Module 8: Energy Efficiency in Building Electrical Systems

Learning Objectives

After completing this module, you will be able to
- Describe building performance standards that have an impact on energy efficiency;
- Identify and assess energy efficiency opportunities for lighting systems; miscellaneous plug loads; motors, drives, fans and pumps.

8.1 Applicable building performance standards

8.1.1 The South Africa Energy and Demand Efficiency Standard (SAEDES®)

SAEDES is the proposed Energy and Demand Efficiency Standard for existing and new commercial buildings under the **National Mode of Acceptable Practice for Cost, Energy and Environmentally Effective Building Design, Construction, Operation and Maintenance Products, Systems and Professional Service** program. The draft version available at the time of preparing this course was published by DME in February 1999.

A detailed treatment of the Standard is beyond the scope of this course. However, it is instructive to consider what it has to say about commercial buildings and the applicability of its performance criteria on public buildings which are the focus of this audit program.

SAEDES is based on the policy statement expressed below. The issues that the standard speaks to, ***with respect to commercial buildings***, include:
- Minimizing the use of ozone depleting substances (ODS)
- Minimizing the emission of greenhouse gases and so mitigating the impact of building operations on climate change
- Conserving non-renewable energy resources
- Optimising building performance—in particular, energy efficiency—and achieving the economic benefits inherent in this strategy.

The purpose of the standard is to reduce the energy demand (kW) and consumption (kWh) of all energy sources in commercial buildings. It applies to new and existing buildings, and all of the systems of which they are comprised.

Among its provisions, the Standard sets requirements for:
- Minimum demand and energy efficiency of new buildings
- Performance parameters such as
  - temperature control,
  - ventilation rates,
  - lighting levels (see Table 8.1),
  - water discharge temperatures and shower flow rates,
  - building envelope and glazing design criteria (including a requirement for double-glazed windows in locations where climatic conditions exceed 1300 heating degree days (base 18°C)),
  - wall, floor and roof insulation requirements,
  - infiltration limits,

- the analysis of climate in terms of HDD (using base 18°C) and CDD (using base 10°C); Table 8.2 provides HDD and CDD data for selected locations;

- the application of other existing international standards to specific building components and systems (for example, ANSI/AAMA 101-1988 to aluminium windows or ASTM D 4099–89 to PVC windows, or the broadly applicable ASHRAE Standard 90.1-1989R for new building design).

POLICY STATEMENT

Concern for Environmental Impact of the SAEDES Guideline

The South Africa Department of Minerals and Energy is concerned with the impact of energy on both the indoor and outdoor environment.

The government of South Africa and its citizens must strive to minimize any possible deleterious effects on the indoor and outdoor environment of the building and its systems while maximizing the beneficial effects that these systems provide, consistent with the accepted and practical state of the art.

It is the SAEDES Guideline's goal to ensure that the building, systems and components within the scope of this guideline do not impact the indoor or outdoor environment in a negative manner.

The Department of Minerals and Energy (DME) together with all South African's will continue to generate up-to-date energy policy and guidelines. Through this guideline and support material, appropriate sections may contain up-to-date material that can be systematically revised.

South Africa will take the lead with research and dissemination of energy and environmental information of its primary interest and will seek out and disseminate information from other responsible governments and organizations, which is pertinent.

Those whom utilize SAEDES must consider the effects of the buildings design and selection of equipment and systems within the scope of the system's intended use, and expected misuse. The disposal of hazardous materials, if any, must also be considered.

The South Africa Energy and Demand Efficiency (SAEDES) Guideline's primary policy for environmental impact will be at the site where equipment within the scope of building components and systems will operate. However, energy source selection and the possible environmental impact due to the energy source and energy transportation may be considered by users of the Guideline - if that is thought appropriate by the user.

The Standard also provides detailed technical criteria for the calculation of building performance parameters such as overall heat transfer coefficients, etc.

Table 8.1: SAEDES Lighting Levels and Specific Powers in Common Use

Area	Lux	W/m^2
General Office Space	400	17
Computer Rooms & Drafting Areas	600	26
Public Areas (Foyer & Corridors)	200 - 400	7 - 17
Stairs	50 - 100	3 - 5
Kitchen	200-300	10 - 16
Toilets	100	5
Car Park	50 - 100	3 - 5
Plant Rooms	100 - 200	5 - 10
Retail	400 - 800	8 - 25

Table 8.2: Climatic Data for Selected South Africa Cities

City	Latitude	Longitude	SI Units (°C)					
			Elev (m)	HDD	CDD	Win. Des. 99%	Summer DB 2,5%	WB 2,5%
CapeTown/ D F Malan	33,97S	18,60E	46	936	2474	22	72	53
Johannesburg	26,13S	28,23E	1694	1066	2362	13	65	51
Pretoria	25,73S	28,18E	1330	639	3,238	14	69	51

Among its other sections, SAEDES:

- provides designers with the opportunity to deviate from specific criteria provided that the overall energy performance of the building meets or exceeds standards requirements;
- promotes the application of renewable energy sources to supply building needs (e.g. solar heating);
- sets building operation and maintenance requirements;
- defines the function of ESCOs, energy performance contracting, and third party financing for energy efficiency projects;
- provides considerable reference data including climate data (HDD and CDD) throughout the country, equipment standards, etc.

8.1.2 SABS 0400-1990 Ventilation Requirement Standard

SABS 0400-1990 sets air requirements for various applications, some of which are shown in Table 8.3.

Table 8.3: Ventilation Air Requirements (SABS 0400-1990)

Occupancy	Minimum Air Requirement, l/s (per person except where noted)	
	Smoking	Non-smoking
Educational Buildings		
Classrooms	-	7,5
Laboratories	-	7,5
Libraries	-	6,5
Shops		
Malls, arcades, warehouses	7,5	7,5
Sales floors, showrooms, dressing rooms	7,5	7,5
Garages	per m^2 floor area	per m^2 floor area
Parking garages	7,5	7,5
Ticket kiosks	5,0	5,0
Libraries		
General	-	6,5
Bookstock	-	3,5
Offices		
General	7,5	5,0
Meeting and waiting spaces	7,5	5,0
Conference and board rooms	10,0	5,0
Cleaner’s rooms	1,0	1,0

8.2 The building as an energy system

Modern buildings are complex structures; there are significant interactions among the various systems of which they are comprised. The energy auditor needs to look holistically at the building when recommending efficiency measures to ensure that these interactions are taken into account.

8.2.1 Energy interactions of building systems

Among the interactions that need to be considered are the following:

- A lighting retrofit from incandescent to fluorescent lighting, because of the improved efficiency, will reduce the internal heat gain of the building; therefore, in the heating season, the building heating plant may experience an increased load, and in the cooling season, the AC system will experience a decreased load.
- Because the AC system not only cools, but dehumidifies the building, the same lighting retrofit could result in a now over-designed cooling plant to operate less frequently to maintain temperature, but as a result, allow humidity to increase.
- Building envelope improvements to increase insulation and decrease infiltration will have effects similar to those noted above on the heating and cooling plant; also, reducing infiltration could require an increase in fresh air supply in order to maintain occupant comfort and meet indoor air quality standards.
- ***What are some other interactions that you need to consider?***

8.2.2 The impact of measures on power quality, IAQ, and GHG emissions

Some efficiency measures may have negative impacts on some operational factors, as well as positive side-effects on others. The auditor needs to take both into account.

- Modern high efficiency lighting systems, while delivering more illumination for the same power consumption as incandescent fixtures, may introduce harmonics into the electrical distribution system, and adversely affect the operation of electronic equipment such as computers. Power quality effects such as this need to be considered when measures are recommended so that design features can be added to overcome them.

8.3 Energy Efficient Lighting

A lighting system is defined as all of the components necessary to meet a requirement for illumination. This includes all components from the switch that controls the power to the lamps all the way to the reflectance of the space in which the lighting system operates. This is shown pictorially in Figure 8.1

The first consideration when examining lighting systems for energy savings

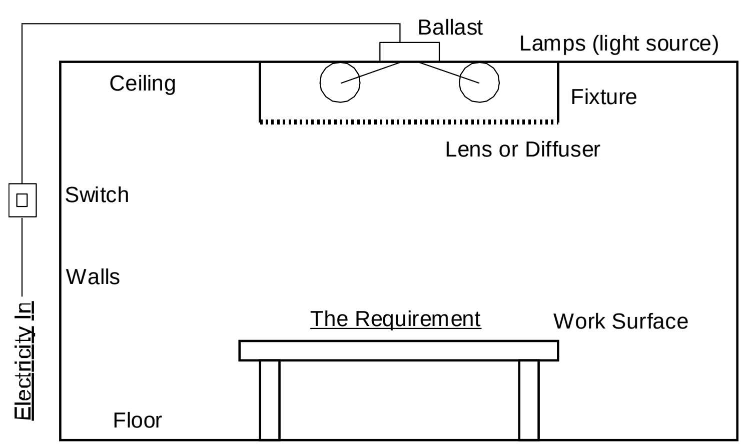


Figure 8.1 A Lighting System

opportunities must always be the requirement for illumination, defined by:

- the duration of illumination required and,
- the level of illumination required.

While significant savings may be achieved through modifications to lighting systems, inappropriate actions can have a far more dramatic effect on worker and occupant productivity and comfort.

The following questions examine a lighting system primarily from the perspective of the requirement:

- ❑ *Are lights on when the space is unoccupied?*
  This may be due in part to a lack of switching, say in a large open space. Also occupants may not be fully aware of the value in switching off lights upon leaving.

- ❑ *Are lights on in an area served by daylight?*
  Again a lack of switching may prevent occupants from turning off lighting when daylight is sufficient. If curtains have been closed to avoid daylight it may be that glare problems exist. Daylight may not always be appropriate.

- ❑ *Is lighting switched from breakers?*
  Breakers were not designed for frequent switching and typically will only allow switching of large areas resulting in lighting in local unoccupied areas.

- ❑ *Is there sufficient and convenient switching available?*
  Occupants may not be able to conveniently control lighting.

- ❑ *Is the level of light appropriate for the task at hand?*
  This may suggest a reduction in significantly over-lit areas which offers an energy savings opportunity. But, it may also suggest an increase in lighting which while consuming more energy could yield comfort and productivity benefits. If changes are to increase/decrease illumination levels, then this is the best time to consider other changes to the system including more efficient light sources.

- ❑ *Is regular maintenance performed?*
  A dirty lighting system will not deliver as much light as a clean one. This may reduce light levels to unacceptable levels or result in installation/use of more lighting and hence more energy consumption. A clean fixture is an efficient fixture. If the fixture is chronically dirty it may be that it is not appropriate for the type of environment in which it is installed.

There are several options available to improve the **match of requirement** to usage of the lighting system including:

- ❑ *Provide more levels of switching*
  Switches that control too large an area can result in unnecessary illumination of unoccupied spaces. Consider re-wiring and adding switch control that is appropriate to the patterns of use of the space.

- ❑ *Use time clocks and/or photocells on outdoor lights*
  Outdoor lighting should almost always be automatically controlled; otherwise, it tends to be overlooked.

- ❑ *Use motion sensors to switch lights*
  Motion sensors work well in areas that are limited in size, and have irregular occupancy patterns.

- *Use timer switches to control lights*
  A good application of timers would be in a warehouse in which occupants are present infrequently, or possibly small washrooms where lights (and fans) tend to be forgotten.

- *Use photocell switching on window fixtures*
  Photocells can be used to switch off a row of lights near a window when the amount of light from outside is sufficient for the activity in the space. Care should be taken to avoid glare when utilizing window light.

- *Use task lighting & turn off overhead lights*
  Using overhead lighting to illuminate very localized tasks is not optimal. Overhead lighting can be reduced to minimum levels for safety (access), and task lighting can be used with levels specific to each task. A desk lamp is a good example of task lighting.

Finally, the following opportunities address the **efficiency of the light source** and delivery system:

- *Use most appropriate design and maintenance*
  Re-consider the overall design of the lighting system present. This should involve performing illumination level calculations, and consideration of the number, position, type and maintenance of fixtures.

- *Convert to a more efficient light source*
  Often converting from one source to another will yield the same illumination level for a fraction of the energy cost. Consider the sources listed in Table 8.5 and the relative light efficiencies – correctly called efficacies. Figure 8.2 presents the same information graphically. As part of the above design analysis, consideration of the light source efficiency could be made.

Table 8.4
LIGHTING TERMINOLOGY AND BASIC UNITS

Quality	Measure of	Symbol	Unit	Definition
Luminous Intensity (candlepower)	Ability of a source to produce light in a given direction	I	Candela (cd)	Approx. equal to the luminous intensity produced by a standard candle
Luminous Flux	Total amount of light	Φ	Lumen (lm)	Luminous flux emitted in a solid angle of 1 steradian by 1 candela point source
Illuminance (illumination)	Amount of light received on a unit area of surface (density)	E	Lux (lx)	One lumen equally distributed over one unit area of surface
Luminous Exitance	Density of light reflected or transmitted from a surface	M	lm/m^2	A surface reflecting or emitting 1 lumen per unit of area
Luminance (brightness)	Intensity of light per unit of area reflected or transmitted from a surface	L	cd/m^2	A surface reflecting or emitting light at the rate of 1 candela per unit projected area

8.3.1 Meeting the Need (Ref. Core Training Program, Module 7, SIEMP)

The lighting system must be designed and operated to meet the need for illumination at the lowest expenditure of energy. Lighting levels that are considered appropriate for various building locations and functions are summarized in Table 8.6.

The quality of the light is also an important consideration in meeting the need. There are two characteristics of the light source that define quality: colour rendering index (CRI), and colour temperature.

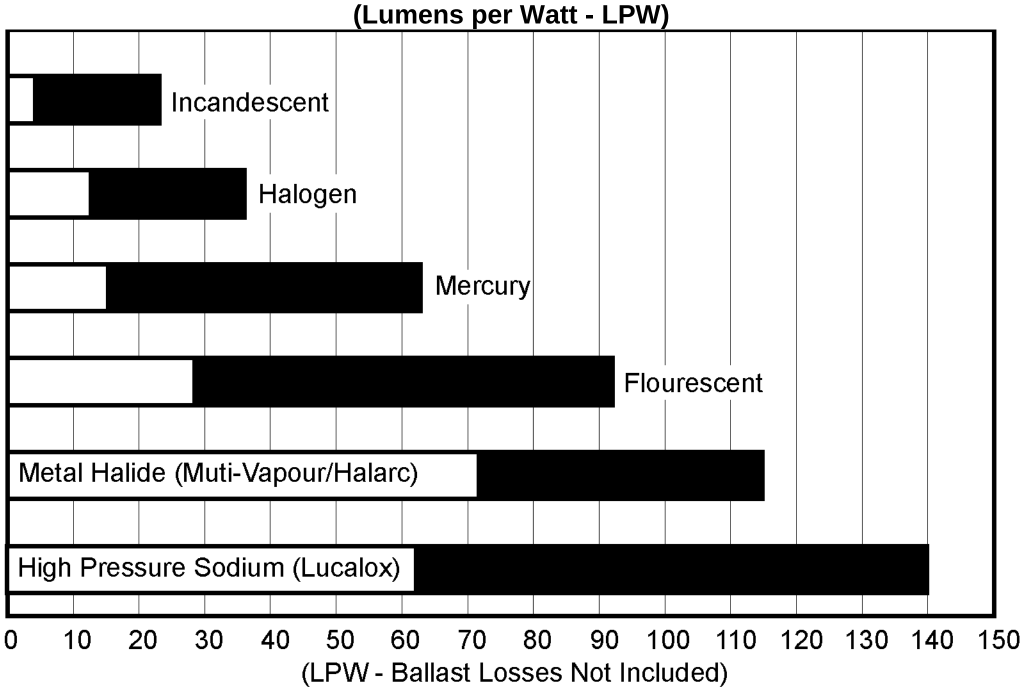
(Ref. http://www.goodmart.com/facts/light_bulbs/cri.aspx)

- **Colour Rendering Index**: CRI is a unit of measure that defines how well colours are rendered by different illumination conditions in comparison to a standard (i.e. a thermal radiator or daylight). CRI is calculated on a scale from 1-100 where a CRI of 100 would represent that all colour samples illuminated by a light source in question, would appear to have the same colour as those same samples illuminated by a reference source. To put it another way, low CRI causes colours to appear washed out and perhaps even take on a different hue, and high CRI makes all colours look natural and vibrant.

Table 8.5 Light Source Efficacy

Lamp Type	Lumens/Watt
Incandescent	10 - 18
Mercury Vapour	20 - 50
Fluorescent	40 - 100
Metal Halide	60 - 100
High Pressure Sodium	60 - 120
Low Pressure Sodium	90 - 200

Figure 8.2
LAMP EFFICACY
(Lumens per Watt - LPW)



- **Colour Temperature** describes certain colour characteristics of light sources. A "blackbody" is a theoretical object which is a perfect radiator of visible light. As the actual temperature of this blackbody is raised, it radiates energy in the visible range, first red, changing to orange, white, and finally bluish white.

Colour temperature describes the colour of a light source by comparing it to the colour of a blackbody radiator at a given temperature. For example, the colour appearance of a halogen lamp is similar to a blackbody radiator heated to about 3000 degrees Kelvin. Therefore it is said that the halogen lamp has a colour temperature of 3000 degrees K- which is considered to be a warm colour temperature.

Though color temperature is not a measure of the physical temperature of the light source, it does correspond to the physical temperature of the blackbody radiator when the colour appearance is the same as the source being tested.

Table 8.6
RECOMMENDED ILLUMINANCE LEVELS,
POWER DENSITIES AND SURFACE REFLECTANCES

Area and Task	Illuminance	Power Density	Reflectances %		
		W/m^2	Ceiling	Walls	Floor
Offices - accounting - drafting - general	750 - 950 750 - 950 540 - 700	25 25 18	70 - 80	40 - 60	20 - 40
Corridors	210	5.5			
Lobbies	320	9			
Cafeterias and Kitchens	320 - 500	14	70 - 80	40 - 80	20 - 40
Lecture Rooms	540 - 700	18	70 - 80	40 - 60	20 - 40
Toilet Areas	320	9			
Laboratories	750 - 950	25	70 - 80	40 - 80	20 - 40
Production - general	750 - 950	25			
Warehouses	320	9			
Roadways	50	2			
Parking	50	2			

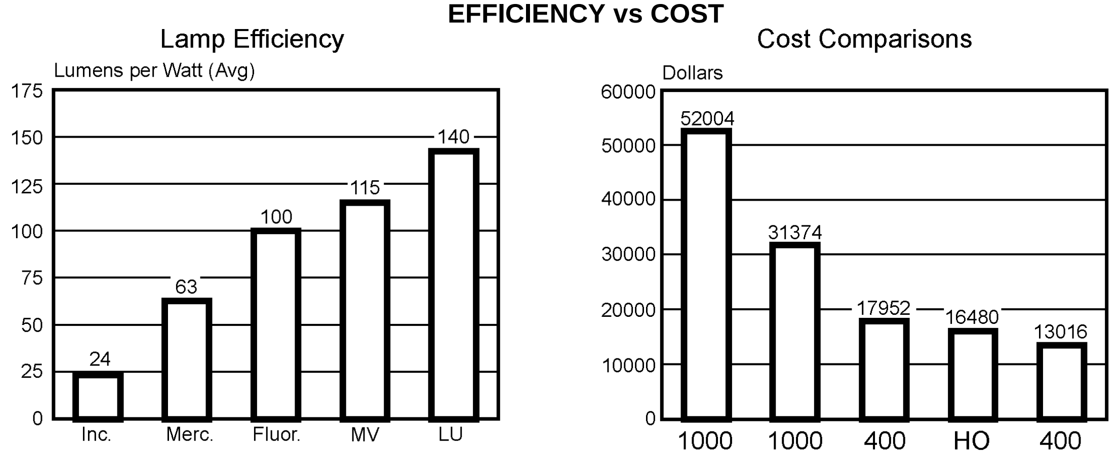
8.3.2 Alternative Light Sources

The characteristics of various commonly used light sources are summarized in Table 8.7.

Table 8.7
COMPARISON OF TYPICAL LIGHT SOURCE CHARACTERISTICS

Characteristic	Lamp Type					
	Incandescent (Tungsten-Halogen)	Low Pressure Discharge		High Pressure Discharge		
		Fluorescent	LPS	MV	MH	HPS
Efficacy Initial Lumens/watt	20 (23)	70	140	50	80	120
Rated Life Hours	1,000 (2,000)	12,000 -20,000	18,000	16,000 -24,000	7,500 -15,000	20,000 -24,000
Ballast Required	No (Yes)	Yes	Yes	Yes	Yes	Yes
Colour of light	Warm	Cool/Warm	Yellow	Cool/Warm	Cool	Warm
Lamp Cost	Low	Low	Low	Medium	High	High
Lamp Lumen Depreciation Factor (LLD)%	90 99	85	103	75	70	90
Operating Cost Comparative only	1.0	0.25	0.15	0.36	0.22	0.2
Warmup/Restrike Time Minutes	Instant	Immed	12/0.5	7/7	5/10	3/1

Figure 8.3
EFFICIENCY vs COST



The Higher the Efficiency - the Lower the Cost of Light

Table 8.8
CHARACTERISTICS OF INCANDESCENT LAMPS

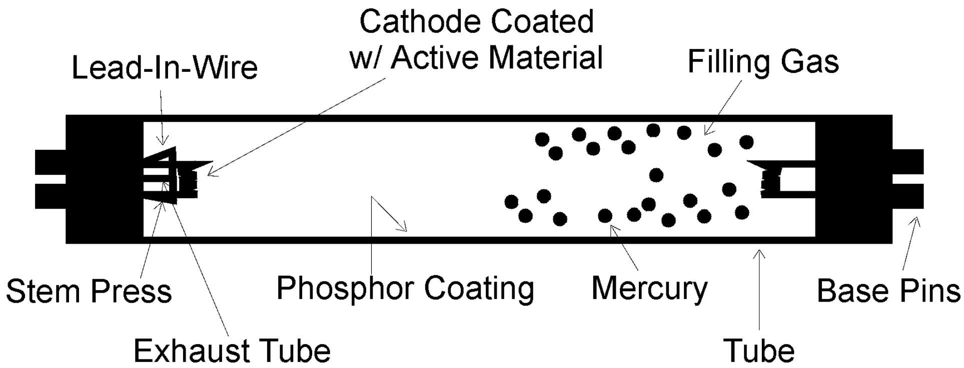
Lamp Designation	Rated Lamp Watts	Lamp Life (hours)	Initial Lumens	Initial Lumens Per Watt
Standard				
A-Standard	40	1,500	455	11.4
A-Standard	60	1,000	860	14.3
A-Standard	75	750	1,180	15.7
A-Standard	100	750	1,690	16.9
R-Reflector	50	2,000	435	8.7
R-Reflector	75	2,000	850	11.3
R-Reflector	150	2,000	1,825	12.2
High Efficiency				
A	34	1,500	410	12.1
A	52	1,000	800	15.4
A	67	750	1,130	16.9
A	90	750	1,620	18.0
PAR	55	2,000	520	9.5
PAR	65	2,000	700	10.8
PAR	90	2,000	1,400	15.6
Double-Ended Quartz				
T	500	2,000	11,000	22.2
T	1,000	2,000	23,000	23.4
T	1,500	2,000	35,000	23.9

8.3.2.1 Fluorescent Lamps

The fluorescent lamp is by far the most common light source used in buildings. It is a tubular, low-pressure discharge lamp containing small amounts of mercury. The fill gas is argon. The lamp tube is coated on the inside with phosphor. In operation, ultraviolet radiation resulting from luminescence of the mercury vapour due to a gas discharge is converted to visible light by the phosphor. As with all gas discharge lamps a ballast is needed to aid starting and to sustain operation. As a linear lamp with a large surface area, its brightness is comparatively low and its potential for discomfort and glare is low. Principal applications are office and industrial interiors and utility areas in the home. Fluorescent lamps are most commonly made with glass tubular bulbs varying in diameter from 16 mm (e inches) to 54 mm (2c inches) and in overall length from 150 to 2440 mm (6 to 96 inches). (See Figure 8.4.)

The fluorescent bulb is historically denoted by a letter, denoting its shape, and a number, indicating its diameter in multiples of 1/8 inch. Thus T12 is a 1½ inch diameter tube. Other letter codes include C (circular) and U (u-shaped).

Figure 8.4
FLUORESCENT LAMP PARTS



Electrodes, hermetically sealed into the bulb, one at each end, are designed to operate on either a glow or a discharge mode, and are referred to as "cold" and "hot" cathodes respectively. The "hot" cathode design results in a more efficient lamp operation, with the result that most fluorescent lamps are designed for this mode of operation. Typically the luminous efficacy or light output in lumens per watt for a T12 fluorescent lamp is in the order of 60 lumens/W. This represents a power conversion efficiency of 10%. The operation of a fluorescent lamp is controlled by a ballast which is connected in series with the lamp. The ballast provides the required starting and operating voltages and limits the lamp current after the arc has developed (the lamp, in common with all discharge lamps, has a negative volts-amp characteristic).

High Output Fluorescent Lamps

Fluorescent lamps are further classified by their operating current, *i.e.* the current that flows through the lamp, not the current taken from the supply. Standard lamps operate at 430mA, High Output (HO) lamps operate at 800mA, and Very High Output lamps operate at 1500mA.

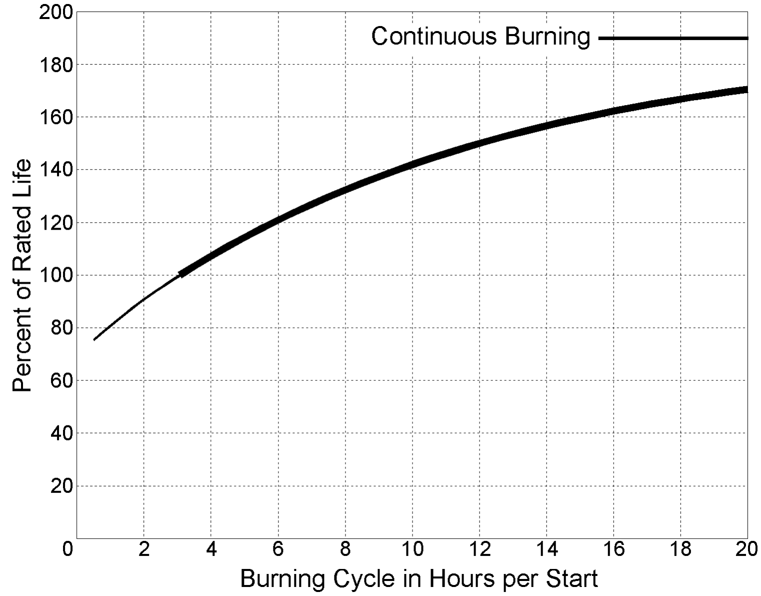
Rated Life of Fluorescent Lamps

The rated life of a fluorescent lamp is a median value of life expectancy.   It is normally defined as the total operating hours at which, under a three-hour operating cycle, 50% of a large number of installed lamps would be expected to be still burning. Typically this will range from 7,500 to 20,000 hours. The burning life of a "hot" cathode lamp is a factor of the rate of loss of the electrons from the cathode. This occurs during starting and operation. The shorter the burning cycle the shorter the burning life. For example a lamp operated continuously can be expected to burn almost twice as long as a similar lamp operated for only three hours per start. This is illustrated in Figure 8.5. This fact has given rise to the belief that fluorescent lamps should not be switched off for short periods of time as the resulting lamp life loss will be more that the cost of saved energy. In general switching a fluorescent lamp off for even 10 minutes will usually be cost effective. The life of a "cold" cathode lamp is not similarly effected.

Ballast and starter characteristics are also a key factor in the operational life of preheat started lamps. Ballasts which do not provide correct starting or operating voltages can greatly affect lamp life.

Proper heating of rapid start lamp electrodes is a critical factor. Poor lamp to lamp holder contact or incorrect wiring can result in little or no electrode heating. Lamps operating in this mode will fail prematurely, say after 50 to 500 burning hours.

Figure 8.5
LAMP LIFE vs BURNING CYCLE



Effects of Voltage Variations

Line voltage, whether too high or too low, will also adversely affect lamp life. Low voltage can cause starting problems which can seriously deteriorate the electrodes. Voltages above normal cause excessive lamp operating currents leading to premature lamp failure and overheating of the ballasts. Generally supply voltages should be maintained within a ± 5% of rated voltage of the ballast.

Energy-Saving Lamps and Ballasts

Energy saving fluorescent lamps are available in most sizes and colour for rapid start, preheat and instant start fixtures. They are lower wattage, in the order of 12% than the equivalent standard lamp but are nearly equal in light output.

Energy saving ballasts are also available; High Efficiency and Electronic Rapid and Instant Start.   Savings in energy using electronic ballasts can be as much as 25%. Fluorescent lamps controlled by electronic ballast operating at high frequency, 20 kHz, are 10% more efficient. Electronic control starters are also available for preheat starting. Although up to 25 times more expensive, electronic starters last longer and start lamps without flicker, thus extending lamp life.

Retrofitting energy efficient ballasts is not a good investment because of the relatively high initial cost, but their use in new installations should be seriously considered. Relamping with energy saving lamps may be more attractive depending on your energy and lamp costs.

Compact Fluorescent Lamps

Compact fluorescent lamps are available from various manufacturers as replacement for incandescent lamps up to 100W.   The lamps, complete with electronic ballasts, are designed to be used in the lamp holder of the incandescent lamp to be replaced, with no modifications required.

Typical compact fluorescent lamps with their wattage and equivalent incandescent lamp wattage are shown in Table 8.9. Although more expensive (up to 20 times) they consume less than 25% the energy for the same light output and last up to 10 times as long.

Table 8.9
CHARACTERISTICS OF FLUORESCENT LAMPS

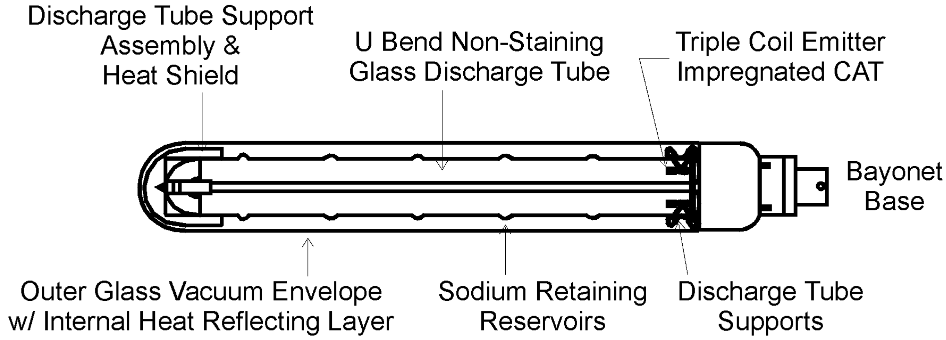
Lamp Desigation	Lamp Length (in)	Lamp Watts	Total Watts Including Ballast 1 Lamp	(2 Lamp)	Lamp Life (hours)	Initial Lumens	Initial Lumens Per Watt
Compact *							
9W		9	11		10,000	600	55.0
13W		13	15		10,000	900	60.0
18W		18	20		10,000	1,200	60.0
Preheat Start							
T-12/CW	48	40	52	96	20,000	3,150	60.6
T-12/CW	60	90	110	204	9,000	6,400	58.2
Instant Start - Slimline 430 mA Single Pin Base							
T-12/CW	48	41	64		9,000	3,000	46.9
T-12/CW	60	42	66	(106)	9,000	3,585	54.3
T-12/CW	72	57		(110)	12,000	4,650	66.4
T-12/CW	96	75		(140)	12,000	6,300	78.8
T-8/CW	72	38	54	(160)	7,500	3,030	56.1
T-8/CW	96	51	67	(107)	7,500	4,265	63.6
Lightly Loaded Rapid Start 430 mA Bi Pin Base							
T-12/CW	48	41	53	(95)	20,000	3,150	59.4
T-8/CW	48	32	37	(71)	20,000	2,900	78.4
T-8/CW	60	40	46	(91)	20,000	3,650	79.4
Medium Loaded Rapid Start 800 mA Recess DC							
T-12/CW	48	63	85	(146)	12,000	4,300	50.6
T-12/CW	72	87	106	(200)	12,000	6,650	62.7
T-12/CW	96	113	140	(252)	12,000	9,150	65.4
Highly Loaded Rapid Start 1500 mA Recess DC							
T-12/CW	48	116	146	(252)	9,000	6,900	47.3
T-12/CW	72	168	213	(326)	9,000	10,640	50.0
T-12/CW	96	215	260	(450)	9,000	15,250	58.7

9W replaces Standard A 40W
13W replaces Standard A 60W
18W replaces Standard A 75W

8.3.2.2 Low Pressure Sodium (LPS) Lamps

The LPS lamp is the most efficient light source presently available, although its quality severely limits its applications in buildings. The LPS is a discharge lamp where the arc is carried through vaporized sodium, producing the characteristic yellow sodium light colour. Lamp shape is a single ended tubular, containing a U-shaped arc tube. (See Figure 8.6.) Unlike other light sources, LPS lamp wattage rises with use to approximately 3% above initial value at rated life. This is coupled with an increase in light output of approximately 5% above initial. As a result, the LPS lamp is able to maintain fairly uniform output during its life. The monochromatic yellow characteristic of LPS renders all colours to appear yellow or as shades of brown. It is most suitable for outdoor area and security lighting.

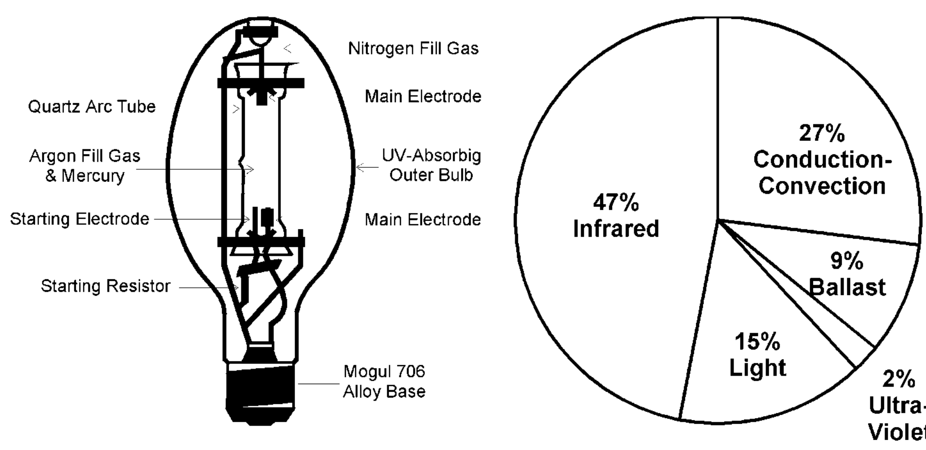
Figure 8.6
LOW PRESSURE SODIUM LAMPS



8.3.2.3 High Intensity Discharge (HID) Lamps

The mercury vapour (MV) lamp is the original point source discharge lamp in which the arc is struck through mercury vapour to produce visible as well as ultraviolet light. Operating pressures of HID lamps are in the order of 1 to 10 atmospheres. Lamps are constructed with two bulbs, an inner bulb of quartz which contains the arc, and an outer bulb to shield the arc tube from temperature variations and to filter out the UV radiation. It is important to ensure that the outer bulb is intact to keep people from the dangers of exposure to UV radiation. Lamps are available that automatically switch off when the outer bulb is broken. The light colour of the clear mercury lamp is predominantly greenish-blue and not very flattering to complexions. Phosphor coated or colour improved mercury lamps correct this by producing a warmer colour effect for indoor applications. The lamp is started by a separate electrode/resistor circuit in the lamp. Starting takes up to 3 minutes. As with all HID lamps a serious voltage dip lasting only a few cycles, or

Figure 8.7
MERCURY VAPOUR LAMPS

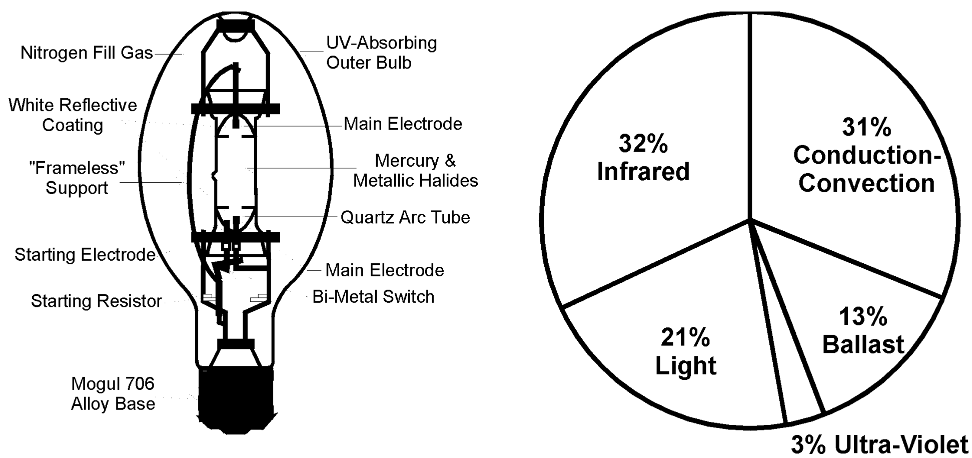


loss of supply for only ½ cycle will cause the lamp to go out. The lamp must cool down and the gas pressure drop, a period of up to 7 minutes before it will restrike. MV has been superseded in efficiency and colour quality by other lamps in the HID family. Users are well advised to consider metal halide and/or high pressure sodium types as more efficient alternatives to MV.

8.3.2.4 Metal Halide (MH) Lamps

The MH lamp is an improved version of the mercury lamp where additive iodine compounds are present in the arc tube to produce a whiter colour light at a higher efficacy than MV. Rated life of this lamp is typically 15,000 hours at present but, with continuing improvements in design, is expected to increase towards the 24,000 hour rating typical with the other HID sources.   Standard MH lamps require different ballasts from MV types.   Most lamp manufacturers, however, have special MH lamps that will work on specific types of MV ballasts. The "white" light produced by Metal Halide lamps make them the choice for sports fields and architectural lighting, and for colour sensitive industrial processes. The lamp warm up and restrike time of up to 10 minutes is a major disadvantage. Double ended lights are available, designed for sport lighting, that can be restruck instantaneously by application of a high voltage spike, 20,000 volts, to the starting electrode.

Figure 8.8
METAL HALIDE LAMPS



8.3.2.5 High Pressure Sodium (HPS) Lamps

HPS lamps utilize a ceramic arc tube containing sodium, mercury and xenon gas. The HPS ballast differs from other HID ballasts in that starting is accomplished by a high voltage pulse. The arc tube of the HPS lamp is too small to accommodate a separate starting electrode.   The xenon gas acts as a starting gas and as the arc tube heats up, the mercury and sodium vapourize to produce the golden-white discharge. Restrike time with the high voltage pulse is about one minute. Restrike can be achieved instantaneously by applying a 40,000 volt spike. Less expensive solutions incorporate a quartz incandescent lamp or a second arc tube in the same glass envelope. Principle applications are in roadways, area and industrial lighting. However, HPS can also be used in non-colour sensitive areas, such as warehouses and gymnasiums. Generally HPS lamps cannot be used with MV or MH ballasts.

Figure 8.9
HIGH PRESURE SODIUM LAMP

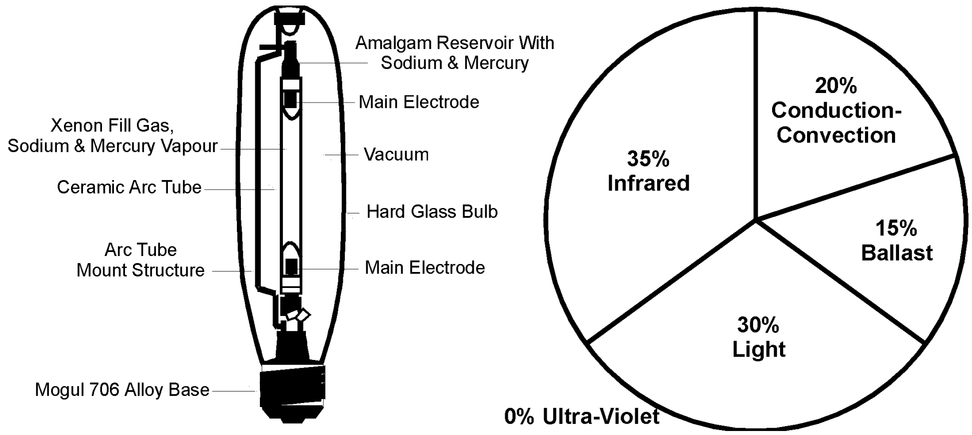


Table 8.10
CHARACTERISTICS OF HIGH PRESSURE DISCHARGE LAMPS

Lamp Designation	Lamp Watts	Total Watts including Ballast 1 Lamp	(2 Lamp)	Lamp Life (hours)	Initial Lumens	Initial Lumens Per Watt
MERCURY VAPOUR						
Phosphor Coated						
	250	285	(570)	24,000	11,000	38.6
	400	455	(880)	24,000	23,000	505
Self-Ballasted						
	250			12,000	5,000	20.0
	400			16,000	9,000	21.1
METAL HALIDE						
Clear						
	75	90		15,000	5,000	55.6
	150	180		15,000	11,250	62.5
	250	300		15,000	20,000	66.7
	400	475		20,000	40,000	84.2
HIGH PRESSURE SODIUM						
Clear						
	70	95		24,000	6,000	63.2
	100	130		24,000	9,500	73.1
	150	190		24,000	16,000	84.2
	200	250		24,000	22,000	88.0
	250	305		24,000	27,500	90.2
	400	475		24,000	45,000	105.3

8.3.3 Energy Management Opportunities – Lighting

- **Switch off Unnecessary Lights**

Switch off lights in unoccupied areas, and in areas where daylight provides adequate lighting levels. Switching can be done manually or by automatic control. Manual switching can be facilitated by providing light switches at strategic points. Automatic controls include photo cells, occupation sensors and time switches. Perhaps the cheapest solution is to delegate the responsibility for switching off lights to operating and security staff.

- **Remove Redundant Fixtures**

Many plants undergo modifications and reorganization. Areas are redesignated and equipment moved but the lighting system is not correspondingly updated, with the result that lights may become redundant. An example of this is where a new office has been built within an existing covered area. The original lighting over the new office becomes redundant and should be removed. Energy and lamp costs are reduced, and the removed fixtures can be reused.

- **Fixture Delamping**

This measure simply entails removing selected lamps from existing light fixtures. Either lamps are removed in a uniform pattern throughout specific areas to reduce overall lighting or selected lights that do not contribute to task or safety lighting are removed. Fluorescent fixtures generally have two lamps operating on a common ballast. Removal of one lamp will cause the other lamp to extinguish. Either both lamps should be removed or one lamp replaced by a dummy tube. In the former case the fixture should be disconnected from the supply as the ballast will continue to consume power, at approximately 15% of the lamp wattage. Dummy tubes are available at approximately the same cost as standard lamps. In areas where lamps have burnt out and production has not been adversely affected, delamping should be implemented as soon as possible.

- **Fixture Relamping**

Fixture relamping is the replacement of an existing lamp with a new more efficient light source. Fixture relamping will involve more initial cost than delamping.

Examples of relamping:

Existing Standard Lamps	Energy Efficient Equipment
Incandescent A Lamp	Energy Saving A Lamp Halogen A Lamp Compact Fluorescent
Incandescent R Lamp	Energy Saving R Lamp Compact Fluorescent Halogen PAR Lamp
Incandescent PAR Lamp	Lower wattage PAR Lamp Energy Saving PAR Lamp Halogen PAR Lamp Compact Fluorescent

T12 Fluorescent Lamp 4ft (430 mA - 40 watts)	34 watt ES (Energy Saving) Lamp 28 watt T-8 System
T12 Fluorescent Lamp 8ft (430 mA - 75 watts)	60 watt ES Lamp
T12 HO Fluorescent Lamp 8ft (800 mA - 110 watt)	95 watt ES Lamp 60 watt ES or 75 watt Lamp
T12 VHO Fluorescent Lamp 8ft (1500 mA - 215 watt)	185 watt VHO ES Lamp 95 watt ES Lamp

- **Fixture Modifications or Replacement**

Fixture modifications cover a wide range of techniques which may be implemented to improve existing lighting systems:

- **Remove Or Replace Fixture Lenses**

  Lighting levels can be increased by removing fixture lenses. In bigger areas in excess of 16 m^2 resulting glare may be a problem. In such cases the lens could be cleaned or replaced.

- **Retrofit the Existing Lighting System with A More Efficient System**

  Replace outdoor tungsten halogen lights with high pressure sodium, or indoor mercury vapour lights with high pressure sodium.

- **Replace Inefficient Ballasts**

  This measure is usually only cost effective if the existing ballast has burnt out.

- **Cleaning Light Fixtures, Lamp Reflectors and Room Surfaces**

Although regular maintenance may not directly save energy costs, the lighting system will be more efficient and effective. Depending on the environment, lamps and reflectors should be cleaned every 1½ - 3 years for open fixtures. Fixture lenses should be cleaned every ½ - 1½ years. Regular cleaning can reduce light loss by up to 30%. By maintaining room reflectances light loss can be further reduced by an additional 10%. A regular maintenance programme should be instigated before any other energy conservation measures are considered.

8.3.4 Worksheets

Worksheets 8-1 and 8-2 at the end of this module provide templates for calculating the value of lighting retrofits.

8.4 Plug Loads

"Plug loads" refer to those many electricity consuming devices that are not permanently hard-wired into the building electricity distribution system. They include office equipment, kitchen and cafeteria appliances, portable heaters and coffee makers, and so on. While small energy consumers individually, in total they can comprise a significant portion of the electrical load in the building.

Typically retrofits do not address these loads. However, in assessing opportunities for savings, the auditor should consider what the impact will be of changes in usage patterns (e.g. turning off computers at the end of the work day) or in equipment selection (specifying energy efficient models for all new purchases—e.g. using Energy Star® compliant devices or similar guidelines).

Guide to Energy Efficient Equipment Selection

Energy Star® is a government run program developed by the US Department of Energy, and adopted in Canada (for one). It provides energy ratings for a wide range of electrical devices, both domestic appliances as well as office equipment. A comparison between compliant and non-compliant equipment is illustrated in the following example. This calculation is done using a savings calculator available from Energy Star at http://www.energystar.gov/index.cfm?c=bulk_purchasing.bus_purchasing.

(Please insert the relevant figures in the gray boxes.)	**ENERGY STAR- Labeled Unit**	**Non-ENERGY STAR- Labeled Unit**
Number of units*	1,000	1,000
Watts per unit in "sleep" mode**	45.0	NA
Initial cost per unit* (estimated retail price)	$1,400	$1,400
Assumed product lifetime (years)	4	4

* *One unit is defined as having a central processing unit (CPU) and a monitor. NA = Not Applicable; see product assumptions.*

** *Please input this figure from the Program Compliant Products List at www.energystar.gov. To find the Watts in sleep mode, refer to both the Computer List and the Monitor List. Then, add the two numbers together and enter the total value into the appropriate cell above.*

OPERATING COSTS FOR 1000 COMPUTER(S) AND 1000 MONITOR(S)

	ENERGY STAR- Labeled Unit	Non-ENERGY STAR- Labeled Unit
Annual Operating Costs‡		
Energy cost	$17,361	$39,013
Maintenance cost	$0	$0
Total annual operating costs	$17,361	$39,013
Life Cycle Costs‡		
Lifetime operating cost (energy and maintenance)	$63,019	$141,612
Purchase price for 1000 unit(s)	$1,400,000	$1,400,000
Total life cycle costs	$1,463,019	$1,541,612

‡ *Please note that all costs, except initial cost, are discounted over the products' lifetime. Annual costs exclude the initial purchase price.*

BENEFITS OF ENERGY STAR FOR 1000 COMPUTER(S) AND 1000 MONITOR(S)

For an additional investment of	**$0**	, purchasing 1000 ENERGY STAR-compliant
computer(s) and monitor(s) could save approximately	**$78,593**	over the products' lifetime. Therefore, your
estimated net savings would be	**$78,593**	. With simple payback, the annual maintenance and
energy savings would pay back the initial investment in	**0.0**	year(s).† These savings are the equivalent
in carbon emissions of removing approximately	**168.21**	automobiles from the road for a year.

† *Please note that a payback period of zero years means that the payback is either immediate, or it is less than one year.*

Please keep in mind that this analysis provides a simple estimate of product savings. To determine the true product savings, consult the individual EPA and DOE programs, or call 1-888-STAR-YES.

8.5 Motors, drives and driven equipment

8.5.1 Electric Motors

An important energy consuming technology is electric motors. However, motors are not the end-user of the energy. Consequently they should not be the first consideration when seeking energy saving opportunities. The load driven by the motor often offers far more opportunity for energy saving than the motor itself.

A simple example will illustrate this point. Consider a 20 HP motor driving a pump 24 hours per day, 365 days per year. The motor is operating at an efficiency of 85%. A new energy efficient motor would operate at 87.5% efficiency. Is this a good savings opportunity? It may be, but the first question we need to ask is does the pump need to operate continuously? If we can achieve a 10% reduction in pump run time, the savings would be 3 times what the motor efficiency improvement would be. A further question would be to assess the operating conditions of the pump since even greater efficiency improvements are possible in that part of the system.

Regular maintenance will yield energy savings. It is suggested that **the system driven by the motor** always be considered first. Once that is complete then one could consider the replacement of the motor.

8.5.1.1 Motor Operational Opportunities

Before considering replacement of a motor, there are a number of operational opportunities that are worth considering:

Ensure Proper operating conditions:

- ❑ balanced and correct voltage can save 3-5% of motor energy and prolong the life of the motor – Figure 8.10 shows the relationship between motor losses and voltage balance for a 3 phase motor.
- ❑ ensure that the frequency of starting is within the motor’s capability.

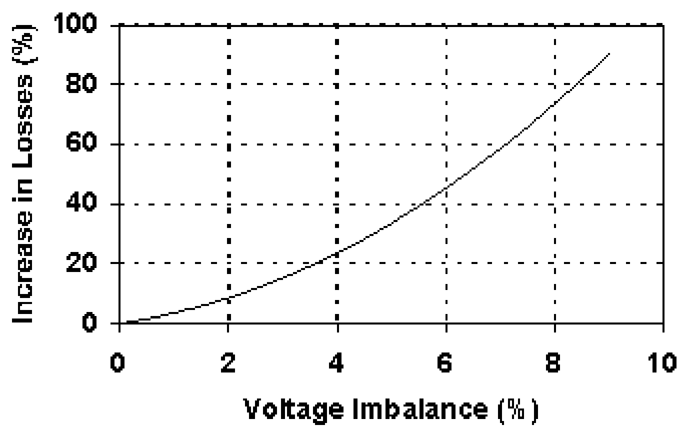


Figure 8.10: Motor Losses Due to Voltage Imbalance

Good maintenance:

- clean motors will run cooler, last longer and use less energy – the primary contributor to motor failure is heat.
- proper lubrication will maintain efficiency,
- provide appropriate protection devices
- carry out regular mechanical and electrical diagnostics for larger motors.

8.5.1.2 Motor Replacement Issues

Before considering a replacement of any motor with a more efficient or high (premium) efficiency motor one must first ensure that the motor is properly matched to its load – fan, pump, compressor etc. Typically, AC induction motors deliver a fairly constant efficiency down to approximately 50% of nameplate output, as depicted in Figure 8.11. Below that point efficiencies tend to decline rapidly. Many motors are designed to have optimal efficiency at 75% of rated output; a certain amount of over-sizing has been anticipated by the motor designer.

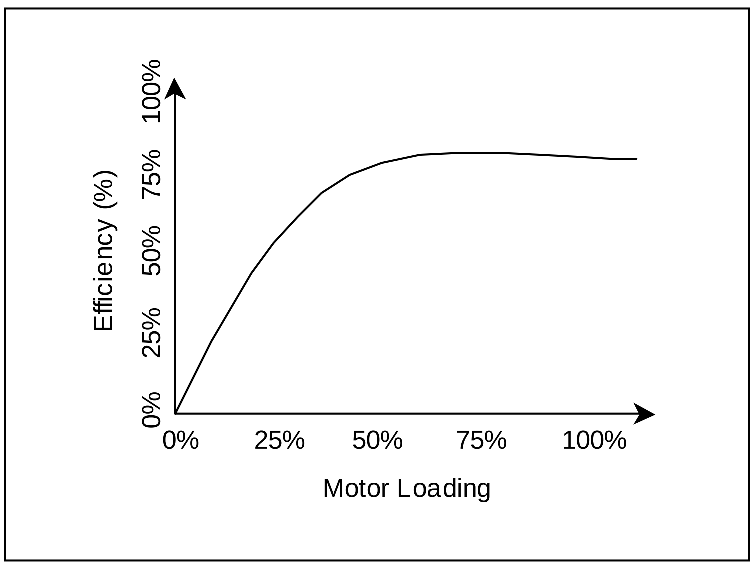


Figure 8.11: Motor Efficiency versus Loading

8.5.2 Fans and Pumps

Fans and pumps are the mechanical conversion devices used to satisfy the requirements for fluid movement and could easily use one half of all of the electricity consumed in the plant. Although their individual efficiencies can range up to 80 %, their faulty application, misuse and lack of regular maintenance can lead to extensive savings opportunities.

8.5.2.1 Assessment of Fans and Pumps

Fans and pumps have to work into and in harmony with their respective fluid distribution systems. When they are operated on either side of their ideal operating conditions (too much/too little flow or into too much/not enough pressure) their reasonable efficiencies can drop off at a dramatic rate.

Thus a three step approach is suggested:

1) Determine the need for flow and match the delivered flow in time and volume.
2) Analyze the distribution systems - look for ways to reduce resistance to flow.
3) Ensure that the pump or fan is the correct one for the application and is operating at close to optimal conditions - if not reconsider the pump/fan selection.

Figure 8.12 shows the relationship between pressure, flow and the optimum operating point for a centrifugal pump. The most efficient operation of the pumping system is at the optimum point with minimum possible flow restriction. A similar set of relationships exist for centrifugal fans and blowers.

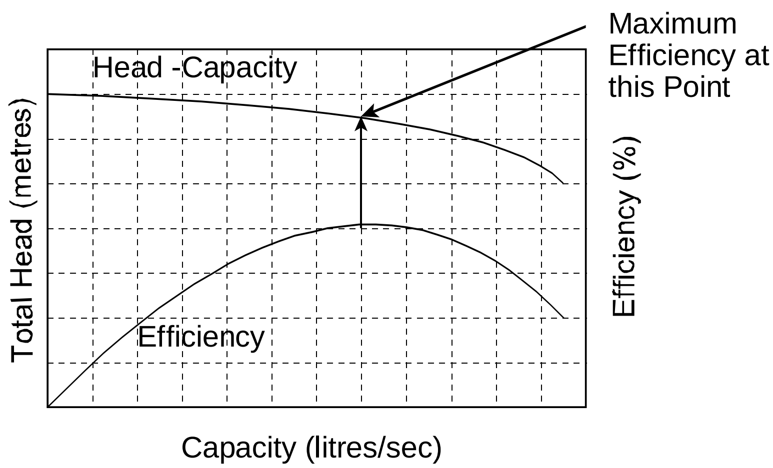


Figure 8.12: Optimum Pump Operation

8.5.2.2 Questions Leading to Opportunities

- ❑ *Is the fan/pump being throttled at the discharge?*
  Capacity control by discharge throttling will result in extremely low system efficiencies. If the system is operating at low volume delivery for extended periods, it may be oversized. Sometimes throttling may not be obvious. A half open valve in a pumping system is not easy to spot.

- ❑ *Is the fan/pump doing a meaningful job?*
  Sometimes standby or backup pumps/fans will run unnecessarily.

- ❑ *Is the fan/pump correctly sized?*
  As mentioned previously, a clue to this may be the necessity to control the unit's capacity. Less obviously, the fan/pump may be operating at a condition that yields the desired capacity but in a very inefficient region of the unit’s operating characteristic.

- ❑ *Check fan/pump curves; is the equipment operating efficiently?*
  Following from the previous question, obtain the unit's characteristic curve and check the efficiency.

- ❑ *Does the requirement for air/liquid vary?*
  In certain circumstances this may be obvious - say in a variable volume ventilation system. Less obvious would be the case in which at present a fixed

volume of ventilation air is delivered, while occupancy may vary. During certain times of the day it may be possible to reduce the flow significantly.

- *Can the fan/pump be slowed down?*
  If there is a requirement for varying flow within the system? Could this be achieved by reducing the fan/pump's speed? Would this cause other operational problems?

- *Can the system head be reduced, ducts/pipes cleaned?*
  The system head, or resistance to flow may be increased by an accumulation of contaminants in the system. Make sure all filters/strainers are well maintained. Often poor pipe or duct routing may unnecessarily increase the resistance to flow.

- *Is the fan/pump excessively noisy, hot or vibrating?*
  Noise, heat and vibration, while causing maintenance problems, also are losses of energy. On a small motor drive, a loose belt could easily waste 5-10% of the energy transmitted. Also, a pump that is operating in the incorrect inlet pressure range will cavitate – producing noise and damaging the pump impeller.

- *Are there leaks in the air distribution ducts system?*
  Losses of the active fluid in a system lead directly to energy loss. While in pumping systems these may be obvious and are usually repaired quickly, leaks in air distribution duct work goes unchecked in many cases.

- *Is the fan being throttled at the inlet?*
  This is more efficient than discharge throttling, check to make sure that variable flow over the range provided is necessary.

8.5.2.3 Selected Savings Opportunities

More detailed analysis is required for these opportunities:

- *Clean and balance air distribution systems*
  Air distribution systems that are poorly maintained will increase the power required by the fan to circulate air. Avoid excessive closing of dampers when balancing a system. Consider fan speed and hence flow reductions after balancing a system in order to minimize the use of dampers for flow control.

- *Check overall fan/pump sizing and efficiency*
  Changes after the initial design of a system can result in inefficient fan/pump operation. This results when the conditions imposed upon the fan/pump are not ideal for the type and/or size of fan/pump. By re-considering the design and operating conditions of the fan/pump, it may be possible to make changes that will result in higher efficiency.

- *Eliminate air flow reduction with dampers/fluid flow control with valves*
  Controlling the capacity of air/fluid that a system delivers by speed control (as described in the previous item) is far more efficient than conventional methods of flow control such as discharge dampers/inlet guide vanes on fans or throttling valves on pump systems.

- *Use a booster fan/pump*
  In a situation where the pressure differential that a fan/pump will operate under is relatively high, it may be possible to achieve a higher system efficiency and lower power requirements by utilizing a booster fan/pump to assist the main fan/pump.

- *Reduce fan/pump speed*
  When the speed a centrifugal fan or pump is reduced by 50%, the flow delivered is reduced by 50% but, the power required to drive that fan/pump may be reduced by up to 87.5%. Methods of speed reductions include a two speed motor, sheave or pulley changes, the use of a mechanical variable speed device, or the use of an electrical variable speed drive appropriate to the application at hand. Even small reductions in centrifugal fan/pump speed will result in large reductions in power. Figure 8.13 illustrates this saving opportunity graphically.

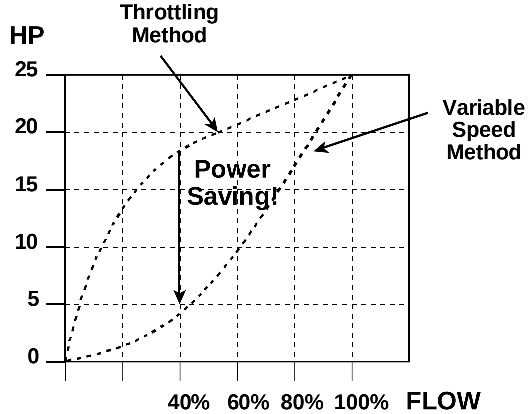


Figure 8.13: The Power-Flow Relationship

8.5.2.4 A Simple Variable Speed Example

This simple example will consider the following situation:

A fan is used to supply air to a process furnace. The requirement for air in the furnace varies over the duration of each heat, typically 10 hours. Flow variation is facilitated with a discharge damper on the fan. The Fan is driven by a 150 kW motor. Operating data is as list in Table 8.11. The motor input power, time and flow requirement is measured, the Energy used is calculated from the time and power input.

Table 8.11: Existing Operating Parameters

Flow Required	Time (hours)	Motor Input Power (kW)	Energy Used (kWh)
100%	2	163	652
50%	6	124	496
25%	2	98	196
Total Electrical Energy Used			1344

As outlined in the previous section, the opportunity that exists here is to utilize a variable speed drive (VSD) to modulate the flow rate by varying the motor speed. The power-flow relationship of Figure 8.13 can be used to estimate the motor input power with a VSD.

Table 8.12 gives the fractions of full power required by the fan at each of the flow rates, under variable speed conditions. The motor input power is calculated from the full motor input power and the fraction. In this example we assume that the motor's efficiency is maintained somewhat constant at all speeds when used with the VSD. Again the energy used is a product of time and power.

Table 8.12: Proposed Operating Parameters

Flow Required	Time (hours)	Fraction of Full Power	Motor Input Power (kW)	Energy Used (kWh)
100%	2	100%	163	326
50%	6	24%	39	234
25%	2	6%	16	32
Total Electrical Energy Used				592

The result here shows that the VSD application reduces the energy required to 44% of the original amount saving 592 kWh per heat cycle. On an annual basis, for 600 heats per year, this would save 355,000 kWh.

8.6 Compressed Air Systems

While an important energy consumer in industrial facilities, compressed air systems are also found in buildings, for example to supply air to pneumatic control systems.

Compressed air is an expensive utility, and it is rare that enough attention is paid to the maintenance that these systems require. As typical compressed air system efficiencies range from 5 to 20 % the cost of energy in the form of compressed is at least 5 times that of electricity. Small changes to the systems can provide large savings opportunities with quick payback periods.

With the high cost of the delivered energy form, actions to reduce the end-use are most important. For this reason reduction in air leakage is the number one priority. Ironically, leaks may consume from 10 to 35% of a system's capacity for air delivery. Reduction in air leakage translates directly to savings in electricity to the compressor.

8.6.1 Efficiency Strategy

Operational actions are by far the most cost effective opportunities in these systems. A simple strategy with four categories of actions would be:

1. Reduce leaks.

2. Manage end-use:

- ❑ Ensure that the end-use is appropriate,
- ❑ Ensure that appliances operate at correct pressure,
- ❑ Use properly engineered nozzles where appropriate,
- ❑ Valve off equipment when not in use,
- ❑ Only use dry air when and where necessary.

3. Minimize pressure drops:

- ❑ in the distribution system,
- ❑ at the compressors' intake system,
- ❑ avoid unnecessary air dryers.

4. Operate compressors efficiently:

- ❑ sequence multiple units to avoid light loading,
- ❑ maintain and lubricate.

These actions and more are discussed in detail in the following sections. First a set of questions that may uncover opportunities:

- ❑ *Are you supplying leaks in distribution system/end use?*
  The amount of energy lost to air leaks is directly proportional to the volume of air leaked.

- ❑ *Is the supply pressure higher than required to overcome pipe loss?*
  Is the compressor delivering air at a pressure significantly above that of the highest end use requirement ? If so, there may be restrictive piping in the distribution system.

- ❑ *Can you reduce the requirement for air?*
  Is compressed air being used inappropriately? The most common occurrence of this is using air to clean up.

- ❑ *Can compressor inlet pressure be raised?*
  Are there unnecessary restrictions in the inlet piping, possibly the filter is dirty?

- ❑ *Can compressor inlet temperature be dropped?*
  Is the inlet air to the compressor outside or inside - cooler air is often available outside.

- ❑ *Is compressor drive system efficient?*
  For smaller units - are drive belts tight?

- ❑ *Do screw compressors have proper capacity control?*
  Does the compressor have suction (inlet) throttling or slide valve control? Suction throttling is highly inefficient at low air flows.

- ❑ *Is storage capacity large enough?*
  Does the compressor(s) cycle frequently - if so, maybe a larger receiver is necessary.

8.6.1.1 Detailed Opportunities

- ❑ *Reduce leaks in air distribution system and at point of use.*
  A simple test (timing compressor cycles when no air is being used) will determine the magnitude of leaks in the system. By performing the test twice, with and without the appliances connected will show the leakage at the point of use.

- ❑ *Reduce compressed air system pressure*
  Any reduction in the pressure of air delivered by the compressor will directly yield power savings at the compressor. For example, make sure that if the supply air pressure is 105 psig, that is actually required. If the system is sized properly a reduction of 5-7 psig may be possible.

- ❑ *Reduce compressed air requirements*
  Compressed air can be a large consumer of electricity. For this reason a survey of where air is being used can be very useful. Just as a load inventory will uncover wasteful uses of electricity - a compressed air survey can reveal significant opportunities for air consumption reduction and hence electricity savings.

- ❑ *Ensure low inlet restrictions (clean air filter)*
  By ensuring low inlet air restrictions the compressor requires less power to compress the air.

- *Reduce inlet air temperature (relocate the intake)*
  Colder air is denser and thus for each volume compressed allows the compressor to deliver more air. Overall this improves the efficiency of compression, reducing energy consumption.

- *Provide sequencing control of air compressors*
  In a multi-compressor installation, sequencing of the compressors to best meet the demand for air will result in a higher overall efficiency. Such a control scheme would attempt to fully load the operating compressors by starting and stopping the various units present.

- *Use screw compressors with capacity control*
  Screw compressors without slide valve capacity control operate with very low efficiency when they are operating at partial capacity. A fully unloaded screw compressor with only suction throttling capacity control may consume up to 80% of its full load horsepower. Sequencing of the compressors as described above can avoid operation at partial loads for extended periods.

- *Consider two stage compression with cooling*
  Two stage compression is a more efficient method of compressing air, but also more costly from an equipment capital cost standpoint. In some instances a retrofit may be possible.

8.6.1.2 The Cost of Compressed Air Leaks

The major source of losses in a compressed air system is leaks in fittings, hoses, connections, etc. Leaks can account for up to 30% of compressed air and, thus, electrical consumption. Some typical leakage rates for different hole sizes are:

Hole Diameter	Air Leakage @ 600 kPa (87 psi) (Gauge)
1 mm	1 l/s
3 mm	10 l/s
5 mm	26.7 l/s
10 mm	105.7 l/s

Simplified Air Leakage Test

Step 1. Determine the free air delivery capacity (Q) of your compressor (liters/second).

Step 2. During a time when equipment is connected but not being used on the compressed air system, turn on the compressor and allow it to come up to full pressure.

Step 3. Record the time (t) until the compressor starts again (loads).

Step 4. Record the time (T) until the compressor stops (unloads).

Step 5. Repeat the measurements at least four times.

Step 6. Average the t and T cycles.

Step 7. Calculate the leakage:

$$\text{Leakage} = \frac{Q \times T}{T + t} \text{ litres/second}$$

Savings and Payback Calculations

After determining the leakage using the above rate, the cost of these leaks can be calculated:

Leakage Cost (R/Yr.)

$$= \frac{\text{Leakage (L/s)}}{\text{Q (L/s)}} \times \text{Full Load (kW)} \times \text{Operating Time (hrs/yr.)} \times \text{Energy Cost (R/kWh)}$$

Where:

Leakage: Calculated using above test

Q: Delivered air capacity (from nameplate)

Full Load kW: Measured or from nameplate (Volts x Amps x Power Factor x √3 (for 3 phase only)

Operating Time: the hours per year that the compressor is energized (not just the actual time it is running).

Energy Cost: From current electric rates, use second block energy charge.

This calculation will show the annual cost of the leaks. While it would not be possible to eliminate 100% of the leakage, the magnitude of the cost as calculated here will give you some indication of the level of repairs which can be justified on a payback calculation.

Worked Example:

Given:

Q (air delivery capacity)	=	236 L/s
Full load nameplate kW	=	125 kW
Operating time	=	4 022 hrs/yr.
2nd block energy cost	=	R.25/kWh

Measured:

	T(on time)	t(time between starts)
	30	180
	32	178
	33	188
	30	182
Avg.	31.25 sec.	182 sec.

$$\textbf{Leakage} = \frac{Q \times T}{T + t} = \frac{236 \times 31.25}{31.25 + 182}$$

$$= 34.58 \text{ L/s}$$

Energy Loss Due to Leakage	=	(34.58/236) x 125 kW x 4,022 hrs/yr.
	=	73 666 kWh/yr.
R Lost Due to Leakage	=	R0.25/kWh x 73 666 kWh/yr.
	=	R18 420/yr.

Worksheet 8-1 Lighting System Opportunities

Verify the Need		
	Lower Cost / Operational	**Higher Cost / Technological**
Match the Need		
Maximize Efficiency		
Optimize Energy Supply		

Worksheet 8-2: Lighting System Retrofit Savings Calculation

Existing Demand:

_________ lamps x _________ kW/lamp = __________ kW

x R _________ / kW / month x 12 months / year = R ____________ /year

Existing Energy:

_________ kW x ___________hrs/year = ____________ kWh/year

x R _________ / kWh (marginal) = R ____________ /year

_________ lamps x (_________ hrs/yr ÷ ___________ life hrs)

X R __________ lamp (replacement) = R ____________ /year

Total Existing Cost . . . . R __________ /year

Proposed Demand:

_________ lamps x _________ kW/lamp = __________ kW

x R _________ / kW / month x 12 months / year = R ____________ /year

Proposed Energy:

_________ kW x ___________hrs/year = ____________ kWh/year

x R _________ / kWh (marginal) = R ____________ /year

Proposed Re-lamping:

_________ lamps x (_________ hrs/yr ÷ ___________ life hrs)

X R __________ lamp (replacement) = R ____________ /year

Total Proposed Cost . . . . R ___________ /year

R __________ - R___________

Simple Payback = ______________________________ = ___________ **years**

R ___________