4 ELECTRICITY

4.1. ELECTRIC ENERGY

4.1.1. Definitions

In the following sections reference will be made to various terms; to enable a better understanding, the following identification is provided:

Ampere (Current): The ampere, the rate of flow of a unvarying electric current.

Coulomb (Quantity): The quantity of electricity conveyed by one ampere flowing for one second.

Farad (Capacitance): The farad is the electrostatic capacitance which will hold a charge at a pressure of one volt.

Joule (Energy): The joule is the energy conveyed by one watt during one second, the kilowatt hour (kWh) is one kilowatt hour flowing for one hour.

Voltage (Difference in Electrical Potential): The difference in electrical potential between two points in the circuit indicated the energy required to move charge from one point to another (1 Volt = 1 Joule/coulumb). One volt is required to produce one ampere in a resistance of one ohm. 1 kilovolt (kV) = 1,000 volts.

Volt - Ampere: The product of the rated load amperes and the rated range of regulation in kilovolts (kVA).

Watt (Power): The watt is the power generated by a steady current of one ampere at a pressure of one volt. The kilowatt (kW) = 1,000 watts. One horsepower = 746 watts.

4.1.2. Introduction

Listed below are five basic ways to reduce electric costs. Of these, only the first involves a reduction in energy consumption while the remainder detail some special situations not directly related to the quantity of electricity consumed but rather the cost of consumption.

1. Reduce Electrical Uses.
2. Power Factor Improvements.
3. Load Factor Improvements.
4. Electric Billing Verification.
5. Rate Structure Corrections.

4.1.3. Reduce Electrical Use

The detailed use of electricity will be discussed under the separate sections in this manual, but the conservation message can never be delivered too many times. Basically, electricity should be conserved, like any other resource, and not wasted, as in the simple but common example of lights or equipment consuming energy during periods when rooms remain unoccupied or production lines experience downtime. Corrective action requires cognizant, conscientious employees cooperating with energy-minded management to identify areas of waste and suggest conservation practices.

Distribution System

The electrical power distribution system, from the source to utilization points, consists of electric lines of varying sizes, switches and circuit breakers designed for maximum carrying capacity, transformers and protective equipment. As related to the total consumption at any industrial plant, this system usually involves losses of 3 percent or less. Consequently, rarely does any practical savings potential in transmission systems appear to warrant investment in conservation.

The voltage in an electric circuit will drop in proportion to the circuit resistance. Resistance varies with wire size, temperature and metallic material. Thus, as conductor losses increase, current necessary to deliver a given amount of power increases at any point in the circuit as power derives from the product of the voltage and current. This principle applies likewise to switches, circuit breakers, and protective equipment.

The question of energy conservation possibilities should be examined in relation to the individual components in the system. In the case of the transmission lines it can be shown that doubling the conductor sizes reduces resistance losses by 75 percent; however, usually savings do not justify the expense as conductor cost related to the total electric investment comes to about 10 percent. Because doubling the conductor sizes essentially doubles cost, the savings potential deserves little attention.

As previously mentioned, energy losses from switches, circuit breakers, and protective equipment also deserve minimal attention as replacement with more energy-efficient devices equalizes costs with benefits. However, in the case of defective contacts or other parts, malfunction may cause overheating and imminent failure of the part(s) causing an outage. Monitoring and inspection to diagnose abnormally high temperature operation of these items will help prevent costly power outages and subsequent downtime. Replacement with more energy efficient devices when failure occurs incrementally improves energy conservation with little or no expense over normal, less efficient practices. To sum up, the distribution system will offer few opportunities unless monitoring and replacement of parts before failure practices are observed saving on future electricity costs and preventing expensive downtime.

Transformers do represent an area of potential savings during the condition of lightly loaded equipment. Shrinking loads or incorrectly forecasted plant expansions often manifest themselves during transformer examination by the industrial assessor. Unloaded motors incur no-load losses continually, as do transformers, although newer model transformers adjust based upon loading conditions. Older transforms incur continual power losses on the basis of full-load rating, not that of the load served and the industrial assessor investigates the possibilities of redistributing existing loads to permit scrapping of under-loaded transformers. Implementation decisions must allow favorable comparison of the cost of both installing new connecting cables and disposal of existing equipment with power savings from the elimination of no-load transformer losses. For the case involving older transformers disposal cost should be compared with not removing the equipment, later removal and future growth of waste disposal costs, and the cost of emergency disposal if an explosion damages the transformer. Close examination of the materials within the transformers for hazardous and poisonous substances for inclusion in the energy conservation and pollution prevention write-up will help present the entire picture and consequence scenario to the client.

Use of Electricity in the Industry

Electrical energy use, commonly found in the following systems and operations, presents significant opportunities for exploration during the industrial assessment:

- Mixing operations
- Melting and refining metallic and non-metallic materials
- Holding molten material
- Material Transportation
- Cleaning and finishing (air compressors)
- Miscellaneous assembly equipment
- Computers and other controls
- Material handling
- Packaging operations
- Environmental controls
- Lighting
- Heating, Ventilation, and Air Conditioning

4.1.4. Power Factor

Power factor quantifies the reaction of alternating current (AC) electricity to various types of electrical loads. Inductive loads, as found in motors, drives and fluorescent lamp ballast, cause the voltage and current to shift out of phase. Electrical utilities must then supply additional power, measured in kilovolt-amps (kVA), to compensate for phase shifting. To see why, power must be examined as a combination of two individual elements. The total power requirement can be broken down into the resistive, also known as the real component, and reactive component. Useful work performance comes from the resistive component, measured in kilowatts (kW) by watt meter. The reactive component, measured in reactive kilovolt-amps (kVAR), represents current needed to produce the magnetic field for the operation of a motor, drive or other inductive device but performs no useful work, does not register on measurement equipment such as the watt meter. The reactive component significantly contributes to the undesirable heating of electrical generation and transmission equipment formulating real power losses to the utility.

Power factor derives from the ratio of real, usable power (kW), to apparent power (kVAR). During the industrial assessment recommendations toward reduction of the power factor in fact indicate reduction of reactive losses. To accomplish this goal, the industrial electricity user must increase the power factor to a value as close to unity as practical for the entire facility. The supplying utility should be consulted for the determination of the requisite amount of capacitance necessary for correction to the desired power factor. The number in the table is multiplied by the current demand (kW) to get the amount of capacitors (kVAR) needed to correct from the existing to the desired power factor. Mathematically, power factor is expressed as

$$PF = \frac{kW}{kVA}$$

Power factor can also be defined as the mathematical factor by which the apparent power is multiplied in order to obtain active power.

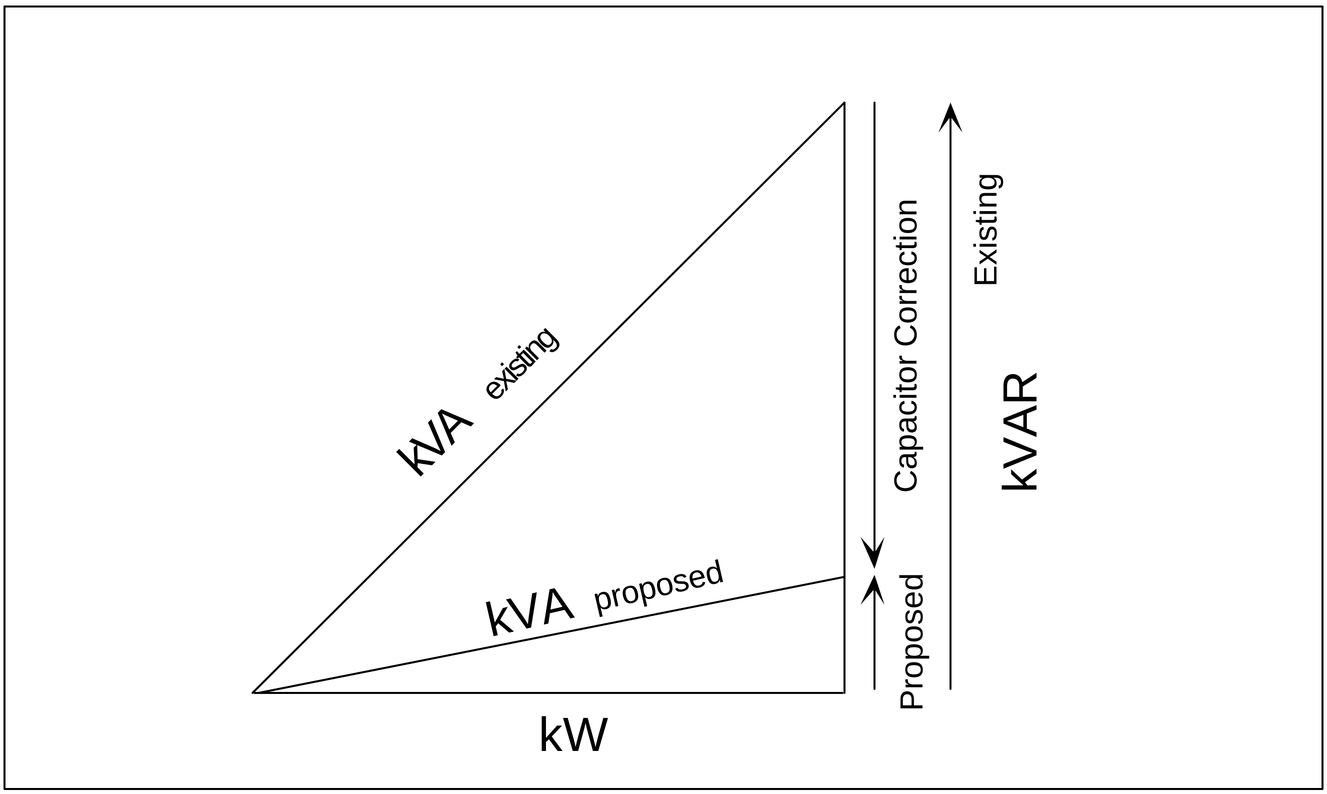


Figure 4.1: Components of Electrical Power

Example: Consider a 480 volt 3-phase system with an assumed load and instrument readings as follows: the ammeter indicates 200 amps and wattmeter reads 120 kW. The power factor of the load can be expressed as follows:

The apparent power for a 3-phase circuit is given by the expression

$$kVA = \frac{E \times I \times \sqrt{3}}{1000} = \frac{480 volts \times 20 amps \times 1.73}{1000} = 290.6 kVA$$

Therefore:

$$PF = \frac{kW}{kVA} = \frac{120}{290.6} = 41.2\%$$

From the above example it is apparent that by the decreasing power drawn from the line (kVA) the power factor can be increased.

Power Factor Improvement

Preventive measures involve selecting high-power-factor equipment. For example, when considering lighting, only high-power factor ballast should be used for fluorescent and high-intensity discharge (HID) lighting. Power factor of so-called normal-power factor ballast is notoriously low, on the order of 40 to 55 percent.

When induction motors are being selected, the manufacturer's motor data should be investigated to determine the motor power factor at full load. In the past few years, some motor manufacturers have introduced premium lines of high-efficiency, high-power-factor motors. In some cases, the savings on power factor alone can justify the premium prices charged for such motors. Motors should also be sized to operate as closely as possible to full load, because power factor of an induction motor suffers severely at light loads. Power factor decreases because the inductive component of current that provides the magnetizing force, necessary for motor operation, remain virtually constant from no load to full load, but the in-phase current component that actually delivers work varies almost directly with motor loading.

Corrective measures for poor power factor involve canceling the lagging current component with current that leads the applied voltage. This cancellation can be done with power-factor-improvement capacitors, or by using synchronous motors. Capacitors have the effect of absorbing reactive current on a one-to-one basis, because almost all of the current flowing through a capacitor leads the applied voltage by 90 degrees. A capacitor rated at 100 kilovolt-amperes capacitive (kVAC) will, therefore cancel 100 kilovolt-amperes reactive (kVAR).

Synchronous motors provide an effective method of improving power factor because they can be operated at leading power factor. Moreover, power factor of a synchronous motor to serve a load with actual power requirements of 1,000 kW, improves power factor on the load center from 80 percent to 89 percent. This improvement at the load center contributes to an improvement in overall plant power factor, thereby reducing the power factor penalty on the plant electric bill. The burden on the load center, plant distribution system, and entire electric-utility system is 400 kVA less than if an induction motor with a power factor of 85 percent were used. Power factor can be improved still more by operating the synchronous motor at leading power factor.

The Table 4.1 can be also used to determine the amount of capacitors needed to correct a power factor. The required amount of capacitors needed in (kVAR) can be determined from:
kVAR = D x CF
where

D = maximum annual demand, kW
CF = correction factor

EXISTING POWER FACTOR	**NEW POWER FACTOR**					
	1.00	0.95	0.90	0.85	0.80	0.75
0.66	1.138	0.810	0.654	0.519	0.388	0.256
0.68	1.078	0.750	0.594	0.459	0.328	0.196
0.70	1.020	0.692	0.536	0.400	0.270	0.138
0.72	0.964	0.635	0.480	0.344	0.214	0.082
0.74	0.909	0.580	0.425	0.289	0.159	0.027
0.76	0.855	0.526	0.371	0.235	0.105	
0.78	0.802	0.474	0.318	0.183	0.052	
0.80	0.750	0.421	0.266	0.130		
0.82	0.698	0.369	0.214	0.078		
0.84	0.646	0.317	0.162	0.026		
0.86	0.593	0.265	0.109			
0.88	0.540	0.211	0.055			
0.90	0.484	0.156				
0.92	0.426	0.097				
0.94	0.363	0.034				
0.96	0.292					
0.98	0.203					
0.99	0.142					

Table 4.1: Power Factor Correction

General Considerations for Power Factor Improvements

Poor power factor penalizes the user in three ways.

1. It robs the distribution system of capacity that could be used to handle the work-performing load.
2. It results in currents higher than necessary to perform a given job, thereby contributing to higher voltage drop and electrical system losses.
3. It can result in electric power billing penalties depending on the schedule terms.

A plant's power factor penalty can be determined from the monthly utility bills. The method of billing for low power factor varies widely among utilities. Often no penalty is imposed unless the power factor falls below a certain minimum, typically 85 percent to 90 percent. In other situations, a penalty is involved for any reduction below 100 percent. For this reason, each rate schedule must be studied separately to determine the potential savings involved for improving power factor.

Some equipment, such as high power factor lighting ballasts or synchronous motors, has inherent power factor improvement. With other equipment, notably induction motors, power factor is a function of the mode of operation. Operation of an induction motor below full load will significantly reduce the power factor of the motor. Therefore, motors should be operated close to full load for the best power factor. Power factor also becomes progressively lower for slower speed motors. For example, the decline in power factor below 90 percent for a 1,200-rpm motor is 1.5 times greater than for an 1,800-rpm motor; for a 900-rpm motor, the decrease is more than double that for an 1,800-rpm motor.

The use of power factor improvement capacitors is the simplest and most direct method of power factor improvement. Capacitors can be bought in blocks and combined to provide the required amount of capacitive reactance or individual capacitors can be installed at each motor. Capacitors already in use should be checked annually to ensure all units are operating. Inoperative capacitors negate the power factor improvement for which their installation was intended. Diminishing returns are realized as power factor approaches 100 percent. Generally, 95 percent (based on normal full load) is the economic break-even point in a power factor improvement program; up to this point, improvements usually show a good return on investment.

4.1.5. Electrical Demand / Load Factor Improvement

The plant's load factor should be analyzed to determine the opportunity for improvement. Load factor improvement is synonymous with demand control.

Potential Savings

The potential savings for demand limiting depends on such factors as

- The plant's profile (Variations in kW demand.)
- The availability of sheddable loads
- The rate schedule

Together these factors determine the relative importance of the demand charge to the plant's total electric bill. Controlling demand becomes more important if the schedule includes a ratchet clause that involves payment based on the highest peak occurring in the previous 12 months.

Definition

Load factor is the ratio of the average kilowatt load over a billing period to the peak demand. For example, if a facility consumed 800,000 kWh during a 30-day billing period and had a peak demand of 2,000 kW, the load factor is:

Load Factor = (800,000 kWh/720 hrs) / 2,000 kW = 0.55 or 55%

A high-load factor usually indicates that less opportunity exists for improvement because the load is already relatively constant.

System Analysis

The user will obtain the lowest electric cost by operating as close to a constant load as possible (load factor 100 percent). The closer a plant can approach this ideal situation, the lower the monthly demand charge will be. The key to a high-load factor and corresponding lower demand charge is to even out the peaks and valleys of energy consumption.

To analyze the opportunity for demand reduction, it is necessary to obtain data on the plant's demand profile. The demand profile is best obtained from the utility's record of the kW demand for each 15- or 30-minute interval. If no demand recording is made as a routine part of the billing procedure, the utility will usually install an instrument temporarily to provide the customer with this information. A plot of this data will show the extent of the peaks and valleys and indicate the potential for the limiting demand. If sharp peaks or an unusually high demand for one shift or short period occur, the opportunity for demand control should be investigated further. If the demand curve is relatively level, little opportunity exists for reducing demand charges by peak shaving. In order to level out peaks in the demand profile, it is necessary to reduce loads at these times. Consequently it is necessary to identify the various loads that could be reduced during periods of high demand. The major users of electricity will provide the most likely sources for limiting demand. Accordingly, a list of the largest users, their loads, and their operating schedules should be prepared. The smaller loads can be ignored as they will not be able to affect the demand materially. An examination of this list will often suggest which loads do contribute or are likely to peak demands. When the load pattern is not easily determined, a recording wattmeter can be installed at individual loads to provide a more detailed record of load variations.

Ways to Reduce Demand

Consideration of demand control often begins with automatic demand controllers. However, several other approaches should be considered first.

- Stagger Start-Up Loads:
  If a high-peak load is determined to result from the simultaneous start-up of several loads, such as might occur at the beginning of a shift, consideration can be given to staggering start-up of equipment to span two or more demand intervals.

- Reschedule Loads:
  Peak demands are usually established at particular times during the day shift. A review of the operating schedule may show individual loads can be rescheduled to other times or shifts to even out demand. This technique can provide significant gains at little or no cost. For example, operation of an electric oven might be rescheduled to the evening shift if the oven is not needed full-time. Another example is conducting routine testing of the fire pump during periods when peak demands are not likely to occur.

- Increase Local Plant Generation:
  When some electricity is generated by the plant, plant generation can be temporarily increased to limit demand. In some cases, any venting of excess low-pressure steam from the turbo-generator for short periods may represent a lesser penalty than the increased demand charge.

- Install Automatic Demand Control:
  After an investigation has been made of the above approaches, if an application for automatic demand control still appears to exist, a more detailed analysis of conditions should be made. The minimum peak demand that can be established will depend on the downtime that is acceptable without causing undue interference with normal operations and the available sheddable load.

To determine the extent of downtime necessary to achieve a given kW reduction, it is necessary to tabulate the size and frequency of peak demands. A sufficient number of months should be similarly studied to develop a representative profile. Seasonal or production variations may also exist although it is likely the variations in peak demands will remain relatively the same.

A suggested method of analysis is to tabulate the 10 to 20 highest peak demands occurring during a typical month in descending order, as shown in the example given in Table 4.2. In this case, limiting the demand to the lowest value shown (5,990 kW) would reduce the electrical demand by 330 kW. The monthly saving based on $9.40/kW would be $3,100, or on an annual basis, $37,200.

Date	Time	kW	kW Above 5990
May 10	10:00 a.m.	6320	330
May 24	10:30 a.m.	6220	230
May 14	11:00 a.m.	6145	155
May 5	1:30 p.m.	6095	105
May 20	2:30 p.m.	6055	65
May 15	10:30 a.m.	6025	35
May 15	10:00 a.m.	6010	20
May 8	2:00 p.m.	6000	10
May 9	2:00 p.m.	5995	5
May 13	1:30 p.m.	5995	5
May 5	2:00 p.m.	5990	--

Table 4.2: Highest Demands for Hypothetical Billing Period of May

To effect this reduction requires a total sheddable load of at least 330 kW. If additional sheddable loads are available, a greater reduction in peak demand can be considered. It should be noted that the task of eliminating a peak becomes progressively harder as the demand limit is set lower because the frequency of the peaks increases. For example, limiting the demand to 6,220 kW for a reduction of 100 kW from the peak demand requires shedding a total of 960 kW for 30 minutes over 10 separate occasions. In other words, in the second case it was necessary to shed a load almost three times longer for an equivalent reduction in demand. As further limiting of demand is attempted, progressively longer periods of equipment outage are required. A point is eventually reached where the interference with normal operation outweighs the benefits or no more sheddable loads are available.

To determine the sheddable loads, review the list of the larger electrical loads which have already been identified. These loads should be divided into two major categories.

1. Essential: Loads that are essential to maintain production or safety. Unscheduled shutdowns on these loads cannot be tolerated.

2. Nonessential or sheddable: Loads in this category can be shut down temporarily without significantly affecting operations or worker comfort. Examples of such loads are air conditioning, exhaust and intake fans, chillers and compressors, water heaters, and battery charges. Electric water heaters represent a load that can usually be shed.

The practical extent of peak shaving can now be determined based on the schedule of sheddable loads and the pattern of peak demands. The number and type of loads to be controlled will determine the type of demand controller needed. Automatic demand controllers are offered in a wide range of prices from several thousand dollars to tens of thousands of dollars. For different applications, the more sophisticated controllers may be necessary. For normal demand control, the less expensive controllers will be more than adequate.

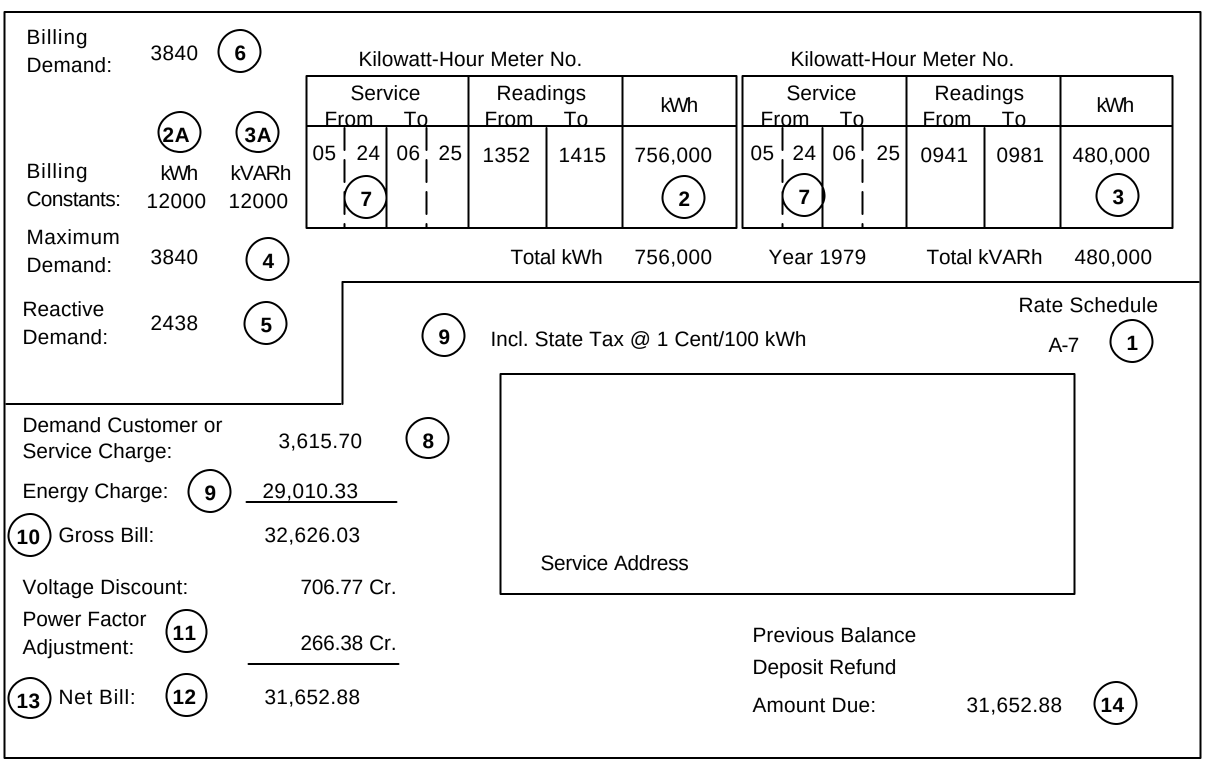
Annual savings can be calculated and compared to the costs of installing a demand control system. As part of the installation, demand controllers will require a pulse signal from the utility to synchronize the utility's demand interval with the demand controller's.

4.1.6. Reading the Bill

The cost of purchasing electrical power from utility companies is derived from four major factors; energy charge, fuel-adjustment charge, demand charge, and low power factor penalty.

Other incidental items which will affect the power charges are character of service, service voltage, and equipment charges. These are fixed charges.

Example of a Typical Electric Bill



1. The utility rate schedule A-7 is the key to analyzing the electric bill. It is normally included as part of the contract.

2. The energy used expressed in kilowatt-hours (kWh) is determined by the difference of two monthly meter readings times the billing constant (2A). The billing constants (2A) and (3A) are also described as “Meter Multipliers”. They are determined by the product of the current and potential transformer ratios installed at the particular location.

3. The reactive power used, sometimes called “wattless power”, expressed reactive kilowatt ampere hours (kVARh) is determined from a separate reactive meter similar to the kWh meter (2) above.

4. The maximum demand in kilowatts for the current month is read from a separate register on the kWh meter. The value is the largest quantity of kilowatts consumed during a time interval prescribed in the contract.

5. The reactive demand in kVAR is calculated from the formula kVAR = kW (kVARh/kWh).

6. The billing demand is the average of the maximum demand for the past 11 months and the current month’s demand. The minimum is half of the past 11-month value.

7. Date and time span of the current billing.

8. The service charge, as specified in the rate schedule, is based on the billing demand item 6 and the service charge, is also used as the minimum billing if the energy usage falls to a low value.

9. The electrical energy charge is based on the kilowatt hours used as shown in item (2). Certain adjustments are made to the energy charge determined from the meter readings as follows:

   a) Energy cost adjustment known as “ECAC” varies with the change in fuel cost to the utility.
   b) Fuel balance factor is usually a credit.
   c) Load management factor.
   d) State tax as indicated on the monthly bill.

10. The gross bill is the summation of items (8) and (9).

11. The voltage discount is available for services that are metered on the high voltage or primary side of the power company transformer. This discount is made to compensate for the utility transformer losses which are now included in item (2).

12. The power factor adjustment may be a penalty or a discount depending on the amount of reactive power, item (3), required by a plant. Power factor is defined as the ratio of the kW to kVA, sometimes stated as the ratio of “real power to the apparent power’. This value is not read directly

from the utility meters but must be calculated. A simpler method, using a hand calculator, is to solve as a right angle triangle where power factor (PF) is:

$$PF = \frac{kW}{kVA} = \frac{kWh}{RkVAh}$$

$$(kVAh)^2 = (kWh)^2 + (RkVAh)^2$$

This month's

$$PF = \frac{756000}{\sqrt{(756000)^2 + (480000)^2}} = 0.844$$

%PF = 100 x 0.844 = 84.4% Power Factor

On this rate schedule a power factor over 70.7% provides a credit; below a penalty, however, other utilities may use a different break even point - 85% is used by many.

13. City tax where applicable.

14. Net bill is the summation of all of the above charges, adjustments and credits.

4.1.7. The Energy Charge

Energy charge is based on the number of kilowatt hours (kWh) used during the billing cycle. The total kilowatt hours are multiplied by the energy charge for total energy billing. The energy charges can vary with the type of service, voltage, and energy consumption. Example energy rate schedules are as follows:

Example 1: General service schedule that is applied to electrical load demand of up to 8,000 (kWh) kilowatt hours per month. Thus a non-demand charge schedule, the cost of energy and demand are one charge.

Example 2: Rate schedule A-12 is applied to electrical load demand of 30 to 1,000 kilowatt of demand per month. This schedule has an energy charge, fuel-adjustment charge, demand charge, and low power factor penalty.

Example 3: Rate schedule A-22 is applied to electrical load demands of 1,000 to 4,000 kilowatt of demand per month. This schedule has an energy charge, fuel-adjustment charge, demand charge, and low power factor penalty. The rate schedule has a "time of day" billing rate for energy and demand for both summer and winter. The summertime hour periods are from May 1 to September 30; the energy and demand charges change between the following hours:

Peak hours - 12:30 pm to 6:30 pm = 6 hours
Partial peak hours - 8:30 am to 12:30 pm = 4 hours
Partial peak hours - 6:30 pm to 10:30 pm = 4 hours
Off peak hours - 10:30 pm to 8:30 am = 10 hours

The wintertime hour periods are from October 1 to April 30; the energy demand charges change between the following hours:

Peak hours - 4:30 pm to 8:30 pm = 4 hours
Partial peak hours - 8:30 am to 4:30 pm = 8 hours
Partial peak hours - 8:30 pm to 10:30 pm = 2 hours
Off peak hours - 10:30 pm to 8:30 am = 10 hours

Example 4: Rate schedule A-23 is applied to electrical load demands of 4,000 and above kilowatts (kW) of demand per month. All other charges and "time of day" billing hours and periods are the same as rate schedule A-22. Additional rates are available for the purchase of supply voltage of 4,500 or 12,000 volts, this schedule provides for a high voltage discount of the total energy and demand charges.

4.1.8. The Demand Charge

This charge compensates the utility company for the capital investment required to serve peak loads, even if that peak load is only used for a few hours per week or month. The demand is measured in kilowatts (kW) or kilovolt amperes (kVA). These units are directly related to the amount of energy consumed in a given time interval of the billing period. The demand periods vary with the type of energy demand; the high fluctuating demand has a short demand period which can be as short as five minutes, but generally demand periods are of 15 or 30 minutes. The period with the highest demand is the one used for billing demand charges.

> *Example*: If the demand for a plant is 70 kilowatts for the first 15-minute period, and for the next 15-minute period the demand increases to 140 kilowatts and then drops back to 70 kilowatts for the remainder of the billing period (one month), the billing demand for that month is then 140 kilowatts. This represents the interval of maximum energy demand from the utility company for the month.

Demand charges can be a significant portion of the total electric bill; in some cases, demand charges can amount to as much as 80 percent of the bill. The demand charge can be reduced by smoothing out the peaks in energy demand by rescheduling of work or through a demand control program to shed loads when a demand limit is approached. This concept is particularly important for plants using electricity for major processes such as melting.

4.1.9. Power Demand Controls

The power demand controller automatically regulates or limits operation in order to prevent set maximum demands from being exceeded. The role of such a power demand controller has been widely recognized, the “time of day” billing rates will make it far more necessary in the future. The type of controller best suited for a plant operation is that which will predetermine the demand limit and the demand interval.

The overall usage of power is constantly monitored from the power company meter, the power usage of all the controlled loads is also monitored. By having this information the controller can calculate when an overrun of the desired demand limit will occur. The controller will delay any shed action to allow time for loads to shed normally. When it is determined that it will be necessary to shed one or more loads to keep from exceeding the demand, the controller, at the last possible moment, will shed the necessary loads. This means that shedding will occur only once during a demand interval and maximum use of available power will be realized.

4.1.10. Demand Shifting

Due to the lack of availability and the increased cost of natural gas and petroleum products, industry has come to rely on electrical power as a major source of energy. The use of electrical energy has increased at a greater rate than was anticipated and therefore a critical shortage has also been created in some areas. This is particularly true during the normal working day hours. Over the past few years this condition has caused situations known as “brown-outs”, which is controlled curtailment of power.

Even with power companies doing their best to cope with the problem by building new generating stations, installing additional equipment in existing facilities, and operating all equipment at maximum capacity, they still have not been able, in some cases, to keep up with the rapid growth in the demand for electrical energy.

The demand for electrical energy is not constant, but occurs in peaks and valleys. Power companies are obligated to have enough equipment available to meet a customer’s peak demand, even though this equipment is only used during the peak periods and is not in use during most of the working day. In order to finance the equipment necessary to provide this peak demand service for industrial users, the power demand charge was created. In some localities this high demand rate is the rate which is paid for the next year, even if it is never reached again, and the price paid for power demand can be very high.

With peaks and valleys in electrical demand caused by electrical melting during the normal work day, maximum demand peaks should be controlled by sequencing the furnace's operation and maximum power input to each furnace. By applying this procedure, the revised operation would level out the peak demands and produce a flat demand profile during normal daytime melting. With this melting operation the "load factor" would be improved, thus preventing high maximum demand peaks, which are developed through operating all machines at full load at the same time.

4.2. MOTORS

Motors represent the largest single use of electricity in most plants. The function of an electric motor is to convert electrical energy into mechanical energy. In a typical three-phase AC motor, current passes through the motor windings and creates a rotating magnetic field. The magnetic field in turn causes the motor shaft to turn. Motors are designed to perform this function efficiently; the opportunity for savings with motors rests primarily in their selection and use.

4.2.1. Idle Running

The most direct power savings can be obtained by shutting off idling motors, thereby eliminating no-load losses. While the approach is simple, in practice it calls for constant supervision or automatic control. Often, no-load power consumption is considered unimportant. However, the idle no-load current is frequently about the same as the full-load current.

An example of this type of loss in textile mills occurs with sewing machine motors that are generally operated for only brief periods. Although these motors are relatively small (1/3 horsepower), several hundred may be involved at a plant. If we assume 200 motors of 1/3 horsepower are idling 90 percent of the time at 80 percent of full-load ratings:

Cost of idling = 200 motors x 1/3 hp x 80% of load x 6,000 hrs/yr x 90% idling x $0.041/hp-hr = $11,800

A switch connected to the pedal can provide automatic shutoff.

4.2.2. Efficiency at Low Load

When a motor has a greater rating than the unit it is driving requires, the motor operates at only partial load. In this state, the efficiency of the motor is reduced (see Figure 4.2). The use of oversized motors is fairly common because of the following conditions:

Personnel may not know the actual load; and, to be conservative, select a motor larger than necessary.

The designer or supplier wants to ensure his unit will have ample power; therefore, he suggests a driver that is substantially larger than the real requirements. The maximum load is rarely developed in real service. Furthermore, most integral horsepower motors can be safely operated above the full-load rating for short periods. (This problem may be magnified if there are several intermediaries.)

When a replacement is needed and a motor with the correct rating is not available, personnel install the next larger motor. Rather than replace the motor when one with the correct rating becomes available, the oversized unit continues in use.

A larger motor is selected for some unexpected increase in driven equipment load which has not materialized.

Process requirements have been reduced.

For some loads, the starting or breakaway torque requirement is substantially greater than the running torque; thus, oversizing of the motor is a frequent consequence, with penalties in the running operation.

Plant personnel should be sure none of the above procedures are contributing to the use of oversized motors and resulting in inefficient operation.

Replacement of underloaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency. This arrangement is generally most economical for larger motors, and only when they are operating at less than one-third to one-half capacity, depending on their size.

The identification of oversized motors will require taking electric measurements. The recording wattmeter is the most useful instrument for this purpose to analyze the load over a representative period of time.

Another approach which provides an instantaneous reading is to measure the actual speed and compare it with the nameplate speed. The fractional load, as a percent of full nameplate load, can be determined by dividing the operating slip by the full-load slip. The relationship between load and slip is nearly linear Other motors at the plant can often be used as replacements, reducing or eliminating the investment required for new motors. Adapter plates and couplings to accommodate the smaller motors are the major expense. Scheduling the changes to coincide with maintenance of the motors minimizes the installation costs.

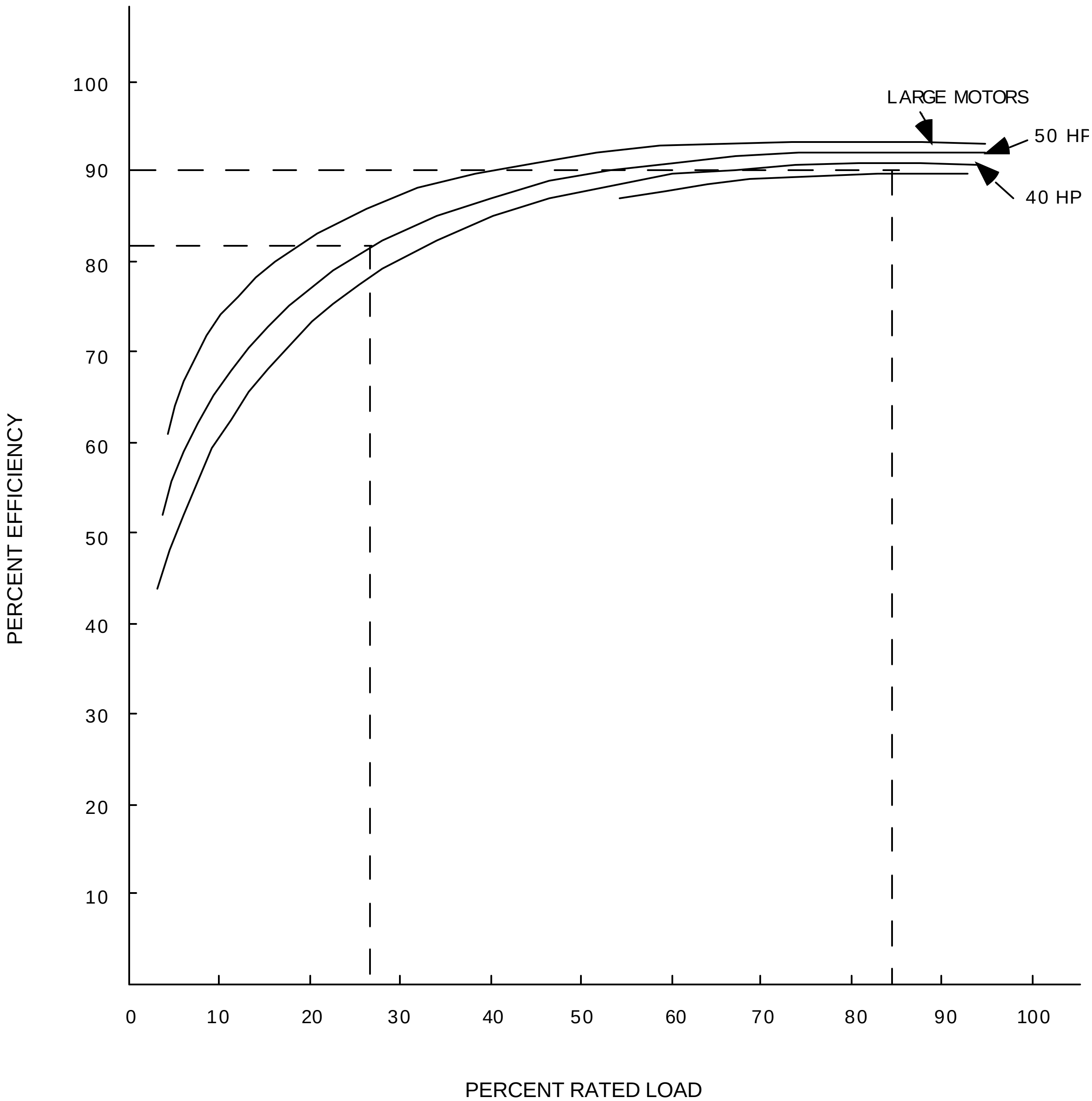


Figure 4.2: Motor Efficiency

(Typical T-Frame, NEMA Design B Squirrel Cage Induction Motor-1,800 rpm)

For example, the annual savings for replacing a 50-horsepower motor operating at 25 percent of rated load with a 15-horsepower motor which will operate near full load is:

$$L_{FL} = 0.746(hp)\left(\frac{1}{Eff_{FL} - 1}\right)$$
$$L_{PL} = 0.746(hp)(PL)\left(\frac{1}{Eff_{PL} - 1}\right)$$

where

L = losses - kW

Eff = motor efficiency

subscripts

FL = at full load

PL = at partial load

$$L_{FL} = 0.746(15)\left(\frac{1}{0.9 - 1}\right) = 1.24kW$$
$$L_{PL} = 0.746(50)(0.25)\left(\frac{1}{0.837 - 1}\right) = 1.82kW$$

Reduction in Losses = 0.58 kW

Annual Savings = 0.58 kW x 6,000 hrs/yr x $0.05/kWh = $174

4.2.3. High-Efficiency Motors

Purchase of high-efficiency motors should be standard practice with any new purchases. Payback of the premium paid for high-efficiency motors is usually less than two years for motors operated for at least 4,000 hours and 75 percent load. An exception may exist when the motor is only lightly loaded or operating hours are low, as with intermittent loads. The greatest potential occurs in the 1 to 20 horsepower range. Above 20 horsepower efficiency gains become smaller, and existing motors over 200 hp are already relatively efficient.

When motors are supplied by an equipment manufacturer, high-efficiency motors should be specified at the time of purchase. Otherwise, manufacturers normally supply motors of standard design because of their lower cost. Because of competitive pressure, these types of motors are likely to be less efficient. They have a lower power factor, not possible to spare, and they are more difficult to rewind.

The higher efficiency of high-efficiency motors is obtained by the use of thinner steel laminations in the stator and rotor; use of steel with better electromagnetic properties; addition of more steel; increase of the wire volume in the stator; improved rotor slot design; and the use of smaller more efficient fans. Each of these approaches involves more material, increased material costs, or higher manufacturing costs, which accounts for the higher first cost. However, the 25 to 30 percent higher initial cost is offset by lower operating costs. Other benefits of high-efficiency motors include less effect on performance from variations in voltage phase imbalance, and partial loading.

The calculation of simple payback for energy-efficient motors can be complex because of the variables involved. Determination of the operating cost of the motor requires multiplying the amount of electricity the motor uses by the number of hours the motor is operated and by the user's electrical cost. Each of these factors has its own variables, including changes in production schedules, variations in motor load, and demand charges. Some of these figures may be difficult to pinpoint.

Even when savings calculations are attempted, they can be subject to error because the actual efficiency of the particular motor is generally not known. All manufacturers do not use the same test technique to measure efficiency; as a result, ratings stamped on nameplates may not be comparable. Most manufacturers in the United States use a "nominal" efficiency that refers to a range of efficiencies into which a particular motor's efficiency must fall. Statistical techniques are used to determine the "minimum" efficiency of a motor with any given nominal efficiency. For example, a nominal efficiency of 90.2 percent has a minimum efficiency of 88.5 percent.

Many users report adopting high-efficiency motors as standard practice without attempting to justify the premium except in the case of larger-sized motors. In general, paybacks of approximately one year have been experienced.

Specific motors vary from published ratings. For instance, a 100-hp, 1,800-rpm, totally enclosed, fan-cooled motor from one manufacturer has a guaranteed minimum efficiency of 90.2 percent at full load in the standard line and 94.3 percent in the high-efficiency line. The equivalent size motor of another manufacturer has the same 90.2 efficiency rating for the standard model, but the high-efficiency model has a guaranteed minimum efficiency of 91.0 percent. Verification of actual efficiency of a particular motor requires the use of sophisticated testing equipment.

Because of this variation, the use of the guaranteed minimum efficiency is more conservative in evaluating savings because all motors should be equal to or higher than the value specified. Table 4.3 & Table 4.4 compare standard T-frame TEFC motors with high-efficiency motors.

	Standard T-Frame TEFC				**High Efficiency TEFC**			
	Nominal Average Expected Efficiecy			Guaranteed Minimum	Nominal Average Expected Efficiency			Guaranteed Minimum
Horse power	Full Load	75% Load	50% Load	Full-Load Eff	Full Load	75% Load	50% Load	Full-Load Eff
10	83.0	82.0	81.0	Not Available	90.2	91.0	91.0	88.9
15	84.0	84.0	83.0		91.7	92.4	92.4	90.6

20	86.0	87.0	87.0		93.0	93.6	93.6	92.0
25	86.0	87.0	87.0		93.0	93.6	93.0	92.0
30	88.0	88.0	88.0		93.0	93.6	93.6	92.0
40	88.0	88.0	87.0		93.6	94.1	93.6	92.7
50	89.0	89.0	89.0		94.1	94.1	94.1	93.3
75	91.5	91.5	91.0		95.0	95.0	94.5	94.3
100	92.0	92.0	91.0		95.0	95.0	95.0	94.3
125	91.5	91.5	90.0		95.0	95.0	94.1	94.3
150	93.0	93.0	91.5		95.8	95.8	95.4	95.2
200	93.0	93.5	93.0		95.8	95.8	95.8	95.2

Table 4.3: Typical Efficiency Comparison for 1 800 rpm Motors: General Electric

	Standard T-Frame TEFC				**High Efficiency TEFC**			
	Nominal Average Expected Efficiency			Guaranteed Minimum	Nominal Average Expected Efficiency			Guaranteed Minimum
Horse power	Full Load	75% Load	50% Load	Full-Load Eff	Full Load	75% Load	50% Load	Full-Load Eff
10	88.5	87.8	85.2	86.5	90.2	90.4	89.3	88.5
15	88.5	88.2	86.1	86.5	91.7	91.9	91.0	90.2
20	88.5	88.6	87.2	88.5	91.7	91.9	90.9	90.2
25	90.2	89.2	86.7	88.5	93.0	93.3	92.8	91.7
30	90.2	89.9	88.0	88.5	93.0	93.3	92.8	91.7
40	90.2	89.7	87.9	88.5	93.0	92.6	91.0	91.7
50	91.7	91.2	89.5	90.2	94.1	93.7	92.4	93.0
75	91.7	90.8	88.4	90.2	94.1	93.8	92.6	93.0
100	93.0	92.6	91.0	90.7	95.0	94.8	93.8	94.1
125	93.0	92.5	91.0	90.7	95.0	94.6	93.5	94.1
	Nominal Average Expected Efficiency			Guaranteed Minimum	Nominal Average Expected Efficiency			Guaranteed Minimum
Horse power	Full Load	75% Load	50% Load	Full-Load Eff	Full Load	75% Load	50% Load	Full-Load Eff
150	93.0	92.5	91.5	90.7	95.0	94.7	93.7	94.1
200	94.1	93.6	92.3	93.0	95.0	94.9	94.2	94.5

Table 4.4: Typical Efficiency Comparison for 1 800 rpm Motors: Westinghouse

4.2.4. Reduce Speed/Variable Drives

When equipment can be operated at reduced speeds, a number of options are available. Following examples are representative for the all industries.

Variable Frequency AC Motors

When centrifugal pumps, compressors, fans, and blowers are operated at constant speed and output is controlled with throttled valves or dampers, the motor operates at close to full load all the time--regardless of the delivered output. Substantial energy is dissipated by these closed dampers and valves. Significant energy savings can be realized if the driven unit is operated at only the speed necessary to satisfy the demand. Variable speed drives permit optimum operation of equipment by closely matching the desired system requirements.

Variable-frequency AC controllers are complex devices, and until recently have been expensive. However, they work with standard AC induction motors which allows them to be easily added to an existing drive. With lower equipment cost and increased electric costs, they become cost effective in many applications. Many types of pumps (centrifugal, positive displacement, screw, etc.) and fans (air cooler, cooling-tower, heating and ventilating, etc.), as well as mixers, conveyors, dryers, colanders, crushers, grinders, certain types of compressors and blowers, agitators, and extruders, are driven at varying speeds by adjustable-speed drives.

The following example illustrates the energy savings for an adjustable-speed drive on a fan. Figure 4.3 shows a fan curve for pressure versus flow characteristics. The intersection of the fan and system curve at point A shows the natural operating point for the system without flow control.

If a damper is used to control the flow, the new operating point becomes point B. However, if flow control is done by fan speed, the new operating point at reduced speed becomes point C.
The respective horsepowers are shown on the horsepower curves as points B' and C'.

Determination of the energy savings requires calculating the horsepower based on the fan curve and the duty cycle at which the fan is operating. The results for a fan controlled by damper are assumed to be as follows:

CFM %	Fan hp	Duty Cycle	Weighted hp
100	35	10	3.5
80	35	40	14.0
60	31	40	12.4
40	27	10	2.7
		Total	32.6

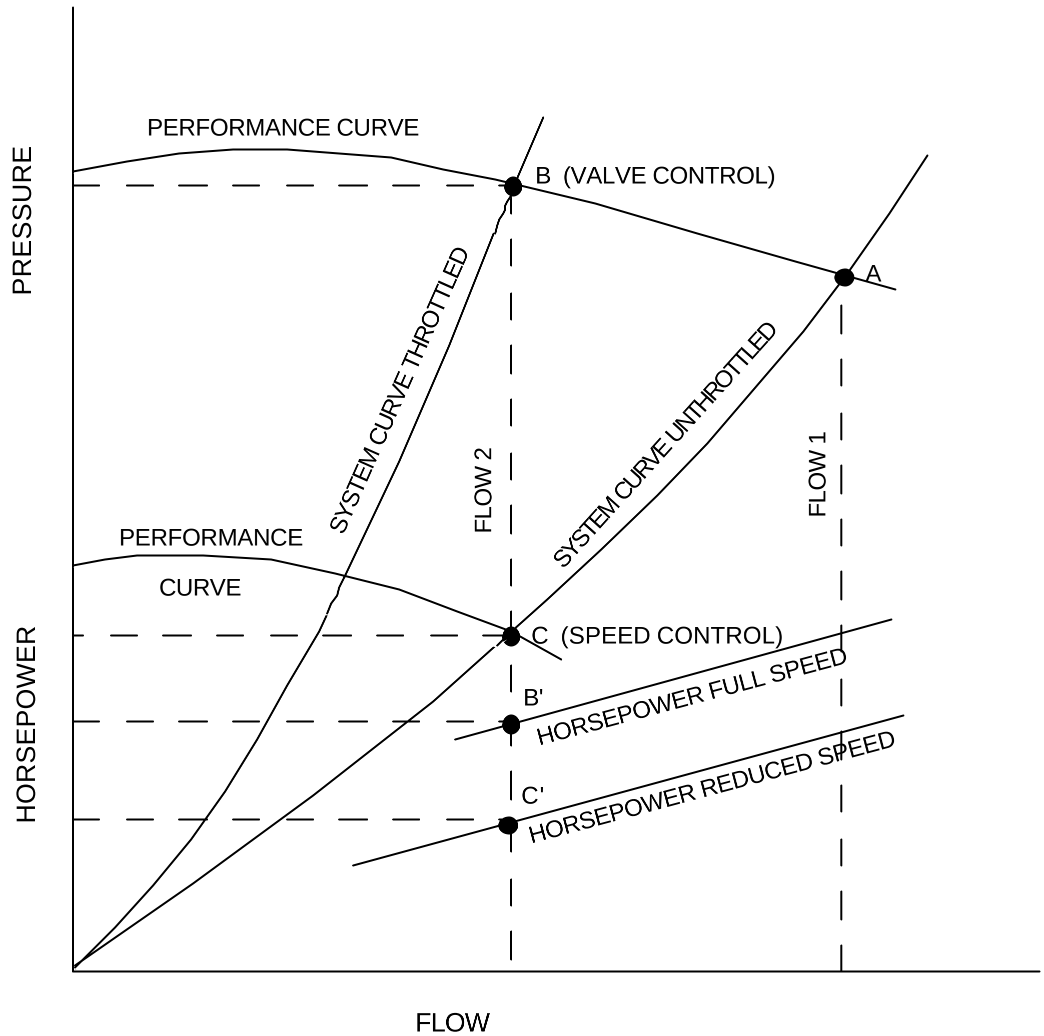


Figure 4.3: Fan Drive: Variable Speed vs. Valve Control

For machines that have a free discharge, the fan affinity formula below is used to calculate the reduced horsepower for a variable speed drive.

$$\frac{hp_1}{hp_2} = \left(\frac{N_2}{N_1}\right)^3$$

For example, the horsepower for a fan operated at one half speed is:

$$\frac{hp_1}{hp_2} = \left(\frac{0.5}{1}\right)^3 = 12.5\% \text{ of full load}$$

Consequently, significant savings are possible when speeds can be reduced.

The new fan horsepower with variable speed is:

CFM %	Fan hp	Duty Cycle	Weighted hp
100	35	10	3.5
80	18	40	7.2
60	7.56	40	3.024
40	2.24	10	0.224
		Total	13.948

The variable speed drive requires less than half the energy of the outlet damper for this particular duty cycle.
The annual savings (AS) is:

AS = (32.6 hp - 13.948 hp) x 6,000 hrs x $0.041/hp-hr = $4,590/yr

The installed cost of variable drive for a 35-hp motor is approximately $10,000. Equipment costs per hp decrease significantly with size, starting at about $250/hp for a 75-hp motor.

In actual practice, the efficiency of the motor should be factored in for a more accurate savings calculation based on kW input. The efficiency of the motor begins to drop significantly below 50 percent of rated capacity.

The above calculations assume a free discharge. If a static head is present, as in the case of a pump, the static head changes the system curve so that the affinity laws cannot be used directly to calculate the horsepower at reduced speed. In this case, precise knowledge of the pump and the system curves is required. Then detailed analysis with the aid of a computer is advisable.

Solid State DC Drives

Similar energy savings can be realized by varying speed with a DC drive. First cost is greater than for a variable frequency AC motor drive, particularly in a retrofit situation where the existing AC motor can be used directly with the electric controller. Brush and commutator maintenance is also a major cost with DC drives. DC systems are also more sensitive to corrosive and particle-laden atmospheres which are common in an industrial environment.

Accordingly, AC drives are preferred unless process conditions requires some of the special characteristics of a DC system such as very accurate speed control, rapid reversal of direction, or constant torque over rated speed range. Applications include driving of extruders, drawing machines, coaters, laminators, winders, and other equipment.

Other established techniques for varying the speed of a motor are electromechanical slip devices, fluid drives, and the wound-rotor motor. These devices control speed by varying the degree of slip between the drive and the driven element. Because the portion of mechanical energy that does not drive the load is converted to heat, these devices are less efficient and are used primarily because of special characteristics in a given application. For example, fluid drives might be used for a crusher because they are characterized by generally high power capacities, smooth torque transmission, tolerance for shock loads, ability to withstand periods of stall conditions, inherent safety (totally enclosed with no moving contact), and a tolerance of abrasive atmospheres.

Because AC and DC drives alter the operating speed of the prime mover, they are preferred for energy conservation reasons.

Mechanical Drives

Mechanical variable-speed drives are the simplest and least expensive means of varying speed. This type of adjustable sheaves that can be opened or closed axially, thus changing the effective pitch at which the belt contacts the sheaves.

The chief advantages of mechanical drives are simplicity, ease of maintenance, and low cost. Their chief advantage is a moderate degree of maintenance and less accurate speed control (normally 5 percent).

Belt drives are available for low to moderate torque applications over a power range to 100 hp. Efficiencies of belt drives are 95 percent, and reduction ratio can be as much as 10:1.

Metal chain drives for high torque are also available. These are similar in principle to belt drives, but use metal belts instead of rubber-fabric belts.

Single-Speed Reduction

When a single speed will satisfy the need for speed reduction, less expensive options are available. Although variable speed offers the advantage of using optimum speed in all situations, if the speed range is narrow and the portion of time operated at the lower speeds is small, a slower single speed is probably the most cost-effective approach.

Belt drives: With a belt drive, a speed reduction can be accomplished at minimum expense by simply changing belt sheaves. Since the change can be conveniently reversed by reinstalling the old sheaves, this method has application when a reduced output is needed only for an extended period, such as seasonally. Another opportunity may exist when production levels are reduced for an indefinite time, but the original capacity may be required again in the future.

Gear reducers: A similar approach may be taken with a gear change where gear reducers are used.

Motor change: A slower-speed motor can also be substituted when a one-time speed reduction is needed.

Two-Speed Motors

A two-speed motor is an economical compromise between a fixed single-speed and a variable drive. As illustrated in the previous example, energy savings are significant because the power required is proportional to the cube of the speed (rpm). In practice, a slight increase may result from friction losses. This approach can be used in combination with some throttling to control output within a narrower range.

Two speeds can be obtained with a single winding, but the slower speed must be one-half of the higher. For example, motor speeds might be 1,800/900, 1,200/600, or 3,600/1,800. When a motor at other ratios is required, two sets of stator windings are necessary. Multispeed squirrel-cage motors can also be obtained which have three or four synchronous speeds.

The cost of two-speed motors is approximately twice the cost of a single-speed motor. If a motor can be operated at the slower speed for any appreciable time, the savings will easily justify the added investment. Multispeed motors also need more expensive starters because the overload protectors must be sized differently at each speed.

4.2.5. Load Reduction

A reduction in motor load is, of course, one of the best means of reducing electric costs. Proper maintenance of equipment will also reduce motor load by eliminating friction losses from such sources as the misalignment of equipment, frozen bearings, and belt drag. Proper lubrication of all moving parts such as bearings and chain drives will minimize friction losses. The substitution of ball or roller bearings for plain bearings, particularly on line shafts, is another good power saver.

4.2.6. High-Starting Torque

Loads requiring “normal” starting torque can be satisfied by a National Electrical Manufacturers Association (NEMA) B motor (the general-purpose motor most commonly used in industrial plants) or a NEMA A motor. Where high-inertia loads are involved, selection of a motor specifically designed for high-torque capability can permit use of a smaller motor. A NEMA B motor sized to handle high-starting loads will operate at less-than-rated capacity once the load has been accelerated to full speed. On the other hand, selection of a smaller motor of NEMA C or D design can provide the same starting torque as a NEMA B motor but will operate closer to the full-rated load under normal running conditions.

4.2.7. Rewound Motors

Rewinding can reduce motor efficiency, depending on the capability of the rewinding shop. Shops do not necessarily use the best rewind procedure to maintain initial performance. In some cases the loss inefficiency, particularly with smaller-sized motors, may not justify rewinding.

Ideally, a comparison should be made of the efficiency before and after a rewinding. A relatively simple procedure for evaluating rewind quality is to keep a log of no-load input current for each motor in the population. This figure increases with poor quality rewinds. A review of the rewind shop's procedure should also provide some indication of the quality of work. Some of the precautions that must be taken are as follows:

- When stripping to rewind a motor, unless the insulation burnout is performed in temperature-controlled ovens an inorganic lamination insulation had been used, the insulation between laminations may break down and increase the eddy current losses
- Roasting the old winding at uncontrolled temperature, or using a hand-held torch to soften varnish for easier coil removal, should signal the need to go elsewhere.
- If the core loss is increased as a result of improper burnout, the motor will operate at a higher temperature and possible fail prematurely.
- If the stator turns are reduced, the stator core loss will increase. These losses are a result of leakage (harmonic) flux induced by load current and vary as the square of the load current.
- When rewinding a motor, if smaller diameter wire is used, the resistance and the I2R losses will increase.

Rewinding techniques vary among repair shops and should be investigated before deciding where to have motors rewound.

A rewinding method developed by Wanlass Motor Corporation claims to increase efficiencies as much as 10 percent. The firm's technique involves replacing the winding in the core with two windings designed to vary motor speed according to load. Claims of improved efficiency have been disputed and trade-offs have been determined to exist in other features of motor design (cost, starting torque, service life, etc.) While the Wanlass motor has been in existence for over a decade, potential users should recognize that the design remains controversial and has been generally regarded in the motor industry as offering no improvement over that which can be achieved through conventional winding and motor design techniques.

4.2.8. Motor Generator Sets

Solid-state rectifiers are a preferred source of direct current (DC) for DC motors or other DC uses. Motor-generator sets, which have been commonly used for direct current, are decidedly less efficient than solid-state rectifiers. Motor-generator sets have efficiencies of about 70 percent at full load, as opposed to around 96 percent for a solid-state rectifier at full load. When the sets are underloaded, the efficiency is considerably lower because efficiency is the product of the generator and motor efficiencies.

4.2.9. Belts

Closely associated with motor efficiency is the energy efficiency of V-belt drives. Several factors affecting V-belt efficiency are

1. Overbelting: A drive designed years ago with ratings in existence then should be reexamined. Higher-rated belts, with resulting increase in efficiency.
2. Tension: Improper tension can cause efficiency losses of up to 10 percent. The best tension for a V-belt is the lowest tension at which the belt will not slip under a full load.
3. Friction: Unnecessary frictional losses will result from misalignment, worn sheaves, poor ventilation, or rubbing of belts against the guard.
4. Sheave diameter: While a sheave change may not be possible, in general, the larger the sheave, the greater the drive efficiency.

Substitution of the notched V-belt (cog belt) for the conventional V-belt offers attractive energy savings. The V-belt is subjected to large compression stresses when conforming to the sheave diameter. The notched V-belt has less material in the compression section of the belt, thereby minimizing rubber deformation and compression stresses. The result is higher operating efficiency for the notched V-belt.

Given a 60-hp motor, annual operating cost (6,000 hrs) is $18,000. A conservative 1 percent improvement in efficiency results in annual savings of $180. The premium cost for six, size 128 belts is $78.

4.3. ***LIGHTING***

Many lighting systems that represented good practice several years ago are inefficient in view of today's higher electrical costs. A lighting conservation program not only saves energy but is also a highly visible indication of management's interest in conserving energy in general. The importance of lighting conservation, therefore, should be considered not only for its dollar savings but also for its psychological effect on the plant's entire conservation program.

Table 4.5 shows the minimum average in service footcandles for lighting the interior of service buildings and areas. The illumination level specified is to be provided on the work surface, whether this be horizontal, vertical, or oblique. When there is no definite work area, it is assumed that the illumination is measured on a horizontal plane, 30 inches above the floor.

4.3.1. Lighting Standards

The first step in any lighting conservation program is to adopt a lighting standard. A new standard issued by the Illuminating Engineering Society provides for a range of illuminance instead of a single value. Within the recommended range, the level of illuminance can vary depending on the age of the workers, the importance of speed and accuracy, and the reflectance of the task background.

DuPont's recommended illumination levels for various working conditions are shown in Table 4.5. Management should adopt these or similar lighting standards to ensure uniform application of lighting levels. Without a standard, reductions in lighting are often nonuniform or inconsistent and may result in insufficient illumination in some areas.

LIGHTING SERVICE BUILDING INTERIORS

Area	Footcandles* in Service	Area	Footcandles* in Service
Offices		Machine and millwright shops	
Private	70	Rough bench and machine work	50
Small	70	Medium bench and machine work and tool maker's shop	100
General	70		
Stenographic	100	Fine bench and machine work	200**
Drafting rooms	125	Extra fine bench and machine work	500**
Files		Paint shops	
Active	30	Ordinary hand painting, rubbing, and finishing	30
Inactive	10		
Mail room		Fine finishing	70
Sorting	50	Spray painting booth	30
General	30	Sheet metal shops	
Conference rooms	70	Ordinary bench work	30
Corridors and stairways	20	Layout bench	70
Toilets and washrooms	20	Machines--presses, shears, stamping, etc.	50
Rest rooms	10		
Janitor's closets	10	Welding shops	
Lunch areas	30	General illumination	50

Main entrances	
Patios	5
Doorways and foyers	20
Lobbies	30
Interview rooms	50
Exits, at floor	5
Medical and first aid	
Reception	50
First aid rooms	125
Doctor's offices	70
Nurse's offices	70
Dressing rooms	20
Cot rooms	20
Telephone equipment	
Switchboards	50
Terminal and rack equipment	50
Reproduction area	
Blue print room	50
Locker and shower and wash rooms	20
Mechanical equipment operating areas (fan rooms, etc.)	20
Electrical equipment operating areas (motors, etc.)	20
Inactive storage	5
Loading docks and ramps	10
Store and stock rooms	
General--live storage	20
Rough bulky material	10
Bin area used for dispensing	
Small stock items	50
Tool cribs	30
Gate houses	
Pedestrian entrance	20
Car entrance	5
Solvent storage and dispensing	
Storage in drums	5
Dispensing	10
Cylinder sheds	10
Pump houses	20
Warehouses--general traffic area	5
Warehouses (in storage aisle at floor level)	15
Precision manual arc welding	1,000**
Carpenter and woodworking	
Rough sawing and bench work	30
Medium machine and bench work	50
Fine bench and machine work	100
Electrical shops (maintenance)	
General	30
Bench work--general	70
Insulating coil winding	100
Testing	70
Instrument shops (maintenance)	
General	50
Bench work	100
Pipe shops	
General (bending, etc.)	20
Cutting and threading	30
Laboratories--hoods, benches, and desks	
Research	70
Control	50
Power and steam plants	
General	50
Front of panels (vertical at 66 inches above floor)	
Centralized control room	40
Ordinary and boiler control boards	30
Bench boards (horizontal)	50
Boiler room--main floor and basement	20
Boiler room--galleries and stairs	10
Gauge boards--front of panel (vertical)	30
Crusher house	10
Coal conveyors and ash handling equipment	5
Condensers, deaerators, and evaporators	10
Auxiliaries, boiler feed pumps, tanks, compressors, power switchgear, battery rooms, screen house, intake well, transformer rooms, etc.	20
Catwalks	3
Water-treating area	20
Refrigeration compressors, air compressors, etc.	20

* The illumination level in any area should be increased so that it is not less than 1/5 the level in any adjacent area.
** Obtained with a combination of general lighting and specialized supplementary lighting.

MANUFACTURING GENERAL ˜			
Area	Footcandles in Service	Area	Footcandles in Service
Hand furnaces, boiling tanks, stationary dryers, stationary and gravity crystallizers, etc.	20	Electrical operating equipment (motors, general controls, etc.)	20
Mechanical furnaces, generators and stills, mechanical dryers, evaporators, filtration mechanical crystallizers	30	Electrical control rooms where equipment requires frequent checking, adjustment, etc.	30
Tanks for extractors, cooking nitrators, percolators, electrolytic cells	30	Weigh scales, gauges, thermometers, rotameters, etc.	
		Vertical on face of dials, scales, etc.	30
Tank and vat porthole lights, etc.		Control laboratories	50
Light interiors	20	Outdoor platform and tank farms	
Dark interiors	70	Active areas	5
Beaters, ball mills, grinders	30	Inactive areas	0.5
Mechanical operating equipment (compressors, fans, pumps, etc.)	20	Stairs, ladders, and steps	3

˜ Operating personnel do not perform exacting visual tasks except at process control panels, scales, gauges, thermometers, etc. Necessary lighting generally is obtained with combination of general lighting plus specialized supplementary lighting

LIGHTING OUTDOOR AREAS y			
Area	Footcandles in Service	Area	Footcandles in Service
Bulletin and poster boards	10-V	Railroad yards	0.2
Flood lighting--building exteriors	15-V (max)	Roadways	
Entrances		Curves and intersections	0.5
Active (pedestrian or conveyance, or both)	5	Platforms, catwalks, stairs, ladders, etc.	
		Platform operating decks	5
Inactive (normally locked, infrequently used)	0.5	Catwalks, stairs, and ladders	3
Loading and unloading platforms	3	Storage yards	0.5
Freight car and truck interiors	3	Plant parking lots	
Outdoor work areas	3	General parking areas	0.3
Protective lighting		Entrances, exits, and walkways	2
Boundaries and fence	0.2	Gasoline dispensing pumps	3
Vital locations or structures	5		
Building surroundings	1		
General inactive area	0.1		

ψ As a matter of reference in comparing outdoor lighting values, the intensity of full moonlight at the earth's surface is approximately 0.025 footcandles.

Table 4.5: DuPont Recommended Illumination Levels

4.3.2. Light Meter Audit

After standards have been adopted, a light meter audit to determine the existing lighting levels should be conducted for the entire plant. The condition of the lamps and fixtures should be taken into account when the audit is made. The cleanliness of the fixtures has an important effect on the light output. Also, some depreciation of light intensity occurs over the life of most lamps. If group relamping has been used, the lighting level will depend on the age of the lamps. Light loss of 10 to 15 percent is normal for standard 40 W fluorescent lamps that are approaching end of life.

4.3.3. Methods to Reduce Costs

A couple of examples how to save electric energy are given in the sections below. Some of them are rather simple and the implementation requires only the will to overcome some old entrenched habits of the people at the work place.

Turn off Lights

The most obvious and beneficial step to conserve energy is to turn off lights when they are not needed. This approach often requires an extensive publicity program to enlist the support of all employees. First-line supervisors must understand that conserving light is as much a part of their job responsibility as improving productivity. An effective way for members of management to show support for energy conservation is to turn off lights in their own offices when unoccupied.

Frequently, lights can be turned off in storage or operating areas that are not in use or are seldom occupied during periods of reduced production on the evening or the midnight shift. For example, it is common practice to leave office light on until the cleaning crew has completed its work instead of turning them off as soon as the offices are vacated.

The lighting circuitry may not provide the flexibility needed for a partial curtailment. In this case, the cost to modify the wiring must be compared with the potential energy savings to determine whether rewiring is justified.

Fluorescent lamps are commonly left on over noon hours or other short periods because of the belief that frequent starts will shorten tube life. This problem is substantially reduced now with tubes that are more tolerant of starts and the increased cost of energy compared with the tube cost. The break-even point for fluorescent lighting is usually 5 to 15 minutes, depending on the electric rate, lamp cost, and lamp replacement labor rate. With incandescent lights, however, energy will be saved each time they are turned off. For high-intensity discharge (HID) lamps, it is usually not practical to turn lights off for brief periods (less than 30 minutes) because of the long lamp restart time.

Automatic Controllers

A technique for ensuring that lights are turned off when the room is unoccupied is to use presence detectors (infrared, capacitance, or ultrasonic) that detect when the room is unoccupied and will automatically turn off the lights. One lighting control product, for example, uses an ultrasonic sensor which can handle up to four 20 amp circuits. This allows control of electrical devices as well as lights. The unit costs about $150 uninstalled. The presence of people in a room is determined by a sensor that detects interruptions in the ultrasonic sound waves transmitted by the unit. The sensor then sends a signal to a controller to turn lights on or off. The sensor has a time-delay knob that can be manually set anywhere from 1 to 12 minutes to ensure that equipment stays on for a certain period of time after a room is occupied.

As an example, annual savings for a unit controlling 5,000 watts of lighting that reduces lighting by two hours per day, five days per week at $0.05/kWh would be $125.

Another device that is used to avoid leaving lights on needlessly is a microprocessor-based automatic lighting control. These relatively inexpensive devices can be programmed to turn off lights when not needed. For example, one programmable controller being offered for about $500 can control up to 50 switches. The user can override the off function by turning on lights at his particular area. This is done with individual wall switches that cost about $30 per unit installed. When a lighting circuit turns off according to schedule, the toggle switches are moved to the off position. Switches can also be used alone with an existing energy management system. The traditional approach has been to install lighting control systems separately, but firms are attempting to incorporate lighting systems with an energy management system because it is more cost effective.

A plant which has the opportunity to turn off significant unneeded lights at various times should consider one of the many automatic lighting controls available.

Remove Lamps

Another direct method to reduce lighting is simply to remove lamps from service where less light is needed. This approach frequently applies to offices or areas in which uniform lighting has been provided. For example, if the fixture is located over an office doorway, lamps can often be removed without reducing the illumination level at the desktop. Office lighting loads can frequently be reduced 25 percent by this arrangement.

In four-lamp fixtures, two of the four lamps can be removed if only a partial reduction in illumination is possible.

Excess lighting is also frequently provided in aisles, particularly when natural daylight may be sufficient. Lighting levels in storage areas are often higher than needed. This situation can develop when former operating areas are utilized for storage. Removal of lamps from these less-critical areas does not affect production.

Ballasts in fluorescent fixtures continue to consume current (approximately 10 percent of total load) after the lamps have been removed. The entire fixture should, therefore, be disconnected if lamps are removed (except for some lamp systems that have circuit interrupting lamp holders).

Maintain Lamps

Dirt and dust accumulations on the fixtures greatly affect lamp efficiencies. Light intensity can depreciate up to 30 percent by the time lamps are replaced; in extremely dirty conditions, depreciation can be higher. A minimal cleaning schedule for an average industrial environment is to clean fixtures when the lamps are replaced. The number of lamps required to provide the desired illumination level will depend on the plant’s maintenance program. Initially, additional lighting to offset the gradual depreciation of light caused by dirt must be provided. If clean luminaires will improve lighting levels enough to permit the removal of some lamps, more frequent lamp maintenance may be justified. Cleaning costs must be balanced with energy costs to determine the optimum cleaning schedule.

Dirty or discolored luminaire diffusers can also reduce light output considerably. Replacement or complete removal may allow the lighting requirements to be satisfied with fewer lamps.

Lower-Wattage Fluorescent Lamps and Ballasts

A reduction in fluorescent light level by removing lamps from service can result in a spotty effect that is unattractive or provides an unacceptably low or nonuniform level of illumination. An alternate approach to energy saving is substitution of lower-wattage fluorescent lamps and ballasts. The substitution may or may not reduce the lighting level, depending on the type of lamp used. Because the variety of fluorescent lamps is so extensive, the following discussion refers to the general purpose 4-foot rapid start lamp, but reduced-wattage lamps are also available in other sizes and types.

a) Standard Lamp: The standard lamp for many years has been the 40-watt cool white, CW (or warm white, WW) lamp. This is the least expensive lamp, but also the least energy efficient. Several more cost-effective fluorescent lamp systems are available which use less wattage.

b) Energy Saver (ES) Lamp: A first-generation reduced wattage or energy-saving lamp was introduced in 1974 in 35-watt ratings (now typically rated at 34 watts). These lamps can be used as direct replacements for 40-watt lamps in existing luminaires. They emit the same color white light as the lamps they replace. Energy consumption is reduced by 13 to 15 percent with a comparable reduction in light output. The conversion to the lower illumination level need not cause personnel problems because the level of illumination will temporarily increase if the existing system is relamped as a group and the luminaires are cleaned. The ES lamps cost approximately 40 percent more than the standard lamps. If the lower lumen output is acceptable, the energy savings results in an attractive payback.

c) Lite White Lamps: A second generation of reduced-wattage lamps, generically designated as "lite white", is available when more lumen output is needed than the ES lamp provides. The lite white lamps consume about the same energy as the ES lamps (34 watts) but with only about 6 percent reduction in light output. The color of light, however, has a somewhat lower color-rendering index than that of the cool white lamps. Although lite white color differs from cool white, the lamps are considered compatible in the same system. These lamps cost about 50 percent more than the standard lamps.

d) Lite White Deluxe: If color rendition is important, a third generation of ES lamp, designated as "lite white deluxe", can be used. This lamp combines the high efficiency of the lite white lamp with even better color discrimination than the standard lamp. The lite white deluxe costs approximately three times as much as the standard lamp, but it can still be justified on the basis of energy saving. For example, a lite white deluxe costs $2.30 more than the standard lamp. Annual energy savings would be $1.80 (6,000 hrs. @ $0.05/kWh) for a payback of 1.3 years. If conditions permit use of the lower cost ED or lite white lamp, payback is about four months.

e) Sylvania has a lamp that operates at only 32 watts in the ES and lite white deluxe type. The premium is about 10 percent more and provides a similar payback of about four or five months on the premium.

f) Ballasts: Several options are available in the ballasts that can be used with any of the lamps described above. The standard electromagnetic ballast is the least efficient but also least expensive type ballast. It is normally provided by the luminaire manufacturer unless another type is specified. The standard electromagnetic ballast is not economical in sizes of 34 watts and above.

g) ES Ballasts: A more efficient low-loss or energy-saving electromagnetic ballast is also available. In evaluating the ballasts, the savings must be considered as a unit with the lamps since the more efficient ballasts permit the lamps to operate at lower wattage as well. A two 34-watt lamp system with an ES ballast saves 8 to 10 watts over the same system with a standard ballast. The premium for the high-efficiency ballast is approximately $6. Annual savings would be about $2.70 (6,000 hrs. @ $0.05/kWh).

h) Electronic Ballasts: More energy-saving electronic ballasts can also be used. Electronic ballasts operate at a frequency of 25 kilohertz (25,000 Hz) compared to the 60 hertz for standard ballasts. The higher frequency allows the lamps to operate at lower wattage. ES lamps must be used with rapid start ballasts. Good quality fluorescent luminaires manufactured in recent years are normally equipped with such ballasts.

Initial problems of reliability with the electronic ballasts appear to have been overcome. Electronic ballasts, however, have many small components and a relatively short product history compared with the simple construction and long-established high reliability of the magnetic ballasts.

With electronic ballasts, approximately 10 less watts per two 34-watt lamp system are saved over the same system with an energy efficient ballast. The premium for the electronic ballast over an ES ballast is about $13. Annual savings would be $3.00 (6,000 hrs @ $0.05/kWh). The payback for the electronic ballast is about twice as long as that of the energy-saving ballast. Comparative prices for standard ballast, energy-saving magnetic ballast, and electronic ballast are approximately $16, $22, and $35, respectively.

i) Performance-Matched Systems: For minimum wattage systems it is necessary to use performance-matched fluorescent systems in which the lamp and ballast are specifically tailored to each other for optimum efficiency. Such systems might not operate satisfactorily if other than their designated companion ballasts and lamps are used. However, performance-matched systems use considerably less energy (28 watts per lamp) than the conventional 40-watt systems.

The premium necessary for the electronic ballasts with these systems may reduce the payback to unacceptable levels. However, when four lamps can be operated off of one ballast, the economics are more attractive. Plants should evaluate the high-performance systems based on their electrical rates, conditions, and payback standards.

Energy-saving lamps are designed to operate closer to the optimum operating temperatures than conventional lamps and are not suitable for use in ambient temperatures below 60°F. At the lower temperatures ES lamps may be difficult to start or show sign of instability in operation by flickering. Accordingly, some low-temperature applications, such as warehouses, may not be suitable for ES lamps.

Below 60°F, standard fluorescent lamps will have a lower light output depending on the draft and lamp enclosure. Plastic sleeves or other jacketing that can retain heat can improve output when the light output has been noticeably reduced. However, light output will also start to decrease if above-bulb-wall temperatures exceed 100°F.

Some problems with ballast failure have been reported by users of ES lamps. ES lamps cause a slight increase in voltage across the capacitor, which in turn can cause premature failure in older ballasts. The problem, therefore, should be considered temporary until overage ballasts have been replaced.

A general problem to provide a more energy-efficient lighting system in a retrofit situation would be to replace any 40-watt lamps with one of the 34-watt lamps most suitable to the plant's conditions. This substitution can be done as individual lamps burn out, or they can be replaced on a group basis. The rapid payback usually justifies group replacement. More energy-efficient ballasts should also be substituted, but only as replacements are needed.

When a lower illumination level is acceptable but removal of a lamp would cause a problem of uneven illumination, a more uniform reduction in light level can be achieved by substituting special lamps.

Sylvania markets two versions of an ES lamp called Thrift/Mate. These lamps are intended to replace only one of a pair of lamps on the same ballast. When so installed, both the Thrift/Mate and the conventional lamp operate at reduced wattage. The two versions, designated TM33 and TM50, reduce energy consumption by 33 and 50 percent, respectively. The reduction in light output of the luminaire is equivalent to the reduction in power consumption.

Another method is to replace one of the two fluorescent lamps in a two-lamp fixture with a phantom tube. The phantom tube produces no light itself and the remaining real lamp in the fixture produces only about 70 percent of its normal illumination. The net result is a saving of two-thirds in the power used, with an illumination level of about one-third of that normally derived from a two-lamp fixture.

Fluorescent Retrofit Reflectors

Specular retrofit reflectors for fluorescent fixtures are available in two basic types: semirigid reflectors, which are secured in the fixtures by mechanical means, and adhesive films, which are applied directly to the interior surfaces of the fixture. Either silver or aluminum may be used as the reflecting media. On the average, silver film reflectors have a reflective film index between 94 and 96 percent; the index for aluminum is 85 to 86 percent. (Film applied directly to the existing fixtures is generally less efficient than the semirigid reflectors since it conforms to the fixture contours and cannot be formed to direct light in any specific manner.)

In regard to the energy aspects of the reflectors, manufacturers claim the reflectors permit the removal of two lamps from a four-lamp dirty fixture, the illumination directly underneath the fixture is essentially the same. But at angles to either side of the fixture, the decrease is much more significant. The fixture has been changed from a diffuse fixture to a sharp cut-off fixture. The additional illumination level with the reflectors is due in part from enabling the remaining two lamps to operate at a lower temperature, which increases their light output 6 to 12 percent.

While removal of two lamps reduces energy 50 percent, the comparison is not on an equal basis and several trade-offs should be recognized.

- As mentioned, the light pattern is more limited in area. The result can be nonuniform lighting on the work plane, dark spots between the fixtures, and darkened walls.
- The above claim of equivalent illumination is based on a comparison with a dirty fixture. The footcandles with two lamps and reflector is only 65 percent as much as four lamps with a clean conventional fixture.

- Lamp failure in a delamped fixture will not have the partial illumination provided by the second pair of lamps. Consequently, prompt replacement of burned-out lamps becomes more critical.
- The efficiency of any reflector depends on how well it is maintained. Even in a clean office environment the loss of light output due to dirt buildup in an unmaintained fixture can be as much as 35 percent. The reflectors may be more difficult to clean than normal fixture surfaces.
- Silver films are relatively new and their durability is somewhat unknown.
- The cost of a reflector often approaches the price paid for a new fixture. Approximate installation costs for the reflectors range from $35 to $65.

If the above trade-offs are acceptable, then the energy savings would justify their use. However, if a one-third reduction in light output is acceptable, a more cost-effective option would be to use the Thrift/Mate lamps and possibly upgrade the cleaning schedule. The illumination from a clean two-lamp fixture will be equivalent to the illumination from a dirty two-lamp fixture with the retrofit reflector. Also, if unequal lighting is acceptable, possibly one-third of the existing fixtures could be removed instead.

Lamp Relocation

Poorly arranged light wastes energy. Traditionally, light systems have been designed to provide a uniform level of light through out on entire area. However, with the increased cost of electric energy, the emphasis today is on designing illumination for the type of task and the location where it will be performed.

Nonuniform light is actually more visually pleasing as well as less energy-consuming. When the actual work area is properly lighted, the remaining area requires only a moderate level of general lighting to provide reasonable visibility and to prevent an excessive brightness imbalance, which can cause visual discomfort.

Task lighting has a number of advantages:

- High light levels are concentrated only where needed and are matched specifically to the seeing task. Overall lighting energy usage is thereby reduced.
- Less heat is liberated by the lighting system.
- Lighting is usually more easily relocated as operations change.
- Luminaire maintenance and lamp replacement expenses are usually less because they are more readily accessible.
- Units are individually controlled, permitting them to be shut off when not needed.
- Lighting effectiveness is improved by permitting the most advantageous positioning. Reflection and shadows can be avoided.

Lighting System Replacement

Existing incandescent or mercury lighting systems are usually candidates for replacement. Incandescent lighting is suitable for certain applications, but its low efficiency makes it uneconomical for general illumination. A rapid payback can almost always be shown for replacing mercury with more efficient light sources, and especially with high-pressure sodium.

If a lighting system must be designed to fit a new or modified installation, the alternative systems, listed with their relative output in Table 4.6, should be considered.

High-pressure sodium (HPS) lamps provide the most light per energy input and are the most economical when their color characteristics are suitable (The decided yellow color of low-pressure sodium lamps is usually unsatisfactory for most industrial areas). This lamp is offered in a wide choice of wattages, ranging from a nominal 70 watts to 1,000 watts. Luminaire manufacturers also offer a broad variety of luminaires suitable for various applications in outdoor lighting, manufacturing, and office lighting.

Approximate Initial Lumens per Watt Including Ballast

	Smaller Sizes	**Middle Sizes**	**Larger Sizes**
Low Pressure Sodium	90	120	150
High Pressure Sodium	84	105	126
Metal Halide	67	75	93
Fluorescent	66	74	70
Mercury	44	51	57
Incandescent	17	22	24

Table 4.6: Alternative Lighting Systems

HPS lighting has found wide acceptance as warehouse lighting, where color rendition is usually not critical. The high ceiling height common in warehouses is well-suited to HPS lighting. To meet the challenge of illuminating warehouse aisles, asymmetrical luminaires specifically designed for aisle lighting are available. Overlap of light between fixtures will be adequate even if the luminaires are as much as three times as far apart as their mounting height from the floor. HPS luminaires are also available for low mounting heights. The flexibility of HPS lighting has permitted significant inroads into areas that were formerly reserved for fluorescent lighting.

For comparable wattage, HPS lamps deliver about 50 percent more lumens than mercury lamps, and 500 percent more than incandescent light sources. Efficacy of most sources increases at higher wattages, so for maximum economy, the HPS lighting system should be designed to use the largest sized lamps that are consistent with good lighting practice and controlled brightness.

4.3.4. Summary of Different Lighting Technologies

The potential for energy savings in lighting is twofold, the industry has produced some money (but not many) energy saving products primarily because design engineers have specified excessive lighting levels over the years, and secondly some technological advances have occurred.

Incandescent

Incandescent lighting can be described by the following features:

- Light produced by heating an element until it glows.
- Main reason for use is color rendition and dimming, although recently dimming has been made available for other types of light.
- Reduced wattage/reduced output replacements are now available although no more efficient.
- One type of PAR lamp is now being offered which has a infrared reflective film which makes the filament hotter and brighter.

Fluorescent

Fluorescent lighting can be summed as follows:

- Light is produced by emitting an electronic field which causes the phosphorous to glow (fluoresce).
- More efficient.
- Varying levels of color rendering are available depending on the quality of the rare earth phosphors, and the cost. Color rendering is arbitrary way to compare the color of the light using sunlight as 100 percent.
- New T8 (one inch diameter) lamps produce light more efficiently than previous lamps, but must be used with electronic ballasts.
- Compact fluorescent - twin tube, exit signs. (mention temperature, ref.)

High Energy Discharge

The following types of lamps fall under the high energy discharge category.

- Mercury Vapor
- Metal Halide
- High Pressure Sodium
- Low Pressure Sodium

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