AN ENERGY AUDIT MANUAL FOR SMALL MANUFACTURING COMPANIES
WITH A CASE STUDY OF MAUGUS MANUFACTURING COMPANY

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Master of Science

by
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Chapter 1

Introduction

The goal of the thesis is to compile generic procedures in the form of a manual that will help small manufacturing companies identify and save money on energy costs. Currently no such manual is known to exist.

Information on how to perform an energy audit is widely scattered through text books, journal articles, and trade magazines. Information on Heating Ventilation and Air Conditioning (HVAC) and building audits can be found in the American Society of Heating Refrigeration and Air Conditioning Engineering (ASHRAE) journals. Information on motors, lighting options, and utility tariff structures can be found in various Institute of Electrical and Electronic Engineering (IEEE) journals. Information on cogeneration can also be found in IEEE journals and in articles in the Journal of Engineering for Gas Turbines and Power.

Small companies often do not have the experienced staff needed to conduct an audit. They also might not have the financial resources to hire an outside firm for the audit. Usually this means that the audit is simply not done. Without the necessary staff and financial resources something is needed that would enable a small company to perform an audit on their manufacturing facilities. The thesis presents an easy to use approach that would enable a small company to conduct their own energy audit. In the manual are procedures
that would allow a company to systematically go through the plant and plant processes to identify means of saving money on energy costs.

An energy audit catalogs all incoming energy streams and accounts for how that energy is consumed. The incoming energy is determined by utility bills for such things as electricity and gas. Delivery receipts and plant records can be used to determine the amount of stored on-site energy such as propane and fuel oil.

Once the incoming energy streams are determined, data is then taken from the machines to determine how much energy each machine consumes. All energy is then converted into Btu so that a comparison can be made between the energy streams. The energy patterns are then evaluated to see if any cost effective improvements can be made to reduce energy consumption. The goal of the energy audit is to use energy as effectively as possible, thereby reducing the amount paid for that energy.

Also included in the energy audit is the potential use of cogeneration. Cogeneration uses one source of input energy to produce two forms of useful output energy. Typically the output of a cogeneration unit is thermal and electrical energy.

A cogeneration unit can either be a topping or a bottoming cycle unit. With the topping cycle, electricity is produced first and then the heat from the prime mover that
would normally be discarded as waste is recovered and used as process heat. This process heat can be used for hot water, drying, or used for steam creation.

In the bottoming cycle, heat given off by a high temperature process such as a blast furnace or a kiln is recovered and used to generate electricity. The topping cycle is the more common of the two since most plants do not have high temperature needs. (1,269)

This segment of the thesis is not intended to determine whether a specific cogeneration unit is viable, rather it is a preliminary study to determine whether the use of cogeneration should be pursued, for a particular company.

Included is a discussion of cogeneration operation and a means of ascertaining the feasibility of cogeneration. Facilities may wish to sell power back to the utility. To accommodate this a discussion of the various types of relays and controls needed to connect the facility with the utility is provided.

Cogeneration may be ideal for companies that produce large amounts of flammable waste. The waste would normally have to be hauled away. Through the use of cogeneration the waste might be used to fuel a cogeneration system.

Maugus Manufacturing in Lancaster, Pennsylvania was kind enough to allow their facility to be used as a test site. Maugus had expressed an interest in cogeneration and wished to know if it was a viable option. An energy audit was performed
at both of Maugus' two plants. The possibility of cogeneration was also investigated. Several ways of lowering their electrical costs were explored. The tax rate of Maugus was also studied to determine if Maugus could reduce the amount spent on taxable electricity.
Chapter 2

An Energy Audit Manual for Small Manufacturing Companies

2.1 Introduction to Energy Audits

An energy audit catalogs all incoming energy (gas, propane, steam, electricity, etc.) and accounts for how that energy is used. Ideally the audit will account for all energy that is expended. That is energy expended will equal the energy purchased. However, there will be some energy unaccounted for due to losses and small overlooked items.

The intention of the energy audit is to determine if there are any energy conservation opportunities available to the facility and how to implement them. The energy audit typically converts all energy streams into BTU's. This way a comparison in cost and consumption can be made between the various forms of energy (2,3).

Ideally energy efficiency is carried out without reducing production levels and forfeiting quality or safety. Energy conservation opportunities should only be done if they can be economically justified. A few of the benefits of energy management include protection against increasing fuel prices and an improved usage of raw materials and labor. (3) Energy efficiency will also lead to a decreased consumption of fossil fuels which will in turn reduce the amount of stack emissions. Reducing stack emissions will have an environmental savings in the form of avoided fines and permit costs. (4)

The energy audit is broken down into several different
categories. They are: the Heating Ventilation and Air Conditioning (HVAC) audit, the building audit, the electrical audit, and the utility audit. Also explained are various types of Energy Management Systems (EMS), such as demand limiters and optimal start systems. Figure 2.1 is a general overview of an energy audit. The audit also breaks down energy consumption into the different energy operations of the plant, such as lighting, heating, refrigeration, and other large loads.

2.2 Heating Ventilation and Air Conditioning (HVAC)

The HVAC audit is primarily concerned with maintaining the air quality of the building. This includes determining the air flow rate of the system, the conditioning of building areas, the ductwork of the system, and the potential use of heat exchangers.

2.2.1 HVAC Air Flow Rate

The ventilation system of a building not only circulates heat and cooling, but also maintains the Indoor Air Quality (IAQ). Toxins are emitted from certain construction materials that were used during the construction of the building and from various manufacturing processes. Therefore, the first item to consider in a HVAC audit is the air flow rate at the intake of the ventilation system. This is to determine if the air flow rate is enough to remove building and manufacturing
Figure 2.1 Overview Of Energy Audit Process.
toxins such as soldering and paint fumes.

Check the local and state code regulations to determine if the air flow rate is adequate. If there are no toxins released into the working environment due to manufacturing, the American Society of Heating Refrigeration and Air Conditioning Engineering (ASHRAE) recommendation is 20 CFM per person. (1,8)

If, however, there are toxins released by a manufacturing process, the Occupational Safety and Health Association (OSHA) Threshold Limit Value (TLV) of the substance must be considered. TLV is the amount of a substance per volume of air that a person can safely work in. A higher concentration of the toxin may prove to be a health hazard. The ventilation system has to be adapted to maintain the TLV. Two means of insuring that the toxin levels are kept to a minimum is to dilute the toxin by constantly bringing in outside air or to remove the source of the toxin. (5,127)

If the air flow rate exceeds the building code requirements and is capable of removing manufacturing toxins the speed of the fan may be reduced. The benefit of reducing the fan speed is that less heat will be exhausted in the winter and less cooling in the summer and of course it will consume less energy since it is doing less work. (5,2) Figure 2.2 is a flow chart for examining the air flow rate of a HVAC system.
Figure 2.2 Flow Chart For Examining HVAC Air Flow Rate.
2.2.2 HVAC Conditioning

HVAC systems are often designed for peak loads. For this reason they often move more air than is needed. It may be possible to cycle HVAC systems off for 15 min./hr. This will save money since the fans and the pumps will not be operating. However, it will not save on space heating and cooling, since the temperature requirements of the building will still have to be met.

If this method of conservation is considered, care should be taken to insure that the ventilation requirements of the building are still met. Also to be considered is the effect stress will have on starting and stopping the motors. (5,192)

Conditioning of all areas that are infrequently used should be reduced or stopped entirely to minimize the amount of heating and cooling energy wasted. However, one should be careful not to lower the heat to a point where water pipes in the area will freeze. HVAC systems should also be turned down during unoccupied hours. (5,165) For large areas where relatively few people are working, such as warehouses, portable heaters can be used for local heating to prevent heating the entire building. (6)

Another source of conditioning losses is heat lost through the roof. Hot air will rise to the ceiling and will eventually escape through the roof. A ceiling fan may be installed to push the air down into the room and thus reduce
the loss of this heat. This will also lower the cost of heating because warm the air will be confined to the lower areas of the room where the thermostats are located. (1,165) Air conditioning ducts located in the upper parts of a room should be brought down to lower levels. This will make cooling more effective and reduce cooling loads from the roof. (7) Figure 2.3 is a flow chart for examining the conditioning of a HVAC system.

2.2.3 HVAC Ductwork

The filters and the ductwork itself of the HVAC system should be regularly checked to guarantee that they are free of debris. This will ensure that air flow is unobstructed and ease the work done by the fans.

One of the functions of the HVAC system is to remove water from the air. Mold spores may grow in the pans used for collecting the water. These pans should be regularly cleaned to prevent mold spores from growing and possibly being transmitted by the HVAC system.

HVAC ductwork should also be insulated to restrict heat loss. Often this is done by taping fiberglass insulation around the duct. (5,95) Figure 2.4 is a flow chart for examining the ductwork of a HVAC system.

2.2.4 HVAC Heat Exchangers

In a HVAC system it may be possible to partially
HVAC Conditioning

Reduce/Stop Conditioning Of Unoccupied Areas

Reduce/Stop Conditioning During Unoccupied Hours

Avoid Lowering Temperature To Point Where Pipes May Freeze Or Damage To Equipment Might Occur

Is More Air Being Moved Than Needed?

No

Yes

May Be Possible To Cycle HVAC Off For 15 min/hr

End

Figure 2.3 Flow Chart For Examining HVAC Conditioning.
Figure 2.4 Flow Chart For Examining HVAC Ductwork.
condition the incoming air with the exhausted air that has already been conditioned. This will help reduce the energy needed to condition incoming air. A heat exchanger is a device used to transfer heat from one process to another. Heat exchangers for HVAC systems transfer heat from one duct to another. When using a heat exchanger one must be sure that the incoming air is not contaminated by the exhaust.

Three types of HVAC heat exchangers are heat wheels, air exchangers, and the coil run-around cycle. Heat wheels are made of a ceramic or other heat absorbing material and rotate from an exhaust duct into an intake duct. Exhaust air passes through the wheel while the wheel absorbs the heat from the exhaust. The wheel then rotates into the intake duct where it releases its heat. Heat wheels are also capable of capturing latent heat. Latent heat is the energy needed to change a substance, such as water, from a liquid to a gas. Figure 2.5 is a drawing of a heat wheel.

Air exchangers have a network of channels within a steel box. The exhaust and intake air are passed through alternating channels. As the intake and exhaust streams pass over one another the heat is transferred. Figure 2.6 is a drawing of an air exchanger.

With the coil run-around cycle the exhaust is passed through a coil and the heat is transferred to a fluid. The fluid is then pumped back to the intake coil where the heat is released. Since the heat is transferred to a fluid, this type
Figure 2.5  Diagram of Heat Wheel. (5,111)

Figure 2.6  Diagram of Air Exchanger. (5,111)
of heat exchanger is well suited for situations when the intake and exhaust ducts are not located close together. Figure 2.7 is a drawing of the coil run around cycle. Figure 2.8 is a flow chart for determining which type of heat exchanger is suitable for a HVAC system.

![Circulating Fluid Diagram](image)

**Figure 2.7** Coil Run-Around Cycle. (5,112)

2.3 Building Audit.

The primary reason for the building audit is to reduce the heating and cooling needs of the building. This type of audit requires knowledge of the layout, dimensions and construction materials used in the building.

2.3.1 Identifying Air Leaks in Buildings

One of the main activities of the audit is to identify
Figure 2.8 Flow Chart For Examining Heat Exchangers.
Figure 2.9 Heat Loss Due to Air Infiltration. (5,166)
all the cracks and gaps around the doors and the windows. Other items to investigate are stairwells, dampers, and exhaust hoods. Figure 2.9 displays how much heat can be lost given an indoor temperature of 65°F. To use the graph the outdoor temperature and the flow rate of the incoming air must be known. (5,121)

Inexpensive weather stripping can be used to seal the gaps around doors and windows. If a doorway is used frequently by a forklift or another type of vehicle, vinyl strips or an air curtain can be installed to cut down on heat losses.

Outdoor dampers and seals should be examined to insure that the blades close tightly. If need be the dampers should be replaced with an opposed blade damper. Figure 2.10 is a
diagram of an opposed blade damper.

Heat entering stairwells is not necessarily lost, but heating them serves little purpose. Therefore, stairwells and other vertical shafts should be isolated from the rest of the building where practical. (5,127)

Exhaust hoods have to remove large volumes of air in order to remove smoke, fumes, and other particulate from the working environment. However, the air removed by the exhaust hood has to be brought in and conditioned by the HVAC system. Therefore, it is desirable to minimize the amount of air removed by the exhaust hood and still remove the contaminates from the work area.

Operations that produce fumes and irritants should be moved to one area, if possible, so that a single exhaust system can control the toxin levels. Moving these operations to a single area will also decrease the chances of the fumes escaping and building up in other areas of the plant. It will also limit the number of air changes that the HVAC system will have to make up. (8,12)

Another option would be to set exhaust hoods so they operate at the minimum capture velocity needed for the area. The minimum capture velocity of an exhaust hood is the minimum amount of air a hood can draw and still remove fumes and irritants from the air. One means of accomplishing this is to install a false hood in the existing hood. This increases the velocity of air removal, yet decreases the overall volume of
Another idea would be to install a fan in the exhaust hood that draws outside air past a heating coil. This would prevent the HVAC system from having to condition the makeup air. (5,135) Figure 2.11 is a flow chart for examining sources of air infiltration.

2.3.2 Building Construction and Insulation

Heat can be lost or gained through the roof, walls, and windows of the building. The amount of heat conducted through a surface depends on the difference in temperature, the length of time the difference lasts, the area the two surfaces have in common, and the thermal resistance of the material that the heat is passing through. The thermal resistance or R value of a material refers to how well the material resists the flow of heat. (1,217)

The roof color of a building will have an effect on the heating and cooling loads of the building. A dark color roof will reduce heating loads in the winter, but will cause higher cooling costs in the summer. The opposite is true with a light color roof. In most cases cooling is done with electricity, which is a relatively expensive form of energy. Because of this the cooling load of the building will generally determine the color of the roof. (5,137)

Windows transmit a large amount of radiant energy, which will decrease heating loads in the winter but can dramatically
Figure 2.11 Flow Chart For Examining Sources of Air Infiltration.
increase cooling costs during the summer months. (1,152) Window shading can enhance energy efficiency by controlling solar gain or lessening radiated heat loss. Window shading can be done with curtains, blinds, or by coating the window with a reflective tint. (9)

2.4 Electrical Audit

The electrical audit consists of examining the utility tariff structure, identifying the major loads, and studying the possibility of using an Energy Management Systems (EMS).

2.4.1 Utility Tariff Structure

The demand charges and energy charges form the majority of the electricity tariff. The demand charge is based on the average maximum amount of power consumed over a 15, 30, or 60 minute interval. Demand charges increase as the demand increases because utilities have to bring more expensive units on line to meet the increasing demand. (10) The energy charge is a charge for the amount of kWh consumed during the billing period.

Some electric utilities may offer time-of-day billing. This allows a plant to consume electricity during off peak hours without having to pay the full amount of demand charges. For example, if the utility's peak demand hours were from 8 am to 4 pm the plant could time delay some of its load so that it would have a higher demand after 4 pm then during the peak
hours and pay less for it than if it occurred during the peak hours. However, the company would still have to pay the full amount for the energy charges.

Electric utilities may impose a penalty for having a low power factor. The lower the power factor the greater the line losses. One way to correct a low power factor is to add a capacitor bank in parallel to a plant's electrical system. (5,212)

Table 2.1 is provided to determine the amount of kvars necessary to correct the power factor. The power consumed by the plant in kW is multiplied by the value in Table 2.1 to determine the amount of kvars needed. The means of producing this table and a discussion on the impact of power factor is given in Appendix B.

Utilities may also offer industrial packages. These packages may save a company money depending on the nature of the package and whether or not the company qualifies for the package. Figure 2.12 is a flow chart for examining a utility's tariff structure.

2.4.2 Identifying the Major Loads

Motors used for compressors, refrigeration units, etc. can consume a large amount of electrical energy. Creating a table of the major electrical loads can be useful for determining the power each load consumes. Equation 2.1 is used to determine the amount of power consumed.
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Table 2.1  Power Factor Correction.
Figure 2.12 Flow Chart For Examining Utility's Tariff Structure.
Where $P$ is the three phase power consumed in Watts, $V_{\text{rms}}$ is the line voltage, $I_{\text{rms}}$ is the incoming current and $PF$ is the power factor of the machine. (11,427)

The table should include the type, number and the length of time the machine operates. Information from the name plate of the machine can give an idea of how much electricity is being consumed by the machine. However, this is the rating of the machine at full load and most machines do not run at full load. For an accurate calculation the line amperage and the power factor of the machine must be known. This table can then be used to determine if there is a more economical way of using electricity. Figure 2.13 is a flow chart for creating an electricity usage table.

2.4.3 Lighting

20% of the electricity used in the United States is used for lighting. (12,1) Light only areas that are needed to do the task. Replace incandescent lights with more efficient fluorescent lights where possible.

Several factors such as glare, dirt, and age may contribute to poor light quality. Lights that are positioned directly above or in front of a work surface may cause a glare on the surface and decrease visibility. A solution to this problem would be to relocate the lights to the sides of the work area. In some cases up to 33% of the lights may be
Loads

Determine Power Factor Of Plant

Identify Major Loads

Collect Horsepower Ratings For Each Machine

Determine Yearly Time Of Operation For Each Machine

Calculate Yearly Power Consumption For Each Machine

Determine Amount Of Energy Consumed By Lighting Fixtures

End

Figure 2.13 Flow Chart For Examining Electricity Usage.
removed and still maintain good visibility.

Light levels of fluorescents gradually decrease throughout their lifetime. Work areas should be routinely relamped to keep light levels at an optimum. Dirt on lights and their reflective surfaces can dramatically reduce light levels, so lights should be periodically cleaned. Also turn off lights in unoccupied rooms. (13)

If a decision is made to replace existing light fixtures, install the new lights in a small area. Fluorescents lose a significant amount of light within the first week of operation. Allow the lights to burn for one hundred hours before measuring light levels and making a decision on the fixtures.

For outside lighting, sodium vapor lights are generally best. However, sodium lights will cause the surroundings to appear to be yellow. Determine if color rendering is important before making a decision on outdoor lighting. (14)

Natural lighting may be used to decrease lighting loads. Depending on how many sides daylight enters, natural lighting can account for 40% to 90% of the lighting load. The percentages are given with the assumption that in the absence of natural lighting fluorescent lights would be operating from 7 am to 5 pm. (15) Figure 2.14 is a flow chart for examining the lighting systems.
Figure 2.14 Flow Chart For Examining Lighting Systems.
2.4.4 Motors

Motor loses arise from a number of sources. The resistance of the copper windings of the stator and the conductive bars of the rotor dissipate energy through wasted heat. The core of the motor is the source of two loses, eddy currents and hysteresis. Eddy currents are currents that circulate within the core and produce heat. Hysteresis is the energy required to magnetize the core. Also the cooling fan attached to the shaft of the motor causes windage losses.

Energy efficient motors can be used to help reduce the above losses. Energy efficient motors use a lower loss core. This reduces the amount of eddy currents and the heat produced by them. The core is lengthened, which results in the reduction of energy required to magnetize the core.

The resistance of a conductor is inversely proportional to its cross sectional area. Therefore, if the cross sectional area of the stator windings and the conductive bars of the rotor are increased the resistance is lowered and less energy is dissipated as heat. And since less heat is produced a smaller cooling fan may be used in the motor. (16)

High efficiency motors are more expensive than standard motors. The motors may be economically justified for operations where the motor is running for long periods of time at near full load.

Many standard motors are used with pumps and fans for flow control. A mechanical means of flow control, such as a
damper or valve wastes energy by increasing the flow resistance. A variable speed motor would in part relieve the problem by allowing the user to select a slower or faster speed depending on the amount of flow needed.

Large motors that idle for long periods of time should be equipped with a sensor to shut the motor off. The sensor detects when the motor is idling and after a determined amount of time the motor is shut off. (17)

The correct sizing of motors is also important. A motor operating at less than 50% of rated load is very inefficient. However, for maximum efficiency motors should not be operated at full load either. In general motors are the most efficient operating at about 75% of full load. Therefore, a 7.5 hp load is better handled by a 10 hp motor then a 7.5 hp motor operating at full load. (18) Figure 2.15 is a flow chart for examining motors.

2.4.5 Office Equipment

The electrical energy consumed by office equipment can account for 5% to 20% of the electrical load in a commercial building. The energy used for this equipment is even higher if the energy needed to remove the heat produced by the office equipment is taken into account. Two means of reducing the electrical load are to reduce the amount of time the equipment is running or to reduce the electrical load of the equipment.

One system used to limit computer running time is an
Figure 2.15 Flow Chart For Examining Motors.
Automatic Power Management System (APMS). APMS consists of a power surge bar with a microprocessor connected to the keyboard. The system monitors keyboard and mouse activity and checks to see if the computer is performing any operations. After the computer has been idle for a set amount of time APMS shuts the computer off. Each of the outlets on the surge bar can be programmed for a different shut off time or can be programmed to never shut off.

Stickers reminding users to turn off their computers when they are done can also be used. However, this method loses its effectiveness over time. (19)

The second way of reducing the electrical and cooling loads associated with office equipment is to reduce the amount of electricity consumed by the equipment and thus reducing the heat produced. There is no distinguishable difference in heat given off by computers and monitors that are sitting idle from when they are performing operations. (20) Therefore, the computer and monitor must be designed to consume less electricity. In 1992 the Environmental Protection Agency introduced the energy star program. In order for manufacturers to use the logo both the computer and the monitor must consume less than 30 watts each. (21)

2.4.6 Electricity Use at Night

Equipment left on overnight can consume a significant amount of energy. The electrical load factor (ELF) and the
occupied load factor of a plant (OLF) can detect electricity used at night. ELF is the total number of kWh used during a period divided by the maximum amount of kW used during the period times the period. OLF is simply the amount of occupied hours during a period divided by the period. When ELF exceeds OLF electricity is being used at night. (22)

Assume that a plant is operating eight hours a day. The OLF for this period is eight divided by twenty four or 0.33. Now assume that the plant has a flat load profile of 80 kW as given by Figure 2.16. The ELF of this plant is 0.33 and is the same for any flat load profile of eight hours in a twenty four hour period. Any electricity used outside the eight hours will cause the ELF to increase. An example is given in Figure 2.17. A five kW load is running throughout the night and increases the ELF to 0.375.

A rise of a tenth or more can indicate that there is a large amount of electricity being used. In most cases there will be small electrical loads that operate during the night such as refrigerators, water fountains, etc.

2.4.7 Energy Management Systems (EMS)

Energy Management Systems (EMS) are devices that are used to control and limit the amount of electricity used. A few of these systems are sensors, Optimal Start System (OSS), and demand limiters. These systems are often used to control the lighting and HVAC systems of a plant or building.
Figure 2.16 Flat Load Profile of 80 kW for an Ideal Plant.

Figure 2.17 Flat Load Profile of 80 kW With a 5 kW Use at Night.
For areas that are infrequently used, installing infrared sensors to control lighting may be a possibility. The sensors would insure that the lights are turned on only when the room is in use. This type of control is useful for storerooms, hallways, and other areas where people are likely to be moving about. (5,189)

Another option might be to install a time clock to automatically shut off the lights and equipment when they are not needed. Time clocks can also be used to control HVAC systems. This is particularly useful for offices that are only occupied during specific hours. (2,92)

An Optimal Start System (OSS) measures the outdoor temperature and compares it to the desired indoor temperature. Using this information it then determines the best time to start the HVAC system so that the building is at the specified temperature when it is to be occupied. If the system heats or cools the building too quickly or not fast enough the system will make an adjustment to compensate. (5,203)

The purpose of a demand limiter is to reduce energy costs through lower demand charges while still using the same amount of energy. The demand limiter monitors the utility's meter and attempts to predict the load demand of the plant. If the limiter predicts that the load will exceed the plant setpoint then load is shed. Caution should be used when selecting which loads are to be shed. Loads typically shed are HVAC systems, refrigeration units, or any load that will not affect
the safety or the productivity of the plant. (5,201)

As an example of a demand limiter, Figure 2.18 shows a demand profile of a plant. The limiter is set to shed loads if the demand exceeds 150 kW. The limiter sheds a total of 50 kWh of load. It is assumed that the plant will use the 50 kWh at some other time. Ideally this energy would be spread evenly through out the day. Figure 2.19 shows how the 50 kWh might be redistributed.

By leveling out the demand profile the total cost of the energy bought has been reduced by reducing the demand charges and the efficiency of the energy used has been increased. The electrical efficiency of a plant is called the load factor. The load factor is calculated by dividing the average power consumption by the peak amount of power consumed. Ideally the load factor would be one. Which would result in a flat load profile. This flat profile would also have the minimum cost for that block of energy. (5,197)

A microprocessor controls sensors used to measure the temperature, humidity, and pressure of the HVAC system. The microprocessor then determines the needed response and sends a signal to a valve, damper, or actuator in order to maintain or establish the desired conditions. One more type of EMS is the mini-computer base system. This type of system can be programmed to give special reports on energy consumption and through customized programs can control the HVAC systems for the entire building. This system can also integrate fire and
Figure 2.18 Load Profile of a Hypothetical Plant.

Figure 2.19 The Peak Load Is Removed and Redistributed.
security alarms. (1,114) Figure 2.20 is a flow chart explaining various types of EMS.

2.5 Utility Audit

The utility audit is used to evaluate the handling and usage of steam, air, and water.

2.5.1 Boiler Audit

Boilers should be maintained so that they will produce the maximum amount of heat from the fuel used. The goal is to tune the boiler so that the fuel is completely consumed. To check that a boiler is operating efficiently a composition analysis should be done on the stack gasses. A sign of incomplete combustion is a high content of CO and a low content of CO₂. If it is determined that the boilers are not running efficiently a boiler technician should be brought in to correct the problem. (5,215)

The boiler should be examined to find any defective gaskets, cracked bricks, etc. These items may allow air to enter the boiler and will affect the fuel to air ratio, which in turn will affect the efficiency of the boiler.

The efficiency of the boiler can be increased by preheating the combustion air and the fuel used. This can be done by channeling the exhaust gasses through a heat exchanger. By doing this the flame temperature is raised and allows a more thorough combustion.
Figure 2.20 Flow Chart For Examining EMS Systems.

1. Consider the use of time clocks or intermittent switches in the area.
2. Are there areas that are infrequently used?
   - Yes: Proceed to the next step.
   - No: End.
3. Can loads be safely shed if plant load demand is more than desired?
   - Yes: Consider the possibility of using a demand controller to void load profiles.
   - No: End.
4. For large HVAC systems, consider the possibility of using an optical start or microprocessor system to manage HVAC equipment.

Flow Chart:
- Start
- Energy Management Systems
- HVAC Systems
- Lighting & Equipment
- Are there areas that are infrequently used?
- Yes: Consider the use of time clocks or intermittent switches in the area.
- No: End.
- Can loads be safely shed if plant load demand is more than desired?
- Yes: Consider the possibility of using a demand controller to void load profiles.
- No: End.
- For large HVAC systems, consider the possibility of using an optical start or microprocessor system to manage HVAC equipment.
- End.
Boilers generally operate at maximum efficiency when they are fully loaded. If during the cooling season the boiler is not operating at capacity the efficiency of the boiler drops. To alleviate this a large boiler may be replaced with several smaller modular boilers. Each boiler that is on line should be operating at full capacity. The modular boilers can be brought on line as needed and can be fired up rather quickly. (5,224) Figure 2.21 is a flow chart for examining boilers.

2.5.2 Air Compressor Audit

Air leaks in a compressed air line can cause a significant energy loss. Doubling the area of the leak will quadruple the amount of air lost. Therefore, it is important to check seals, joints, and the line itself to insure that there are no leaks. (5,227) Figure 2.22 depicts how much air is lost from a compressed air line given the area of the hole. The means of producing this graph is given in Appendix B.

An equation for determining how much air escapes a compressed air system is given in Equation 2.2.

$$R = \frac{V}{\Delta t} \left( \frac{P_1 - P_2}{P_{atm}} \right)$$

Where $R$ is the air escaping the system in cfm. $V$ is the system volume in ft$^3$. The system volume includes the volume of the air lines as well as the tank. $P_1$ and $P_2$ are the initial and final pressures in psig. $P_{atm}$ is the atmospheric pressure in psia. And $\Delta t$ is the time interval it takes for...
Figure 2.21  Flow Chart For Examining Boilers.
Figure 2.22 Air Lost From Compressed Air Line.
the system to drop from a pressure of $P_1$ to $P_2$.

To use Equation 2.2 close all valves that lead directly into machines. This will isolate the compressed air system. Charge the system until it has reached operating pressure. Record the pressure. This is the initial pressure $P_1$. Turn off the compressor and measure the amount of time it takes for the initial pressure to drop 10%. This is the pressure $P_2$. (23)

The inlet temperature of an air compressor will affect its efficiency. The lower the air temperature the denser the air is and the less energy used to compress it. (24) For every degree Fahrenheit difference an approximate savings of 0.2% can be made on the energy cost. An outside damper may be installed to draw air from outside when temperatures are cooler than inside. (2,179)

Dust and foreign objects in the air supply can cause a compressor to fail. An inertial separator followed by a cloth or paper filter can remove small particulate. The filters should be cleaned regularly to keep the compressor running smoothly. (25)

Some machines may need to operate at a higher pressure. If this is the case then it may be economical to use a smaller compressor at high pressure and lower the pressure of the larger compressor. This would alleviate the cost of running a large compressor at a high pressure in order to suit the needs of a few machines. (5,227) Figure 2.23 is a flow chart
Compressor Bank

Are There Holes In Compressor Lines Or Seals?  Yes  Repair Leaks.

No

Can Cooler Outside Air Be Brought In Through Compressor Intake?  Yes  Install Deepen To Bring In Cooler Outside Air

No

Does The Line Pressure Exceed The Needs Of The Machines?  Yes  Decrease Line Pressure. If High Pressure Is Needed For One Machine It May Be Possible To Use A Smaller Compressor At A Higher Pressure.

No

End

Figure 2.23 Flow Chart For Examining Compressor Bank.
2.6 Energy Consumption Profile

A historical profile of the energy usage of a plant is created by tabulating the various forms of energy and energy fuels used, such as electricity, propane, steam, etc. Each type of energy should be tabulated to determine the yearly consumption of a particular form of energy.

The table should also include whether the energy was used for lighting, heating, manufacturing, etc. All forms of energy, except for water, are then converted to Btus. This will allow a comparison between the several forms of energy used. After examination the table may prove that an operation would be more economical if it consumed larger quantities of a different fuel at a less expensive cost. (26) Table 2.2 is a listing of the Btu value of various forms of energy. The examination of water is used to detect leaks in any of the operations and to determine if it can be used more efficiently. Figure 2.24 is a flow chart for creating an energy profile for a plant.

2.7 Cogeneration

2.7.1 PURPA

The Public Utilities Regulatory Policies Act (PURPA) was passed in 1978 to encourage the use of cogeneration. It does this by removing many of the barriers that utilities had
Figure 2.24 Flow Chart For Creating An Energy Profile.
traditionally put in the way of would be cogenerators. (11,9)

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>BTU per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracite Coal</td>
<td>12,900 per lb</td>
</tr>
<tr>
<td>Bituminous Coal</td>
<td>14,000 per lb</td>
</tr>
<tr>
<td>Lignite Coal</td>
<td>11,000 per lb</td>
</tr>
<tr>
<td>Kerosene</td>
<td>134,000 per gal</td>
</tr>
<tr>
<td>No. 2 Fuel Oil</td>
<td>139,000 per gal</td>
</tr>
<tr>
<td>No. 4 Fuel Oil</td>
<td>150,000 per gal</td>
</tr>
<tr>
<td>No. 5 Fuel Oil</td>
<td>152,000 per gal</td>
</tr>
<tr>
<td>No. 6 Fuel Oil</td>
<td>153,000 per gal</td>
</tr>
<tr>
<td>Propane</td>
<td>91,600 per gal</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>1,030 per cf</td>
</tr>
<tr>
<td>Electricity</td>
<td>3,412 per kWh</td>
</tr>
</tbody>
</table>

Table 2.2 BTU Conversion Factors for Fossil Fuels. Adapted from (2,15).

One of the reasons utilities opposed cogeneration is that they feared it would decrease their revenues. PURPA was proposed during the oil embargo which caused electricity prices to increase and growth to decrease. An added concern was that a few utilities had already made financial commitments to expand their capacity. (27,1-4) However, a potential advantage of large scale usage of cogeneration to utilities is that they do not have to install more operating capacity and therefore do not have to raise the capital to fund the project. (28)

PURPA forces utilities to buy cogenerated power at the same price the utility would bear if it were to generate the
power. The utilities must supply the cogenerator with a connection to the power grid. Additional power will be supplied to the cogenerator if needed at a reasonable cost. Cogenerators are exempt from federal and state utility regulations and reporting requirements. (29)

In order for a facility to be covered by PURPA it must be a Qualifying Facility. To do this the facility must generate electricity and useful heat from a single fuel source. A utility can not have more than 50% ownership of the facility. The operating efficiency of the facility when using oil or natural gas as the primary fuel must be greater than or equal to 42.5%. According to the Federal Energy Regulatory Committee (FERC) electrical power is twice as valuable as the thermal energy. Therefore, the necessary efficiency of a Qualifying Facility is defined as the electric power plus one half of the useful thermal energy. The efficiency rating increases to 45% if the thermal energy is less than 15% of the output energy.

There are two ways to become certified as a Qualifying Facility. The first is to be self certified. This would entail a detailed description of the facility and its function, the fuel used, the percent ownership, and the efficiency of the cogeneration unit. This description is then sent to FERC for approval.

The second way is to be certified through FERC. A more detailed description of the unit is necessary. But, if done
in this manner the facility would get FERC protection from utilities resisting the cogeneration unit. (1,13)

2.7.2 Types of Cogeneration

Cogeneration uses a single source of fuel to produce two forms of energy. When electricity is produced the waste heat is typically released to the environment. Cogeneration recovers some of the waste heat to perform additional work. By doing this the fuel efficiency of the plant is increased.

Cogeneration can either be a bottoming or a topping cycle. When heat is produced first for process requirements and then used to produce electricity it is called a bottoming cycle. When electricity is produced first then useful heat recovered for some other use it is called a topping cycle. (30) Topping cycles are the most common because most facilities do not have high temperature needs. Figure 2.25 is an example of a topping cycle. A bottoming cycle is generally used when large amounts of heat can be captured from a plant process such as a blast furnace, kiln, or a metal hardening operation such as a heat treat plant. (1,269) Figure 2.26 is an example of a bottoming cycle. The bottoming cycle generally requires a waste heat temperature of 600°F or higher. (27,2-24)

Another type of cogeneration is the combined cycle. A combined cycle captures the steam exhausted from the first electric generation cycle and uses it to produce additional
Figure 2.25 Topping Cogeneration Unit With Combustion Turbine.
Figure 2.26  Diagram of a Bottoming Cycle Cogeneration Unit. Modified from (1,270).

Figure 2.27  Diagram of a Combined Cycle Cogeneration Unit.
electricity. (31) Combined cycles are normally larger than 30 MW. (27,2-23) Figure 2.27 is a diagram of a combined cycle.

A cogeneration unit can also either be thermal following or electric following. Thermal and electric following refers to whether the cogeneration unit follows the thermal load or the electric load of the plant. (32) Most cogeneration units are thermal following. Therefore, the unit is generally sized to match the thermal load. (27,4-4)

A cogeneration unit has three basic parts. They are the prime mover, the generator, and the heat exchanger. The prime mover transforms chemical or thermal energy into mechanical energy. The mechanical energy provided by the prime mover is then used to drive the shaft of a generator. The heat produced by the prime mover is captured with a heat exchanger. The heat is then used for space heating, hot water, or process steam.

Cogeneration units less than 1 MW are typically prepackaged. The prime mover, generator, and heat exchanger are mounted on a single platform. Units larger than 1 MW are custom made for a particular application. (27,2-21)

2.7.3 Prime Movers

The prime movers generally used are reciprocating engines, combustion turbines, and steam turbines. Reciprocating engines are quite efficient in smaller sizes and
are available from 5 kW to 20 MW. (27,2-23) Heat is recovered from the exhaust gases and the water jacket of the engine. Almost all of the heat from the water jacket and about 50% of the exhaust heat can be used. Reciprocating engines are well suited for small scale cogeneration projects. This is because they can be brought up quickly and can be cycled on and off if need be. (11,37)

The combustion turbine consists of a compressor, a combustor, and the turbine itself. The electrical output of the generator is used to drive the compressor. Because of this the power output is affected by the air inlet temperature. If the air is warm the compressor has to do more work to compress the air and therefore has to divert power from the output. If a combustion turbine is used it may be economical to cool the inlet air.

Combustion turbines are available from 200 kW to 150 MW. The efficiency of a combustion turbine rises with its size. The turbine exhaust temperature can be around 1000° F. The exhaust gases are generally rich in oxygen so they can be used for further combustion if necessary. Reciprocating engines are more efficient than smaller combustion turbines of the same size. (11,50)

Steam turbines are available from 200 kW to 1000 MW. They provide the most flexibility of the output power to thermal power. (11,60)
2.7.4 Generators

Synchronous generators are usually used when the facility wishes to isolate itself entirely from the grid or if the plant desires to protect itself from a possible power grid failure. Induction generators are usually not capable of operation without the utility grid. This is because the induction generator requires reactive power from the grid to provide a magnetic field. When the grid fails this source is removed and the induction generator is no longer capable of generation. (11,78)

An induction generator can be operated in isolation if capacitors are used to provide reactive power. However, the generator voltage and frequency drops under load. (33,326)

2.7.5 Heat Exchangers

Waste heat is heat that is generated by a process and released into the atmosphere but, could be used for further processing. A heat exchanger is a means of recovering this heat. The waste heat released by a process is usually in the form of a liquid coolant or a gas exhaust.

The type of waste heat to be recovered is broken up into three categories. The high temperature range is over 1200° F. The medium temperature range is from 450° F to 1200° F. And the low temperature range is from 250° F to 450° F. Temperatures below 250° F are generally not worth recovering. (1,125)
Medium to high temperature heat from exhaust gases can be used to preheat inlet air for boilers, furnaces, and ovens. Low to medium temperatures can be used to preheat water entering a boiler or make up heating water for the boiler. Exhaust gases can also be used to generate steam that can in turn generate electricity or be used for mechanical power.

The heat exchanger is used to separate one process from another. This is done for a number of reasons. The first one is that the exhaust stream of one process may contaminate the intake stream of another and vice versa. Also there may be a substantial pressure difference between the two streams. The fluid used in heat exchangers is better able to transfer the heat over long distances. (1,128)

When selecting a heat exchanger the heat exchange capacity, the temperature of the fluids being used, and the chemical composition of both fluids need to be considered. Also to be considered is the minimum temperature of the waste heat used and the allowable pressure drop in the two fluids. There are many different types of heat exchangers available. The type of exchanger selected will depend on the processes being considered.

Single or multipass exchangers refer to how many times the hot fluid is passed over the fluid to be heated. Exchangers can be parallel (Figure 2.28), counter (Figure 2.29), or cross flow. In a parallel flow exchanger both fluids are moving in the same direction. The opposite is true
Figure 2.28  Diagram of Parallel Flow Heat Exchanger.
(1,133)

Figure 2.29  Diagram of Counter Flow Heat Exchanger.
(1,133)
for the counter flow type. When the two fluids are passed at right angles to each other it is termed as a cross flow exchanger.

A gas-gas recuperator transfers heat by means of radiation. It is formed by two concentric lengths of tubing. The inner tube carries the exhaust gas and the outer tube carries the gas that is to be heated. Counter flow heat exchangers are more efficient, but parallel flow will increase the life expectancy of the inner tube. (1,137)

Heat wheels are used in low to medium temperature situations. The heat wheel's axis is placed in between and parallel to the exhaust and intake ducts. The wheel rotates from the hot air duct to the cold air duct. The heat wheel is made from a ceramic or another type of material that readily absorbs heat.

As the wheel enters the exhaust duct it absorbs the heat and then releases it into the intake duct. The primary limitation to the heat wheel is that it may experience uneven expansion if the temperature differences are extreme. This will make it harder to maintain a seal between the two ducts and may risk contamination.

Some heat wheels are made to absorb latent heat. Latent heat is the heat that is trapped in water vapor. This is particularly useful in HVAC systems as it raises the humidity level of the incoming air. However, this type of heat wheel may also absorb some contaminants from the exhaust stream. If
this becomes a problem installation of filters upstream from the wheel may correct it. Another alternative would be to blow a small amount of air through the wheel to remove dust and gases. Since heat wheels are motor driven they can control the temperature of the intake duct by varying the speed of rotation. (1,142)

Air preheaters are used for low to medium temperature applications. They transfer heat by passing the intake gas through a channel that is adjacent to the hot exhaust gas. The two gases are only separated by a thin wall of metal.

Heat pipes are a bundle of pipes that are sealed at both ends with a wick and heat transfer liquid on the inside. Heat pipes are placed in between ducts. Heat is absorbed at one end of the pipe where it evaporates the heat transfer fluid. The vapor then travels to the cooler end of the pipe. It then condenses giving off its heat. The vapor travels back to the hot end of the pipe by gravity or by capillary action. (1,148) Figure 2.30 is a drawing of a heat pipe.

Gas-liquid or liquid-liquid finned tube exchangers consist of tubes with metal fins on the outside of the pipe. The fins are used to increase the surface area contact between the two fluids so that the heat exchange will be more efficient. The cold fluid passes through the finned tube while the hot fluid passes over it. (1,150) Figure 2.31 is a drawing of a gas-liquid exchanger.

How well a heat exchanger works largely depends on how
Figure 2.30 Diagram of Heat Pipe Exchanger. (5,111)

Figure 2.31 Diagram of Gas-liquid Exchanger. (5,113)
clean the fuel is. If the fuel used is dirty then the gases produced during combustion will contain ash and particulate that could make heat recovery difficult. Some of the particulate may have a tendency to slag. A rapping mechanism to dislodge the ash and a hopper to collect the ash should be used if large amounts of ash are to be expected. Using bare tubes instead of finned tubes which might become clogged will aid in keeping the heat exchanger clean. (34).

2.7.6 Cogeneration Loading

A cogeneration plant can be thermally base loaded, electrically base loaded, used for peak shaving, or used for emergencies. The term base loaded means that the cogeneration unit is running at full load. The remaining energy required is provided by the utility. Figure 2.32 is an electrically base loaded plant.

Peak shaving is used when the plant wishes to avoid additional demand charges. This is done by bringing the cogeneration unit on line when the plant is at its peak electrical consumption. Figure 2.33 is an example of a peak shaving system. (35,112)

Peak shaving cogeneration can improve the load factor of a plant, but since it has a limited operating time it may not be economically feasible. (36) However, a utility that has high demand charges may make peak shaving appealing. These utilities are likely to have recently installed nuclear or
Figure 2.32  Base Loaded Cogeneration Unit.

Figure 2.33  Peak Shaving Cogeneration Unit.
hydroelectric capacity which have high capital costs, but fairly low operating costs. (37)

2.7.7 Feasibility of Cogeneration

Before deciding on a cogeneration system a decision must be made to determine if cogeneration is technically and economically feasible.

There are many items to consider when evaluating a cogeneration project. The first item to consider is why a plant might turn to cogeneration. Obviously if a plant intends to sell most of the electricity back to the utility profit is the main reason. However, for smaller plants that intend to use the power they generate, high electricity prices and poor power quality are the main reasons small plants cogenerate. (38)

Also to be considered is what type of fuel is to be used. Natural gas is the primary fuel used for cogeneration. (39,3-31) Can the fuel be secured through a long term contract? How much supplemental electricity and boiler fuel will be needed? If the plant is intending to sell the electricity to the utility how much effort is needed to connect to the utility grid?

As mentioned earlier most cogeneration units are sized for thermal demand. The sizing of the unit is done by examining the load duration curve (LDC) of the thermal needs. A LDC is a graph of how frequently a load occurs and is
arranged in descending order. If a plant has a steam load as given in Figure 2.34 then the LDC of the steam load would be given by Figure 2.35.

The cogeneration unit is then sized to be base loaded at the knee of the LDC, which is at 29 kW. This is the point of greatest efficiency and operation. The efficiency of the cogeneration unit decreases if it is operated at part load. (40) The unit, however, may be sized a little larger to get a maximum payback. The same approach can be used if the unit is to be sized according to an electrical load. (41)

When deciding on a unit try to match the equation:

\[
\frac{TCOGEN}{ECOGEN} = \frac{TPLANT}{EPLANT}
\]

(2.3)

Where TCOGEN and ECOGEN are the thermal and electrical outputs of the cogeneration unit. TPLANT and EPLANT are the thermal and electrical needs of the plant. It is important to note that the thermal and electrical needs of the plant should be coincident in the above equation. The cogeneration unit should be sized toward the minimum of this demand. If the only thermal needs are a seasonal heating load then the use of cogeneration would be hard to justify.

Also to be considered are the hours of operation. A large cogeneration unit will not be economical if it is to be cycled on and off. Smaller reciprocating engines are capable of operating in this manner. (1,264)

Multiple units may be a better choice than a single large
Figure 2.34  Steam Load Profile of a Hypothetical Plant.

Figure 2.35  Load Duration Curve of Steam Load Profile.
unit if a large amount of generation is needed. A large unit will have a lower capital cost, but multiple units will have increased redundancy and minimize utility purchases during maintenance and forced outages. (37)

Since the demand ratio of thermal to electrical energy may vary throughout the day, a means of storing the heat may be necessary. A Heat Recovery Steam Generator (HRSG) is one way to store excess thermal energy. Figure 2.36 is a diagram of a cogeneration system with a HRSG. (42)

Fire tube and water tube are two general types of HRSG. The exhaust gas of a fire tube HRSG flows through the pipe and its heat is radiated to the water on the outside. The opposite is true for the water tube HRSG. The advantages of a fire tube HRSG are that it can handle gas at high temperatures and it is easier to clean so a dirty fuel may be used. A water tube HRSG has the advantages of handling high gas mass flow rates. (43)

A company may decide that a cogeneration project is technically possible, but cannot raise the money to finance the project. Third party ownership may be an option in this case. In many cases, the third party will accept the financial risks of owning and operating the cogeneration plant. The company in return agrees to purchase a certain amount of thermal heat and electricity from the third party. The remaining electricity is then sold to the utility. Most third party projects are 10 MW or more.
Figure 2.36 Diagram of a Cogeneration Unit With a Heat Recovery Steam Generator.
Another type of financing is to lease a cogeneration unit. Leasing is generally done with small prepackaged cogeneration units. The lessor designs, builds, and maintains the unit in exchange for rental payments. Leasing is particularly attractive to companies who do not have the time and expertise to operate a cogeneration unit. (11,190)

2.7.8 Connecting to the Power Grid.

Through PURPA if the cogenerator produces excess power it may sell the power to the utility. In order to sell power the cogenerator will have to follow the guidelines set up by the utility for connection to the network. The utility generally requires a switch that can disconnect the cogenerator from the network. This switch would be controlled by the utility to insure that a de-energized line is not accidentally energized by the cogenerator and endangering the safety of a utility crew that may be working on the line. (44,14)

The control switch may also be used to clear a fault. If the cogenerator is using an induction generator it will not be able to sustain a fault current. This is because an induction generator requires outside excitation and cannot operate without the utility grid. However, a synchronous generator is self exciting and may be able to sustain a fault current.

The cogenerator will also have to provide a means of synchronizing the cogenerated power with the utility power. The utility will require a variety of relays to insure the
quality of the power. They generally include voltage, frequency, and phase relays. The utility may also install a power relay to guarantee that the cogenerator does not supply more power than what the purchase contract specifies.

The amount of protection needed will depend on the size of the cogenerator and the location of the connection. In most cases the system is much stronger than the cogenerator. Therefore, the cogenerator is unlikely to cause significant voltage variations in the transmission lines. However, if the two are more closely matched the cogenerator may be able to cause undesirable voltage variations. (44,4)
Chapter 3
The Maugus Manufacturing Company Study

3.1 Introduction

The Maugus Manufacturing Company is a small company in Lancaster Pennsylvania. The company manufactures brushes that are used to apply solvents, polishes, and other chemicals.

Maugus has two manufacturing plants. Plant I has 7,200 sq. ft. of manufacturing and 5,000 sq. ft. of storage. Most of the machines in Plant I are driven by motors of 1 hp or less. Plant I currently pays $19,196, $6,703, and $4,266 annually for electricity, fuel oil #2, and propane respectively. Electricity is used for lighting and manufacturing. Fuel oil #2 heats the first floor of Plant I. Propane is used for heating the second floor of Plant I and is also used for manufacturing.

Plant II has 17,000 sq. ft. of manufacturing space and 13,400 sq. ft. of storage. Plant II houses the larger machines, mainly the blanking presses and the plastic extruders. Plant II currently pays $24,682 and $13,498 annually for electricity and natural gas respectively.

3.2 The Maugus HVAC Audit
3.2.1 HVAC Air Flow Rate

The upstairs of Plant I contains the Solder Room. The Solder Room has 6 solder machines that are used to solder the applicator brush to the cap. Two fans have been installed to
remove the fumes produced by these machines, one to bring air in and the other to push air out. The fans are installed on opposite ends of the room. The fans run constantly as long as the machines are operating. This is the only ventilation for Plant I.

Plant II in the past has had problems with rusting brush handles. During the summer with the high temperature and humidity the tin used in the brushes would start to rust. Maugus installed two fans controlled by a thermostat to keep air moving through the plant and avoid rusting. This is the only ventilation for Plant II and it is used only during the summer.

3.2.2 HVAC Conditioning

Both of Maugus's plants turn back their thermostats to 60° F at night from a daytime temperature of 70° F. Screw compressors are present in both of Maugus's plants. During the winter the heat produced by these screw compressors is vented into the building to aid the boiler system. Neither Plant I or Plant II is air conditioned.

3.2.3 HVAC Ductwork

The only ductwork in both of Maugus's plants come from their boilers. The filters for the ductwork are routinely replaced. The ductwork is insulated.
3.2.4 HVAC Heat Exchangers

Neither of Maugus's plants have heat exchangers of any kind.

3.3 The Maugus Building Audit
3.3.1 Identifying Air Leaks in Buildings

Windows in both plants are covered with plastic frames during the winter to prevent air leaks. Maugus has placed vinyl strips between the factory and doors leading to the dock area to reduce the amount of heat lost. During the winter the screw compressor vent leading to the outside is closed off.

3.3.2 Building Construction and Insulation

Both of Maugus's plants are constructed of cinder blocks. Figures 3.1 and 3.2 are the floor layouts of Plant I and II respectively. Plant II was originally two separate buildings. The two buildings have been joined together to form Plant II. The joining space between the two buildings is the only section of Plant II that has any ceiling insulation. This insulation is 6 1/4 inches of fiberglass and has an R value of 19. This area also has 8 4 ft X 4 ft skylights to help light the area. Most areas of Plant I and Plant II are not easily accessible to insulate. However, the ceiling could be insulated by drilling holes every 3ft into ceiling paneling and blowing the insulation in. (48) Both Plant I and II have recently installed black membrane roofing.
Figure 3.1 Floor Layout of Plant I.

Figure 3.2 Floor Layout of Plant II.
3.4 The Maugus Electrical Audit

3.4.1 Utility Tariff Structure

Both of Maugus's plants are covered by Pennsylvania Power and Light's (PP&L) GS 3 rate structure. The GS 3 rate charges $6.82 per kW of demand. The billing demand kW is the maximum average power supplied for a 15 minute interval. The tariff rates for kWh consumption are given in Table 3.1.

<table>
<thead>
<tr>
<th>Rate (kWh)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.0559/kWh</td>
<td>For the first 150 kWh/kW</td>
</tr>
<tr>
<td>$0.0473/kWh</td>
<td>For the next 100 kWh/kW</td>
</tr>
<tr>
<td>$0.0427/kWh</td>
<td>For the next 150 kWh/kW</td>
</tr>
<tr>
<td>$0.0385/kWh</td>
<td>For the remaining kWh</td>
</tr>
</tbody>
</table>

Table 3.1 PP&L's Tariff Structure for kWh Used.

To help clarify PP&L's rate structure a sample billing of Plant I is given in Table 3.2. Plant II is billed in the same manner.

PP&L offers two incentives to its customers. The first is Time-of-Day metering. This would allow a company to spread large electrical loads over longer off peak hours and not incur large demand charges as a result of those loads. The company will still have to pay the full cost of the energy consumed. The peak hour windows for PP&L are 7 AM to 3 PM, 8 AM to 4 PM, and 9 AM to 5 PM. The option for Time-of-Day
DEMAND
KWH USED
14880 KWH

DEMAND CHARGE $6.82/KW FOR THE FIRST 125 KW

$6.82/KW * 85 KW $579.70 A

KWH CHARGES

$0.0559 FOR THE FIRST 150 KWH PER KW OF DEMAND

150 KWH/KW * 85 KW 12,750
$0.0559/KWH * 12,750 KWH $712.73 B

REMAINING KWH TO BE BILLED

2,130

$0.0473 FOR THE NEXT 100 KWH PER KW OF DEMAND

100 KWH/KW * 85 KW 8,500

KWH

$0.0473/KWH * 2,130 KWH $100.75 C

REMAINING KWH TO BE BILLED

0

$0.0427 FOR THE NEXT 150 KWH PER KW OF DEMAND

150 KWH/KW * 85 KW 0

$0.0427/KWH * 0 KWH $0.00 D

REMAINING KWH TO BE BILLED

0

$0.0385 FOR ALL ADDITIONAL KWH

$0.0385/KWH * 0 KWH $0.00 E

BASE COST=(A+B+C+D+E) $1,393.18 F
CREDIT ADJ. -0.023 * F ($32.04) G
PA SURCHARGE 0.0207 * (F+G) $28.18 H
ENERGY CHARGE
$0.011258/KWH * 14880 KWH $167.52 I
PA SALES TAX 0.06 * 0.25 * (F+G+H+I) $23.35 J

TOTAL=(F+G+H+I+J) $1,580.19

Table 3.2 Example Bill for Plant I.
metering costs $11.77 per month for a minimum of one year. (11)

The second incentive is the Industrial Development Initiatives Rider (IDI). PP&L provides IDI as an incentive for companies to expand. IDI establishes a base period of twelve months ending December 31, 1991. If a company signs the IDI contract, the demand charge will be reduced $2 per kW for every kW above the base kW. There will also be a reduction of $0.01 per kWh for every kWh in excess of the base kWh. IDI will be in full effect through December 31, 1997. On January 1, 1998 the billing adjustments will be reduced to 70%. On January 1, 1999 the billing adjustments will be reduced to 35%. And on January 1, 2000 all provisions of IDI will terminate. (12) Maugus's overall demand has remained fairly constant since 1991 and would not be able to benefit from the IDI Rider.

The possibility of power factor correction for Maugus was also examined. Plant I and II have lagging power factors of 72.2% and 79.7% respectively. Plant I's power factor is rather low. However, PP&L does not penalize companies for having a low power factor and therefore there is no incentive to correct it. PP&L only does power factor correction to increase the amperage to a facility.

Columbus Southern Power, an electric utility in Ohio, does impose a penalty for having a low power factor. An example of how their billing practices would affect Maugus if
Maugus was in their area is given in Appendix B.

3.4.2 Identifying the Major Loads

The major load of both plants are the screw compressors. Tables 3.3 and 3.4 can also be used for identifying the major loads of both plants.

3.4.3 Lighting

Nearly all of Maugus's artificial light comes from fluorescent lighting. There are a few incandescent lights in storerooms and in the basement of Plant II. The lights and reflective surfaces are kept clean. However, lights that are dimming are generally not replaced until they burn out.

To reduce the lighting needed for their warehouse area Maugus has installed 8 4 ft x 4 ft skylights in Plant II. Diffuse light enters the buildings on all sides. In many cases the windows are opaque. Many of Maugus's windows have been blocked over for security reasons.

3.4.4 Motors

Most of the motors in Maugus's plants are 1 hp or less. These motors run intermittently and are not individually much of a draw on the electrical system. None of the motors at Maugus are used for flow control.

Both plants have large motors that are being used to run the screw compressors. These motors run continuously at near
full load. It may be beneficial to replace the screw compressor motors with higher efficiency motors to lessen the amount of electricity consumed by the motors. The compressors are often left idling during lunch. The compressors should be turned off manually or a sensor installed that would shut the compressor off after a determined amount of time has elapsed.

3.4.5 Office Equipment

Neither Plant I or Plant II have any office equipment.

3.4.6 Electricity Use at Night

The utility that serves Maugus, Pennsylvania Power & Light (PP&L), supplied Maugus with a strip chart of their power consumption. The chart covered from September 18, 1992 to October, 19 1992. The strip chart indicates the power consumption of both plants every 15 min for the entire period. The chart is not presented here due to its length, but clearly indicates that both plants consumed an average of 2 kw during the night and the weekends. Given that Plant I's average power consumption is about 73 kw and Plant II's average power consumption is about 110 kw this is not a significant amount. Since PP&L supplied the strip chart, the electrical load factor (ELF) and the occupancy load factor (OLF) were not examined.
3.4.7 Energy Management Systems

Neither of Maugus's plants have energy management systems. Infrared light management systems may be placed in the basement and storage areas of Plant II to minimize energy used for lighting in these spaces.

3.4.8 Pennsylvania Sales Tax Exemption on Electricity

To encourage manufacturing, the Pennsylvania Department of Revenue offers a sales tax exemption on all electricity directly used for manufacturing. This offering is not intended to save energy. In fact it is an incentive to consume more energy while paying less for that energy.

Manufacturing is defined to start as soon as raw materials are changed in form, phase, or chemical composition. The manufacturing process ends once the product has been packaged for end use. Any electricity used to handle the product once manufacturing has begun is exempt from sales tax. This includes electricity that may be used to transport the product from one machine to another. The exemption also applies to any equipment used to control a machine and maintain the quality of the product.

Any pollution control devices are exempt from sales tax. A pollution control device is anything that purifies outgoing air or water. If a machine, such as a fan, is simply used to move air or water outside the plant without purifying it then it is subject to sales tax.
Electricity used in the handling of raw materials or the packaged product is subject to sales tax. Any energy used for lighting, ventilation, and space heating and cooling are also subject to sales tax.

In order for Pennsylvania's Department of Revenue to accept the recommended sales tax exemption the facility must be able to provide a utility survey. A utility survey must be supplied for every meter where an exemption is being claimed. The utility survey should be done by an outside consulting firm, a plant engineer or someone who is qualified to conduct the survey.

The survey must include the name of the equipment to be exempt and a description of what it does. The power consumption per machine and the amount of time the machine is operating is to be included in the survey. The power consumed by the machines is then summed and divided by the total power consumption to arrive at the tax exempt percentage. Along with the survey, a copy of the canceled checks and utility bills to verify payment of the tax, and a description of the business operation should be sent. (10)

Currently both of the Maugus plants are 75% exempt. A survey was done to decide if this exemption was still valid. Table 3.3 and Table 3.4 are the surveys of Plant I and Plant II respectively. From these tables it was determined that Plant I should remain at 75% and Plant II should become 83% exempt. Increasing the exemption of Plant II from 75% to 83%
<table>
<thead>
<tr>
<th>Name</th>
<th>#Units</th>
<th>HP/Unit</th>
<th>Total HP</th>
<th>Total kw</th>
<th>Hrs/Yr</th>
<th>Kwh/Yr</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filler Head</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>0.75</td>
<td>1928</td>
<td>1446</td>
<td>Fills tube with brushes</td>
</tr>
<tr>
<td>Automatics</td>
<td>6</td>
<td>2</td>
<td>12</td>
<td>8.95</td>
<td>1928</td>
<td>17256</td>
<td>Forms tube and inserts brushes</td>
</tr>
<tr>
<td>Tuber</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.49</td>
<td>1200</td>
<td>1788</td>
<td>Forms brush tube</td>
</tr>
<tr>
<td>Solder Machine</td>
<td>6</td>
<td>0.5</td>
<td>3</td>
<td>2.24</td>
<td>2169</td>
<td>4859</td>
<td>Solders applicator to cap</td>
</tr>
<tr>
<td>Conveyor</td>
<td>5</td>
<td>0.25</td>
<td>1.25</td>
<td>0.93</td>
<td>1928</td>
<td>1793</td>
<td>Conveys product to box</td>
</tr>
<tr>
<td>Glass Rod Conveyor</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.37</td>
<td>32</td>
<td>12</td>
<td>Conveys rod caps to box</td>
</tr>
<tr>
<td>Glass Rod Machine</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.75</td>
<td>32</td>
<td>24</td>
<td>Press glass rod into caps</td>
</tr>
<tr>
<td>Shaver</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>0.75</td>
<td>1928</td>
<td>1446</td>
<td>Cuts brush to length</td>
</tr>
<tr>
<td>Brush Vacuum</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.75</td>
<td>1928</td>
<td>1446</td>
<td>Vacuums cuttings from shaver</td>
</tr>
<tr>
<td>Compressor</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>7.46</td>
<td>2290</td>
<td>17083</td>
<td>Expells parts from machines</td>
</tr>
<tr>
<td>Compressor</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>7.46</td>
<td>2290</td>
<td>17083</td>
<td>Expells parts from machines</td>
</tr>
<tr>
<td>Tin Cutter</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.75</td>
<td>192</td>
<td>144</td>
<td>Cuts tin sheets to size</td>
</tr>
<tr>
<td>Reducer</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>0.75</td>
<td>300</td>
<td>225</td>
<td>Reduces handle of brush</td>
</tr>
</tbody>
</table>

Table 3.3  Tax Exempt Electricity From Plant I.
<table>
<thead>
<tr>
<th>Name</th>
<th>#Units</th>
<th>HP/Unit</th>
<th>Total HP</th>
<th>Total kw</th>
<th>Hrs/Yr</th>
<th>kwh/Yr</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil Feeder</td>
<td>7</td>
<td>0.5</td>
<td>3.5</td>
<td>2.61</td>
<td>1928</td>
<td>5032</td>
<td>Feeds coils into machines</td>
</tr>
<tr>
<td>#7 Stake</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.37</td>
<td>160</td>
<td>59</td>
<td>Places cap on brush handle</td>
</tr>
<tr>
<td>Package Sealer</td>
<td>1</td>
<td>0.4</td>
<td>0.4</td>
<td>0.3</td>
<td>500</td>
<td>150</td>
<td>Seals brushes in plastic bags</td>
</tr>
<tr>
<td>Vibrating Feeder</td>
<td>6</td>
<td>0.16</td>
<td>0.96</td>
<td>0.72</td>
<td>129</td>
<td>93</td>
<td>Feeds caps into bowl feeder</td>
</tr>
<tr>
<td>Bowl Feeder</td>
<td>6</td>
<td>1</td>
<td>6</td>
<td>4.47</td>
<td>1928</td>
<td>8618</td>
<td>Orient caps for solder machine</td>
</tr>
<tr>
<td>Air Drier</td>
<td>1</td>
<td>1.85</td>
<td>1.85</td>
<td>1.38</td>
<td>2290</td>
<td>3160</td>
<td>Removes oil from air lines</td>
</tr>
</tbody>
</table>

Table 3.3 Continued.
<table>
<thead>
<tr>
<th>Name</th>
<th>#Units</th>
<th>HP/Unit</th>
<th>Total HP</th>
<th>Total kw</th>
<th>Hrs/Yr</th>
<th>Kwh/Yr</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chopper</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.75</td>
<td>384</td>
<td>288</td>
<td>Grinds waste plastic</td>
</tr>
<tr>
<td>Lg. Extruder</td>
<td>1</td>
<td>20</td>
<td>20</td>
<td>14.91</td>
<td>2169</td>
<td>32340</td>
<td>Extrudes plastic</td>
</tr>
<tr>
<td>Sm. Extruder</td>
<td>1</td>
<td>7.5</td>
<td>7.5</td>
<td>5.59</td>
<td>1085</td>
<td>6065</td>
<td>Extrudes plastic</td>
</tr>
<tr>
<td>Winder</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.12</td>
<td>1928</td>
<td>2159</td>
<td>Winds plastic sheet into coil</td>
</tr>
<tr>
<td>Winder</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.75</td>
<td>1928</td>
<td>1446</td>
<td>Winds plastic sheet into coil</td>
</tr>
<tr>
<td>Wick Cutter</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.75</td>
<td>482</td>
<td>362</td>
<td>Cuts air wick to length</td>
</tr>
<tr>
<td>Dauber</td>
<td>10</td>
<td>0.75</td>
<td>7.5</td>
<td>5.59</td>
<td>1928</td>
<td>10778</td>
<td>Attaches stem to applicator</td>
</tr>
<tr>
<td>Wick</td>
<td>1</td>
<td>0.75</td>
<td>0.75</td>
<td>0.56</td>
<td>88</td>
<td>49</td>
<td>Forms frame of applicator</td>
</tr>
<tr>
<td>DTU Brush</td>
<td>2</td>
<td>1.35</td>
<td>2.7</td>
<td>2.01</td>
<td>1928</td>
<td>3875</td>
<td>Inserts bursh into sleeve</td>
</tr>
<tr>
<td>Conveyor</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.37</td>
<td>1928</td>
<td>713</td>
<td>Transports applicator</td>
</tr>
<tr>
<td>DEB</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.75</td>
<td>1928</td>
<td>1446</td>
<td>Inserts applicator into cap</td>
</tr>
<tr>
<td>Hand Liner</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.37</td>
<td>1928</td>
<td>713</td>
<td>Orient cap caps</td>
</tr>
<tr>
<td>Liner Press</td>
<td>4</td>
<td>0.5</td>
<td>2</td>
<td>1.49</td>
<td>1928</td>
<td>2873</td>
<td>Press out cap liners</td>
</tr>
<tr>
<td>Wick Stitcher</td>
<td>1</td>
<td>0.25</td>
<td>0.25</td>
<td>0.19</td>
<td>1928</td>
<td>366</td>
<td>Stitches wick to frame</td>
</tr>
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</table>

Table 3.4 Tax Exempt Electricity From Plant II
<table>
<thead>
<tr>
<th>Name</th>
<th>#Units</th>
<th>HP/Unit</th>
<th>Total HP</th>
<th>Total kw</th>
<th>Hrs/Yr</th>
<th>Kwh/Yr</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto Cap Liner</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1.49</td>
<td>1928</td>
<td>2873</td>
<td>Stamps out cap liner</td>
</tr>
<tr>
<td>Dauber Pusher</td>
<td>2</td>
<td>0.75</td>
<td>1.5</td>
<td>1.12</td>
<td>1156</td>
<td>1295</td>
<td>Pushes dauber onto caps</td>
</tr>
<tr>
<td>Cap Pusher</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.37</td>
<td>1928</td>
<td>713</td>
<td>Pushes cap onto brush</td>
</tr>
<tr>
<td>Cap Threader</td>
<td>3</td>
<td>1.5</td>
<td>4.5</td>
<td>3.36</td>
<td>1928</td>
<td>6478</td>
<td>Threads cap</td>
</tr>
<tr>
<td>Blanking Press</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td>11.19</td>
<td>1928</td>
<td>21574</td>
<td>Punch out cap shells</td>
</tr>
<tr>
<td>Vibrating Feeder</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>0.75</td>
<td>1928</td>
<td>1446</td>
<td>Orient caps for threader</td>
</tr>
<tr>
<td>Press Feeder</td>
<td>3</td>
<td>0.25</td>
<td>0.75</td>
<td>0.56</td>
<td>1928</td>
<td>1080</td>
<td>Feeds metal into press</td>
</tr>
<tr>
<td>Cap Liner</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.49</td>
<td>384</td>
<td>572</td>
<td>Lines threaded caps</td>
</tr>
<tr>
<td>Compressor</td>
<td>2</td>
<td>30</td>
<td>60</td>
<td>44.74</td>
<td>2290</td>
<td>102455</td>
<td>Expells parts from machine</td>
</tr>
<tr>
<td>Lg Extruder B. Heater</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>4.47</td>
<td>535</td>
<td>2391</td>
<td>Melts plastic</td>
</tr>
<tr>
<td>Lg Extruder Die Heater</td>
<td>2</td>
<td>1.34</td>
<td>2.68</td>
<td>2</td>
<td>289</td>
<td>578</td>
<td>Prevents plastic from hardening</td>
</tr>
<tr>
<td>Lg Extruder Pen Heater</td>
<td>9</td>
<td>0.54</td>
<td>4.86</td>
<td>3.62</td>
<td>289</td>
<td>1046</td>
<td>Prevents plastic from hardening</td>
</tr>
</tbody>
</table>

Table 3.4 Continued
<table>
<thead>
<tr>
<th>Name</th>
<th>#Units</th>
<th>HP/Unit</th>
<th>Total HP</th>
<th>Total kw</th>
<th>Hrs/Yr</th>
<th>Kwh/Yr</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sm Extruder B Heater</td>
<td>3</td>
<td>1.05</td>
<td>3.15</td>
<td>2.35</td>
<td>267</td>
<td>627</td>
<td>Melts plastic</td>
</tr>
<tr>
<td>Sm Extruder Flange Heater</td>
<td>1</td>
<td>1.21</td>
<td>1.21</td>
<td>0.9</td>
<td>144</td>
<td>130</td>
<td>Prevents plastic from hardening</td>
</tr>
<tr>
<td>Sm Extruder Pen Heater</td>
<td>2</td>
<td>0.34</td>
<td>0.68</td>
<td>0.51</td>
<td>144</td>
<td>73</td>
<td>Prevents plastic from hardening</td>
</tr>
<tr>
<td>Air Drier</td>
<td>1</td>
<td>1.85</td>
<td>1.85</td>
<td>1.38</td>
<td>2290</td>
<td>3160</td>
<td>Removes oil from air lines</td>
</tr>
<tr>
<td>Large Chiller</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>3.73</td>
<td>2169</td>
<td>8090</td>
<td>Hardens plastic</td>
</tr>
<tr>
<td>Small Chiller</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.24</td>
<td>1085</td>
<td>2430</td>
<td>Hardens plastic</td>
</tr>
</tbody>
</table>

*Table 3.4 Continued*
would mean a yearly savings of $137.

The State of Pennsylvania allows a company to claim three years of back taxes if it can be determined that the company was taxed too much. In order to claim the back taxes the company must submit proof that the taxes have been paid. This is done by providing the Pennsylvania Department of Revenue with copies of the canceled checks and the electric bills indicating how much tax was paid for the period of the claim. The back taxes of Maugus's Plant II would amount to approximately $411 for three years.

3.4.9 The Plant I Power Spike

Maugus management was concerned about an electric power spike that Plant I is experiencing. They wanted to know how much the spike was costing them and how they could correct it. To examine the power spike a historical record of Plant I's power consumption was constructed. Figures 3.3 and 3.4 show the demand profiles of 100 hours for Plant I and Plant II respectively. This data was obtained through PP&L. Plant I has an operational load factor of 0.92 and Plant II has a load factor of 0.91. The operational load factor means that only the time the plant was operating was considered in calculating the load factor of the plant. This indicates that both plants are operating close to their maximum demand.

To estimate the cost of the spike, the maximum load of 85 kW was reduced to 77 kW. 77 kW is the average of the
Figure 3.3 Demand Profile of Plant I From 9/28/92-10/19/92.

Figure 3.4 Demand Profile of Plant II From 9/28/92-10/19/92.
remaining peak loads. If this reduction is made a savings of $788 a year can be made. This represents about 4.5% of Plant I's yearly electrical bill. Maugus had assumed that they were paying thousands of dollars for the spike. Once the cost of the spike was brought to their attention they were not as concerned about it.

The cause of the spike was addressed next. The spike generally occurs during the afternoon. However, it does not happen every day. Maugus does not do any special clean up procedures or specific operations that would cause an increase in demand.

Since the air compressors are the major load of the building with 10 hp and 20 hp motors, the spike is likely to originate from one of its air compressors. The rest of the motors for Plant I are less than 5 hp. Individually the smaller motors would not have much of an affect on the load profile of the plant and it is unlikely that they would surge simultaneously. Readings were taken from the compressors to isolate the spike. The readings indicated that one of the compressors was running for a longer period of time in the afternoon then it was in the morning. However, this only resulted in a 1.1 kW increase from the morning and is not enough to account for the spike which is approximately 7 kW. However, as stated earlier the spike does not occur every day. Further readings would be needed to verify the spike was originating from one of the compressors.
As an ideal case of eliminating the spike, a flat load profile of 23 kW was presented to Maugus. This flat 23 kW profile was obtained by averaging Plant I power consumption over a 24 hour period. This would result in a savings of $6,900 per year for Maugus. However, to achieve the savings Maugus would have to operate three shifts. Since Maugus would have to hire additional staff for the shifts, they determined that this scenario would not be feasible.

The use of a load limiter was also suggested to Maugus. A load limiter would shed certain loads once the power demand exceeded a specified level. Maugus did not like the idea of having some of their machines shut down in the middle of production.

Time-of-day metering was also looked into as a way of alleviating the cost of the spike. However, the spike is not predictable. It may well appear during the on peak hours and then Maugus would have to pay for both the time of day metering and the spike. Therefore, this was ruled out as an option.

3.5 The Maugus Utility Audit
3.5.1 The Boiler Audit

The heat for Plant II and the downstairs of Plant I is provided by boilers. Plant II has a high pressure line feed boiler and Plant I has a dual fire boiler. Both boilers are routinely maintained and are cleaned of scale and inspected at
least once a year. The heating for the upstairs of Plant I is provided by propane heaters. Propane is also used for the torches of the solder machines.

3.5.2 Air Compressor Audit

The electrical use by both plants is dominated by the screw compressors. The compressors of Plant I and II represent 47% and 45% of the electrical load.

The compressors of both plants are fitted with louvered ducts to draw air from the outside or the inside, whichever is cooler. Cooler air is denser than warmer air. The denser the intake air the less work the compressor has to do. During the winter the exhaust air is vented inside the building and is used for heat. During the summer the exhaust air is vented outside.

Maugus has had problems with loss of air pressure in the compressor tanks over night. The valves leading from the compressor should be turned off to prevent air from escaping through the lines and through the machines themselves. The valve should also be inspected to insure that it is sealed properly.

3.6 Energy Consumption Profile

Maugus consumes electricity, natural gas, propane, and fuel oil #2. Graphs detailing the amount of energy consumed and how that energy is used can be found in Appendix A.
The propane torches of the solder machines in Plant I are left on during the lunch break. It was suggested that the torches should be turned off during this time. However, the time taken to relight and adjust the torches would be too time consuming. The only means Maugus has of monitoring the propane used are the billing statements. They do not have a means of determining the amount of propane used from hour to hour. Therefore, a cost estimate could not be done.

3.7 Cogeneration Feasibility

One way in which cogeneration can be feasible is if the facility produces a waste product that could be used as a fuel or generate enough waste heat that could drive a cogeneration unit. Maugus does not produce any substantial amount of waste product that could be used as a fuel.

The only major source of heat at Maugus is given off by the screw compressors. The heat from the screw compressors is approximately 190° F. There is one in both of Maugus's plants. During the heating season the heat from the compressors is vented into the plant. During the summer months the heat is vented outside. The heat given off by the compressors is not enough to run a cogeneration unit.

Another possibility for cogeneration would be if the facility had a need for the heat that would be produced by a cogeneration unit. However, Maugus's heating needs are for space heating only, which is seasonal. In order for
cogeneration to be economical Maugus would have to have a continual demand year round for the heat produced. Due to the lack of needed heat and waste fuel, cogeneration is not a viable option for Maugus.

3.8 Result of Energy Audit

Overall Maugus uses its energy quite well. There are a few improvements, however, that were suggested to them. Most of the energy savings are associated with Plant I. If Maugus can repair the leaks in the compressed air line system and install a motor shut off sensor the estimated annual savings is $514. This represents 3% of Maugus' electrical bill for Plant I. This figure is probably higher because it only accounts for the time the compressor is needlessly running. The compressed air line system is constantly losing air throughout the day that the compressor must make up. If the power spike of Plant I could be removed it would represent a savings of $788 a year, which is 4% of Maugus' annual electric bill for Plant I.

The only means of saving on energy costs for Plant II was the Pennsylvania sales tax exemption on electricity used for manufacturing. Plant II is currently at 75% exempt and can be upgraded to 83% exempt. This would be a savings of $137 annually. Maugus can also claim the back taxes it has paid for the last three years, which amounts to $411.

The compressors are generally left on during the 30
minute lunch breaks. A motor sensor should be installed on
the compressors to turn them off when the compressors have
been idling for a set period of time. Overnight the
compressors lose much of their pressure. In the mornings they
have to be turned on 15 minutes before operations start to
build up to 100 psi. Since this is the major load of the
plants, anything that can be done to reduce their operating
time would be beneficial. The compressors should certainly be
turned off during lunch time. Also, the compressor lines,
joints, and valves should be inspected for air leaks and
repaired. 45 minutes a day amounts to the compressors running
a total of 180 hrs/yr. The cost of running those compressors
for that amount of time is approximately $514 per year.
Chapter 4
Conclusions

An easy to use generic manual has been created to allow small manufacturing companies to perform their own energy audits with in-house personnel. The manual was then applied to Maugus Manufacturing Company in Lancaster, Pennsylvania.

Some of the ideas presented in the manual were not able to help Maugus but, they were able to take advantage of a few of them. The most important item is their compressors. The compressors by far are the largest load of the both plants. By repairing the leaks in their compressor network and by minimizing the amount of time the compressors are running Maugus will be able to save approximately $500 a year.

Though the manual was tested at Maugus Manufacturing, it is generic enough to be used for a wide variety of small companies. An improvement to the manual would be to discuss types of equipment that could be used for conducting an audit. Examples of audit equipment might be infrared scanners to detect cold spots in the walls and the ceiling, building compression tests to identify all the points of air infiltration, and pitot tubes to measure the velocity of air in a duct. However, these items will add a significant cost to the energy audit performed.
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Appendix A

Energy Consumption Graphs of Maugus Company's Plant I and II

Figure A1  Fuel Cost of Plant I.

Figure A2  Fuel Cost of Plant II.
Figure A3  BTU Energy Distribution of Plant I.

Figure A4  BTU Energy Distribution of Plant II.
Figure A5  Electric Distribution of Plant I.

Figure A6  Electric Distribution of Plant II.
**Figure A7** kWh Consumption of Plant I. 1992 vs 1993.

**Figure A8** kWh Consumption of Plant II. 1992 vs 1993.
Figure A9 kW Consumption of Plant I. 1992 vs 1993.

Figure A10 kW Consumption of Plant II. 1992 vs 1993.
**Figure A11** Natural Gas Consumption of Plant I. 1992 vs 1993.

**Figure A12** Natural Gas Consumption of Plant II. 1992 vs 1993.
Figure A13 Propane Used for Heat at Plant I. 1992 vs 1993.

Figure A14 Propane Used for Manufacturing at Plant I. 1992 vs 1993.
Figure A15 Water Consumption of Plant I. 1992 vs 1993.

Figure A16 Water Consumption of Plant II. 1992 vs 1993.
Figure A17  Fuel Oil #2 Consumption of Plant I. 1992 vs 1993.
Appendix B

Description of How Figure 2.9 and Table 2.1 Were Generated

B.1 Figure 2.9 Compressed Air Line Loss

The two equations that govern the flow of fluids are Bernoulli's equation and the conservation of mass flow equation. Bernoulli's equation is given below. (49,387)

\[ P_1 + p_1gy_1 + \frac{1}{2} p_1 v_1^2 = P_2 + p_2gy_2 + \frac{1}{2} p_2 v_2^2 \] \hspace{1cm} (B1)

The subscripts 1 and 2 indicate the inlet and outlet conditions. \( P \) is the pressure measured in Pascals (Pa). \( p \) is the density of the fluid measured in kg/m\(^3\). \( g \) is the gravity of the earth. \( v \) is the velocity of the fluid measured in m/s.

The mass flow rate equation is given below. (49,385)

\[ \Delta m = p_1 v_1 A_1 = p_2 v_2 A_2 \] \hspace{1cm} (B2)

Again, the subscripts 1 and 2 are the inlet and outlet conditions. \( p \) and \( v \) are the same as in Equation B1. \( A \) is the area that the fluid is flowing through and is measured in m\(^2\). \( \Delta m \) is the mass flow rate measured in kg/m.

These two equations were used to create Figure 2.9. The method of creating the graph follows. A compressed air line has a hole in the line of known area. It is desired to know how much air is flowing through the hole. The compressor tank has a volume of 100 gallons, which is equal to 0.378m\(^3\).

In Equation B1, \( g \), the force of gravity, can be neglected.
since its effect on air is quite small. This results in the following equation.

\[ P_1 + \frac{1}{2} P_1 v_1^2 = P_2 + \frac{1}{2} P_2 v_2^2 \] (B3)

Assuming that the diameter of the hole is the same on the inside of the line as it is on the outside, the area terms in Equation B2 can be cancelled, leaving:

\[ P_1 v_1 = P_2 v_2 \] (B4)

The velocity of the air coming out of the line \((v_2)\) is to be solved for. Substituting Equation B4 into Equation B3 and rearranging the terms yields:

\[ v_2 = \sqrt{\frac{2P_1 (P_1 - P_2)}{P_2 (P_1 - P_2)}} \] (B5)

\(P_1\) is the pressure inside the tank. \(P_2\) is the atmospheric pressure. And \(p_2\) is the density of air at atmospheric conditions, which is 1.293 kg/m\(^3\). This leaves \(p_2\) to be found. It is found from the equation below.

\[ p = \frac{MP}{RT} \] (B6)

\(p\) and \(P\) are the same as in Equation B1. \(T\) is the temperature measured in Kelvins. \(R\) is the Ideal Gas Constant, which is 8.314 J/mol K. \(M\) is the molecular mass. For air \(M\) is 29 x 10\(^{-3}\) kg/mol. (49,378)

Equation B7 is used to find the temperature of the air inside the tank.
\[ T_1 V_1^{\gamma - 1} = T_2 V_2^{\gamma - 1} \] \hspace{1cm} (B7)

V is the volume of the air at inlet and outlet conditions measured in m³. \( \gamma \) is the ratio of heat capacities for the gas. For air \( \gamma \) is 1.4.

Rearranging terms and solving for \( T_1 \), Equation B8 is arrived at.

\[ T_1 = \frac{T_2 V_2^{\gamma - 1}}{V_1^{\gamma - 1}} \] \hspace{1cm} (B8)

Once the temperature is known the density of the gas can be determined and the velocity of the air escaping from the hole can be found and from this the mass flow rate of air can be found. (49,511)

B.2 Table 2.1 power factor correction table

The average power of a single phase ac load is given by Equation B9. (50,427)

\[ P = V_{\text{rms}} I_{\text{rms}} \cos(\theta v - \theta i) \] \hspace{1cm} (B9)

\( \theta v \) is the voltage angle measured in degrees and \( \theta i \) is the current angle measured in degrees. The difference in the angles is called the power factor angle. The cosine of this difference is called the power factor. When \( \theta v \) and \( \theta i \) are equal the difference is zero. This corresponds to a power factor of one and therefore, according to Equation B9 the maximum amount of power is delivered.
If the power factor angle is in between -90 and 0 degrees the load is capacitive. When it is between 0 and 90 degrees the load is inductive. Since cos(θ) = cos(-θ) a means of distinguishing the two is needed. A capacitive load is said to be leading and an inductive load is said to be lagging.

As θv and θi move out of phase with one another the power factor starts to approach zero. This limits the amount of power that can be used. The example below illustrates the affect power factor can have.

Assume a load consumes 88 kW at a power factor of 0.707 lagging. The line voltage is 480 Vrms and the transmission line resistance is 0.08 Ω. Figure B1 is a diagram of the circuit. (50,428)

To see the effect power factor has on the circuit the power supplied by the utility (Ps) will be calculated for a 0.707 lagging PF and then calculated for a 0.90 lagging PF.

\[ I_{\text{rms}} = \frac{P}{(\text{PF})V_{\text{rms}}} \]

\[ I_{\text{rms}} = \frac{88 \times 10^3}{0.707 \times (480)} \]

**Figure B1** Circuit for Examining the Effect of Power Factor.
The power that the utility must supply is then:

\[ P_{s} = P + R I_{\text{rms}}^2 \]

\[ P_{s} = 88 \times 10^3 + 0.08(259.3)^2 \]

\[ P_{s} = 93.38 \text{ kW} \]

Increasing the PF to 0.90 causes the current and power to be:

\[ I_{\text{rms}} = 203.7 \text{ A} \]

\[ P_{s} = 91.32 \text{ kW} \]

In the first case the utility has to generate 93.38 kW to supply the load with 88 kW. By increasing the PF to 0.90 lagging, the utility has to generate 91.32 kW to supply the same amount of power.

The increased PF causes the transmission line current to be reduced. This lowers the amount of power lost due to \( I^2R \) line losses. This power is lost to the utility. Therefore, it would be beneficial to them for the load to have a PF as close to one as possible.

As a means of increasing PF a capacitor bank can be added in parallel with the load, as shown in Figure B2. Most industrial loads are inductive. Adding a capacitive load \( Z_c \) to the circuit will help to balance the reactive power seen at the load and cause the net voltage and current angles to be
more in phase with each other.

The amount of capacitance added will depend on the amount of VARs needed to bring the PF to a desired level. VAR is the unit for reactive power. Reactive power is present whenever there is an inductance or a capacitance in a circuit. Equation B10 is used to find the necessary VARs. (50,435)

\[
Q = P \left( \tan(\arccos \theta_d) - \tan(\arccos \theta_a) \right) \quad \text{(B10)}
\]

Where \( \theta_d \) and \( \theta_a \) are the desired and actual PF. \( P \) is the power consumed by the load measured in kW. Equation B10 was used to create Table 2.1.

B.3 Columbus Southern Power Billing Practice As Applied To Maugus Manufacturing Company

![Circuit Diagram](image)

**Figure B2** Circuit With Capacitance to Correct Power Factor.

As seen in section 4.5 Pennsylvania Power & Light does not impose a penalty for having a low power factor. Therefore, Maugus has no incentive to raise their power factor. A hypothetical example is given to show the financial impact a low power factor may have. Assume that Maugus is in
Columbus Southern Power's (CSP) service area. CSP is an electric utility in south eastern Ohio. CSP imposes an excess kva charge. kva is the apparent power delivered to the load. The power factor of the plant and the apparent power are related by the equation:

\[ PF = \frac{P}{S} \quad \text{(B11)} \]

Where PF is the power factor. P is the demand power in kW and S is the apparent power in kva.

The same demand kW and kWh used in Table 3.3 for Plant I will be used in the example. According to CSP's GS3 rate, the demand charge is $12.629/kW. The energy charge is $0.01231/kWh. The excess kva charge is $0.907/kva. The load is considered to have excess kva if the inverse of the power factor is greater than 1.15. This corresponds to a power factor of 87%. (51)

Plant I has a demand of 85 kW and consumes 14880 kWh. The power factor of Plant I is 72% lagging. Under these conditions Plant I would have to pay $18.50/month more than if it could operate at a power factor of 87%. This represents 1.5% of the base charge. This is not a significant amount of the total electric bill. The calculations for arriving at these figures are given in Table B1.
<table>
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<tr>
<th>Category</th>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Charge</td>
<td>85 kW * $12.629/kW</td>
<td>$1,073.46</td>
</tr>
<tr>
<td>Energy Charge</td>
<td>14880 kWh * $0.01231/kWh</td>
<td>$183.17</td>
</tr>
<tr>
<td>Excess kVA</td>
<td>1/PF = 1/.72 = 1.39 &gt; 1.15</td>
<td></td>
</tr>
<tr>
<td>Plant kVA</td>
<td>85 kW * 1.39</td>
<td>118.15 kVA</td>
</tr>
<tr>
<td>Allowed kVA</td>
<td>85 kW * 1.15</td>
<td>97.75 kVA</td>
</tr>
<tr>
<td>Excess kVA</td>
<td>118.15 kVA - 97.75 kVA</td>
<td>20.40 kVA</td>
</tr>
<tr>
<td>Excess kVA Charge</td>
<td>20.40 kVA * $0.907 kVA</td>
<td>$18.50</td>
</tr>
<tr>
<td>Total Base Charge</td>
<td></td>
<td>$1275.13</td>
</tr>
</tbody>
</table>

**Table B1**  Example Billing of CSP's GS3 Rate.