the left-most side. Opening the doors on the left-most side of the machine results in even higher mist levels, as air is continuing to bypass the point where oil mist is generated in the machine.

Data for the high pressure Davenport machine 24 can be seen in Table 8, which shows the multiple scenarios and their associated oil mist readings. Additional data for a non high pressure machine can be seen in the Appendix, and it shows similar relationships at lower magnitudes.

Table 8– Davenport machine 24 (high pressure) door positioning effects on mist levels, in mg/m^3

	Left-most door closed	Left-most door partially open
Right-most door closed	2.7	5.2
Right-most door partially open	1.3	4.0

Benefits
This option allows for optimized mist collector performance. By generating the correct flow pattern, maximum suction can draw oil mist away from the operator and out of the machine to be filtered.

Economic Analysis
The capital investment is negligible since only the door positions are being modified.

Implementation Status
The status of this suggestion is: Recommended. Shop personnel, including Davenport operators, were educated on the preferable position during on site MnTAP presentation. The recommended position is the set up that some operators were already using, however, awareness was increased to the sensitivity of the positions.

Reduction Option 2.3: Modify building ventilation

Summary
Energy Reduced (per year): 47,800 kWh in cooling costs ; Oil mist level affects unknown
Implementation cost: Unknown
Cost savings (per year): $1,900
Payback period: Unknown
Status: Not enough information for recommendation. Modifications may save air conditioning costs but could come at the expense of air quality. Because of the ties to the chiller condenser, air flows could not be modified for testing and a recommendation could not be reached.

Air flow into and out of the building was investigated and findings can be seen in Table 9 below. Only one of the five shop RTUs, RTUS5, was supplying a minimum level of 10% outdoor air. Due to the large air-cooled condenser exhaust fan, a large amount of air is continuously removed from the building. The amount of air supplied into the building through regulated sources is lower than the amount of air exhausted, leading to negative pressures that cause fresh air to infiltrate into the building. There are likely times in the spring and fall during which RTUs economize and bring in maximum fresh outdoor air for free cooling. During these times, it is more likely than building has positive pressure.

Table 9 – Air balance

Unit	CFM in at original conditions	CFM in at 10% OA	CFM at 100% OA
RTUS1	0	600	6,000
RTUS2	0	600	6,000
RTUS3	0	200	2,000
RTUS4	0	200	2,000
RTUS5	1,080	1,080	10,800
RTUS6	0	1,080	10,800
RTUS7	0	1,080	10,800
EXF3/Shop Bathroom	(1,700)	(1,700)	(1,700)
EXF4/Grinding	(1,200)	(1,200)	(1,200)
Chiller Condenser Exhaust	(6,000)	(6,000)	(6,000)
Air Compressor Loop	3,500	3,500	3,500
Net	(4,320)	(560)	43,000

It is estimated that the air-cooled condenser exhaust fan drives about 0.4 air changes per hour. Since the exhaust fan is tied into the chiller, this air change rate could not be modified during the study. This air change rate influences the costs spent on cooling and conditioning the air at the rooftop units. It may be a valid question whether this air change rate is necessary, especially if at-the-source collection and air filtration is continually maintained and improved. Based with discussions with the previous engineer on staff, the exhaust was a design intent and he felt that that this air flow was necessary.

Another unknown in the ventilation question is whether it is desirable to be operating at negative building pressure. More traditionally, the desired air change rate is driven by a supply rate into the building, allowing air to be conditioned as it enters. If Roberts Automatic were to operate with positive pressure, RTU recirculating fans would need to be set for continuous run and minimum position dampers opened. There would be additional costs for running the recirculating fans, since the RTUs are not always providing cooling in their current operation. The pressurization factor may be more comfort-related and since there aren't any noticeable problems inside the facility, the current settings may be adequate.

Another unusual ventilation procedure was found on the air compressor room ductwork. As shown previously in Figure 11, manual louvers on the compressor room ventilation ductwork allow a portion of the air into the shop. Since the air loop picks up heat from the compressor room, during the summer the air entering the shop here is hotter than normal outdoor air. This heat recovery is undesirable for summer conditions since it acts as additional heat load on the RTUs. To close these louvers permanently during summer may be advantageous for eliminating unnecessary heating loads, however, the ventilation is providing a regulated source of ventilation. Since the building often operates under negative pressure, removing this large intake source would increase negative pressure in the building. To avoid changing the regulated air flows into the building, RTU dampers could be opened to offset the change. However, this again would require constantly running recirculating fans to ensure that the outdoor airflow is always seen.

In summary, the building in its current state is changing air over at a high rate using negative pressure driven by a large exhaust fan. It is questionable whether this air change rate is necessary and if alterations may save some cooling costs. However, potential effects on air quality, pressurization and chiller operation are unknown. Due to the many constraints and the inability to easily modify some of them, a recommendation could not be determined.

Benefits
The current mode of operation may lead to unnecessary cooling costs to the high air change rate. Also, removing heat recovery at the compressor room louvers during the summer time would be advantageous if didn't lead to additional negative pressures. Altering the air balance would likely lower air conditioning costs at some unknown expense to air quality.

Economic Analysis
The costs to modify air flows in the building would probably be minimal. The largest cost would be modifying and reducting the air-cooled condenser's intake to reduce the air change rate. Altering the RTU minimum damper position would be a quick task for the HVAC maintenance technician.

Implementation Status
The status of this suggestion is: Not enough information for recommendation. There is potential for reduced air conditioning costs however the possible side effects on chiller performance and air quality are unkown.

Issue 3: Waste heat utilization

Management Method
Chilled water is created using two chillers and is stored in a large chilled water tank. The water is circulated around the shop to cool cutting oils for individual shop machines. It is also used in a vapor degreaser to condense a part-washing solvent.

The main chiller is a custom-designed system and uses a 25 HP, 4-cylinder compressor. This chiller has two condensers—a water-cooled condenser which allows for waste heat capture, and an air-cooled condenser which exhausts the removed heat from the building. Figure 16 below shows the arrangement of this system. The primary chiller runs continuously through the day and night.

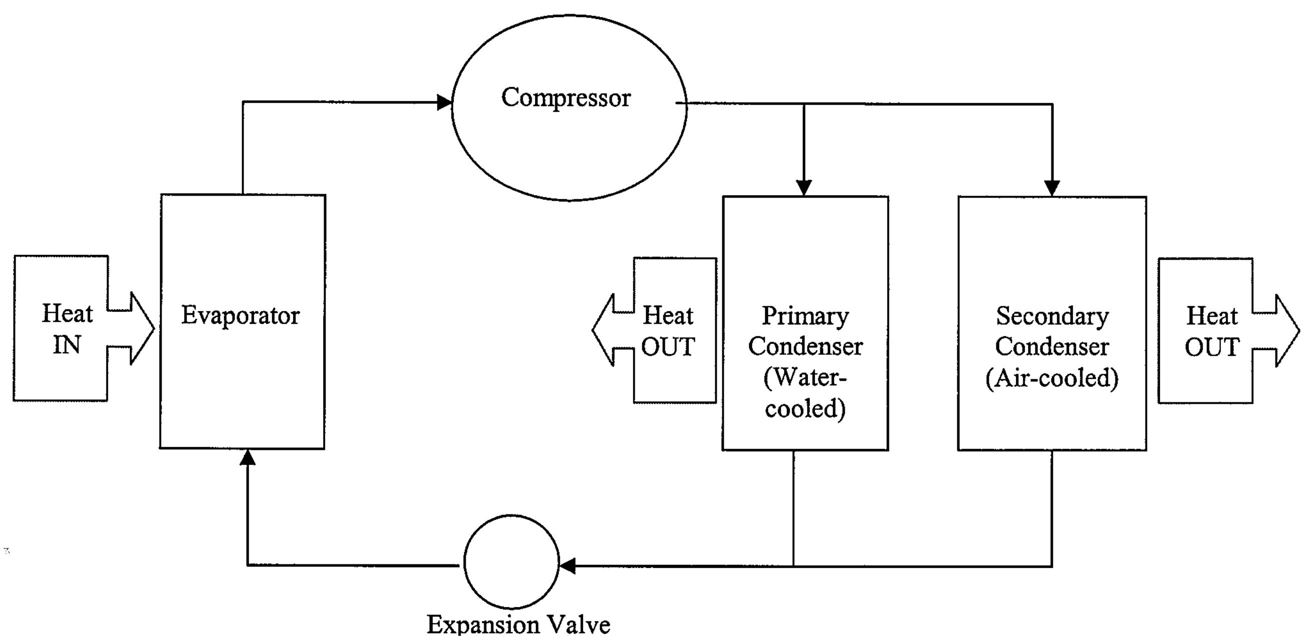


Figure 16– Custom chiller for heat capture

Hot water is created by pumping water through the primary chiller's water-cooled condenser. The hot refrigerant vapor from the chiller system transfers heat to the water stream. The hot water is then used for boiling the part-cleaning solvent in the vapor degreaser. Thus, heat is put into the vapor degreaser with a hot water stream, and the heat is removed from the degreaser using a chilled water stream. The heat is then returned back to the hot water stream, allowing the chiller to also act as a heat pump. A simplified schematic for this process is shown in Figure 17.

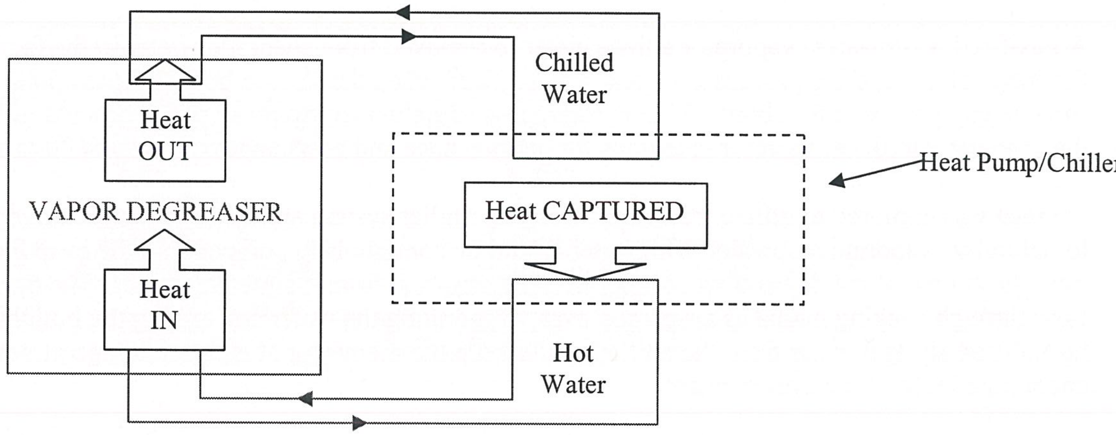


Figure 17 – Hot water production with waste heat capture

The back-up chiller is a newer unit and includes a 6-cylinder compressor driven by a 40 HP motor. It has a single air-cooled condenser located on the roof, with no waste heat capture capabilities. This chiller toggles on and off as needed to meet any cooling demands that the primary chiller cannot supply on its own.

Energy Profile

Energy usage was monitored through datalogging equipment to estimate typical power levels and run times. The primary chiller runs continuously during the week to keep the vapor degreaser operating. On the weekend, the primary chiller only runs for about half of the day. The secondary chiller kicks on and off throughout weekdays as needed, operating about 5 hours per day. The power levels did not differ much from the units' nameplate rated values.

Reasons for Researching Option

The custom main chiller system allows for unique heat capture capabilities. Currently the heat delivered by the primary condenser goes beyond what is needed for the degreaser hot water needs. As soon as the hot water is up to temperature, the refrigerant uses the secondary condenser to dump heat outside the building. Finding new ways to utilize hot water would reduce the time the refrigerant spends in the secondary condenser. This would be a more efficient use of energy already spent in operating the 25 HP chiller compressor.

Reduction Option [3.1]: Atmospheric wastewater evaporator

Summary
Energy reduced (per year): 960 therms/yr
Implementation cost: $7,700
Cost savings (per year): $600/yr
Payback period: 13 years
Status: Not recommended.

A gas-fired wastewater evaporator allows water to removed from spent mopwater in the facility. When the mopwater recycling process is up and running, and when the shop is busier, the evaporator is usually run one day per week for about 10 hours to process 55 gallons of mopwater. The process of boiling off the mopwater in the evaporator is tedious for maintenance and costs approximately $600/yr in gas costs.

An idea was explored to utilize waste heat from the chiller system and existing air streams in the building to naturally evaporate mopwater. Mopwater would be continuously pumped into the evaporation chamber over the course of the day and would require little attention from maintenance staff. The mopwater would flow through packing media as air passed over, evaporating the water and exiting the building as humidified air. Hot water from the chiller would keep the mopwater at elevated temperatures to encourage higher evaporation rates.

A prototype was constructed to determine a baseline and assess feasibility for the desired flow rate. The natural evaporation would need to occur at a rate fast enough to replace most of the work at the gas-fired evaporator. Thus, a target was set for about 4 gallons per hour.

The prototype was unable to reach evaporation rates higher than 0.4 gallons per hour. The prototype used metal chips as packing media and relied on conditioned shop air at 130 CFM to absorb the water. Modifications to the design did not show promising results and the idea was abandoned.

Atmospheric wastewater evaporators are available for purchase, however, they are expensive and most practical when there is no existing means to evaporate water in the facility. There is not enough savings justification in gas and maintenance costs alone for purchasing such a device. This idea would be most feasible if a simple design were to be constructed on site. Since the designs explored could not meet the desired evaporation rates, the idea is not recommended.

Additionally, the mopwater recycling process is not in operation and wastewater is not being processed regularly. Under the current conditions, the gas-fired evaporator is run once a month or less. Thus, there is even less incentive to pursue this idea since minimal gas savings would be seen.

Benefits
This option would be ideal for utilizing existing heat and air flows in the building to drive a process that would eliminate most of the need for a gas-fired evaporator. Costs would be reduced on monthly gas bills and maintenance for mopwater would be streamlined. Unfortunately, designing a system for the required evaporation rate was not practical.

Economic Analysis
The capital investment is the cost of a new atmospheric evaporator, since efforts to design an effective solution for the evaporation requirements failed. An atmospheric evaporator designed for solutions with high solids content is available from Poly Products, Inc. for $7,700.

Implementation Status

The status of this suggestion is: Not recommended. Since the evaporator could not be designed and built on site, the suggestion is not cost-effective. Also, at the current levels, mopwater is not being processed frequently and gas costs are minimal.

Appendices

Appendix A: Recognition and References

Special thanks to the following people for their input to this project:

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Appendix B: Raw data from energy estimations

Table 9 – Annual Electricity Consumption

	kWh/yr	Total %	Adjusted %	$/yr
Shop Rooftop Units	148,211	6.4%	8%	$ 5,928
Office Rooftop Units	21,210	0.9%	1%	$ 848
Air Compressors	391,413	17.0%	21%	$ 15,657
Process Chillers	167,931	7.3%	9%	$ 6,717
Air Filtration Equipment	110,328	4.8%	6%	$ 4,413
Exhaust Ventilation	48,216	2.1%	3%	$ 1,929
Machining Equipment	754,409	32.8%	40%	$ 30,176
Lighting	226,063	9.8%	12%	$ 9,043
Total	**1,867,781**	**81.1%**	**100%**	**$ 74,711**

Appendix C: Small compressor system automation

Figure 17 below shows a schematic of how the 7 ½ HP system could be automated. At the end of the night, an employee would press a button in the compressor room. The button would be under timer controls such that it would reactivate the system the following morning. By pressing the button, the main system would power down. A pressure switch tied to a 3-way solenoid valve would monitor the main system pressure. Once pressure in the main system dropped below 80 psi, the solenoid valve would open the line to the small compressor and close the line to the main system. The small compressor, which would have been plugged in and have a full tank already, would start supplying air once the valve switched. The next morning, the timer controls would turn the main system back on, the main system pressure would rise above 80 psi, the valve would switch back and the small compressor would turn off once its tank filled up.

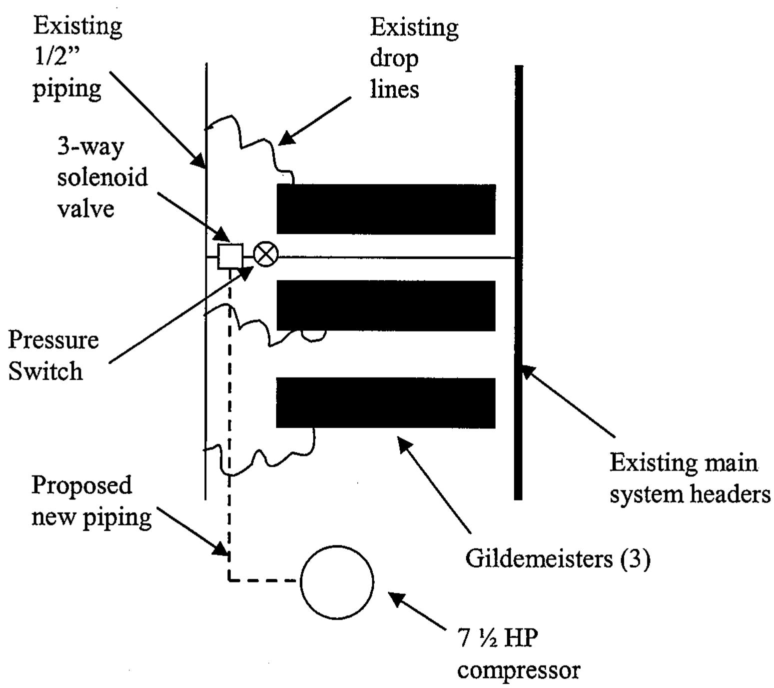


Figure 17 – Automated 7 ½ HP compressor system

Appendix D: Leak Rate Calculation

Equation 1 was used for leak rate estimations, where V is total storage in cubic feet, P_i is the initial shop side pressure and T is the time it takes for P_i to reach half its value once the system has been deactivated.

Equation 1 – Leak rate based on change in pressure

$$LeakRate(CFM) = \frac{V(P_i - \frac{P_i}{2})}{14.7 \times T} \times 1.25$$

Appendix E: Mist collector master list

Department	Mach #	Mist Collector	Condition
Acmes	14	None	
	9	Aercology	
	8	None	
	18	Aercology	
	10	None	
	13	Royal Filtermist (1 of 3 legs)	
	12	Aercology	
	6	Royal Filtermist (1 of 3 legs)	
	5	Royal Filtermist (1 of 3 legs)	
	17	Royal Filtermist (1 of 3 legs)	
	Euroturn	Donaldson	
	16	None	
	15	None	
	2	None	
	11	Royal Filtermist (1 of 2 legs)	
	1	Aercology	
Davenports	33	None	
	27	None	
	32	Royal Filtermist (1 of 3 legs)	
	22	Royal Filtermist (1 of 3 legs)	
	23	None	
	24	Donaldson HEPA	
	29	Aercology	
	26	Royal Filtermist (1 of 3 legs)	
	31	Royal Filtermist (1 of 3 legs)	
	28	Royal Filtermist (1 of 3 legs)	
	30	Royal Filtermist (1 of 3 legs)	
	33	None	
	27	None	
Gildemeisters	1505	Losma	
	Corner machine	Royal Filtermist (1 of 1 legs)	
	1504	Aercology	
	1503	Aercology	
CNC	4285	Royal Filtermist (1 of 2 legs)	
	4219	None	
	4225	None	
	4224	None	
	4223	None	
	4222	None	
	4215	None	
	4210	None	
	4209	None	
	4241	None	

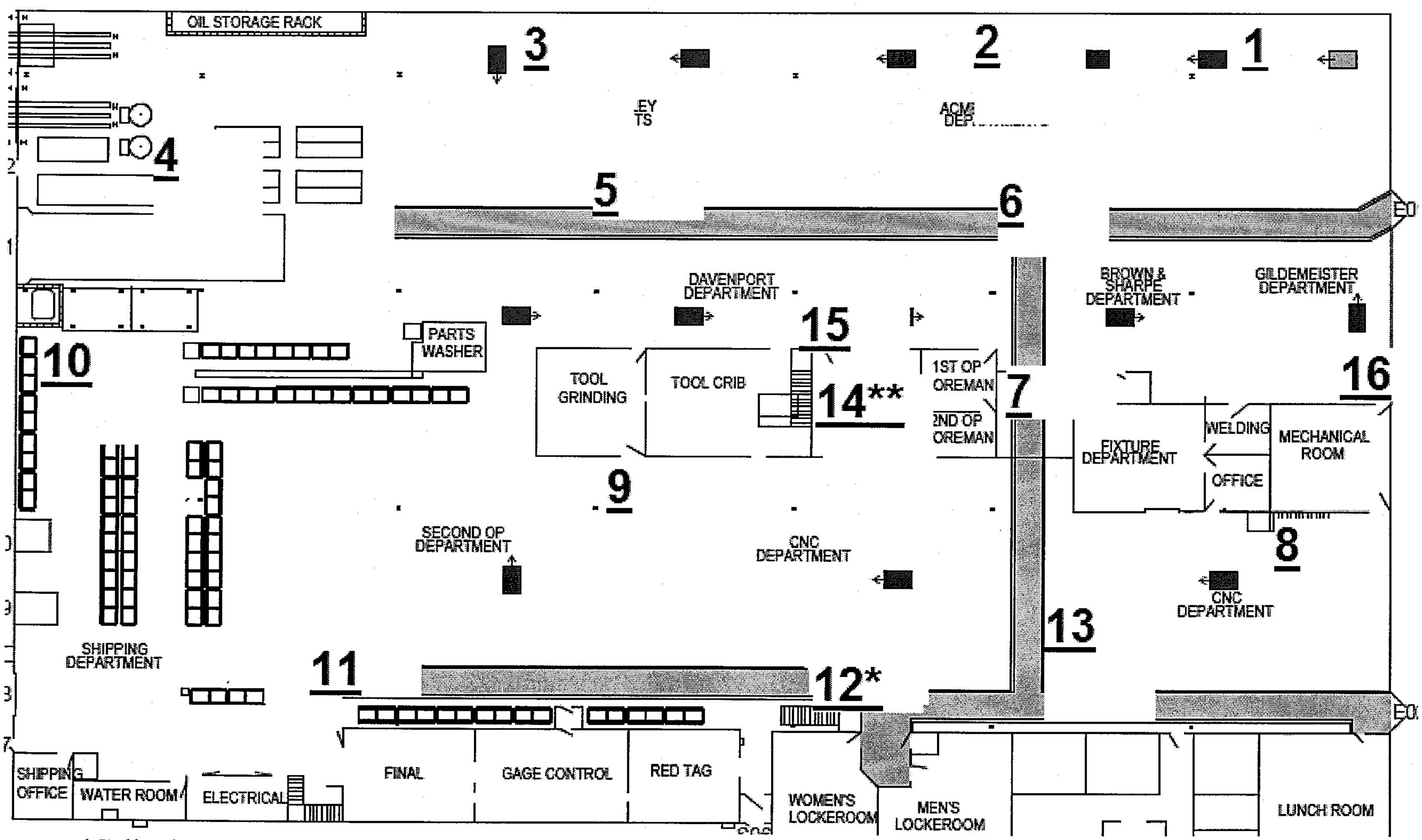
Appendix F: Supplemental DustTrak data

Air quality data was collected by taking oil mist readings at the same 16 points over the course of a few weeks. Table 10 below shows the raw data. The 16 data points are identified in Figure 18 on the following page.

Table 10 – DustTrak point data

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Daily Average
6/9/09 3:30 PM	0.063	0.035	0.037	0.035	0.030	0.029	0.034	0.058	0.058	0.024	0.025	0.134	0.089	0.060	0.031		**0.049**
6/9/09 6:00 PM	0.053	0.031	0.029	0.024	0.031	0.041	0.059	0.065	0.068	0.023	0.024	0.128	0.076	0.051	0.059		**0.051**
6/15/09 9:00 AM	0.333	0.295	0.274	0.276	0.257	0.245	0.274	0.337	0.222	0.244	0.183	0.290	0.282	0.281	0.371		**0.278**
6/15/09 4:00 PM	0.125	0.117	0.121	0.120	0.123	0.115	0.120	0.134	0.193	0.167	0.185	0.145	0.176	0.193	0.119		**0.144**
6/17/09 11:00 AM	0.230	0.260	0.184	0.188	0.188	0.219	0.221	0.235	0.268	0.187	0.264	0.290	0.294	0.241	0.245		**0.234**
6/17/09 5:00 PM	0.090	0.082	0.078	0.105	0.080	0.078	0.077	0.130	0.096	0.091	0.128	0.152	0.125	0.108	0.076		**0.100**
6/18/09 9:00 AM	0.224	0.360	0.248	0.246	0.260	0.300	0.285	0.271	0.255	0.220	0.320	0.305	0.313	0.320	0.340	0.287	**0.285**
6/22/2009 9:30	0.303	0.265	0.252	0.188	0.310	0.332	0.298	0.250	0.240	0.194	0.186	0.252	0.286	0.265	0.315	0.284	**0.264**
6/22/09 2:30 PM	0.290	0.322	0.274	0.240	0.274	0.278	0.275	0.350	0.266	0.242	0.253	0.306	0.320	0.317	0.280	0.260	**0.284**
6/22/09 4:00 PM	0.137	0.112	0.100	0.115	0.106	0.116	0.114	0.176	0.115	0.100	0.100	0.202	0.217	0.146	0.104	0.140	**0.131**
6/22/09 6:00 PM	0.107	0.089	0.077	0.080	0.083	0.093	0.094	0.126	0.090	0.073	0.074	0.123	0.124	0.133	0.080	0.120	**0.098**
6/16/09 11:00 AM	0.230	0.260	0.184	0.188	0.188	0.219	0.221	0.235	0.268	0.187	0.264	0.290	0.294	0.241	0.245		**0.234**
6/24/09 9:00 AM	0.148	0.150	0.136	0.132	0.153	0.134	0.140	0.176	0.210	0.160	0.185	0.200	0.210	0.250	0.140	0.145	**0.167**
6/25/09 9:30 AM	0.312	0.350	0.320	0.400	0.315	0.305	0.300	0.315	0.314	0.340	0.315	0.300	0.335	0.330	0.300	0.300	**0.322**
6/25/09 11:30 AM	0.268	0.403	0.238	0.258	0.312	0.272	0.320	0.310	0.245	0.250	0.244	0.260	0.292	0.305	0.265	0.262	**0.282**
6/25/09 2:00 PM	0.317	0.363	0.246	0.263	0.310	0.280	0.205	0.360	0.265	0.260	0.255	0.320	0.348	0.320	0.300	0.260	**0.292**
6/25/09 4:00 PM	0.171	0.133	0.127	0.132	0.155	0.145	0.353	0.268	0.166	0.128	0.135	0.231	0.268	0.225	0.166	0.151	**0.185**
6/25/09 6:00 PM	0.211	0.163	0.150	0.160	0.194	0.200	0.282	0.280	0.175	0.163	0.180	0.240	0.240	0.270	0.150	0.170	**0.202**
8/17/09 12:00 PM	0.365	0.278	0.307	0.280	0.276	0.276	0.282	0.300	0.435	0.303	0.441	0.375	0.405	0.286	0.275		**0.326**
Point average	**0.209**	**0.214**	**0.178**	**0.181**	**0.192**	**0.194**	**0.208**	**0.230**	**0.208**	**0.177**	**0.198**	**0.239**	**0.247**	**0.229**	**0.203**	**0.216**	

Figure 18 – DustTrak air quality sampling data points



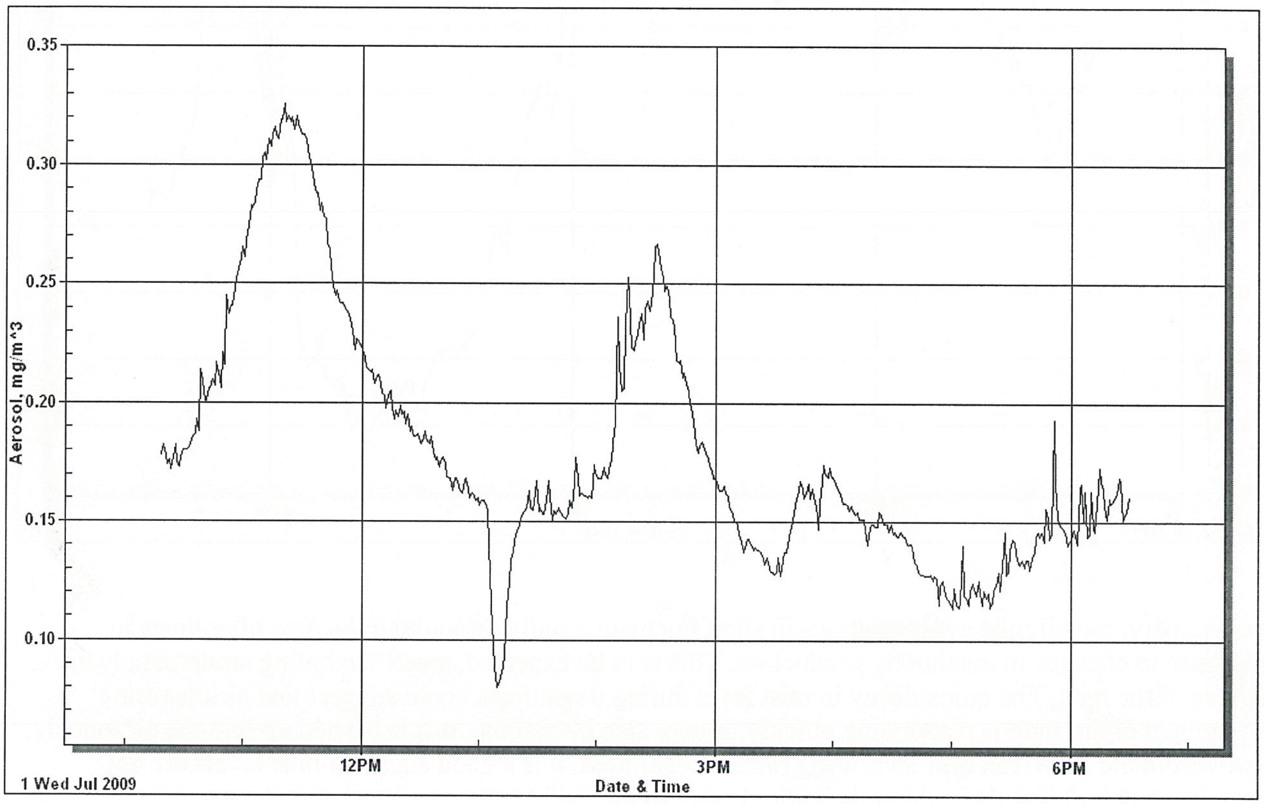
*Collection point 12 was taken from the top of the staircase

**Collection point 14 was taken from the upper-level mezzanine

The DustTrak device has datalogging capabilities, which allowed continuous measurements to be recorded over an extended period. This feature was utilized to monitor oil mist levels from a single location over the course of a shift. The following figures show mist levels over the course of a shift in the CNC and screw machine departments. The logging was setup such that 1-minute average datapoints were collected.

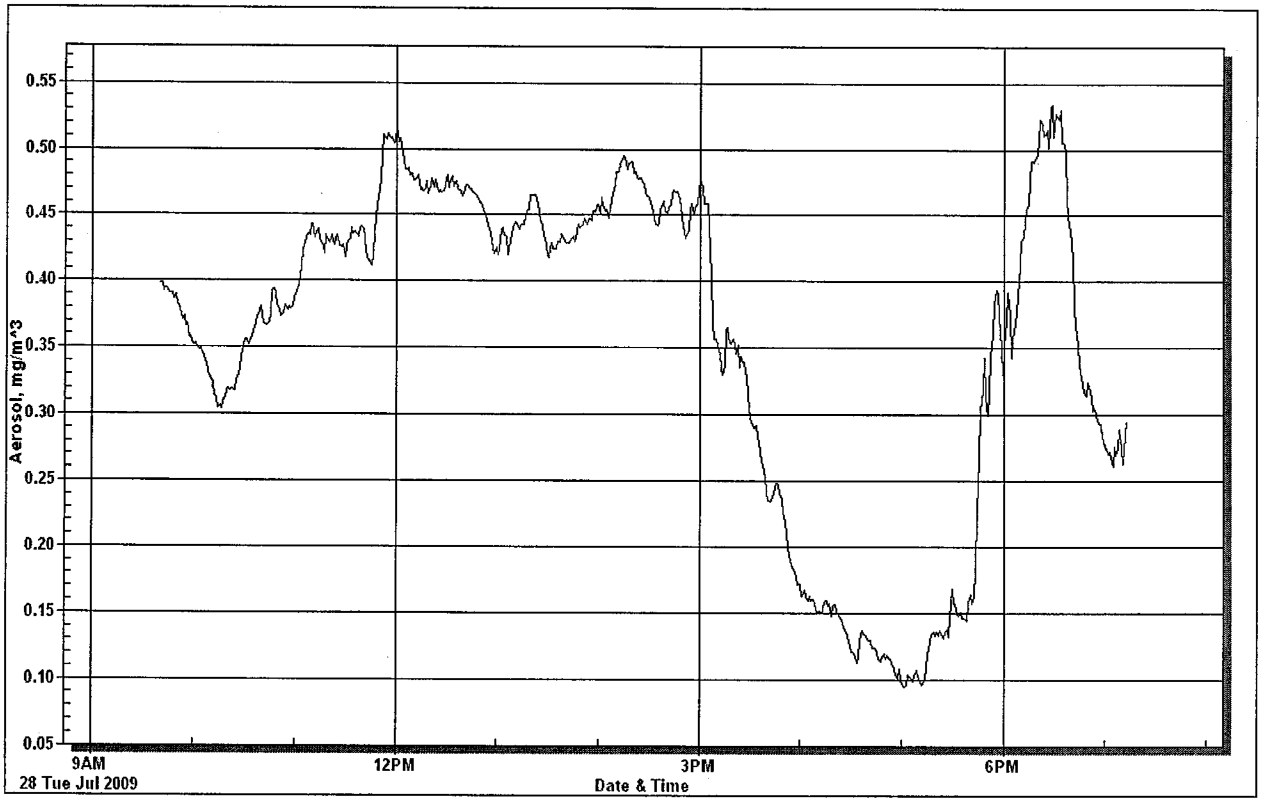
Figure 19 below shows oil mist levels for the screw machine department. The logger was placed at the same location as Collection Point 3, identified in Figure 19. Oil mist levels did not rise above 0.33 mg/m^3 over the course of the day. From the data, mist levels are generally lower, or on the decline, during lower machining production times. Lunch break runs from 12:00P-12:30PM and the 1st shift ends around 4 PM.

Figure 19 – Screw Machine department day-long sampling, July 1, 2009



Another day-long reading was taken for the CNC department, shown in Figure 20. The levels are higher in this department on this day, with a maximum of 0.54 mg/m^3 for a short time. A noticeable drop occurs between 3 PM and 6PM. Again, there is production downtime during this period of the day as first shift is ending a few hours before second shift begins.

Figure 20 – CNC department day-long sampling, July 28, 2009



In summary, the oil mist concentrations in shop fluctuate rapidly throughout the day, oftentimes in response to changes in machining production. This is to be expected, since machining equipment is the source of the mist. The quick decay in mist level during downtimes could suggest that air-cleansing equipment in the shop is responding quickly. It may also be that the mist is carried up into the air quickly, away from the DustTrak unit measuring range. Regardless, it is a good sign that mist levels are not continuously building throughout the entire length of the shift.

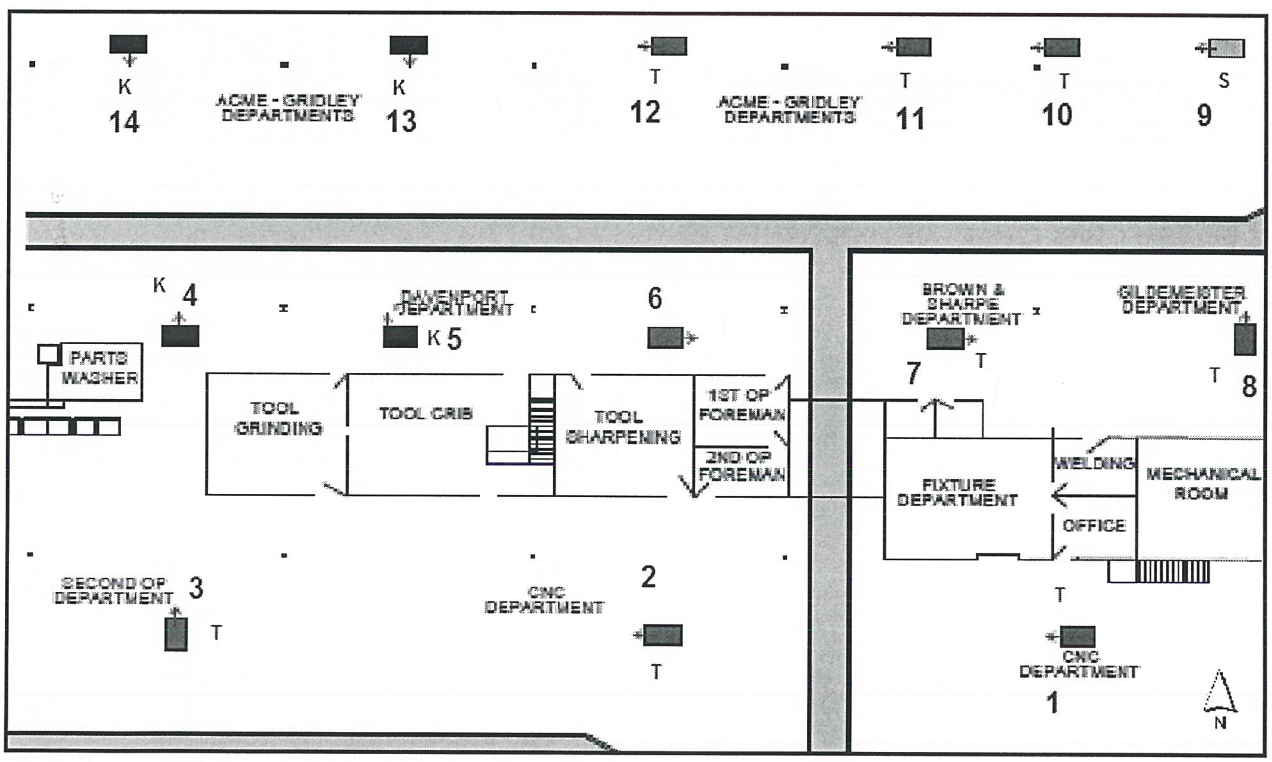
Table 11 – Davenport machine 32 door positioning effects on mist levels, in mg/ m^3

	Northeast	Southwest (Operator)	Southeast
Right-most door partially open	0.25	0.43	0.27
Right-most door closed	0.27	0.72	1.40

Table 12 – Air cleaner effectiveness readings

Air Cleaner ID	Intake	Exhaust	Surrounding area	% Improved
1	0.270	0.150	0.300	44%
2	0.280	0.100	0.300	64%
3	0.373	0.350	0.382	6%
4	0.273	0.160	0.282	41%
5	0.402	0.210	0.380	48%
6	0.489	0.375	0.475	23%
7	0.465	0.105	0.490	77%
8	0.470	0.365	0.440	22%
9	0.380	0.063	0.405	83%
10	0.272	0.220	0.243	19%
11	Broken	Broken	Broken	Broken
12	0.382	0.250	0.371	35%
13	0.355	0.182	0.343	49%
14	0.293	0.135	0.330	54%

Figure 21 – Air cleaner ID locations



Appendix G: Future RTU purchase research

A Carrier product distributor was contacted and quotes were requested for a standard efficiency and high efficiency RTUs for replacing the existing systems on site. Since equipment purchase would not occur until existing RTUs failed, the incremental cost of going from standard efficiency to highest efficiency was assessed. Table 13 shows the individual incremental savings and payback for each RTU, based on estimated run time hours from energy estimating. There is not a large advantage for upgrading to the highest efficiency models, as indicated by the high paybacks and minimal dollar savings. Table 14 shows that total annual savings compared to the existing RTUs. The highest efficiency only saves about an additional $250/yr

Table 13 – High efficiency incremental costs and savings

	kWh saved/yr	$ saved/yr	Incremental purhase cost	Payback
RTUS1	5,206	$ 208	$ 12,810	17
RTUS2	5,206	$ 208	$ 12,810	17
RTUS3	646	$ 26	$ 8,360	173
RTUS4	646	$ 26	$ 8,360	173
RTUS5	0	$ -	$ 29,192	N/A
RTUS6	0	$ -	$ 29,192	N/A
RTUS7	0	$ -	$ 29,192	N/A

Table 14 – Total electricity savings, RTU replacement

	kWh/yr saved	$/yr saved
Replace all with standard efficiency	34,898	$ 1,396
Replace all with high effiency	46,602	$ 1,864