Section 14: Electrical Energy Management
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Introduction
Electricity is a powerful form of energy that is essential to the operation of virtually every facility in the world. It is also an expensive form of energy that can represent a significant portion of a manufacturing facility's cost of production.

This energy management primer is intended to introduce some electricity billing fundamentals, especially focusing on the two major aspects of the electric bill, demand and energy. This section also highlights key aspects of identifying energy-saving opportunities among major industrial processes and equipment.

Electricity billing basics
Most electric utilities serve a designated geographic territory, largely without other competitors having access to their customers. As such, utility prices have often been set by local, state, or federal regulators, entities that review electric utility costs, revenues, investment decisions, fuel prices, and other factors to arrive at a target rate of return. This approved rate of return, coupled with the utility’s cost structure, determine prices customers will pay.

These prices are established in electric utility tariffs, or rate schedules. Rate tariffs are usually established for different classes or sizes of customers. Common class types may include industrial, commercial, residential, municipal, and agricultural. Each customer class may have one or more rate schedules available, and it is common for the electric utility to allow a facility to choose the rate schedule within its class that offers the lowest price.

- **Electricity metering**: Electric utilities meter both the real and reactive power consumption of a facility. The real power consumption, and its integral – energy, usually comprise the largest portion of the electric bill. Reactive power requirements, usually expressed in power factor, can also be a significant cost and will be discussed later.

- **Demand**: Real power consumption, typically expressed in kilowatts or megawatts, varies instantaneously over the course of a day as facility loads change. While instantaneous power fluctuations can be significant, electric utilities have found that average power consumption over a time interval of 15, 30, or 60 minutes is a better indicator of the “demand” on electrical distribution equipment.

Transformers, for example, can be selected based on average power requirements of the load. Short-duration fluctuations in load current may cause corresponding drops in load voltage, but these drops are within the normal operating tolerances of typical machines and within the design parameters of the transformer.

The demand rate, in $/kW, may also be referred to as a capacity charge, since it has historically been related to the necessary construction of new generating stations, transmission lines, and other utility capital projects. Demand charges often represent 40% or more of an industrial customer’s monthly bill.
Energy: The other major component of an electric bill is energy. The same metering equipment that measures power demand also records customer energy consumption. Energy consumption is reported in kilowatt-hours or megawatt-hours. Unlike power demand with its capacity relationship, customer energy consumption is sometimes related to fuel requirements in electric utility generating stations. The cost per kilowatt-hour in a given electric utility rate structure, therefore, is often influenced by the mix of generating plant types in the utility system. Coal, fuel oil, natural gas, hydroelectric, and nuclear are typical fuel sources on which power generation is based.

Load factor – Demand/energy relationship: One useful parameter to calculate each month is the ratio of the average demand to the peak demand. This unit-less number is a useful parameter that tracks the effectiveness of demand management techniques. A load factor of 100% means that the facility operated at the same demand the entire month, a so-called “flat” profile. This type of usage results in the lowest unit cost of electricity.

Few facilities operate at a load factor of 100%, and that is not likely to represent an economical goal for most facilities. But a facility can calculate its historical load factor, and seek to improve it by reducing usage at peak times, moving batch processes to times of lower demand, and so forth. Load factor can be calculated from values reported on practically every electric bill:

\[ LF = \frac{kWh}{(kW \times \text{days} \times 24)} \]

Where LF is Load Factor, kWh is the total energy consumption for the billing period, kW is the peak demand set during the billing period, and days is the number of billing days in the month (typically 28-32). “24,” of course is the number of hours in a day.

Time-of-Use customers may prefer to track load factor only during on-peak time periods. In that case, the kWh, kW, days, and hours/day in the formula are changed to reflect the parameters established only during the on-peak periods.

Typical load factor for an industrial facility depends to a great degree on the number of shifts the plant operates. One shift, five-day operations typical record a load factor of 20-30%, while two-shifts yield 40-50%, and three shift, 24/7 facilities may reach load factors of 70-90%.
Power factor: The relationship of real, reactive, and total power has been introduced previously, and described as the “power triangle.” For effective electricity cost reduction, it is important to understand how the customer’s electric utility recoups its costs associated with reactive power requirements of its system. Many utilities include power factor billing provisions in rate schedules, either directly in the form of penalties, or indirectly in the form of real-power billing demand that is higher than the actual measured peak.

Even if a utility does not charge directly for poor power factor, there are at least three other reasons that a customer may find it economical to install equipment to improve power factor within its facility, thereby reducing the reactive power requirements of the utility. PowerLogic Solutions, volume 1, issue 4 (www.powerlogic.com) describes each of these cost-reduction opportunities in considerable detail.

- Reduce power factor penalties
- Release capacity of an existing circuit
- Reduce heating losses associated with power distribution (often called I2R losses)
- Improve voltage regulation

Graphical comparison of facilities with dramatically different load factors. The three shift facility produces an average demand that is nearly equal to its peak demand, while the average and peak demand for the one shift facility is much less than one.

<table>
<thead>
<tr>
<th>Load Factor:</th>
<th>30%</th>
<th>50%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Demand, kW</td>
<td>1142</td>
<td>685</td>
<td>489</td>
</tr>
<tr>
<td>Energy Usage, kWh</td>
<td>250,000</td>
<td>250,000</td>
<td>250,000</td>
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<tr>
<td>Demand Cost</td>
<td>$11,420</td>
<td>$6,850</td>
<td>$4,890</td>
</tr>
<tr>
<td>Energy Cost</td>
<td>$10,000</td>
<td>$10,000</td>
<td>$10,000</td>
</tr>
<tr>
<td>Total Monthly Bill</td>
<td>$21,420</td>
<td>$16,850</td>
<td>$14,890</td>
</tr>
<tr>
<td>Average Cost/kWh</td>
<td>8.57</td>
<td>6.74</td>
<td>5.96</td>
</tr>
<tr>
<td>Demand Cost As Percent of Total</td>
<td>53%</td>
<td>41%</td>
<td>33%</td>
</tr>
</tbody>
</table>

Fixed Capacitors are best suited for use on electrical systems with no voltage or current harmonics.
**Typical energy auditing process:**
- Evaluate the current rate schedule
- Determine if other rate schedules are available
- Complete the Facility Energy Profile
- Assess no-cost/low-cost energy saving options
- Complete feasibility analysis of energy management project options
- Recommend Energy Action Plan

**Facility energy profile – Where’s the energy going?**

An important initial step in evaluating energy saving opportunities is to estimate both:

- The contribution to peak billing demand, and
- The amount of energy consumption

Of each major load or process within the facility being evaluated.

This Facility Energy Profile helps to focus the energy optimization efforts on those processes or loads that have the most savings potential. This Profile also may identify batch processes or discretionary loads that may be scheduled at times of low demand for the rest of the facility, or during times of off-peak utility prices.

![Graph showing energy consumption by category]

The Facility Energy Profile identifies the major energy consuming processes and equipment in the facility.

The FEP is best developed using actual power measurements from existing facility-wide monitoring systems. Some types of loads, lighting, for instance, may comprise part of the usage of every major circuit in the facility. This fact would suggest that the meter measuring the power consumption of a feeder serving the building’s centrifugal water chillers.

![Diagram showing circuit monitors and power consumption]

Actual power monitoring data from existing circuit monitors measuring the power consumption of individual feeders is the best basis for establishing the Facility Energy Profile.
Demand analysis techniques

Demand analysis is the methodology used to determine if there are opportunities for a given facility to reduce peak demand charges. Demand analysis involves manipulation of historical demand interval data to determine which major processes or loads are operating at times of highest demand; how “steep” or “flat” the facility’s load profile appears; and what times of day these peaks are occurring. Armed with this information, the energy auditor can better evaluate the potential for a variety of demand reduction techniques.

<table>
<thead>
<tr>
<th>July</th>
<th>August</th>
<th>Sept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date/Time</td>
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<td>Date/Time</td>
</tr>
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<td>8/28/03 13:15</td>
</tr>
<tr>
<td>7/18/03 13:30</td>
<td>2,260.90</td>
<td>8/28/03 11:15</td>
</tr>
<tr>
<td>7/20/03 13:15</td>
<td>2,242.40</td>
<td>8/28/03 11:00</td>
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<tr>
<td>7/31/03 11:15</td>
<td>2,221.56</td>
<td>8/28/03 11:30</td>
</tr>
</tbody>
</table>

The demand sort is produced by rearranging individual integrated demand readings for a given billing period. Meters record demand readings chronologically, 3000 or so readings for a 30-day billing period at 15-minute demand intervals; the demand sort utilizes a software tool to distribute the readings from highest to lowest, so that times and values of peak usage are easily analyzed.

<table>
<thead>
<tr>
<th>kW</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
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<td>2200</td>
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</tbody>
</table>

The demand sort table facilitates demand analysis by depicting the number of intervals (or hours) during which the plant’s peak electrical demand exceeded certain levels.

Using the demand sort table, the engineer is able to determine that a reduction in peak demand to 2200 kW at this example facility would have required a demand reduction of 122 kW for 25 15-minute intervals, or 6.25 hours, in August of the sample year.
Demand controls systems are available that perform these basic functions:

- Measure power consumption (demand) in real time
- Predict demand level based on rate of instantaneous usage
- Compare predicted value to target setpoint
- Transmit signals to pre-determined equipment to turn off or curtail power usage if demand is predicted to exceed target kW

These demand controls systems are intended to reduce peak demand for a facility to some predetermined level.

The design engineer’s foremost demand control system challenge is to identify loads in the facility that can be controlled effectively. Ideal load candidates includes those machines or processes that are (1) currently contributing to the facility’s load at peak times, and (2) whose function can be delayed or curtailed at times of peak.

Most facilities lack equipment or processes that fit this ideal description, despite the numerous machines and processes that may be operating at peak times. In fact, successful demand control is usually the exception rather than the rule.

One common candidate for the demand control system is the air conditioning system. Buildings equipped with multiple packaged direct-expansion air conditioning systems are typical targets of demand control sales efforts. Unfortunately, demand control of air conditioning compressors usually leads to loss of temperature or humidity control within the conditioned space, or lack of demand savings.

The reason for this paradox is twofold. One, natural diversity among multiple air conditioning compressors ensures that all compressors are not operating at full load at the same time. Strangely, this fact is often highlighted in the demand control system sales pitch: “Not all compressors are running at the same time, so you should turn some off for short periods of time.”

Secondly, basic thermodynamic principles of moist air and vapor-compression refrigeration systems require compressor power consumption to reduce air temperature and condense moisture. This process is controlled by thermostats and humidistats within the facility. When cooling or dehumidification is removed or reduced at times when these devices are “calling for” them, temperature and humidity will rise in the conditioned space.

So, if not air conditioning equipment, what loads have been successful demand control candidates? An electrolysis process providing chemicals for a paper mill was able to reduce peak demand and flatten the demand profile for the overall facility. A battery-charging system for forklift vehicles in an automotive facility was
capable of producing real demand savings during peak times. Finally, a large induction furnace melting scrap metal proved to be an effective candidate for the rolling mill at a steel plant.

![Graph showing chilled water supply and return temperatures increase over the course of a day due to demand control of inlet guide vanes on a centrifugal water chiller. Space conditions could not be maintained as a result of the demand control.]

**Peak shaving with onsite generators**

How, the engineer might ask, can a facility save money by burning fossil fuel in an onsite generator at a unit cost of 12¢/kWh, when the average unit cost of utility purchased power is 8¢/kWh? Very carefully, is the expected—and accurate—response.

The key to economical peak shaving is to understand and optimize the demand savings associated with generator operation. That is, the onsite generator must be operated the absolute minimum time necessary to reduce peak demand the maximum amount. Because the overall average unit price of electricity is not necessarily equivalent to the effective price of electricity at the plant’s peak.

For example, the facility that pays an overall average unit price of 8¢/kWh probably pays only about 3-4¢/kWh for actual energy consumption, yet an additional $10-$20/kW for demand. At the end of the month, the total billing amount divided by the total kWh usage might yield 8¢/kWh average, but the actual cost of power at its peak—when demand charges are included—may equate to an effective unit price of 20¢/kWh or higher. For the facility with a sharp demand peak, when the peak for the month is set in a few hours or less and the remainder of the time demand is low, peak-shaving at 12¢/kWh can be preferable to paying 20¢/kWh.

**Costs of generated power:** Onsite generators typically utilize natural gas, wood, fuel oil, or steam derived from a fossil fuel or as a part of a production process. Unit fuel costs for fossil fuels are usually calculated based on the fuel’s heating value, an estimated efficiency of the generator system, and the fuel cost.

\[
\text{Cost/kWh} = \text{fuel price/gal} \times \frac{3413}{\text{HV}} \times \frac{1}{\text{efficiency}}
\]

In this equation, HV is the heating value of fuel oil in BTU/gal, and 3413 is the conversion from BTU to kWh. Internal combustion diesel generators typically range in efficiency from 25-30%.

For a typical example, #2 fuel oil may be burned in an IC engine. For a fuel-oil price of $2.00/gal, and a generator efficiency of 25%, the fuel cost/kWh is:

\[
\text{Cost/kWh} = \$2.00 \times \frac{3413}{108,000} \text{ BTU/gal}/0.25 \\
\text{Cost/kWh} = 25 \text{ c/kWh}
\]

Obviously, peak-shaving is much less attractive at a fuel cost of $2.00/gal, unless required generator operation can be predicted accurately and electricity charges are comparably high as well.

**Utility rates affecting peak-shaving generation:** Electric utility rates must be analyzed carefully prior to implementing peak shaving or cogeneration opportunities. Some utilities have special interconnection and protective relaying requirements to ensure that onsite generation does not pose a safety hazard for utility workers. In addition, many utility rate schedules impose standby charges for onsite generation.
These charges are intended to recoup the utility's investment in transformers and other equipment necessary to serve the facility's entire load when the onsite generation equipment is not operating. Without this standby equipment, utilities often reserve the right to replace service equipment with smaller facilities, at risk to the facility of overloading the smaller equipment when onsite generation is not operating.

Facilities with onsite generation may be able to operate this equipment to reduce purchased power requirements during periods of high demand, or high utility prices.

Savings – or losses – associated with operation of peak-shaving generators is dependent on fuel prices, on-peak electricity prices, the amount of time the generator has to operate for a given peak-reduction target, and, most importantly, the accuracy with which plant personnel can predict these variables.

Electricity generation and peak shaving can also be accomplished with steam cogeneration systems typical of paper mills, refineries, and other large industrial processes.


**Lighting control**

Lighting systems in industrial facilities can represent an attractive savings opportunity, especially if lighting systems have not been upgraded or maintained in the past five years. The most cost-effective approach for lighting energy savings is to address the following three issues, in order:

- Turn off lights during times when they are not needed
- Reduce light levels to match the requirements for the tasks being performed in the area
- Replace less efficient lamps, ballasts, or fixtures with more efficient sources

The second priority in lighting conservation involves light level reductions. The Illuminating Engineering Society of North America (www.iesna.org) has established recommended light levels for different types of work tasks and area usage types. In addition, it offers design guidance in laying out lighting systems, estimating light levels by zonal cavity and point-by-point lighting design methodologies.

These light level recommendations are typically described as ranges of footcandles, the footcandle being a quantity of light measured at a horizontal or vertical surface. Light output of a fixture is usually published in lumens. Many manufacturers of lamps and lighting systems offer software tools to aid in designing new systems, or in evaluating changes to existing systems.

### Some lighting essentials

- **Lighting controls work better than people**

  While “turn-off-the-light” programs have been widely utilized in all types of facilities, sophisticated lighting control systems have proven to be much more cost-effective. Certainly, it’s cheaper to have a worker turn off a light, but workers forget, workers may not have access to circuit breakers controlling large banks of industrial lighting fixtures, those same circuit breakers are not designed for daily operation as light switches, and so on.

  Lighting system controls that utilize microprocessors and specially-designed remote-operated circuit breakers are much more effective. These devices can be programmed to accommodate complicated shift configurations, including nights, weekends, and holidays. They also include simple over-ride features for temporary or unusual work schedules. In addition, these systems can be monitored and controlled remotely using standard web-browser software packages, and they can interface with other control devices such as motion sensors or photocells.

- **Light levels decline with age of the lighting system.**

  Several factors contribute to this decline. Lamps, including fluorescent and high-intensity discharge sources like high-pressure sodium and metal halide, experience Lamp Lumen Depreciation, or LLD. The LLD is typically less than 1.0, indicating that average lamp light output at some point in the future is less than light output of a new lamp.
Light levels are also adversely affect by dirt and the accumulation of dust on the light fixture. Luminaire Dirt Depreciation, or LDD, also a factor less than 1.0, is a function of the type of light fixture as well as the environment in which the fixture operates.

Ballast Factor, or BF, is yet another commonly used factor. BF is also a published value that is a function of the type of ballast used to control the arc characteristics of fluorescent and HID lighting systems.

The designer usually applies these factors to the rated light level output of a lighting system, in order to estimate the number of fixtures required to provide the desired light level – not at initial installation, rather at some designated point in the future. For example,

\[
\text{# fixtures} = \frac{\text{total required lumens}}{\text{initial lumens/fixture}} \times (LLD \times LDD \times BF).
\]

Lighting designers need to know the facility’s lamp replacement practices

Manufacturers publish the “rated life” expectancy of a given lamp. This value, usually given in thousands of hours, is not a guarantee that every lamp will extinguish at the same rated-life time. In fact, the “rated life” is a statistical value indicating the point at which half of the lamps of a representative sample will burn out. Some lamps will fail well shy of the rated life; others may last beyond the rated life.

The facility’s lamp replacement practices usually fall into one of two categories:

1. Replace individual lamps as they fail (“spot replacement”)
2. Replace all lamps at a predetermined point in time, even though many of those lamps are still burning (“group replacement”)

Group replacement runs counter to common sense for most people – if it ain’t broke, don’t fix it. That’s why spot replacement is the most common practice by far. There is, however, a sound reason for considering the group-replacement strategy: Economics.

If the lighting designer knows, for example, that a facility will adopt the practice of group replacement, the designer can utilize fewer light fixtures at the outset. That’s because the lamps replaced before their end of life produce considerably more lumens than those allowed to burn to failure. The designer can use a higher LLD in the initial light fixture calculations to achieve the same target footcandle level.

Fewer light fixtures means lower energy costs attributable to lighting, and less heat for the building’s air conditioning system. Labor costs have also been shown to be lower for group replacement as compared to spot replacement. Group replacement can be scheduled to occur during unoccupied times; set up and take down costs are reduced; the cost per lamp itself can be lower with large-quantity purchases.

**Electric motors**

Three-phase squirrel-cage induction motors comprise a considerable percentage of the electrical load in the United States. Design, operation, and maintenance of these machines is well described in other references; this document focuses on their energy efficiency aspects.

Induction motors typically range in full load efficiency from about 87% to 94%. This efficiency is very difficult to measure accurately in the field, requiring a dynamometer and other specialized equipment. Fortunately, energy saving projects associated with electric motors do not require actual efficiency of a given motor to be established.

One of the foremost opportunities for energy savings is to implement a program of replacing – rather than rewinding – induction motors at failure. Rewinding a damaged induction motor is a common practice in industry, but studies have proven that rewinding an induction motor drops its efficiency by a couple percentage points. Multiple rewinds can further reduce the efficiency of the rewound motor.

While a drop in efficiency from 89% to 88% seems insignificant, a quick estimate reveals that this reduction can be costly. A standard efficiency 20 hp motor operating 6000 hours annually, for example, costs about $7000 per
year to operate at an average electricity rate of 7 c/kWh. Once this motor fails, the least-cost option for returning it to service is typically rewinding.

The incremental cost of replacing this failed motor with an energy-efficient motor, however, is only $430. This amount assumes considers the rewound cost, and the labor necessary to perform the motor change-out, as sunk costs.

The annual energy savings associated with replacing the failed motor with an energy-efficient model, at a new efficiency of 92.9%, is approximately $510. The simple payback for the replacement, therefore, is less than one year.

Energy-efficient motor programs are applicable to any AC motor installations utilizing NEMA Design B induction motors. Since the programs are based on replacement at failure, the full savings potential is realized after three years or more.

<table>
<thead>
<tr>
<th>HP</th>
<th>Rewound Efficiency</th>
<th>Standard Efficiency</th>
<th>Energy Efficient Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69.7%</td>
<td>70.7%</td>
<td>82.6%</td>
</tr>
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<td>2</td>
<td>79.5%</td>
<td>80.5%</td>
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<tr>
<td>150</td>
<td>91.5%</td>
<td>92.5%</td>
<td>96.7%</td>
</tr>
</tbody>
</table>

Published efficiencies of typical rewound, standard, and energy-efficient three-phase induction motors.

Electric motors are efficient machines, even at partial load.

But power factor drops off sharply at half load.
Variable-speed drives

There are many devices used to provide AC motor control – starting, stopping, changing speed, varying torque, providing protection from voltage and current anomalies. This section will focus, however, on variable-frequency control devices designed to reduce energy consumption and improve operation of three-phase AC induction motors. See www.squared.com for technical publications that describe these devices in greater detail.

AC motor loads are typically grouped in four major categories:

<table>
<thead>
<tr>
<th>Type of Load</th>
<th>Typical Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable torque</td>
<td>Centrifugal pumps and fans</td>
</tr>
<tr>
<td>Constant torque</td>
<td>Reciprocating pumps, conveyors, hoists</td>
</tr>
<tr>
<td>Constant horsepower</td>
<td>Grinders</td>
</tr>
<tr>
<td>Impact</td>
<td>Punch press</td>
</tr>
</tbody>
</table>

Energy-saving opportunities commonly focus on the variable-torque category, because the energy saving potential is large even with small changes in pump or fan speed control.

This opportunity is driven by the power and speed characteristics of the variable-torque load. The capacity of a pump or fan is directly proportional to the speed. A change in speed of 10% yields a change in pump gpm or fan CFM of 10%.

Brake horsepower, however, is proportionally to the cube of the speed, meaning that a 10% reduction in pump or fan speed can yield a 27% reduction in power consumption.

In addition, pumps and fans are often controlled by mechanical devices in the fluid flow stream, such as dampers, control valves, and guide vanes. These devices are typically much less efficient means of varying pump volume or fan delivery than changing the speed of the pump or fan.

Since most pumps and fans are driven by fixed-speed electric motors, where speed of the driven load is determined by the number of motor poles, AC frequency, and motor slip, varying the speed of a motor requires an external device. This external device is commonly referred to as an adjustable-speed drive, variable-frequency drive, inverter, vector drive, or adjustable-frequency controller.

![Graph showing cubic relationship between torque and horsepower](graph.png)

*Variable-torque loads, such as centrifugal pumps and fans, exhibit a cubic relationship between brake horsepower and speed.*
Compressed air

Compressed air systems can consume a significant amount of electric energy in an industrial facility. Many textile, automotive, chemical, and petroleum facilities operate large, multi-stage air compressors driven by electric motors representing hundreds, thousands, or even ten-thousands of horsepower in capacity. One chemical plant providing raw materials for synthetic textile manufacturing operated one 22,000 hp, and two 8,000 hp compressors in a portion of its process.

While the 22,000 hp compressor is rare, significant energy reduction opportunities associated with compressed air are available.

\[ \omega_{\text{ESP}} = \rho \, V \, T_r \, C_r \left[ \left( \frac{P_{\text{out}}}{P_{\text{in}}} \right)^{\frac{k-1}{k}} - 1 \right] \]

*Power consumption of a typical air compressor is a function of the air volume required (V), the inlet air temperature (T<sub>in</sub>), and the required pressure rise (P<sub>out</sub>/P<sub>in</sub>).*

These opportunities may include:

- Reduce outlet pressure – compressor discharge pressure in some facilities is set too high. Since the pressure rise across a compressor is a key factor in its power consumption, reducing outlet pressure can offer significant savings. Some reasons for excessive pressure may be straightforward; eg, production equipment with lower requirements has replaced older machines without a corresponding reduction in compressed air setpoint. Other reasons may be more complex; eg, piping system losses or leaks may force higher setpoints at the compressors in order to provide adequate air pressure at production equipment.

- Reduce air volume (CFM) requirements – compressed air leaks usually offer the most attractive opportunity for reducing compressed air volume. Some facilities have ignored leaks to the point that one compressor is effectively operating 24/7 simply to serve air leaks.

- Reduce inlet temperature – warm air is less dense than cold air. As the compressed air work equation above indicates, reducing inlet air temperature can reduce the work associated with a compressor. The usual method of reducing air temperature is to provide outside air intakes for the compressor, rather than allowing the compressor to utilize air from a hot equipment room.

- Increase inlet pressure – it’s common to assume that inlet pressure to a compressor is fixed at atmospheric pressure, but this is a misconception. Air compressor inlet systems, especially air filters, need to be kept clean and free of obstructions. Pressure drop across dirty or blocked intakes serves to reduce the pressure at the compressor and increase power consumption.

*Multi-stage air compressors, equipped with inter- and after-coolers to optimize efficiency and provide heat recovery, are common in industrial facilities.*
Centrifugal water chillers

Centrifugal water chillers comprise a significant portion of industrial and large commercial electrical load. These machines are efficient, typically producing a cooling effect two-to-three times greater than the required energy input. Centrifugal water systems were the focus of chlorofluorocarbon (CFC) legislation in the 1980s that drove the replacement or reconditioning of many of these machines. Opportunities still exist, however, for chiller optimization.

One opportunity is to change the operational strategy of multiple chillers operating on a common chilled water header. Typically, these machines are staged so that none are loaded beyond about 80% of their rated capacity. This strategy developed as a result of the published part-load efficiencies of the machines, which tended to produce a U-shaped efficiency curve. The curve indicated that optimal efficiency was obtained at 60%-80% of full load.

Actual measurements in industrial facilities, however, suggest that the laboratory-based efficiency curve is not representative of plant conditions. Cooling load on a typical industrial water chiller system is often influenced by process changes that do not correspond to a linear change in condenser water temperature. The chiller efficiency, therefore, increases with increasing cooling load so that it reaches its optimum point at about full rated capacity.

Other successful strategies for chiller optimization include:

- Chilled water reset – this strategy involves increasing the chilled water supply temperature setpoint to match the requirements of the cooling load. Reset is often performed as part of the control routines in an automatic chiller controller. Chilled water reset can reduce compressor power consumption by 1.5%-2% per degree.

- Reduce condenser water temperature – similar to raising the chilled water setpoint, reducing the condenser water temperature serves to reduce the compressor power requirements. Condenser water temperature reduction of one degree can reduce compressor power consumption by 0.5%-1%.
Monitor and maintain chiller approach temperatures – chiller condensers and evaporators are shell-and-tube heat exchangers that require periodic maintenance to maintain optimum heat transfer characteristics. Since water travels through the condenser and evaporator tubes, solids have a tendency to accumulate on internal tube surfaces, requiring annual “rodding” to remove the scale and restore heat transfer coefficients.

Annual average readings of condenser approach temperature (difference in temperature between condenser water and refrigerant in shell-and-tube heat exchanger) gradually crept up from the initial design value of 6 F to nearly 15 F over three years.

Effect of Scale on Compressor Horsepower


Increase in condenser tube fouling can have a significant adverse effect on compressor power consumption.

Heating, ventilating, and air conditioning systems

HVAC systems should be the focus of a targeted energy study, with similar objectives as the lighting analysis:

- Turn off unnecessary HVAC equipment during unoccupied times
- Match HVAC operation, including temperature and humidity, to minimum occupancy requirements
- Replace inefficient HVAC systems and equipment with energy-saving alternatives

WAGES

WAGES is the acronym for the complete power and energy monitoring system in a typical industrial facility. Industrials are concerned about the costs of Water, Air (compressed), Gas (natural gas), Electricity, and Steam. These systems are often interrelated to the degree that reductions in one utility can increase usage in another. The power monitoring system used by industrials has to have the capability of monitoring each of these parameters accurately, and of posting this information in a common, preferably web-based, format for use by the local site and by remote engineers and managers.

Web-based power monitoring systems allows energy managers to monitor the results of their demand and energy reduction techniques through the internet, and facilitate identification of new opportunities.
Energy survey checklist

Lighting
1. Lighting operating more hours than needed?
   - Reduce operating hours with lighting control system.
2. Areas over lit for task performed?
   - Reduce light levels by disconnecting or replacing lamps or fixtures.
3. Incandescent or quartz lamps operating more than 2,000 hours per year?
   - Convert to fluorescent or other energy efficient source.
   - Convert to energy saving fluorescent, metal halide, or high-pressure sodium.
5. Standard fluorescent lamps operating one shift.
   - Convert to energy saving fluorescent lamps and ballasts.
6. Standard fluorescent lamps operating two or three shifts.
   - Convert to energy saving fluorescent lamps and ballasts.
7. Fluorescent at 18-feet or higher mounting heights.
   - Convert to high pressure sodium.
8. VHO fluorescent fixtures.
   - Convert to energy saving fluorescent, metal halide, or high-pressure sodium.
   - Replace with energy savings electronic ballasts at failure.

Induction motors
1. Motors operating 75%+ full load, more than 6,000 hours per year.
   - Replace with energy efficient motors at failure.
2. Standard V-belts on pumps or fans.
   - Convert to cog V-belts.
3. Fans or pumps that are throttled with dampers or control valves.
   - Consider variable speed drives.

Demand management
1. Sharp demand peaks of short duration (low load factor)?
   - Identify loads to shed or reschedule to off-peak.
2. Batch processes?
   - Shift to off-peak.
3. Consider Time-of-Use savings opportunities.

Exhaust, ventilation, and pneumatic conveying
1. Transport velocities or exhaust flows higher than minimum required?
   - Consider changing belts and sheaves to reduce air velocity.
2. Consider variable speed or inlet vane control.
3. Consider exhaust air heat recovery.
4. Make-up air properly provided for all exhaust?
5. Fume hoods designed to minimize exhaust?
6. Properly designed stack heads (no Chinese hats or caps on outlets)

**Fan-coil unit air handling units**
1. Consider air side economizers.
2. Considered chilled water reset.
3. Consider water side economizer.

**Centrifugal water chillers**
1. Multiple chillers operating on a common header.
   - Fully load one chiller before starting another.
2. Consider chilled water reset.
3. Consider water side economizer.
4. Consider variable speed chiller control (long hours at light loads).
5. Excessive approach temperatures – Check trends or design data.
   - Clean condenser and evaporator tubes.
6. Adding cooling load or chillers?
   - Consider thermal energy storage.

**Cooling towers**
1. Consider variable speed drives for fan motors.
2. Consider PVC fill to replace wood fill material.
3. Consider velocity recovery stacks.

**Boilers**
1. Stack gas temperature > 400 F? (Ideal temperature: 100 degrees plus saturation temperature of the steam)
   - Consider economizer to preheat feedwater or combustion air.
2. Manual or intermittent blowdown?
   - Consider automatic blowdown system.
3. Continuous blowdown?
   - Consider blowdown heat recovery system.
4. Excess air high or unburned combustibles?
   - Consider boiling tuning.
5. Large amounts of high pressure condensate?
   - Consider high pressure condensate receiver.
6. Increase amount of condensate returned.
8. Maintain steam traps.
Heat recovery
1. Waste water streams > 100°F?
   ◦ Consider heat exchanger and/or heat pump.
2. Waste air or gas stream > 300°F?
   ◦ Consider heat exchanger.

Cogeneration
1. Boiler rated pressure 100 psi greater than pressure required by process?
2. Concurrent steam and electrical demands?
   ◦ Consider back-pressure turbine.

Refrigeration
1. Consider hot gas heat recovery.
2. Consider thermal storage.

Compressed air
1. Provide additional small air compressor for loads.
2. Provide outside air intake.
3. Eliminate air leaks.