IMPROVING ENERGY EFFICIENCY IN ELECTRICAL SYSTEMS

NATIONAL ENERGY CONSERVATION CENTRE

ENERCON

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ENERCON
National Energy Conservation Center
ENERCON Building, G-5/2, Islamabad

Ministry of Water and Power
Government of Pakistan

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Foreword

ENERCON, the National Energy Conservation Centre, aspires to lead and coordinate the national efforts to improve energy efficiency and reduce energy waste. ENERCON programs include technical services, training courses, information, publications and special policy studies. Awareness is the first step in the process of efficiency improvement and conservation of energy. In order to create this awareness, ENERCON's strategy includes developing information materials which directly supports it programs.

At this juncture, Pakistan is passing through a very critical phase with respect to availability of energy in any form and especially the energy in the form of electrical energy. With the passage of time, electrical energy has become an integral part of our society. It has assumed a very important role whether we try to consider industrial, commercial, buildings, and residential sector.

The country is facing serious load shedding, at present, and the situation is not going to improve in the very near future if we do not deal with the situation on war footings. To meet the current crisis, definitely, one of the solutions is to increase the generation capacity in the country, which dependent on the availability of thermal energy. Thermal energy resources have also becoming scarce. Therefore, it is time to popularize the use of alternative renewable energy resources available in the country. The Government of Pakistan is striving to promote the use of renewable energy resources, which has to overcome the shackles of financial and other barriers. However, one of the cheapest resources for making the energy, including electrical energy is the judicious and wise use of available energy. It constitutes energy efficiency and conservation. As a nation, it should become our second habit. ENERCON has successfully demonstrated through its projects, carried out in all sectors of economy, that conservation and efficient use of energy is the cheapest source of making energy available for ourselves and for the whole country. It has its financial benefits also. Let all of us make it a common goal and deal with the current crisis on war footings.

ENERCON recognizes that education and training of the managers, professionals, technical staff in the field of energy efficiency and conservation is a very fruitful and rewarding exercise and attempt.

With these objectives, ENERCON has undertaken to revise its manual, which was produced long time ago, and to keep abreast of the current technologies and approach. However, the principles remain the same. Approach to using energy resources intelligently remains the same in essence, whether we are looking at any sector of economy, including the industrial, commercial, buildings or residential sectors.

We at ENERCON consider this manual on electrical systems to be a basic document on the subject, as well as a useful reference for the efficient use of electric energy in the industrial, commercial, buildings and residential sectors of the country. While this manual has been prepared as a companion to ENERCON's training program, it is designed to remain a valuable source of information for future reference.

Managing Director ENERCON

Acknowledgements

The material presented in this manual has been derived from various sources. Major contributions were taken from the following:

1. IEEE – Recommended Practice for Electric Power Distribution for Industrial Plants, USA
2. ASHRAE Handbook
3. NAFPA 70, National Electrical Code, USA
4. National Electrical Code Handbook
5. Electric Power Distribution Handbook, CRC Press, USA
6. The Electricians Handbook, Nexans Canada Inc. Ontario, Canada
7. National Electrical Manufacturer's Association (NEMA)
8. Aerovox, 167 John Vertente Blvd., New Bedford, MA 02745, USA
9. GE, General Electric, USA
10. Rockwell Automation, USA
11. UNEP, Gerlap, SIDA - Energy Efficiency Asia
12. Siemens Industry Inc., USA

Abbreviations

ANSI: American National Standards Institute

ASHRAE: American Society of Heating, Refrigeration and Air Conditioning Engineers

ASTM: American Society for Testing and Materials

CGPM: Conference Generale des Poids et Mesures

CGS: Centimeter-gram-second

EC: Energy Conservation

ECMs: Energy Conservation Measures

ECOs: Energy Conservation Opportunities

EE: Energy efficiency

OEM: Original Equipment Manufacturer

SI: Le Systeme International d'Unites

Contents

Exhibits

Appendices

1 Introduction

The successful definition, implementation, and management of an industrial energy conservation program requires a proper framework and baseline for identifying and evaluating energy conservation opportunities. Energy cannot be saved until it is known where and how it is being used and when and where its efficiency can be improved. In most cases, the establishment of this baseline requires a comprehensive and detailed survey of energy uses and losses; this survey is generally known as the energy survey or energy audit.

Having conducted an energy audit does not, however, constitute in itself an energy conservation program. A number of other conditions must also be met. First, there must be a will to save energy. Second, viable projects must be evaluated according to the company's financial guidelines. Third, financing must be available, and fourth, plant management and staff must be committed to continuing the energy rationalization effort well beyond project implementation, as the benefits of good projects can be lost as quickly as they are gained.

This manual is designed primarily to train the professionals in carrying out electricity energy audits. The information and methodologies described here are equally applicable to industrial plants, institutions and commercial buildings. It describes an organized approach to identify areas of potential energy efficiency improvement in an establishment and quantify them. It does not, however, deal with any of the other conditions (such as financing) for implementing a successful program.

1.1 Units used in this Manual

This manual uses the SI (Le Systeme International d'Unites) metric units of measure.

1.2 This Manual

This manual covers the basic concepts and definition of electrical systems, typical equipment employed, some system applications, conducting surveys for identifying and quantifying energy conservation measures most pertinent to Pakistan.

Much of the basic materials present the review of physics for those who have studied these subjects. In addition, however, some engineering principles and formulas have been included. These principles and formulas have been simplified, and are introduced with practical applications supported by abundant examples.

Chapter 2 introduces the approach to analyze the electricity bill of a facility, whether it is an industry, commercial setup, a building or a dwelling. The chapter further explains various important terminologies applied to understand and analyze the use of electrical energy in a facility. Chapter 3 provides a review of electrical distribution systems and ECOs (energy conservation opportunities), which need to be capitalized. As needed, all the chapters list the possible ECOs and introduction to methodology to quantify them. It further deals with the cables, transformers and the ever-increasing issue of harmonics. Further, the cable sizing is exemplified in an appendix. Chapter 4 describes the power factor, its importance and different procedures adopted to improve the low power factor. It enumerates the benefits accrued due to power factor improvement. Chapter 5 introduces the instruments pertaining to conducting electrical system surveys. Chapter 6 explains the maximum demand with examples and the maximum demand controllers to control maximum demand of a facility in a professional manner.

Chapter 7 presents an overview of lights and lighting systems, with introduction to conducting lighting survey to identify and quantify ECOs. Chapter 8 discusses the important subject of electric motors, its efficiency, motor losses, determination of motor efficiency, quantification of savings for using energy efficient motors, de-rating and guide to selecting motors. Chapter 9 deals with pumps, their selection, ECOs and conducting pumps survey. Chapter 10 presents fans and blowers, types in brief, de-rating of fans and blowers, fan system ECOs, and fan selection. Chapter 11 presents compressed air systems, compressors and their selection, de-rating issues, energy conservation checklist, and undertaking compressed air system survey.

Chapter 12 addresses refrigeration, its methods, equipment employed, refrigeration equipment measurement and analysis, and ECOs. Chapter 13 covers cooling towers, their performance measurement, capacity control, and common ECOs. Chapter 14 is the introduction to heating, ventilating and air conditioning (HVAC) systems, air handing units, HVAC controls, hot water systems and ECOs. Chapter 15 presents the aspect of buildings, heat transfer principles, and topics such as thermal insulation, infiltration, fenestration/windows, shading devices, and fenestration ECOs. Chapter 16 describes financial analysis from the viewpoint of economics of electrical energy conservation, simple payback, and other analytical approaches. It also addresses specific energy consumption and plant energy performance. Chapter 17 details the methodology for conducting an electrical energy survey in a step-by-step organized manner. Typical data collection forms are placed as appendix. Chapter 18 is brief introduction to ISO 50001 – Energy Management Standards, and its benefits.

Illustrative examples are frequently included in the discussions of each chapter to enhance comprehension of the concepts presented. This is especially useful in the calculation of the energy conservation measures.

This manual is not an electrical engineering textbook in the classical sense; however, it will serve as a useful guide for energy engineers who work with the use of electrical equipment and systems, as part of their responsibilities.

2 Electricity Bill Analysis

Understanding of the electricity bill of an establishment provides information on the electricity consumption. It also helps in the identification of cost saving measures.

2.1 Bill Analysis

(a) Is the billing accurate?

It needs to be ensured that meters are functioning properly. Installing the plant's own energy meters to crosscheck utility meters is a good practice. Still better, if meters can be installed for each electricity-consuming department or area. The readings can be used not only to check the utility billing, but even more important, can help in determining the relative consumptions of different departments or areas. This is the first step to energy accounting.

(b) What are marginal costs of demand and consumption?

The cost per kVA of energy demand can be calculated from the bill. The cost may be different to the demand charges of the utility, if the maximum demand charges are based upon the highest reading during the previous eleven months (Ratchet clause[1]).

The energy charges for the kWh consumed can be simply read off the bill.

Analysis of the marginal cost of energy demand and consumption provides us the cost value of the conservation measures. Obviously, the average cost of using one kWh of electricity can be obtained by dividing the total bill by the amount of kWh consumed, but if an energy conservation measure results in reduction in energy consumption (kWh) alone, with no reduction in maximum demand, it would be incorrect to base the value of energy saved on the average cost of electricity. Similarly, measures resulting only in demand reduction would result in savings in demand charges only.

(c) What is the maximum demand?

Maximum demand (MD or MDI) is the average rate at which electricity is consumed during a thirty (30) minute interval. The MD analysis shows the basis of the demand charges billed. If the (MD) is consistently billed on the basis other than the maximum demand established, or it greatly varies every month, the matter should be looked into to remedy the causes.

(d) Is there a power factor penalty?

Power factor penalty is one of the charges that gets noticed easily. Power factor correction is very cost-effective measure with payback of less than a year in most cases.

2.2 Collecting Historical Data

The above information can be expanded to include the historical quantity and cost data to study the effect of seasonal variation in production, climate and other variables. Basing the calculations on one month data can result in gross error in estimates of cost and energy savings. Data should be collected monthly, and records kept for several years back for comparison purposes. Exhibit 2-1 shows a typical form for collecting the historical electricity data. For comparison of the cost of energy, and to have a common reporting unit

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[1] See Chapter on Maximum Demand Control for the explanation of Ratchet clause.

for different types of energy (thermal, electrical both), the Giga-Joule is normally used, where (1 kWh = 0.0036 GJ).

2.3 Standard Definitions and Terminology

Before proceeding further, it is essential to understand the terminology and standard definitions devised to analyze the behavior of energy consumption in a facility. These are explained in the following sections.

2.3.1 Operating Hours

The number of hours in a year that a piece of equipment remains operational should be estimated as accurately as possible. Admittedly, this is an area where substantial error can be introduced, especially in a plant with erratically varying timings, or when power load shedding is a problem.

2.3.2 Energy Consumption

The total consumption in kWh per year for each piece of equipment is calculated by multiplying electric use by operating hour for a specified period.

2.3.3 Percent of Consumption

The contribution of each piece of equipment to the total annual consumption is an important measure. It determines of how important this equipment is relative to others. Energy conservation efforts should first concentrate on equipment that consumes the greatest proportion of energy.

2.3.4 Load or Connected Load

The nameplate kW at full load of the motor or machine is listed. Load in kVA is obtained by dividing the kW of the equipment by its power factor and efficiency at full load, while load in kW is obtained by dividing rated kW by efficiency. For lighting, or for heating units, the total rated power is used as load.

2.3.5 Demand

It is the electric load at the receiving terminals averaged over a specified interval of time. Demand is usually expressed in kilowatts. The interval of time is normally 15 minutes, 30 minutes, or 1 h, based on the particular utility's demand metering interval. In Pakistan, the specified time interval is 30 minutes.

Example: The 30-minute kW demand is 100 kW.

2.3.5.1 Maximum Demand (MDI)

It is the greatest of all demands that have occurred during a specified period, such as, 30 minutes during one month. For utility billing purposes, the specified period is generally one month. It must include demand interval, period, and units.

Example: The 30-minute maximum kW demand for the month was 150 kW.

Exhibit 2-1: Historical electricity use and cost data

Fiscal Year: ____

Tariff Class: ____

Contract Load: ____ kW

Connected Load: ____ kW

	Month	Maximum Demand, kW	Power Factor %	Consumption kWh	Total Cost PKR	Cost per kWh	Consumption G-Joules	Cost per G-Joule
		A	B	C	D	E	F	G
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
	Annual:							
	Avg / Month:							

Remarks: Information based on electricity bills should be collected for the last 3 years.
Information on Electricity Tariffs
Power Factor Penalty
Other Charges

2.3.5.2 Average Demand

It is the average of the demands over a specified period (day, week, month, etc.). It must include demand interval, period, and units. Example: the 30-minute average kW demand for the month was 350 kW.

$$\text{Average Demand} = \frac{\text{Total Energy Consumpton during the period (kWh)}}{\text{Duaration of that peiod (hours)}}$$

And

$$\text{Energy Consumed during MDI Innterval (kWh)} = \text{30 Minute Demand (kW)} \times \frac{1}{2}\text{Hour}$$

2.3.5.3 Diversified Demand

Sum of demands imposed by a group of loads over a particular period. It must include demand interval, period, and units.

Example: The 30-minute diversified kW demand in the period ending at 9:30 was 200 kW.

2.3.5.4 Maximum Diversified Demand

It is the maximum of the sum of the demands imposed by a group of loads over a particular period. It must include demand interval, period, and units.

Example: the 30-minute maximum diversified kW demand for the week was 500 kW.

2.3.5.5 Coincident Demand

Any demand that occurs simultaneously with any other demand, also the sum of any set of coincident demands.

2.3.6 Load Factor

The ratio of the average load over a designated period of time to the peak load occurring in that period. Note that although not part of the official definition, the term load factor is used by some utilities and others to describe the equivalent number of hours per period the peak or average demand must prevail in order to produce the total energy consumption for the period.

Load factor is the ratio of average load and maximum load during a given period, for example, a single day, for a month or for a year. Its value is always less than one, because maximum demand is always more than average demand.

$$\text{Load factor} = \frac{\text{Consumption during the period (kWh)}}{\text{Maximum Demand} \times \text{Number of hours in that period}}$$

$$\text{Load factor} = \frac{\text{Average 30-Minute Demand (kW)}}{\text{Maximum 30-Minute Demand (kW)}}$$

Further, the equipment load factor is the ratio of the load it actually draws and the load it could draw (full load).

$$\text{Equipment Load factor} = \frac{\text{Actual Load of the Equipment (kW)}}{\text{Maximum Load it could Draw (kW)}}$$

Example: Motor of 20 kW drives a constant 15 kW load whenever it is on.

$$\text{Motor Load factor} = \frac{15\text{ kW}}{20\text{ kW}} = 0.75 \times 100 = 75\%$$

By analyzing the load profile and the needs, one may be able to improve the load factor by doing the following:

Demand reduction: Reducing the demand by distributing the loads over different time periods

Increase production: Keeping the demand stable and increasing the consumption is often a cost-effective way to increase production while maximizing the use of energy.

2.3.7 Demand Factor

It is defined as the ratio of the maximum coincident demand of a system, or part of a system, to the total connected load of the system, or part of the system, under consideration. The resultant is always 1 or less and can range from 0.8 to 1 to as low as 0.15 to 0.25 for some plants with very low diversity. The lower the demand factor, the less system capacity required to serve the connected load. It is computed as:

$$\text{Demand Factor} = \frac{\text{Maximum Demand }(\text{kW})}{\text{Total Connected Load (kW)}}$$

Example: If a residence, having 6,000W equipment connected, has a maximum demand of 3,300W, then its demand factor is:

$$\text{Demand factor} = \frac{3.3\text{ kW}}{6.0\text{ kW}} = 0.55 \times 100 = 55\%$$

2.3.8 Diversity Factor / Simultaneity Factor

It is the ratio of the sum of the individual non-coincident maximum demands of various subdivisions of the system to the maximum demand of the complete system. The diversity factor is usually more than one, since the sum of individual maximum demands is greater than maximum demand established. By definition, the diversity factor refers to the percent of time available that a machine, piece of equipment, or facility has its maximum or nominal load or demand (i.e., a 70% diversity means that the device in question operates at its nominal or maximum load level 70% of the time that it is connected and turned on). It is calculated as:

$$\text{Diversity Factor} = \frac{\text{Sum of Individaul Maximum Demands (kW)}}{\text{Maximum Deamand of the System (kW)}}$$

2.3.9 Coincidence Factor

The coincidence factor is the ratio of maximum demand of a system and the sum of individual maximum demands. It is the reciprocal of diversity factor.

$$\text{Coincidence Factor} = \frac{\text{Maximum Demand of the System (kW)}}{\text{Sum of Individual Maximum Deamands (kW)}}$$

2.3.10 Utilization factor / Capacity Factor

This refers to the percent of time that the equipment is operated at load while it is on. For most equipment this factor is 1.0; for the equipment that cycles on and off, or that is idling for part of the time, the capacity factor can be calculated and applied.

The utilization factor gives an indication of how well the capacity of an electrical device is being utilized. It is the ratio of the time that equipment is in use and the total time that it could be in use.

$$\text{Utilization Factor} = \frac{\text{Time that an Equipment is in Use (Hours)}}{\text{Total Time that it could be in Use (Hours)}}$$

It can also be calculated from demand factor and load factor.

$$\text{Utilization Factor} = \text{Demand Factor} \times \text{Load Factor}$$

Example: A motor is used for 8 hours a day, 250 days a year. The hours of operation would then be 2,000, and the motor use factor for a base of 8,760 hours per year would be:

$$\text{Utilization Factor} = \frac{\text{2,000 In Use Hours}}{\text{8,760 Annual Hours}} = 0.2283 \times 100 = 22.83\%$$

In fact, the use factor is applied to get the correct number of hours that a piece of equipment is in use.

2.4 Electrical Energy Balance

A very useful exercise that forms an important part of the electrical energy survey is the performance of the plant electrical energy balance. All that is necessary is some basic survey instrumentation, and a bit of time and effort to determine all necessary information. Plant engineers may argue that the electrical energy balance is too tedious, and with too much margin of error. Nevertheless, the result of a plant electrical energy balance is an excellent understanding of the plant operation and the relative contribution of the various electrical equipment to the overall plant electricity consumption.

The balance is often the starting point for more detailed analysis of energy conservation opportunities. Finally, it can also be used as a basis for calculating equipment operating costs, and determining possible energy savings.

A summary of a plant energy balance for a hypothetical plant is presented in Exhibit 2-2. All the plant equipment is listed, and the useful parameters are measured or calculated. The definition of these and other common parameters is provided below:

Exhibit 2-3 and Exhibit 2-4 will serve the objective of collecting the data on major electricity-using equipment and electricity usage by the connected load.

The plant electrical energy balance in Exhibit 2-2 is within 10% of the sum of the electricity bills for the year. This is considered well within engineering limits. If the bill totals are more than 10% different, then revisions should be made in the load factors, capacity factors, or hours of operation. Any revisions should be based on reasonable assumptions, with practical understanding of what is actually happening in the plant operation.

The plant electrical energy balance shown here is on an annual basis. This is usually the easiest to calculate. However, the same can be performed on a monthly basis. If kWh consumption for actual equipment or department is monitored, this can be an even more accurate exercise.

Exhibit 2-2 also shows the sum of demands. While the sum of all the individual equipment demands should not be expected to be within 10% of the average demand for the year, nevertheless, comparing this total to the individual monthly maximum demands may be enlightening, and provide a better understanding of what equipment really contributes to the maximum demand.

MD Curve

An MD (load) curve can also be plotted on the basis of actual loads and operating schedule of individual loads by following the procedure as below:

- Develop a load profile based on the inventory and operating schedule

- Install MD analyzer and record the load curve for the complete cycle of the operation
- Compare actual recorded maximum demand with the developed load profiles
- If the two do not agree, investigate reasons and where appropriate, modify load inventory, operating schedule and development of load profile (The two curves are considered to agree with each other if they are within a margin of ± 10%.)

Now it will become obvious what loads are contributing to the establishment of MD of the plant/facility, and at what time the MD (peak) is occurring. This information will assist in identifying the total reduction in MD obtained as a result of:

- MD control measures
- Other energy conservation measures, which will reduce both energy consumption as well as MD

Next step should be to:

- Study the process flow diagram, and identify natural break points between various stages of the process where loads could be shut off for some time
- Develop new operating schedule incorporating rescheduling and the shutting off of loads at peak periods and draw new load profiles. In developing the new operating schedule prepare the operating schedule for at least one month. Identify methods, i.e., manual/timer/automatic controls to achieve load scheduling
- Compare existing load profiles and new (developed) load profiles
- Calculate expected annual savings, implementation cost and simple payback period

Further discussion on MD is presented in the chapter on Maximum Demand Control.

Exhibit 2-2: Example of plant electrical energy balance

Equipment	Rated Load		Demand, kW	Load Factor	Capacity Factor	Operation hr/year	Consumption kWh/yr	% of Consumption
	hp	kW						
A	B	C	D	E	F	G	H	I
Mixer 1	200.00	149.20	128	0.85	1.00	7,500	956,250	13.01%
Mixer 2	200.00	149.20	128	0.85	1.00	2,500	318,750	4.34%
Strainer	150.00	111.90	84	0.75	1.00	2,500	211,000	2.87%
Grinder 1	100.00	74.60	60	0.80	1.00	7,500	450,000	6.12%
Grinder 2	75.00	55.95	39	0.70	0.90	7,500	265,950	3.62%
MG Set	250.00	186.50	131	0.70	1.00	7,500	984,750	13.39%
Mill Drivel	150.00	111.90	73	0.65	1.00	7,500	548,250	7.46%
Mill Drive 2	125.00	93.25	70	0.75	1.00	7,500	527,250	7.17%
C. P. Mill	215.00	160.39	139	0.86	0.75	7,500	780,188	10.61%
Chiller Comp.	75.00	55.95	48	0.85	0.75	7,500	268,875	3.66%
Chiller Comp.	75.00	55.95	48	0.85	0.75	7,500	268,875	3.66%
Cyclone 1	25.00	18.65	15	0.80	1.00	7,500	112,500	1.53%
Cyclone 2	25.00	18.65	14	0.76	1.00	7,500	105,750	1.44%
C. W. Pump 1	40.00	29.84	24	0.80	1.00	7,500	180,000	2.45%
C. W. Pump 2	40.00	29.84	24	0.80	1.00	7,500	180,000	2.45%
Dryer 1 Fans 5 @	1.00	0.75	3	4.29	1.00	7,500	24,000	0.33%
Dryer 2 Fans 5 @	1.00	0.75	3	3.75	1.00	7,500	21,000	0.29%
Heat Proc. Mach.	20.00	14.92	11	0.76	1.00	7,500	84,750	1.15%
Circ. Pumps 4 @	20.00	14.92	45	3.02	1.00	7,500	337,500	4.59%
Aux. Machine	38.00	28.35	20	0.71	1.00	7,500	150,000	2.04%
Conveyors 3 @	10.00	7.46	14	1.81	1.00	7,500	101,250	1.38%
Packager	5.00	3.73	3	0.70	0.90	5,000	11,700	0.16%
Boiler Fan	10.00	7.46	7	0.91	0.35	7,500	17,850	0.24%
Boiler Feed Pump	40.00	29.84	27	0.90	0.15	7,500	30,375	0.41%
Condensate Pump 2 @	3.00	2.24	4	1.70	0.50	7,500	14,250	0.19%
		0.00						
Factory Lighting	8.04	6.00	5	0.75	1.00	7,500	33,750	0.46%
Night Lighting	4.02	3.00	2	0.77	1.00	8,760	20,148	0.27%
Machine Shop 0 @	2.00	1.49	12	8.04	0.33	2,500	9,900	0.13%
Cooling T. Pump	25.00	18.65	15	0.80	1.00	6,000	90,000	1.22%
Cooling T. Fan	10.00	7.46	6	0.80	0.75	6,000	27,000	0.37%
Air Compressor 1	25.00	18.65	15	0.80	0.85	7,500	95,625	1.30%
Air compressor 2	25.00	18.65	16	0.85	0.66	7,500	78,705	1.07%
Air Conditioner 8 @	4.00	2.98	20	6.84	0.75	3,000	45,900	0.62%
								0.00%
Total			**1,252**				**7,352,091**	**100.00%**
Summary of previous 12-months bill			**1,160**				**6,684,942**	

Exhibit 2-3: Major energy using equipment

Electric Equipment (reference)			Size (units)	Location	Use / Duty *	Efficiency	Comments
	A	B	C	D	E	F	G
1	Motor						
2	Motor						
3	Motor						
4	Motor						
5	Motor						
6	Motor						
7	Pump						
8	Pump						
9	Pump						
10	Compressor						
11	Compressor						
12	Compressor						
13	Compressor						
14	Fan						
15	Fan						
16	Fan						
17	Other						
18	Other						
19	Other						
20	Other						

* Duty may be termed as Essential/non-Essential and Continuous/Intermittent or stand-by etc.

Exhibit 2-4: Electricity used by connected load

Audit Period: ____________ Avg Cost per kWH (PKR): ____________

	Equipment Description	Electric Use per Device (kWs)	No. of Devices	Total Electric Use (kWs)	Electric Cost per Hour	Operating Hours per Year	Electric Cost per Year (PKR)	Total Yearly Energy Used (kWH)	Comments
	A	B	C	D	E	F	G	H	I
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
						Total Annual:			
							Energy Cost	Fuel Used	

Column D = B × C Column E = D × Avg Cost per kWH

Column G = E × F Column H = D × F

3 Electrical Distribution Systems

Electricity is the cleanest and most efficient method of energy transmission both over long distances, as well as within an establishment. Even so, the losses of transmission and distribution present a significant economic and financial burden, and must be minimized. This chapter reviews some of the basic concepts and equipment involved in the distribution of electricity, especially on the plant or facility level where the costs matter most to the end user.

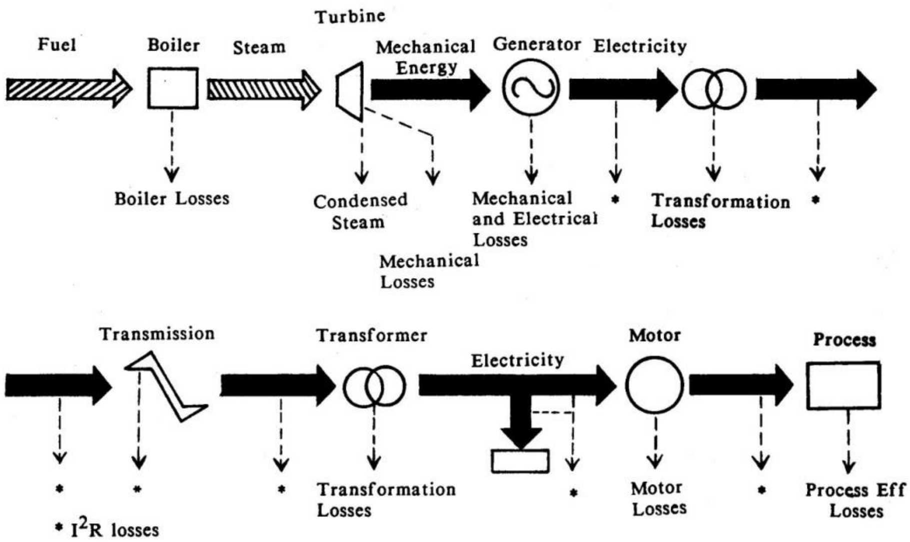
3.1 From Generation to End Use

A summary of the electric power generation and transmission system is shown in

Exhibit 3-1 and Exhibit 3-2. To minimize losses during transmission and distribution, the electric power is distributed at much higher voltages. Following are the most common supply system classifications and corresponding voltages used for distribution of electricity.

Primary transmission	:	500 kV and 200 kV
Secondary transmission	:	132 kV and 66 kV
Primary distribution	:	33 kV
Secondary distribution	:	11 kV
Tertiary distribution	:	415 volts (3-phase)
	:	240 volts (1-phase)
	:	110 volts (1-phase)

Exhibit 3-1: Electrical energy losses – generation to end-use

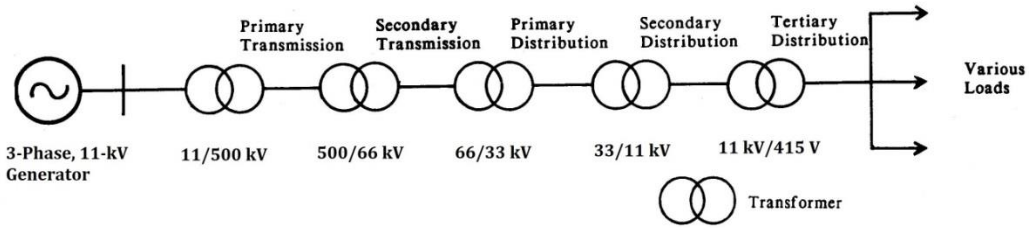


As shown in

Exhibit 3-1 before even entering the plant, distribution system losses occur at every point in the supply system. These transmission and distribution losses represent a significant proportion (up to 25%) of the electrical power produced at the generating station. These losses result from inherent efficiency limits in the distribution equipment, but are aggravated by inadequate design of equipment, improper equipment loading, poor installation of equipment, lack of maintenance, and low power factor.

As in all electrical systems, the technical losses can be divided into the losses due to current flow (also called copper losses, resistance losses, I^2R losses, electrical heating losses) and losses due to electrical equipment design (including iron core or magnetization losses, stray losses, and other losses).

Exhibit 3-2: Electrical power transmission and distribution systems



3.2 Electricity Distribution Systems

Utilities supply electricity to its consumers at different voltage levels according to the requirements and size of the establishment, and the electricity tariff applicable.

3.2.1 Typical System Designs

Three types of designs are used in the transformation and distribution system and are illustrated in Exhibit 3-3 the simple radial system; the primary selective system; and the secondary selective system.

3.2.1.1 Simple Radial System

The simple radial system Exhibit 3-3 (A) is simply one primary feeder and a single transformer through which a secondary bus bar is served. The system is simple, reliable, and economical, but must be shut down for even routine maintenance, and provides no back-up. It is suitable only for non-continuous or batch operations.

3.2.1.2 Primary Selective System

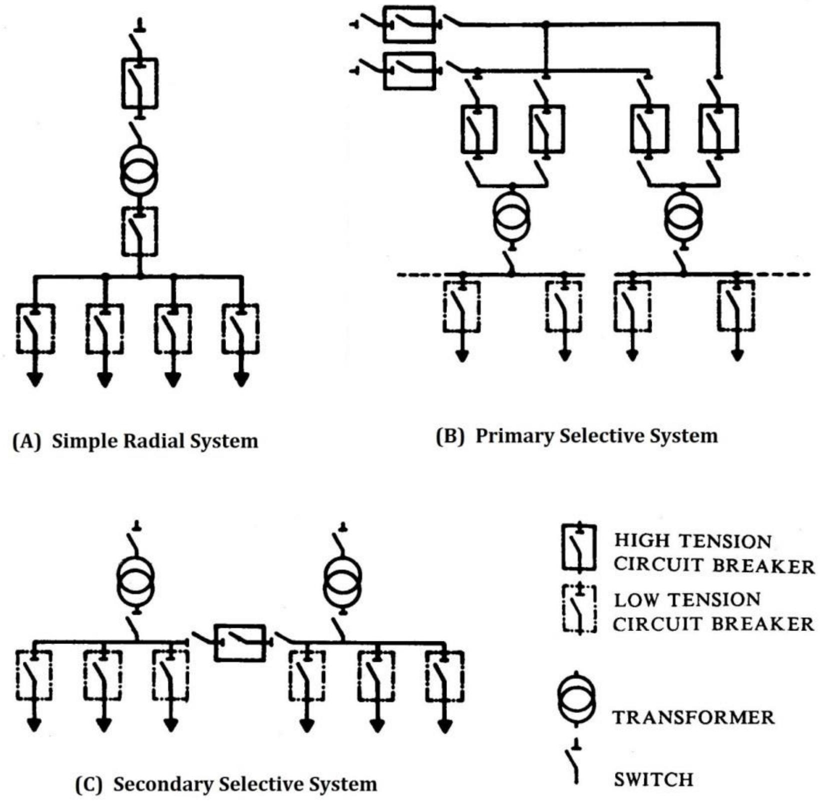
The primary selective system Exhibit 3-3 (B) is comprised of two primary feeders, two equivalent transformers, and two primary transformer disconnect switches on each feeder. In the event of interruption on the normal supply line, the transformer can be switched to the alternate supply without interruption in service. Since the transformers are serving different loads, however, there is still no provision for back-up in case of failure or maintenance of either transformer.

3.2.1.3 Secondary Selective System

The secondary selective system Exhibit 3-3 (C) is more reliable and expensive. It consists of two separate substations joined by a tie breaker. If one transformer or its feeder fails, the other transformer carries the load (subject to its capacity), and service can be re-established with only a momentary interruption.

A still higher degree of reliability can be obtained by using the basic elements of the primary and secondary selective systems together. In this case, two independent interconnected systems can deal with either supply feeder or transformer interruptions.

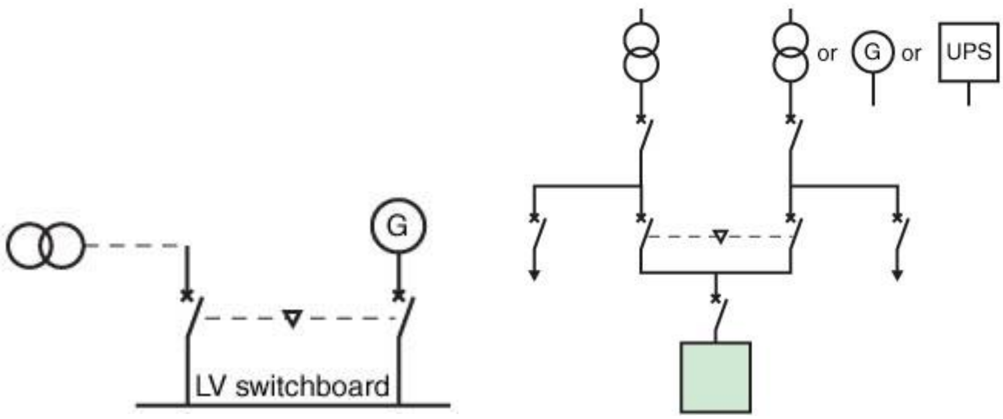
Exhibit 3-3: Typical distribution systems



3.2.1.4 Simple Distribution Systems with Standby Generators

Exhibit 3-4 illustrates two typical the distribution systems for connecting standby generators. The control systems for distribution arrangements containing multiple generators and for uninterrupted supplies become very complex and need expert advice and planning.

Exhibit 3-4: Distribution system with standby generator



(a) (b)

Exhibit 3-4 (a) shows the presence of a backup generator, and (b) illustrates double ended configuration with automatic transfer switch.

3.2.2 Voltage Levels and Wiring Systems

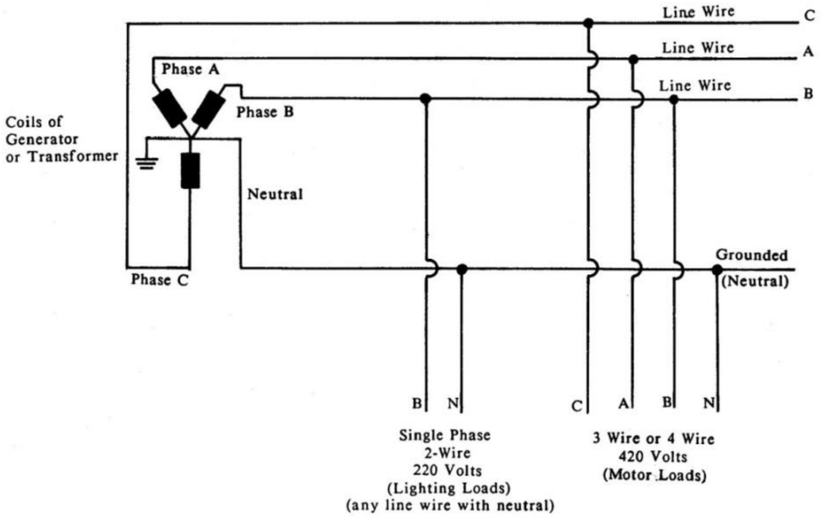
The choice of voltages in a plant is important because all electrical equipment can operate only at given voltage levels and between prescribed voltage limits. Electricity is generated and distributed in a three-phase system, that is, three distinct voltage waveforms 120 degrees out of phase from each other are produced. The three phases are supplied on three separate conductors. In transformers, motors, and other electrical equipment, these three voltages can be combined by connection of coils in two basic ways: the delta connection; and the wye or star connection. The differences between these two systems are important from the standpoints of equipment applications, voltage measurements, and safety concerns such as grounding.

3.2.2.1 Wye and Delta Connections

Exhibit 3-5 shows a typical three-phase four-wire wye or star connection, with the fourth wire grounded and acting as a neutral. In the nominal 415 V system, the line-to-line voltage between any two of the three phases is 420 V, and the line-to-ground or line-to-neutral voltage used for single-phase connections is 220 V. If the line loads are balanced, the neutral conductor operates essentially at ground potential.

All plants basically operate at a nominal three-phase voltage of 420 V (or 385 V). The most common motor rating is 400 V (380 V) and 50 Hz. Single phase loads of 220 V (or 110 V) are commonly used for lighting systems, very small motors, and other minor equipment. Care must be taken that these single-phase loads are balanced among the three phases.

Exhibit 3-5: Three-phase, 4-wire Wye connections



3.2.3 Losses in Plant Distribution Systems

The plant electrical distribution system consists of a wide variety of equipment used to safely supply and control electricity flow. These include wires, busses, and other conductors, as well as switches, breakers, control centers, and transformers. Each piece of equipment has certain inefficiency or energy loss associated with its operation; and over all, an establishment distribution system can be expected to have a loss of between 2.5% and 7.5% of its electricity consumption. Estimates of ranges of losses for typical electricity distribution equipment are given in Exhibit 3-6.

While Exhibit 3-6 shows that the losses for various electrical distribution equipment are small, however, there is a significant difference between the low and high value for each piece of equipment. A factor of 10 for difference in losses is not uncommon between a poorly made device and a quality piece of equipment.

When specifying or purchasing new electrical equipment, these losses (if available from the manufacturer) are important parameters to evaluate, since the improved efficiency of one model over another may result in energy savings which easily pay for the difference in price. Especially with the continued increase in electricity prices, the initial component costs must be very carefully weighed against a higher long term system operating cost. This is especially true in the purchase of cables and transformers. In general, however, when distribution equipment is already installed in a plant, the small absolute difference in losses between one and another model does not warrant its replacement on energy efficiency grounds alone.

Exhibit 3-6: Electrical system losses

Distribution System	Losses at Full Load
Outdoor circuit breakers	0.002% - 0.015%
Medium voltage switchgear	0.005% - 0.02%
Transformers	0.4% - 3%
Load break switches	0.003% - 0.025%
Busway	0.05% - 0.50%
Low voltage switchgear	0.13% - 0.34%
Motor control centers	0.01% - 0.40%
Cable	1% - 4%
Capacitors	0.5% - 2%
End Use Equipment Motors	
1-10 HP (0.746 - 7.46 kW)	14% - 35%
10-200 HP (7.46 - 149.2 kW)	6% - 12%
200-1500 HP (149.2 - 1119 kW)	4% - 7%
Static variable speed drives	6% - 15%
Lighting	3% - 9%

3.3 Conductor Size

The part of the distribution system with the greatest energy loss according to Exhibit 3-6 is the cable or conductor. The cost of this component must be carefully evaluated to ensure that the optimum size is selected to balance the initial costs against the operating costs.

3.3.1 Conductor Energy Losses

The energy losses in a conductor through which electric current is flowing are given by the relation:

$$PL = I^2R$$

Where, PL is the power loss in watts, I is the current in amperes, and R is the resistance in ohms. Thus, power loss in a conductor increases as the square of the current flowing in that conductor. Since resistance of a conductor varies approximately inversely with area, it can be said that the power loss also increases as the inverse square of the conductor diameter.

The energy loss is dissipated as heat, and the conductor carrying capacity or ampacity is determined by the maximum temperature that its insulation can withstand.

The energy loss through a conductor due to current flow described here is present in all electrical equipment. It is especially significant in equipment with large windings of conductor coil, such as transformers, motors, and other induction devices. Since copper is the most commonly used conductor material, this loss is also called the copper loss. It is also referred to as resistance loss, I^2R loss, and electrical heating loss. Resistivity values for various materials are given in Exhibit 3-7.

Exhibit 3-7: Resistivity values for various materials

Material	Resistivity ρ at 20 degree C, micro-Ohms-cm	Temperature Coefficient, per degree C
Aluminum	3.20	0.0039
Brass	7.00	0.002
Copper	1.72	0.0039
Iron, Commercial	13.00	0.0055
Load	21.00	0.0039
Mercury	96.00	0.0009
Nichrome	100.00	0.00044
Silver	1.60	0.0038
Steel hard	47.00	0.0016
Tin	11.50	0.0042
Tungsten	5.30	0.0051
Zinc	6.30	0.004

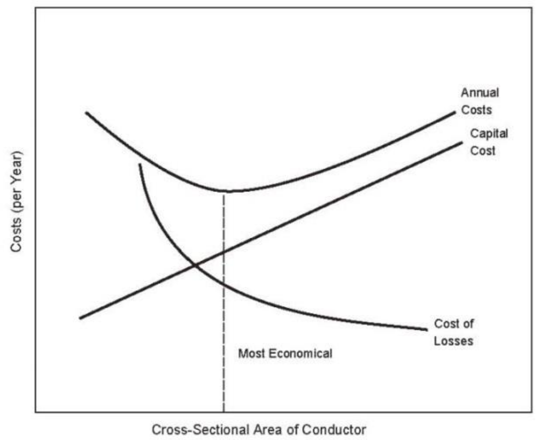
Notes: The resistivity depends strongly on the temperature of the material.
The table above is based on 20 °C reference.
Conductivity σ (1/micro-ohm-cm) at 20 degree C is the inverse of Resistivity.

3.3.2 Optimum Conductor Size

An optimum size of conductor can be determined by comparing the initial costs of different cable diameters with the additional costs of energy losses for the operating life of the cable. A graphical representation is given in Exhibit 3-8. As cross-sectional area of the cable increases, the capital costs increase, but the energy losses (operating costs) decrease. The point on the graph where the sum of both capital and operating costs is a minimum corresponds to the optimum size of the conductor. The graph must be constrained, i.e., limited by the minimum cross-sectional area demanded by either the current rating or the voltage drop according to the electric code. In addition, conductor resistance, operating hours, and energy costs, as well as cost of cable, installation, capital charges, and cost of amortization must be considered.

Individual compensation for power factor improvement (by installing capacitors) on individual pieces of electrical equipment results in reduction in line losses in the distribution system of an establishment as well as throughout the distribution system of the utilities up to the source of generation.

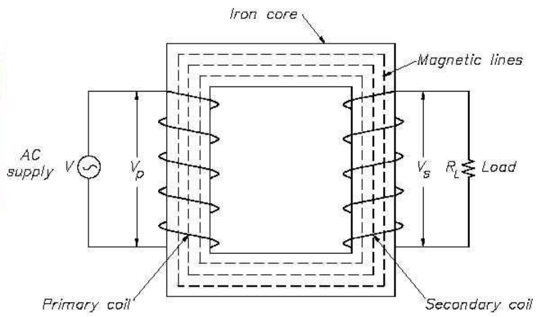
Exhibit 3-8: Most economical conductor cross-sectional area



3.4 Transformers

The transformer (Exhibit 3-9) is a common and indispensable piece of equipment used in all electricity distribution systems. It is a static device that changes the potential level of electrical energy (voltage) from one value to another, working on the principle of electromagnetic induction. Basically, the transformer consists of two coils wound on a closed iron core; as the current passes through the first coil it induces an electromotive force in the second coil, which is dependent on the relative number of turns in the two coils. Thus, the transformer allows the conversion of electric power from one voltage level to another.

Exhibit 3-9: Transformer and its construction



3.4.1 Common Types of Transformers

Transformers are constructed so that their characteristics match the application for which they are intended. The differences in construction may involve the size of the windings or the relationship between the primary and secondary windings. Transformer types are also designated by the function the transformer serves in a circuit, such as an isolation transformer, potential transformers and current transformers. They can also be broadly classified as distribution transformers and power transformers. Transformers should be kept cool. Therefore, air or thermal fluid systems are employed to dissipate the heat generated due to transformer losses.

3.4.1.1 Polyphase Transformers

This type of transformers are commonly associated with three phase electric power, which is a common method of transmitting large amounts of high voltage power, such as the national power grid. In this system, three separate wires carry alternating currents of the same frequency, but they reach their peak at different times, thus resulting in a continuous power flow. Occasionally these "three-phase" systems have a neutral wire, depending on the application. Other times, all three phases can be incorporated into one, multiphase transformer. This would require the unification and connection of magnetic circuits so as to encompass the three-phase transmission. Winding patterns can vary and so can the phases of a polyphase transformer.

3.4.1.2 Dry Transformers

Dry-type transformers are an alternative available to replace oil-filled transformers in special environments, particularly for indoor applications, where the use of oil- filled transformers poses hazardous risks to life and property. Due to technological improvements and safe operation they are gaining popularity. Generally, they are not as efficient as the oil cooled transformers.

General and minimum requirements of transformer data needs to be shown on a transformer nameplate. The standards require the following information and data for transformers rated above 500 kVA

- • Name of manufacturer
- • Serial number
- • year of manufacture
- • Number of phases
- • kVA or MVA rating
- • Frequency
- • Voltage ratings.
- • Tap voltages.
- • Connection diagram.
- • Cooling class
- • Rated temperature in °C
- • Polarity (for Single Phase Transformers)
- • Phasor or vector diagram (For Polyphase or Three Phase Transformers)
- • % impedance.
- • Approximate mass or weight of the transformer
- • Type of insulating liquid.
- • Conductor material of each winding.
- • Oil volume (of each transformer Container/Compartment)
- • Instruction for Installation and Operation

3.4.2 Transformer Losses

Losses are inherent in the voltage conversion process; however, since the transformer has no moving parts, its efficiency can be quite high. Typical full load transformer losses can range between 0.4 and 3%, depending on design, size and operating conditions. Losses can be used in the definition of transformer efficiency as follows:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{(\text{Output} + \text{Losses})}$$

Where, the input, output, and losses are all expressed in W or kW. For a new transformer, an efficiency of 98% or less is considered low.

Transformer losses are divided into (1) iron losses and (2) copper losses. The former result from the alternate magnetization and demagnetization of the iron core, and are essentially independent of load. The copper losses (I^2R) depend on current passing through transformer winding, and vary as the square of the current, i.e., as the square of the kVA load on the transformer at constant voltage. In a low power factor situation, the transformer losses increase for the same useful power (kW). Transformers are always rated in kVA and not in kW.

The transformer losses are affected by the design, quality of the iron core material and the copper wire used in transformer construction. Thus, the initial selection of a transformer with minimum losses is the best way to ensure good efficiency.

Every transformer purchase should be preceded by an analysis of first costs and operating costs. The transformer manufacturer or supplier should be asked to provide a transformer test certificate so that energy losses can be checked and operating costs evaluated.

Exhibit 2-1 shows the losses for

Exhibit 3-10: Typical Losses for Dry and Oil Type Transformers

Losses Between Dry Type Transformers And Oil Transformers

Oil/Liquid Type (Three Phase)*				Dry Type						
				95 kV				125 kV		
KVA	No-Load (W)	Full Load (W)	Total	KVA	No-Load (W)	Full Load (W)	Total	No-Load (W)	Full Load (W)	Total
500	1,330	3,600	**4,930**	500	2,400	7,600	**10,000**	2,500	8,900	**11,400**
750	1,760	6,140	**7,900**	750	3,000	12,000	**15,000**	3,700	13,000	**16,700**
1,000	2,020	6,700	**8,720**	1,000	3,400	13,000	**16,400**	4,400	15,000	**19,400**
1,500	2,810	11,070	**13,880**	1,500	4,500	18,000	**22,500**	5,000	18,000	**23,000**
2,000	3,390	12,920	**16,310**	2,000	5,400	21,000	**26,400**	6,400	23,000	**29,400**

* Oil is not affected by voltage

A comparative study of 2000 kVA dry and oil type transformers shows the following losses.

95kVa transformers operating at 95 kV:

At full load

Oil type transformer losses	Dry type transformer losses
16.310 kW	26.400 kW

At half load

Oil type transformer losses	Dry type transformer losses
8.760 kW	15.900 kW

3.5 Harmonics

Power system harmonics is an area that is receiving a great deal of attention recently. This is primarily due to the fact that non-linear (or harmonic producing) loads are comprising an ever-increasing portion of the total load for a typical industrial plant.

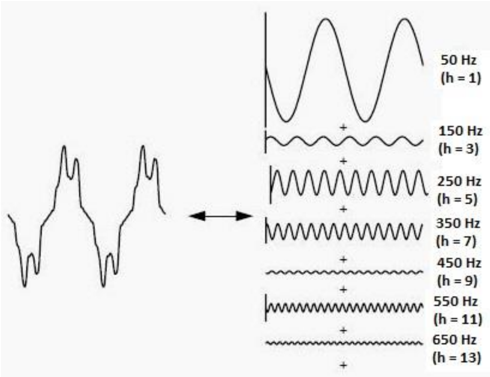
Harmonics are a way of describing distortion to a voltage or current waveform. It is important to understand that harmonics are a steady state phenomenon and repeat with every frequency cycle (50 or 60 Hz frequency cycle). Harmonics should not be confused with spikes, dips, impulses, oscillations or other forms of transients.

A “linear” load connected to an electric power system is defined as a load which draws current from the supply which is proportional to the applied voltage (for example, resistive, incandescent lamps etc.).

“Non-linear” loads are for example computers, variable frequency drives, discharge lighting etc. They create voltage distortion that can affect both the distribution system equipment and the loads connected to it. Use of such devices is ever-increasing.

IEEE 519-1992 defines harmonic as a sinusoidal component of a periodic wave or quantity (for example voltage or current) having a frequency that is an integral multiple of the fundamental frequency; i.e. Harmonic frequencies are equally spaced by the width of the fundamental frequency and can be found by repeatedly adding that frequency (Exhibit 3-11), where “h” denotes the harmonics series produced in a system due to non-linear loads.

Exhibit 3-11: Fourier series representation of a distorted waveform



3.5.1 Effects of harmonics

When a voltage and/or current waveform is distorted, it causes abnormal operating conditions in a power system such as:

- Voltage Harmonics can cause additional heating in induction and synchronous motors and generators.
- Voltage Harmonics with high peak values can weaken insulation in cables, windings, and capacitors.
- Voltage Harmonics can cause malfunction of different electronic components and circuits that utilize the voltage waveform for synchronization or timing.
- Current Harmonics in motor windings can create Electromagnetic Interference (EMI).
- Current Harmonics flowing through cables can cause higher heating over and above the heating that is created from the fundamental component.
- Current Harmonics flowing through a transformer can cause higher heating over and above the heating that is created by the fundamental component.
- Current Harmonics flowing through circuit breakers and switch-gear can increase their heating losses.
- Resonant Currents which are created by current harmonics and the different filtering topologies of the power system can cause capacitor failures and/or fuse failures in the capacitor or other electrical equipment.
- False tripping of circuit breakers ad protective relays.

3.5.2 Control of harmonics

3.5.2.1 IEEE 519-1992 Guidelines

IEEE 519 was initially introduced in 1981 as an "IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters". It originally established levels of voltage distortion acceptable to the distribution system for individual non-linear loads.

The revised 1992 version of IEEE 519 established recommended guidelines for harmonic voltages on the utility distribution system as well as harmonic currents within the industrial distribution system.

3.5.2.2 Methods for Harmonic Mitigation

Majority of large power (typically three-phase) electrical nonlinear equipment often requires mitigation equipment in order to attenuate the harmonic currents and associated voltage distortion to within necessary limits. Depending on the type of solution desired, the mitigation may be supplied as an integral part of nonlinear equipment (e.g., an AC line reactor or a line harmonic filter for AC PWM (pulse width modulation) drive or as a discrete item of mitigation equipment (e.g., an active or passive filter connected to a switchboard). There are many ways to reduce harmonics, ranging from variable frequency drive designs to the addition of auxiliary equipment. Few of the most prevailing methods used today to reduce harmonics are listed below.

1. Delta-Delta and Delta-Wye Transformers
2. Isolation Transformers
3. Use of Reactors / Passive Harmonic Filters (or Line Harmonic Filters)
4. Active filters
5. Power System Design

Harmonics can be reduced by limiting the non-linear load to 30% of the maximum transformer's capacity. However, with power factor correction capacitors installed, resonating conditions can occur that could potentially limit the percentage of nonlinear loads to 15% of the transformer's capacity.

3.6 The Distribution System Survey

Outline for conducting the distribution system survey is:

Distribution System:

6. Evaluate the general condition of the distribution system. In evaluating he will identify loose connections on fuse buses, bus ducts, motors and other electricity distribution components and switch gears, and make appropriate suggestions for improvements.
7. Discuss with the engineer/operations staff and identify any voltage drop problems. Where appropriate, voltage will be measured at the main station and farthest motor/electrical equipment, to estimate the extent of the voltage drop problem.
8. Discuss any voltage fluctuation problems, percentage burn out of motor, and such problems caused by voltage fluctuation. During the survey, the surveyor will be able to identify any such problems.
9. Discuss and where appropriate, measure for current imbalance in the system.
10. Prepare list of problems in the distribution system.
11. Make recommendations to solve the problems identified. They may include:
12. Redistribution of single phase loads to improve current voltage imbalance;
13. Upgrading the distribution systems to eliminate voltage drop.
14. Calculate savings/benefits from the proposed actions.

Transformers

Determine if the plant owns the main transformer by discussing with the engineer/management. If yes, one should proceed as follows:

1. Inspect the transformer to determine the general condition of the transformer and cleanliness of heat exchange surface
2. Determine whether the transformer matches the sanctioned, connected load. If it does not match, determine what should be the rating of the transformer
3. Determine the expected savings from the recommendations.

4 Power-Factor

Electric loads are generally classified into two groups, resistance loads (such as heaters and incandescent lamps) and inductive loads (such as motors, welders, fluorescent lamps and mercury lamps).

Currents flowing through a resistance load are called “effective currents”, i.e., their total electrical energy is converted into heat and light. On the other hand, currents flowing through an inductive load are called “apparent currents”, and they are composed of an" effective current" and "reactive (non-effective) current".

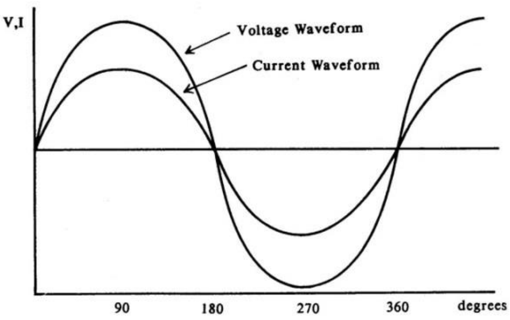
In case of purely resistive loads, the voltage and current waveforms are in phase (Exhibit 4-1a). When inductive loads are present in the system, the voltage and current are no more in phase and the current tends to "lag" in time behind the voltage. The amount of lag, or phase difference, is measured by the phase angle   between the two waveforms as apparent in Exhibit 4-1b. In this case of lagging current, since the voltage and current are no longer in phase, the active power available from the circuit is reduced.

The ratio of effective current to apparent current flowing in an inductive load is referred to as the “power factor”. Mathematically, the value of power factor is equivalent to the cosine of the phase angle θ.

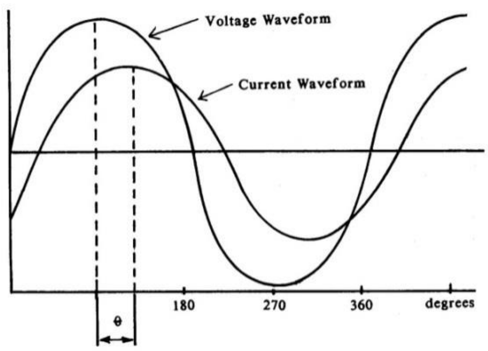
$$\text{Power Factor} = \text{Cos}\,\theta = \frac{\text{Effective Current}}{\text{Apparent Current}} = \frac{\text{Active Power}}{\text{Apparent Power}}$$

Exhibit 4-1: Voltage and current in phase form

(a) Voltage and Current in Phase
Power W = V × I



(b) Current lagging Voltage
Power W = V × I × Cosθ



Power Factor Penalty

Where applicable, the Power Factor Penalty clause states that:

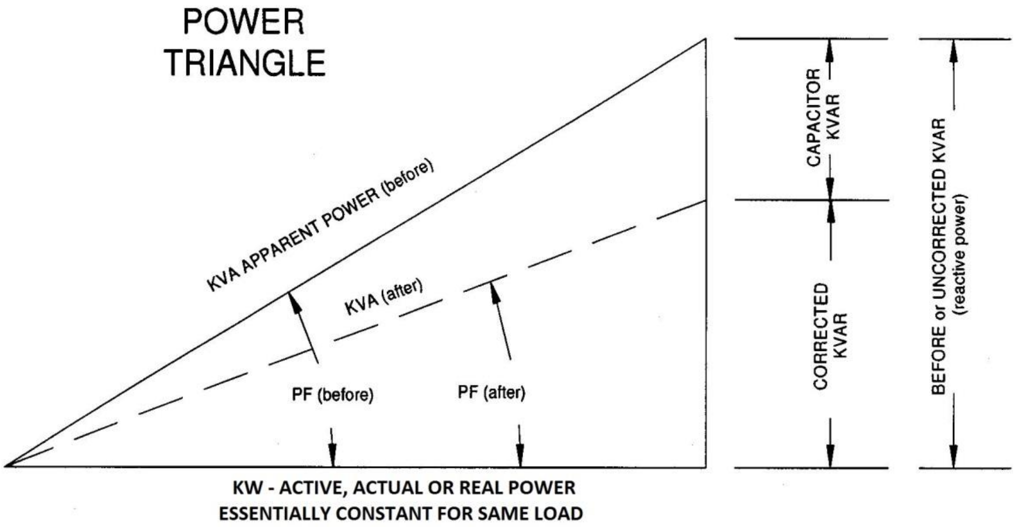
“Average Power Factor of the consumer governed by this tariff, at the point of supply shall not be less than 90 percent. In the event of the said power factor falling below 90 percent, the consumer shall pay a penalty of 2 percent increase in the fixed charges corresponding to 1 percent decrease in the power factor below 90 percent.”

4.1 Power Factor Compensation

As discussed earlier, the lagging power factor occurs as a result of reactive current (i.e., kVAr) flow towards the induction machine. If some of this kVAr flow can be provided from a separate source, then the inductive device will no longer have as much effect on rest of the system, and the power factor will be improved. If all the necessary kVAr flow can be provided by an independent source, then the power factor will improve to unity.

This compensation is depicted graphically in Exhibit 4-2. In the case before correction of the Exhibit, power factor (Cos θ), is low, with high kVA and high reactive current. In the case after correction, the capacitors of the value kVArC are installed, and as a result the reactive component is reduced to corrected KVAr, and the apparent current is also reduced. The useful power does not change.

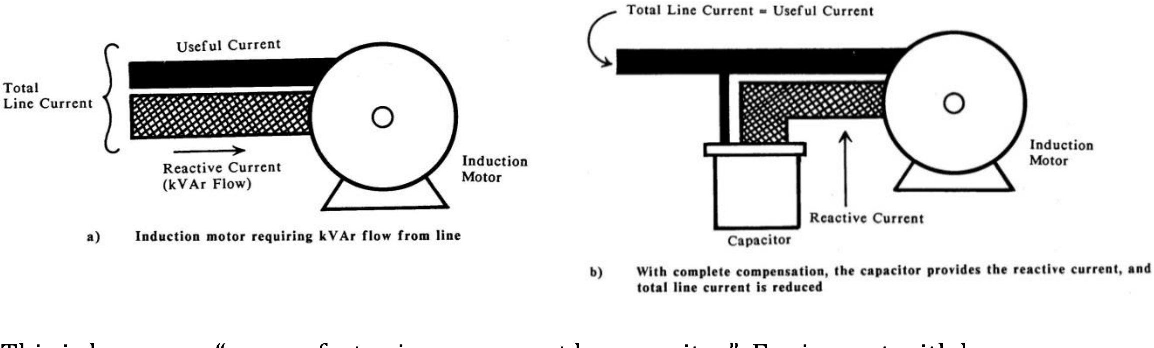
Exhibit 4-2: Power factor compensation or improvement



The capacitors supply the kVAr require by the inductive load, and as result the system is relieved of the supply of the effective power (Exhibit 4-3). As the power factor of the system improves, the apparent power approaches the useful power.

The vector of a current flowing through a capacitor has the exact opposite direction of the vector of a reactive current flowing through an inductive loads. Therefore, when a capacitor is connected in parallel to an inductive load, the capacitor current nullifies the reactive current. Consequently, the apparent current value approaches the effective current value.

Exhibit 4-3: Inductive loads require reactive current (kVAr flow)



This is known as "power-factor improvement by capacitor". Equipment with low power factor are listed in Exhibit 4-4. Three arrangements of power factor compensation by capacitors are described below:

Exhibit 4-4: Equipment with low power factor

Equipment / Device	Power Factor
Induction motors	50% - 90%
Small Dry-pack transformers	30% - 95%
Fluorescent and high intensity discharge lighting fixture ballasts (with no power factor compensation)	40% - 80%
Induction heating equipment	60% - 90%
Arc welders	50% - 70%
Solenoids	20% - 50%

4.1.1 Individual Compensation

Individual compensation or compensation at the source (Exhibit 4-5 a) is the simplest and most effective way to improve power factor. The method has the following advantages:

- Correction affects the entire distribution system, from the capacitor all the way back to the source; thus the capacity of the whole distribution system is increased
- No additional switching is required: the capacitor can be wired in to the equipment it is compensating
- Capacitor sizing is simplified
- Capacitor is physically coupled to the equipment, and can remain attached if the equipment is removed or rewired.

Individual compensation is especially applicable in those systems where particular equipment is identified as contributing to low plant power factor. In this case, the capacitors only need to be installed on the low power factor equipment. Good examples of such applications are fluorescent and high intensity discharge lights or lighting circuits.

A disadvantage of individual compensation is its greater cost per kVAr in case of smaller units. Also, where a load tends to have wide fluctuations, a capacitor adequate for full load compensation may provide overcompensation at low load, causing a leading power factor.

4.1.2 Group Compensation

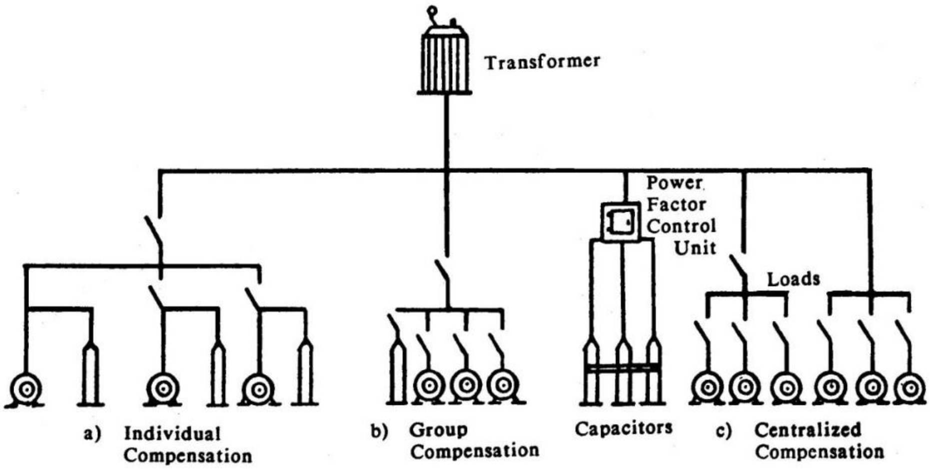
Compensation in groups (Exhibit 4-5 b) offers advantages of economies of scale over individual compensation. Materials and installation costs are reduced, while still providing for increased capacity of the distribution system. A disadvantage, however, is that because of the greater probability of load variation, switching (see next subsection) may be necessary to control the amount of capacitance used, thus increasing initial costs. The term "power factor improvement equipment" is commonly applied to this system and the one described below.

4.1.3 Central Compensation

Central compensation (Exhibit 4-5 c) takes care of the power factor problem of the whole plant all at once. It offers the simplest and usually the most cost-effective installation. Switching capability is a must to control capacitance during load variation. The only disadvantage of central compensation is that it does not increase the capacity of the plant electrical distribution system as the methods above do.

Capacitors are normally installed in steps of 25 or 50 kVAr, or even more, depending on the size of the installation and the accuracy of control required. In addition to the main control gear responsible for energizing and de-energizing of capacitor units, a master control relay, time delay relay, control switches and indicating lamps are the main accessories. The control sensor monitors kVAr, and through the time delay relays causes various steps or banks of capacitors to become energized or de-energized in the circuit according to necessity.

Exhibit 4-5: Installation of power factor improvement capacitors



4.2 Synchronous Motor as a Synchronous Condenser

Synchronous motors are always cited on the list of possible power factor improvement devices, yet their real application in industry is rare. In no case it is cost-effective to purchase and install a synchronous motor for industrial or commercial power factor correction. However, in plants where synchronous motors are available, they can be used as kVAr generators, termed synchronous condensers, to improve the power factor of the electrical system.

4.3 Calculating Required Capacitor Ratings

(a) By Using Table

Capacitor rating (kVAr) can be easily calculated from the table (Exhibit 4-6). kVAr per kW required to improve the original (existing) power factor to corrected (proposed) power factor is read from the table. This value is multiplied by the existing kVA and existing power factor (i.e., existing kW) to obtain the total kVAr required to improve the power factor to proposed value.

Exhibit 4-6 gives multipliers for kW to get the capacitor KVAr needed to increase from original to desired corrected power factor. Use the multipliers to size auto-switched or fixed capacitors for large loads.

Example: Total KW input of load from wattmeter reading 100 KW at a power factor of 60%. The leading reactive KVAR necessary to raise the power factor to 90% is found by multiplying the 100 KW by the factor found in the table, which is .849. Then, 100 KW × 0.849 = 84.9 KVAR. Use 85 KVAR.

(b) By Calculation, kVAr required are:

$$\text{kVAr Required} = \left(\text{Existing MD, kW}\right) \times \left(\frac{\sqrt{1 - PF_1^2}}{PF_1} - \frac{\sqrt{1 - PF_2^2}}{PF_2}\right)$$

Where, PF_1 and PF_2 are the existing and corrected power factors in fractions.

The equation based on transformer rating and proposed power factor of unity, reduces to:

$$\text{Power Factor} = 100\% = (\text{Transformer rating, kVA}) \times \left(1 - \frac{\left(\text{Existing PF\%}\right)^2}{10{,}000}\right)^{0.5}$$

Exhibit 4-6: Power factor improvement table

Original Power Factor (%)	Desired (Corrected Power Factor (%)																				
	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.590	1.732
51	0.937	0.963	0.989	1.015	1.041	1.067	1.093	1.120	1.147	1.174	1.202	1.231	1.261	1.291	1.324	1.358	1.395	1.436	1.484	1.544	1.687
52	0.893	0.919	0.945	0.971	0.997	1.023	1.049	1.076	1.103	1.130	1.158	1.187	1.217	1.247	1.280	1.314	1.351	1.392	1.440	1.500	1.643
53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.458	1.600
54	0.809	0.835	0.861	0.887	0.913	0.939	0.965	0.992	1.019	1.046	1.074	1.103	1.133	1.163	1.196	1.230	1.267	1.308	1.356	1.416	1.559
55	0.768	0.794	0.820	0.846	0.873	0.899	0.925	0.952	0.979	1.006	1.034	1.063	1.092	1.123	1.156	1.190	1.227	1.268	1.315	1.376	1.518
56	0.729	0.755	0.781	0.807	0.834	0.860	0.886	0.913	0.940	0.967	0.995	1.024	1.053	1.084	1.116	1.151	1.188	1.229	1.276	1.337	1.479
57	0.691	0.717	0.743	0.769	0.796	0.822	0.848	0.875	0.902	0.929	0.957	0.986	1.015	1.046	1.079	1.113	1.150	1.191	1.238	1.299	1.441
58	0.655	0.681	0.707	0.733	0.759	0.785	0.811	0.838	0.865	0.892	0.920	0.949	0.979	1.009	1.042	1.076	1.113	1.154	1.201	1.262	1.405
59	0.618	0.644	0.670	0.696	0.723	0.749	0.775	0.802	0.829	0.856	0.884	0.913	0.942	0.973	1.006	1.040	1.077	1.118	1.165	1.226	1.368
60	0.583	0.609	0.635	0.661	0.687	0.714	0.740	0.767	0.794	0.821	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.157	1.299
62	0.515	0.541	0.567	0.593	0.620	0.646	0.672	0.699	0.726	0.753	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.015	1.062	1.123	1.265
63	0.483	0.509	0.535	0.561	0.587	0.613	0.639	0.666	0.693	0.720	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
64	0.451	0.477	0.503	0.529	0.555	0.581	0.607	0.634	0.661	0.688	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
66	0.388	0.414	0.440	0.466	0.492	0.519	0.545	0.572	0.599	0.626	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.966	1.108
68	0.328	0.354	0.380	0.406	0.432	0.459	0.485	0.512	0.539	0.566	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
71	0.242	0.268	0.294	0.320	0.346	0.372	0.398	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
72	0.214	0.240	0.266	0.292	0.318	0.344	0.370	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.370	0.396	0.424	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
77	0.079	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.289	0.316	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
78	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.263	0.290	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
85						0.000	0.026	0.053	0.080	0.107	0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
86							0.000	0.027	0.054	0.081	0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451	0.593
87								0.000	0.027	0.054	0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
88									0.000	0.027	0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
89										0.000	0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370	0.512
90											0.000	0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342	0.484
91												0.000	0.030	0.060	0.093	0.127	0.164	0.205	0.253	0.313	0.456
92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.284	0.426
93														0.000	0.032	0.067	0.104	0.145	0.192	0.253	0.395
94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
95																0.000	0.037	0.078	0.126	0.186	0.329
96																	0.000	0.041	0.089	0.149	0.292
97																		0.000	0.048	0.108	0.251
98																			0.000	0.061	0.203
99																				0.000	0.142
100																					0.000

Examples

1. A plant with a metered demand of 600 kW is operating at a 75% power factor. What capacitor kVAr is required to correct the present power factor to 95%?

a. From Exhibit 4-6, multiplier to improve PF from 75% to 95% is .553.

b. Capacitor kVAr = kW × Exhibit 4-6 Multiplier

Capacitor kVAr = 600 × 0.553 = 331.8

2. A plant load of 425 KW has a total power requirement of 670 KVA. What size capacitor is required to improve the present power factor to 90%?

a. $$\text{Present PF} = \frac{425}{670} = 0.634 = 63.4\%$$

b. From Exhibit 4-6, multiplier to improve PF from 63% to 90% is 0.748.

c. Capacitor kVAr = kW × Exhibit 4-6 Multiplier

Capacitors kVAr = 425 × .748 = 317.9

3. A plant operating from a 480 volt 3-phase system has a metered demand of 258 kW. The line current read by a clip-on ammeter is 420 amperes.

What capacitors kVAr is required to correct the present power factor to 90%?

a. kVAr = √3 × kV x I = 1.73 × .480 × 420 = 349 kVA

b. $$\text{Present PF} = \frac{258}{349} = 0.739 = \text{say } 74\%$$

c. From Exhibit 4-6, Multiplier to improve PF from 74% to 90% is 0.425.

d. Capacitor kVAr = kW × Exhibit 4-6Multiplier

Capacitor kVAr = 258 × 0.425 = 109.6

4.4 Benefits of Power Factor Improvement

The benefits of power factor improvement are:

A. More Effective use of power facilities

- The use of capacitors for power factor improvement at existing power facilities provides a capacity margin for generators, transformers, switches and transmission cables to allow for the installation of additional loads.
- The use of capacitors for power factor improvement at new power facilities allows capacity reduction of generators, transformers, switches and transmission cables, to reduce the overall construction cost.

$$\%\ \text{Reduction in Apparent Power (Apparent Current)} = \left(\frac{\text{Corrected PF}}{\text{Original PF}} - 1\right) \times 100$$

B. Reduced Power distribution loss

- The use of capacitors for power factor improvement reduces power loss at generators, transformers and transmission cables.

$$\%\ \text{Reduction in Power Losses} = \left(1 - \frac{\text{Original PF}^2}{\text{Corrected PF}^2}\right) \times 100$$

Power factor before improvement	**0.6**			**0.7**			**0.8**	
Power factor after improvement	0.8	0.9	1.0	0.8	0.9	1.0	0.9	1.0
(1) Reduction in apparent power or current (%)	33	50	67	14	29	43	13	25
(2) Reduction in power line loss (%)	44	56	64	23	40	51	21	36

C. Reduced Voltage drop

- The use of capacitors for power factor improvement reduces voltage drop in supply lines and hence releases and stabilizes voltage at receiving end to allow more efficient use of loads.

D. Reduced power cost

- Because of these benefits, power companies can cut the cost of power generation and distribution and in turn pass on the savings to users in the form of lower electricity cost elimination of power factor penalty.
- Use of capacitors for power factor improvement can also reduce the MD (billed in kVA).

4.5 Automatic Power Factor Correction Unit

An automatic power factor correction unit consists of a number of capacitors that are switched by means of contactors (Exhibit 4-7). These contactors are controlled by a regulator that measures power factor in an electrical network. Depending on the load and power factor of the network, the power factor controller will switch the necessary blocks of capacitors in steps to make sure the power factor stays above a selected value.

Exhibit 4-7: Automatic power factor control panel

4.6 Capacitors

As discussed earlier, capacitors provide tremendous benefits to distribution system performance. Most noticeably, capacitors reduce losses, free up capacity, and reduce voltage drop:

On ac power systems, capacitors do not store their energy very long — just one-half cycle. Each half cycle, a capacitor charges up and then discharges its stored energy back into the system. The net real power transfer is zero. Capacitors provide power just when reactive loads need it. Just when a motor with low power factor needs power from the system, the capacitor is there to provide it. Then in the next half cycle, the motor releases its excess energy, and the capacitor is there to absorb it. Capacitors and reactive loads exchange this reactive power back and forth. This benefits the system because that reactive power (and extra current) does not have to be transmitted from the generators all the way through many transformers and many miles of lines; the capacitors can provide the reactive power locally. This frees up the lines to carry real power, power that actually does work.

Farad

Unit of capacitance is Farad. A capacitor has a capacitance of one farad when one coulomb of charge is stored due to one volt applied potential difference across the plates. Since, farad is a very large unit, values of capacitors are usually expressed in microfarads (μF).

4.6.1 Capacitor Types

There are several types of capacitors that have been manufactured. Although all capacitors work essentially the same way, key differences in the construction of different capacitor types makes an enormous difference in their properties.

Each capacitor type has its own set of characteristics and applications from small delicate trimming capacitors up to large power metal-can type capacitors used in high voltage power factor correction and smoothing circuits.

The dielectric material between the two plates is the main element of the capacitor that gives rise to the different properties of the different types of capacitors. The type of internal dielectric, the structure of the plates and the device packaging all strongly affect the characteristics of the capacitor and its applications.

Aluminum Electrolytic Capacitors

There are basically two types of Aluminum Electrolytic Capacitor, the plain foil type and the etched foil type. The thickness of the aluminum oxide film and high breakdown voltage give these capacitors very high capacitance values for their size.

The foil plates of the capacitor are anodized with a DC current. This anodizing process sets up the polarity of the plate material and determines which side of the plate is positive and which side is negative.

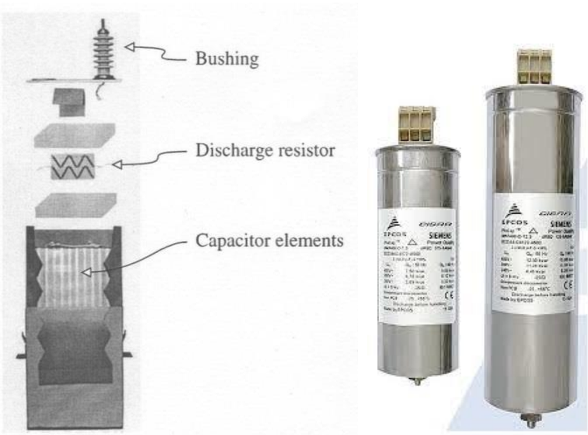
The etched foil type differs from the plain foil type in that the aluminum oxide on the anode and cathode foils has been chemically etched to increase its surface area and permittivity. This gives a smaller sized capacitor than a plain foil type of equivalent value but has the disadvantage of not being able to withstand high DC currents compared to the plain type. Also, their tolerance range is quite large at up to 20%. Typical values of capacitance for an aluminum electrolytic capacitor range from 1uF up to 47,000uF.

Capacitor units are made of series and parallel combinations of capacitor packs or elements put together as shown in Exhibit 4-8. Capacitor elements have sheets of polypropylene film, less than one mil thick, sandwiched between aluminum foil sheets.

Since the electrolyte has the properties to self-heal a damaged plate, it also has the ability to re-anodize the foil plate. As the anodizing process can be reversed, the electrolyte has the ability to remove the oxide coating from the foil as would happen if the capacitor was connected with a reverse polarity. Since the electrolyte has the ability to conduct electricity, if the aluminum oxide layer was removed or destroyed, the capacitor would allow current to pass from one plate to the other destroying the capacitor.

Normally, capacitors are made in cylindrical or rectangular housing.

Exhibit 4-8: Capacitors and its components



4.6.2 How to Test a Capacitor Cell

With a Capacitance Meter

Capacitor cells are rated in microfarad and voltage. The easiest way to test a cell is to measure the microfarads with a capacitance meter.

1. Disconnect power from the capacitor unit and wait one minute after the power has been disconnected to allow capacitors to discharge.
2. Measure microfarads using capacitance meter. The microfarads should be equal to the microfarad rating or up to 5% over the rating.
3. If microfarads are below the minimum, the cell is going bad.
4. Replace bad capacitor cells.

Without a Capacitance Meter

If a capacitor meter is not readily available, the status of a cell can sometimes be determined visually.

1. If the cell can is "bulged out" or "pouched up" on teh top, it is definitely bad.
2. Disconnect power from the capacitor unit and wait one minute after the power has been disconnected to allow capacitors to discharge.
3. Replace bad capacitor cells.

4.7 The PF Survey

Outline of the procedure for evaluating PF opportunities is:

- Find out the existing Power Factor of the plant and the Power Factor Penalty, if any, imposed by the Utility,
- Identify opportunities for individual, group or centralized power factor compensation
- Calculate the size the PF improvement equipment to improve the PF to the required limit fixed by the Utility for imposing the PF penalty,
- Calculate the annual savings in the electricity bill, and carry out the simple payback analysis for the cost of PF improvement equipment

5 Electrical System Survey Instruments

The basic objective of an electrical survey is to identify and quantify where and how much electricity is being used. This requires measurements through various instruments. Since the range of such instruments is very large, only those which are most essential, durable, portable, relatively inexpensive and easy to operate are described below. Before using the instruments, one should carefully read the operating instructions/manuals provided by the instrument manufacturers.

5.1 Ammeter, Voltmeter and Multi-meter

Ammeters (or clam-on ammeters) measure direct or alternating electric current in individual conductors. Most currents dealt with in the electric energy surveys are alternating. The ammeters commonly used are portable and are designed to be easily attached to and removed from an accessible conductor.

The snap - on provision in the construction of the ammeter allows for its current transformer to be easily put around and later removed from a conductor. There are many brands and styles of snap - on ammeters that can read up to 1,000 amperes continuously. This range can be extended to 4,000 amperes continuously for some models with an accessory step-down current transformer.

Voltmeters measure the difference in electrical potential between two points in an electrical circuit. The difference is expressed in volts. Voltage is a basic parameter which must be measured to calculate electrical energy.

Voltmeters used in surveys are usually integrated with the portable snap on ammeters and multi-function instruments (Exhibit 5-1). Operating as a voltmeter, the two voltage probes are clipped or hand held onto the two points being measured.

Exhibit 5-1: Multipurpose Meter

5.2 Watt-meter

The portable Watt-meter is a useful instrument because it gives a direct reading of the flow rate of electric energy in kilowatts. Other methods require measurements and calculations. In an unbalanced three - phase system, this can be a tedious way to determine energy usage.

The basic watt-meter consists of three voltage probes and a snap - on current coil which causes the Watt meter movement. Typical operating limits are 300 kilowatts, 650 volts, and 600 amperes. Watt-meters can be used on both one and three - phase circuits.

5.3 Power Factor Meter

A portable power factor meter is primarily a three-phase instrument. One of its three-voltage probes is attached to each conductor phase and a snap - on jaw is placed about one of the phases. By connecting its Watt meter circuitry, it directly reads the power factor of the circuit to which it is attached.

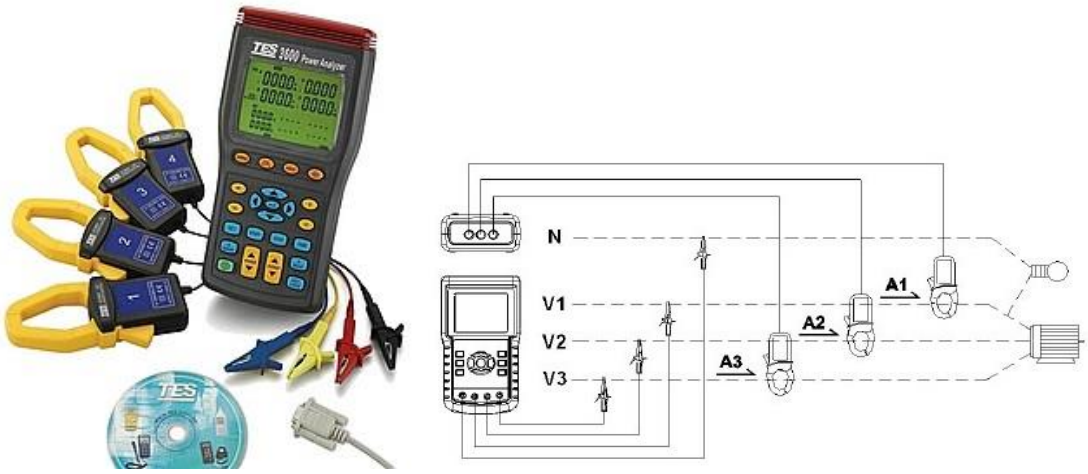
It can measure power factors over a range of 1.0 leading to 1.0 lagging and see capacities up to 1500 amperes at 600 volts. This range covers the bulk of applications found in most of the establishments.

The power factor is a basic parameter whose value must be known to calculate electric energy usage. Diagnostically, the meter is a useful instrument to determine the sources of a poor power factor.

5.4 Electrical Power and Demand Analyzers

The electric power and demand analyzer (Exhibit 5-2 and Exhibit 5-3) is an instrument specifically designed to conduct surveys of the electrical systems including analysis of MD. This is very versatile instrument and can perform many functions. Many models of different makes are available.

Exhibit 5-2: Three-phase power analyzer and connections diagram



Three- phase power analyzer (real time) with data storage, PC interface and software for measuring different parameters including voltage and current is microprocessor-based instrument. It computes all of the necessary parameters for the analysis of any single-phase, two-phase, or three-phase electrical systems; and provides information on the following parameters:

- Voltage measurement
- Current measurement
- Active power measurement
- Apparent power measurement
- Reactive power measurement
- Power factor measurement
- Phase angle
- Frequency measurement
- Harmonic analysis through the software (voltage and current)

In certain models, there is provision for setting demand and energy rate limits which when exceeded, the actual values are printed out and also an audible alarm is activated.

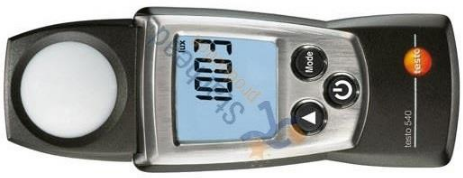
It can be permanently installed at critical locations in a plant where it is important to make sure that demand, energy consumption and power factor do not get out of hand. To conduct the survey of plant's internal electrical system, it is connected at various pre-selected locations for a full operating cycle (a day, a week, or possibly a month), or may be used for very short periods if, for example, simply checking the load or power factor of an individual motor.

Exhibit 5-3: Single-phase power analyzer, micro harmonic, and power factor meter

5.5 Light Meter

The level or intensity of light is measured by a light meter (Exhibit 5-4). The most common light meters in use today employ photo voltaic cells. In a light meter, the photocell is directly connected to a sensitive micro-ammeter calibrated in units of light intensity. Special covers are used to avoid reflection of light from the surface of the photocell.

Exhibit 5-4: Light meter



A light meter is used to measures the amount of light incident upon a surface (illuminance) in Lux or Foot-Candles and the brightness of a light source (luminance) in Foot-Lamberts. In use, the light meter is placed at the task level and a measurement for light level (illuminance) is taken at the plane such as the desktop. In a plant, the reading would be taken at an operator's station or at a critical location on a machine. The light level readings are then compared to standard lighting levels required for certain tasks.

5.6 Thermometer, Psychrometer and Anemometer

Thermometer is used to measure temperature, and fulfills a primary instrumentation need in all energy surveys. Many types of thermometers are available, but their application, durability, and relative cost dictate the choice.

Most air conditioning, ventilation, heating services and operating temperature one generally comes across are within the temperature range of -45^0C to 1200C. For these applications a multipurpose, portable and battery - operated thermometer is preferred. Usually these thermometers are provided with three separate probes for measuring liquid, air and surface temperatures. Specialized temperature measuring devices such as surface, optical, and infrared pyrometers are used depending on application. Recording thermometers are also available which may operate mechanically or electrically.

A Psychrometer measures relative humidity based on the relation of dry - bulb temperature to wet bulb temperature.

Recording psychrometers are used generally. Above 650C, humidity studies require very specialized equipment.

A simple alternative is to use a mechanical psychrometer, which consists of a dry bulb and wet bulb thermometer. From the corresponding wet bulb and dry bulb temperature readings, one can find out humidity of air using the psychrometeric charts.

The air velocity meter (velometer) is a rotary vane or swinging vane anemometer used in field measurements. It is a portable instrument, and has a wide range for measuring air velocity. It gives instant readings on air streams at both ambient and elevated temperatures. It can usually measure air velocities up to 50 m/s. Fittings and special attachments allow for its use in many applications.

Exhibit 5-5 shows a conventional psychrometer, digital psychrometers for measuring dry bulb and wet bulb temperatures; and multi-purpose anemometer.

Exhibit 5-5: Thermometer, Psychrometer and Multi-function Anemometer

The multi-function anemometer/psychrometer can measure air velocity, air flow, relative humidity, dry bulb and wet bulb temperatures, dew point and carbon dioxide (CO_2) concentration. It can take very precise readings on larger size ducts. It can also perform multipoint and timed average calculations, min/max, data hold.

Another flow measurement device used primarily for gases is the "Pitot tube" used in conjunction with a "manometer". The Pitot tube is inserted into the fluid stream for which velocity is to be measured. The Pitot tube operates on the principle that a gas flow across the end of an open tube causes a pressure drop. That pressure drop can be measured with the manometer. The manometer comes in either a portable configuration or one designed for permanent installation where it is known that the velocity profile of the flow stream is known to be flat.

The manometer is a U-shaped tube that is partially filled with a liquid, usually water or mercury. Currently, advanced anemometers are available with Pitot tube attachment.

5.7 Ultrasonic Flow Meter

Easily used and portable instrumentation for liquid flow measurement is not as readily available. The "ultrasonic flow meter" (Exhibit 5-6) consists of a set of transducers that are coupled with a display computer. The transducers are clamped onto the pipe containing the liquid under study. One transducer injects an ultrasonic signal into the fluid that is detected by the other transducer, located downstream and on the opposite side of the pipe from the first transducer. Velocity is determined either by measuring the time required to receive the transmitted signal or by measuring the signal's frequency change.

Exhibit 5-6: Ultrasonic flow meter

The ultrasonic flow meter has several features that are valuable to the energy surveyor. Chief among these is portability. Where permanently installed instrumentation is unnecessary or would interrupt plant operations, the ultrasonic instrument is non-intrusive. The accuracy of the device is excellent, at less than 0.5 percent error linear over the flow rate. Where a pipe network must be analyzed, spare transducer sets can be used with a common display computer. By switching between transducer sets, almost simultaneous readings can be taken.

The ultrasonic flow meter has a number of disadvantages as well. The equipment is expensive to buy. In addition, its application may not be possible with very dirty liquids (those with large quantities of suspended solids). Finally, some types of flow meters may not be usable with sonically non-conductive (concrete) pipes.

5.8 Pressure Gauge

Pressure gauges (Exhibit 5-7) used for monitoring steam and fluid systems are normally "Bourdon tube pressure gauges". A Bourdon tube is closed at one end and has an internal cross-section that is not a perfect circle. If bent or distorted, the tube has the property of changing its shape with internal pressure variation. Bourdon tube pressure indicators can be used to measure pressures in the range of 0 to 70 bars.

5.9 Thermal Imagers

With the passage of time, the thermal imagers Exhibit 5-7Exhibit 5-7 are being extensively used in the conduct of all kinds of surveys.

They offer the benefit of an extensive list of possible applications, such as HVAC, Plumbing, Electrical and Mechanical Inspection, Home and Building Inspection, Road Construction, Equine and Veterinary applications, Workplace Ergonomics, and Predictive Maintenance.

It is important to note that the thermal imagers are easy of-use. They feature a color TFT LCD capacitive touch screen, which allows to navigate the camera’s functions as simply as one can imagine. It also supports automatic image capture, video recording with voice annotations, and the ability to attach and save voice and text annotations to images. They give the option of both infrared and visual images—with picture-in-picture as well as IR (infrared) fusion. Images are saved to a micro SD memory card for convenience, and further use and analysis.

Exhibit 5-7: Pressure gauge

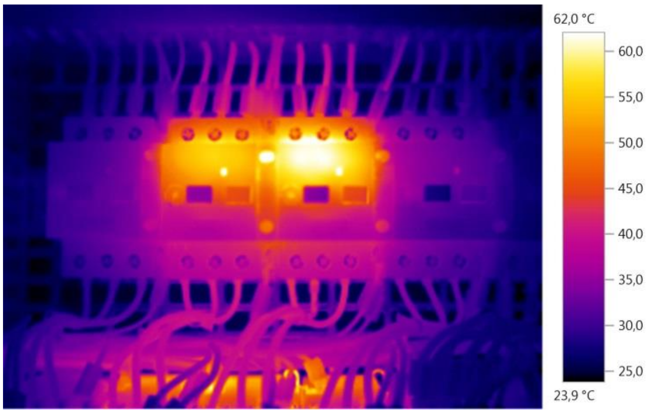
Exhibit 5-8: Thermal imager

The thermal imagers have very high thermal sensitivity. It makes them to pinpoint the location of issues quickly and effectively, while saving time. They are optimized for measurements in low and high temperatures ranges. They also feature an automatic hot/cold spot indicator and a three box area with min/max/average temperatures, as well as an isothermal measurement analysis for detecting high/low temperature intervals. Some of their various applications are listed below:

- Industrial - Inspect Conductor Joint/Cable Clamp Electrical Joint, Fan Motor, Transformer Magnetic Shielding, Generator Iron Loss Test, Cable Overloaded test, Analyze Cable Load Distribution
- Chemical Industry - Inspect Liquid Level, Test Boiler Refractory Lining
- Automobile - Inspect Oil Pines, Brake Pad, Air conditional outlet, Car window
- Building Inspect - Corroded Wall Busheling, Thermal Leakage, Thermal Leakage of Building's Outer Wall

Exhibit 5-9 demonstrates the use of thermal imagers in electrical systems.

Exhibit 5-9: Thermal imaging of electrical equipment and terminals



5.10 Handheld Tachometer

The handheld tachometer is a means of measuring revolutions within the industrial sector, either optically or mechanically. The handheld tachometer can be used for maintenance and calibration of machines that have moving parts. The principle is similar to a bicycle speedometer, where time will be measured until a wheel has completely turned. The handheld tachometer has two different measurement methods (Exhibit 5-10). The handheld tachometer may have a contact connection to the moving parts. Alternatively, the handheld tachometer works with reflecting marks. This is secured on the moving part. As the laser strikes the reflecting mark during rotation, it is reflected and detected in the handheld tachometer via a sensor. Rotation speed and speed can be seen on the handheld tachometer. Certain available handheld tachometers may combine both possibilities, i.e. contact and non-contact connection.

Exhibit 5-10: Contact and Optical Tachometers

6 Maximum Demand Control

The standard practice, all over the world, is that for large electricity consumers the electricity supply authorities base their monthly electricity charges mainly on two parameters: electrical energy consumption (kWh) and maximum demand (recorded in kVA or kW). Maximum demand (MD) charges are an important and appreciable component of electricity bill of large consumers. Depending on the type of electrical loads of an establishment, the use of electricity and number of shifts, the maximum demand (MD) charges typically range from 15 to 40% of the total bill. Thus the purpose of this chapter is to explain how to reduce MD charges without affecting the production, etc.

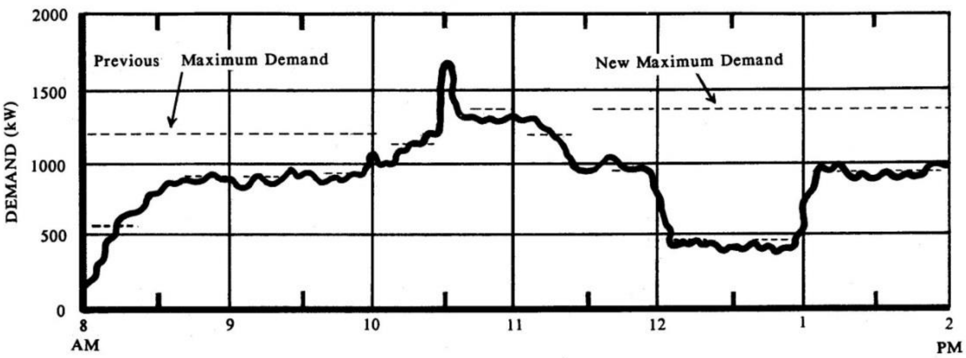
6.1 Recording of Maximum Demand (MD)

The meter installed by supply authority to measure MD is an integrating meter, i.e., it adds up the kVAh (or kWh) consumed over a 15 minute or half hour period. Then the number is multiplied by 4 or 2 respectively to establish the average MD. In the demand meters, there is a pointer-pusher mechanism that advances the demand pointer. After each demand interval the pointer-pusher is reset to zero by a clock, leaving the demand pointer up-scale. During some interval in the billing period, the pointer-pusher advances the pointer to MD point on the scale. It is this point demand that is used for billing.

After the meter is read, the meter reader manually resets the demand pointer to zero using a sealable reset in the meter cover.

Exhibit 6-1 shows a typical load profile of instantaneous peak demand curve for an industrial plant, along with the curve for average MD calculated over 30-minute intervals.

Exhibit 6-1: Load profile of an industrial plant



Demand measured every half an hour is shown as dotted line. A brief peak, measured at 10:30 AM can establish a new maximum demand.

6.2 Why Do Utilities Charge For Maximum Demand (MD)?

MD is the factor which is introduced in the bill to take into account the time-varying nature of consumer loads. And MD charges is the fees which consumers have to pay to the supply authority for its investment in the equipment (generating capability, distribution lines, transformers, switchgear) which must be installed to satisfy the consumers' maximum load requirements. If every consumer's load was absolutely constant there would be no need for a demand charge, since each consumer would pay for his proportion of the equipment costs in his bill for the electrical energy he consumes. But loads vary with time, much more so for some consumers than others. Hence, the MD charges are the way to recover the cost of required equipment while treating each consumer fairly.

Example

As an example, assume there are two consumers, each of whom consumes 1,200 kWh of electrical energy in a day. If each had an absolutely constant load requirement of 50 kW (50 kW × 24 hrs = 1,200 kWh) then a generating capacity of slightly over 100 kW, plus suitable distribution lines and transformers losses would be sufficient to handle their requirements at all times. But if one consumer has a load requirement of 30 kW for 23 hours and 510 kW for one hour then things change (30 kW × 23 hr + 510 kW × 1 hr = 1,200 kWh).

Both consumers still consume 1,200 kWh of electrical energy in a day, but now the supply authority must have a generating and distribution capacity of something over 560 kW to handle the short term load requirements of the second consumer. So, the inclusion of MD charges in the bill will treat both consumers fairly.

6.3 Analysis of Opportunities for MD Control

The 30-minute interval used for MD determination offers a greater possibility of MD control than a 15-minute interval being used in some parts of the world, since more time is available to turn off or reduce loads that may be contributing to the MD peak. The initial steps to a MD management program are listed below:

- Perform the bill analysis and determine if potential for reduction of MD exists
- Determine when the MD occurs, what time of day, what day during the billing period
- Identify loads which contribute to demand peaks, and identify loads which could be reduced or turned off to avoid a demand peak

Study of at least last one year electricity bills will provide the data on, such as: (a) applicable tariff, (b) sanctioned/contract load, (c) MD established during the month, (d) basis of billing demand, (e) pattern of MD established during every month, (f) load factor, as an indication of the MD utilization of the plant.

The analysis of above data will simply provide preliminary indications on MD reduction possibilities.

The load factor of a plant shows how well the MD is distributed over the operating hours. If the MD is constant at all operating hours of the plant, that is the best possible utilization of the installed capacity. The ideal load factor of 1.0 is impossible to achieve, but the higher the load factor, the better is the utilization of plant capacity and lower the average energy cost. For a single shift operation, the load factor is limited to about 0.25 to 0.3, for two-shift operation the maximum load factor could be 0.55 to 0.6, while three-shift operations can achieve load factors as high as 0.85 to 0.9.

A low load factor indicates the potential for spreading the loads to reduce MD. Load factor can be increased by either increasing the consumption at constant demand, or by reducing the demand at constant consumption. Equation for load factor is as the following:

$$\text{Load factor \%} = \frac{\text{Consumption during the period (kWh)} \times 100}{\text{Maximum Demand} \times \text{Number of hours in that period}}$$

6.4 Identification of Types of Loads

To control MD, three types of electrical loads must be identified, i.e., occasional (infrequent) loads, high production operation loads and optional (discretionary) loads. These are discussed below:

Occasional Loads: Occasional loads are critical. Due to ratchet clause in the electricity supply contract, in-attention to demand level for one demand interval (i.e. say for 30 minutes) may affect the bill for the next 11 months. Hence, particular attention should be paid to occasional high load operations.

Example

For example, in a chemical processing plant, one of a pair of 100 kW pumps which operated on alternate days failed. After repair, a 30-minute full-load test was carried out on the pump before it was released for service. Without thinking, the test happened to be carried out at the time of the plant's highest level demand interval for the year. Consequently, the MD charge was raised for 100 kW for the current month, and due to ratchet clause for the next eleven months as well. If the test had been carried out at a time when plant's demand was low, the energy charges would have been the only cost.

While this is an extreme case, it serves to show the kind of thing that can happen when operating under a ratchet clause if continuing attention is not devoted to demand level.

High Production Loads: The first is production equipment, which adversely affects peak demands, and which may be the first target for demand control.

These essential loads may be of continuous, batch or intermittent nature, and are comparatively difficult to manage for achieving reduction in MD.

Optional Loads: Somewhat more manageable situation arises in the case of optional loads, such as, arc furnaces, ventilating fans, induction furnaces, water-heaters, drying ovens, cold storages, battery chargers, pumping equipment, air conditioners, grinders and crushers.

These are classed as optional (or non-essential) loads, at least for short periods of time. For all such loads, interruption for short periods of time will not be noticed by personnel nor affect business operating efficiency. Hence, demand management can be achieved by shedding and restoring (i.e., duty cycling) these loads.

Duty cycling t allows loads to be cycled intermittently and in turn. It allows additional savings to be made by reducing kWh consumption

6.5 MD Survey Instruments

6.5.1 Recording Ampere, kVA and kW Meters

They can be used in, for example:

- Overall plant load over a one-day or longer period, to determine the demand profile, identifying the value and timing of the peak demand
- Overall night time load of a plant or department to check the equipment load over time, possibly identifying unnecessary consumption
- Chiller or air conditioner cycling with time of day
- Cycling time of an air compressor

6.5.2 Electrical Power and Demand Analyzer

It can be permanently installed at critical locations in a plant where it is important to make sure that demand, energy consumption and power factor do not get out of hand. To conduct the survey of plant's internal electrical system, it is connected at various pre-selected locations for a full operating cycle (a day, a week, or possibly a month), or may be used/installed for very short periods if, for example, simply checking the load or power factor of an individual motor.

6.6 Developing and Studying Demand Profile

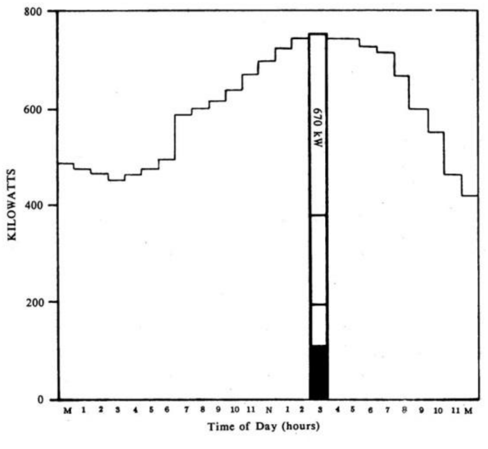
Electricity bill analysis gives only the peak demand for a month. There is no indication of how this peak compares to the balance of the demand profile for the month, nor what combinations of loads caused the peak. This information can only be acquired by monitoring the key points in the internal electrical system.

Once the bill analysis indicates the possibility or need for demand control, load curves or demand profiles can be developed and examined to determine when and from where contributions to MD are coming. The load curves should be plotted starting with the largest time scale as shown below:

Load Curve	Time Period	Source of Data
Monthly Maximum Demand	Last 1 to 2 Years	Electricity Bills
Daily Maximum Demand	1 Billing Period	Plant kW meter
Hourly Demand	1 Maximum Day and 1 Typical Day	Recording Ammeter or kW meter or Power Demand Analyzer

The monthly MD profile can quickly identify the demand pattern over the year, and determine which months may be contributing more to the billing demand, and if there are months which trigger the ratchet clause. The daily MD curve can point out days on which higher demands occur. The hourly demand profile identifies the times of the day when MD occur (Exhibit 6-2).

Exhibit 6-2: Hourly demand profile for one day



As soon as any of these curves are developed, a number of questions immediately arise, such as: Why is one month so much higher than the rest? Why is there so much variation from month to month? Is varying production enough to explain the differing levels? Do the differences correlate with production? Why is not the demand constant from day to day? Why does the daily peak occur at a particular time? The answers to these questions and many others may lead to identification of measures to control MD. Additional measurements may need to be taken in order to identify which particular equipment is contributing to the MD, and to what extent.

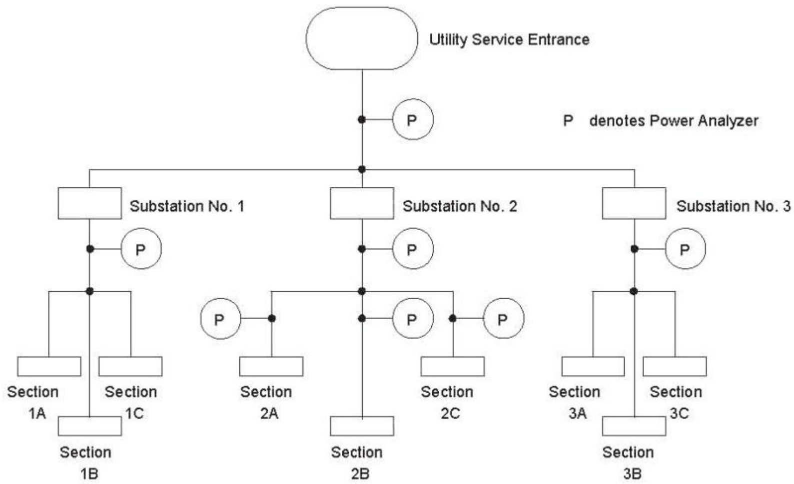
The load curves may also point out the difficulties of achieving reductions in MD. For example, in case of a relatively flat MD curve, that lasts several hours, in order to achieve even a small reduction in demand, some equipment may have to be removed from service for several hours. On the other hand, the peak may be caused by afternoon air conditioning load which could be reduced depending on plant requirements.

Each electrical system is different but they are all spread out like a pyramid, with total plant information available at the peak and more and more detailed information available as the base is approached. At what-ever point a study is made, it must be carried out for a full cycle of operations so that all normal permutations and combinations of loads are encountered. Depending on the type of plant, duration of a full cycle of operation may be a day, but more likely a week and sometimes a complete month or billing period. Exhibit 6-3 shows a typical situation with three substations and three feeders per substation.

A demand profile at the mains provides considerable information about the overall plant. If it peaks radically at a few spots then demand leveling could well lead to a reduction in demand charges. Then it might pay to see if the loads causing the peaks can be shifted to off-peak period. Of course, if the demand profile is reasonably level this may indicate there is little to be gained in attempting to improve the situation.

Assuming that improvements seem possible, then further investigation must be carried out to determine what load combinations are causing the demand peaks and what, if anything, can be done to shift load combinations to reduce these peaks. In a typical plant diagram shown (Exhibit 6-3), the procedure would be to monitor the demand on the output of the three substations and then monitor the individual feeders being supplied by the substations. Provided that the demand studies are carried out at comparable times in the plant operating cycle, and that successive operating cycles show reasonable consistency, then the three substation demand profiles should add up to roughly equal the overall plant profile and the feeder profile sums should roughly equal the respective substation demand profiles.

Exhibit 6-3: Typical connection points for power demand analyzer for conducting the demand survey



With the help of an appropriate demand analyzer, developing a series of such plots for an entire plant and jotting notes of the plots to indicate the principal loads gives a very clear picture of the overall demand situation for the whole plant. Such information is invaluable in guiding procedural steps towards reducing demand charges or in laying the groundwork for an energy management system program if such can be justified.

It is important to remember that changing market forces and shifting equipment requirements continually modify the plant load makeup to some degree. Therefore, periodic studies should be carried out at least at the factory mains, to make sure gains are not permitted to dissipate.

6.7 Methods of Demand Control

Demand leveling is the key to MD control and demand leveling can be achieved by scheduling the loads.

Assuming that in a plant all loads must be run for a certain amount of time and there are constraints on when this time can be, the question is how to schedule the loads so that demand is minimized without interfering with the production of the establishment. While this will probably mean adhering to a somewhat more rigid schedule than previously, the returns in reduced demand charges (and possibly energy charges) can be considerable. As pointed out earlier, this requires a careful time versus load survey of all portions of an establishment for at least one full cycle of operation.

Scheduling high load production operations for demand leveling is a complicated affair, particularly when departments/sections of a company operate essentially independently yet share the same electric supply. If one department is running an electric heat treatment furnace during the same demand interval when another department wants to operate a large press, and these equipment represent a significant portion of installed load, the demand may well peak at a higher than necessary level. To solve a problem like this, if it is practical to solve it at all, it requires interdepartmental cooperation and convincing the overall authority. Situations like this are probably most difficult in attempting to reduce demand levels.

Also, the objective of demand leveling is to make sure that the average demand for one or more demand intervals in a month does not peak substantially over the average demand for the balance of the intervals in the month.

It has been said that demand leveling improvements are both easy and obvious or not worth it. Whether this is true or not depends on the significance of the demand charges as a portion of operating expenses, the characteristics of the plant or establishment, and other factors.

MD can be controlled manually or with the help of automated devices. Advantages and disadvantages exist with both manual and automatic control, and each has a different level of complexity and cost associated with it. While every plant should be practicing manual demand control, only larger plants may find it attractive to install automatic controls.

6.7.1 Manual Demand Control

For purposes of discussion, manual control of demand can be divided into load scheduling and demand monitoring activities.

6.7.1.1 Load Scheduling

The most effective manual method for demand control is to schedule or program the operation of different loads. In some cases, this may simply be a prohibition for certain loads to operate during a specified time; for example, a large crusher should never be operated during the 10 a.m. to 12 noon peak at a particular chemical plant. In other cases, scheduling may define operating times for certain departments, process lines, or machines. In many plants this is easy to do, and may involve a simple but permanent change in schedule. In other plants, schedules may need constant revision as the production changes.

The manual scheduling method should in no way be immediately passed by for a more sophisticated automatic control. Even for automatic controls, manual input and decisions are necessary to ensure continued and proper production levels with the shedding of some loads.

6.7.1.2 Monitoring

Visual monitoring of a demand meter or ammeter, or group of ammeters, at a plant's main switchboard is a useful but not reliable alternate method for manual demand control. A good communication must be developed between the main switchboard and the potential equipment to be turned off so that lag time can be minimized. This is practiced by some plants as standard procedure to guard against unnecessarily high demand peaks.

Alternately, an enhanced manual system can be set up, which includes an alarm bell to ring when the demand exceeds predetermined setpoint. Again, this may only work if careful and immediate heed is paid to the alarm.

6.7.2 Automatic Demand Control

In many plants, the number of different loads with different characteristics may just be too high, and the possible variations just too many for effective manual control. In other plants, where manual control is already working, it may still be possible to reduce demand with the addition of automatic control. Clearly, automatic control is a more sophisticated, versatile and reliable way to ensure limits to peak demand.

In regard to MD control systems it is good practice to keep them as simple as possible while still accomplishing the desired purpose. But in any event it pays to carefully analyze the electrical system before investing large sums in power demand controllers and similar energy control systems. Practicality and economic justification vary widely from establishment to establishment, especially when other ways of accomplishing the same results are considered.

Demand controllers work best in establishments where so called optional (non-essential) loads make up a substantial portion of the installed load base.

6.8 Demand Controllers

MD controllers range from simple monitors which alarm on excess demand up to complex computer-based systems. Except for the monitors which require manual intervention to limit demand, most of the other power demand controllers automatically shed and restore loads to maintain demand at close to some pre-selected limit. In addition to MD control, more sophisticated controllers can also have the following features:

- Time of day control
- Duty cycling control
- Load profile recording
- Data collection facilities with printout
- Fully programmable using keypad and interactive display

Through time of day control unneeded loads can be shut down during off- hours and on weekends and holidays. This type of control really does more to conserve energy consumption than to reduce demand level.

In order to operate effectively, the demand controller must be connected to and provided with a list of loads that can be shed or restored, as well as a procedure or priority for their shedding and restoration. Some type of controllers must also be synchronized with the supply authority demand meter. A more sophisticated controller may also require input of recommended or maximum off times for different loads. Finally, The demand controller must also be provided a setpoint on which all the control functions will be based.

The assignment or designation of a control setpoint for the demand controller will have an impact both on the number of loads shed (and possible disturbance to the process) as well as the amount of savings that can be obtained. To begin with, and assuming the process will allow it, the set-point should be set at not less than 75% of the highest MD during the last eleven months, as the industry will have to pay demand charges of at least this amount in any case.

Generally, the least critical loads should be shed first, followed by more important loads, if necessary. The number of loads that must be shed depends upon the extent to which the setpoint has been exceeded as well as the total kW rating of each load that is being shed. When the controller has been working for some time, and the plant management is accustomed to it, additional reductions in the demand setpoint can carefully be made, making sure to evaluate the impact of shedding each selected load.

A common problem with all demand controllers is short cycling of loads, or the tendency to shed and restore loads rapidly as demand fluctuates. This can be destructive to loads such as air conditioners and large motors. Certain controllers get around this by assigning minimum on-times, minimum off-times, and duty cycles to each load. Duty cycling is the minimum amount of time a load must have been on during the past hour. Other controllers trigger external timers which prohibit the load change until the timer has timed out.

MD controllers are basically of two types: (a) those that require timing synchronization with the supply authority demand interval, and (b) those that do not.

6.8.1 Sliding Window Controllers

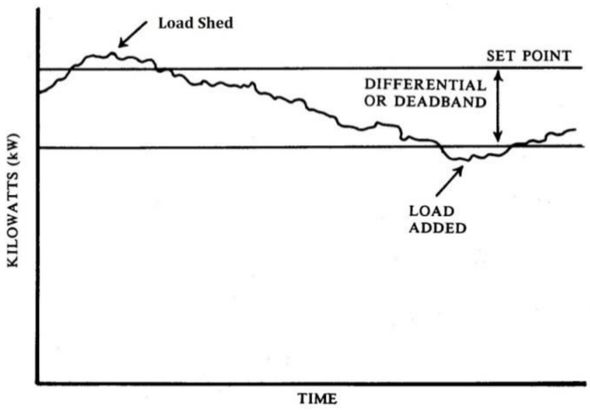
The continuous integration or sliding window controller stores kVAh (or kWh) information accumulated during an interval (say 15 minutes) and averages this information to determine the average power consumption. The information is up-dated every 3 or 6 seconds and the controller continues to develop average demand values It functions independent of supply authorities' demand interval.

Demand control is achieved by shedding or restoring loads based on programmed threshold demand levels and the average demand for the past 15 or 30-minute window (interval). If demand exceeds the high level threshold, loads are shed, and if demand drops to the low level threshold, loads are restored. Fundamentally, loads are shed or restored based on assigned priorities - loads that will affect operations the least are dropped first.

6.8.2 Instantaneous Rate Controllers

A typical method, referred to as the Instantaneous Rate Method, provides a close control of actual demand. In this method (Exhibit 6-4), the level of demand is measured continuously and compared with a preset kVAh (or kW) level setpoint. If the measured value of demand exceeds the setpoint, the controller is activated and begins to shed load until the power demand drops below a lower setpoint determined by a differential or dead-band relative to the higher set-point. When the demand drops below the lower setpoint, loads may be restored or added. This lower setpoint prevents too frequent load add and shed conditions.

Exhibit 6-4: Instantaneous rate method



Other methods of demand control include those based on an ideal curve of how demand would vary within the supply authority's prescribed demand interval, and those based on predictions of whether or not the demand, based on its rate of increase, will exceed a prescribed limit.

6.8.3 Timers

Sometimes timers are just as good. Automatic demand controllers work best where there is a multiplicity of non-essential loads without the presence of dominating high load production equipment or other high loads which absolutely cannot be indiscriminately shed or restored. In the latter situation where there are dominating high loads, or in cases of small establishments where there are only a very few non-essential loads, a timer or programmable sequence controller may do as well as a full-blown demand controller.

For example, if there are 20 ventilating fans serving an area and it is known that two can always be shut down for 10 minutes without anyone noticing it, then a simple timer-sequencer can cycle through the fans shedding and restoring them in some selected order. Air conditioners and electric heaters of various types can be handled in the same way, thus minimizing demand level and energy consumption together, strictly on a time basis. Such simple systems, combined with manual scheduling high production loads, can minimize demand levels even in large industrial sites.

In any event, as stated before, a careful analysis of the entire load situation should be made in light of the applicable electricity rate schedule before demand-leveling load schemes are adopted or investments are made in power demand control equipment.

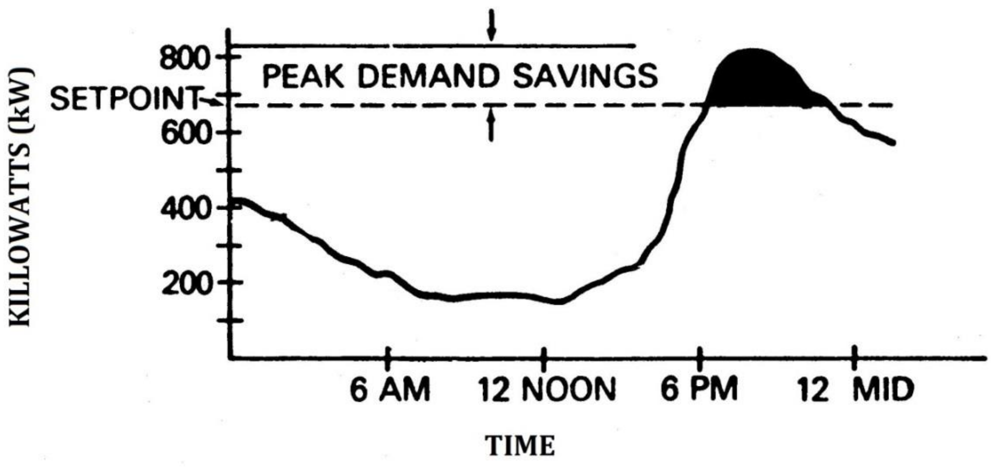
6.9 Justification for Demand Control Systems

A careful analysis of the demand versus time profile for at least one full operating cycle of an establishment should permit a reasonable estimates of what is practical and possible in terms of demand leveling measures, whether automatic or procedural. Projected demand level reductions will give a close indication of anticipated electric bill reductions. These can be compared with the cost, if any, of achieving these demand leveling measures to see if the payback period satisfies company criteria.

Exhibit 6-5 gives example of peak demand savings by load shedding.

Comparing demand charges for the years immediately preceding and following the introduction of demand leveling procedures is straightforward if nothing much has changed. But, if installed load has been modified, business activity moved up or down, or other changes have taken place this comparison is not so simple if the true value of the demand leveling measures is to be determined.

Exhibit 6-5: Peak demand saving by load shedding



Improving Load Factor

A company or commercial institution can lower its maximum demand by improving the load factor. Increasing the load factor will diminish the average unit cost (demand and energy) of the kWh. Depending on the situation, improving the load factor could mean substantial savings.

The load factor corresponds to the ratios between the actual energy consumption (kWh) and the maximum power recorded (demand) for that period of time.

$$\text{Load factor} = \frac{\text{Consumption during the period (kWh)}}{\text{Maximum Demand} \times \text{Number of hours in that period}}$$

Or,

$$\text{Load factor \%} = \frac{\text{Consumption during the period (kWh)} \times 100}{\text{Maximum Demand} \times \text{Number of hours in that period}}$$

By analyzing the load profile and the needs, the facility may be able to improve its load factor by doing the following:

A – Demand reduction: Reduce demand by distributing the loads over different time periods.

B – Increase production: Keeping the demand stable and increasing consumption is often a cost-effective way to increase production while maximizing the use of power.

In both cases, the load factor will improve and therefore reduce your average unit cost per kWh.

6.10 The MD Survey

Procedure for conducting the MD survey is outlined below:

- Find out from the last 12 months' bills, whether the MDI charges for the company are based on (i) 50% of the total sanctioned load (or connected load whichever is considered by electric supply authorities) or (ii) 1 kW higher than the minimum demand in the tariff category. (Note:- This step is already covered under bill analysis).
- Discuss with engineer, operations supervisor when peak demands are liable to occur.
- Identify potential reductions in peak demand through rescheduling of operations.
- Develop a load profile based on the inventory and operating schedule.
- Compare actual recorded maximum demand with the developed load profiles.
- If the two do not agree, investigate reasons and where appropriate, modify load inventory, operating schedule and development load profile.
- Study the process flow diagram, and identify natural break points between various stages of the process where loads could be shut off for some time.
- Develop new operating schedule incorporating rescheduling and the shutting off of loads at peak periods and draw new load profiles. In developing the new operating schedule prepare the operating schedule for at least one month. Identify methods, i.e., manual/timer/automatic controls to achieve load scheduling.
    - Compare existing load profiles and new (developed) load profiles.
    - Calculate expected annual savings, implementation cost and simple payback period.

7 Lighting Systems

Lighting can represent a significant proportion of energy use in most establishments and particularly in commercial buildings. Adequate natural light can only be provided for a limited distance from windows or skylights, and is only available for part of the day. At night, large areas of un-curtained glass become shiny black walls causing discomfort, while during the day they may prove uneconomical due to high solar heat gains (summer) or conductive or convective heat losses (winter). For these reasons, correctly controlled artificial lighting should be provided.

Lighting energy consumption depends on the installed load and the hours of use of the installation. Energy efficient practice ensures that both aspects are carefully considered. The illuminance required for a particular task can be found in various codes for interior lighting. For a given design illuminance, the installed load depends on the efficiency of the lighting equipment: lamps, ballasts and luminaries; the lighting design and the proposed maintenance system. The hours of use are determined by the switching patterns and lighting controls.

Some useful lighting terms are:

Luminous Efficacy:

It is the measure of the lamp light output in Lumens per Watt input.

Lumen:

It is the unit of luminous flux. One Lumen equals luminous flux through a unit solid angle from a point source of one Candela (a Candela is the luminous intensity from a black body at temperature of molten platinum, 2042 °K)

Foot Candle:

It is the illuminance on the surface one square foot in area, on which there is a uniform flux of one lumen.

Lux:

It is the illuminance on a surface one square meter in area on which there is a uniform flux of one lumen.

Phot:

It is the illuminance on a surface of one square centimeter in area on which there is a uniform flux of one lumen.

Foot-Lambert:

It is the luminance of a source, measured in Candela per square centimeter normal to the source.

$$1 \text{ Foot Candle} = 10.764 \text{ Lux} = 0.001076 \text{ Phot}$$

7.1 Types of Electric Lamps

The main types of electric lamps include: tungsten filament lamps and discharge lamps (which include fluorescent tubes), and LEDs (light emitting diodes). Lamp efficacy is generally presented in units of lumens per watt and for comparison purposes control circuit losses of fluorescent and discharge lamps should also be considered. The lamps with the highest lumens per watt provide more illumination per unit of energy consumed. Various types of lamps are described below:

Tungsten filament

A tungsten filament (Exhibit 7-1) is heated to incandescence in a glass envelope usually filled with an inert gas; this type of luminaire fixture does not require any control gear. Characteristics: immediate full light output; most types operate in all positions; light output sensitive to small voltage variations; lamp life sensitive to vibrations and small voltage variations.

Tungsten halogen filament

A tungsten filament is heated to incandescence in a small envelope containing a halogen gas: does not require any control gear, but may require low voltages. Characteristics: immediate full light output; may have restricted operating positional light output; life sensitive to small voltage variations and vibration; the envelope surface is liable to deteriorate if touched with bare hands; almost no decline in light output with time.

High pressure mercury tungsten discharge

An electric discharge in a high pressure mercury atmosphere contained in an arc tube in series with a tungsten filament heated to incandescence, all contained within a glass envelope with a fluorescent coating; does not need control gear (Exhibit 7-1). Characteristics: some light output immediately, but run-up period to 90 percent of full light output requires about 4 minutes; re-ignition after about 10 minutes; operating positions restricted; life sensitive to voltage variations and vibration.

Exhibit 7-1: Incandescent lamp

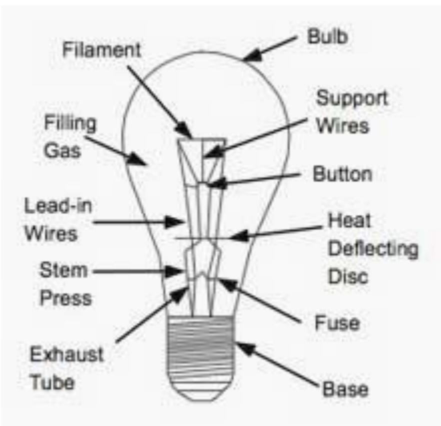
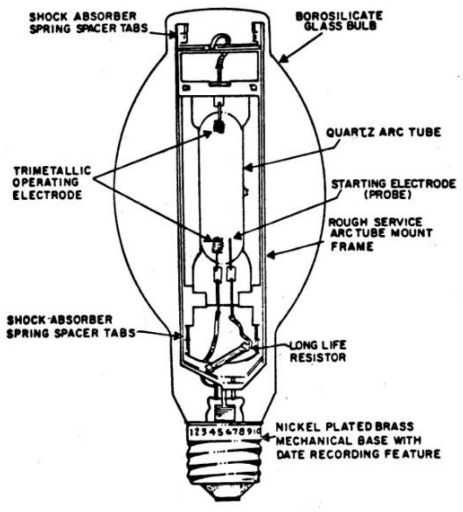


Exhibit 7-2: Mercury lamp



High pressure mercury discharge

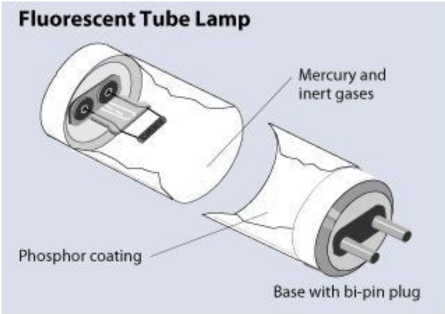
An electric discharge in a high pressure mercury atmosphere contained in an arc tube within a glass envelope with a fluorescent coating; needs control gear. Characteristics: run-up period to 90 percent of full light output requires about 4 minutes; re-ignition after about 10 minutes unless special circuits used; operates in all positions.

An electric discharge in a high pressure mercury atmosphere with metal halide additives in an arc tube, sometimes contained within a glass envelope; the outer envelope may have a fluorescent coating; needs control gear. Characteristics: run-up period to 90 percent of full light output requires about 5 minutes; re-ignition after about 10 minutes, unless special circuits are used; restricted operating positions.

Low pressure mercury discharge (tubular fluorescent)

An electric discharge in a low pressure mercury atmosphere contained in a glass tube, internally coated with a fluorescent material; needs control gear (Exhibit 7-3). Characteristics: immediate light output and restrike; operates in all positions; light output sensitive to ambient temperature; air temperature above and below about 25oC reduces the light output; difficult to start at low temperature. Many sizes of lamps and types of fluorescent coatings produce a wide range of luminous efficacies and color properties. For convenience they are divided into four groups: (1) a lamp group used for application where accurate color judgments are required; (2) a lamp group suitable for general use and having rare - earth, triphosphate coating; (3) a lamp group suitable for general use, but having halo-phosphate coating; (4) a group of compact, low power lamps designed as alternatives to the tungsten filament lamp.

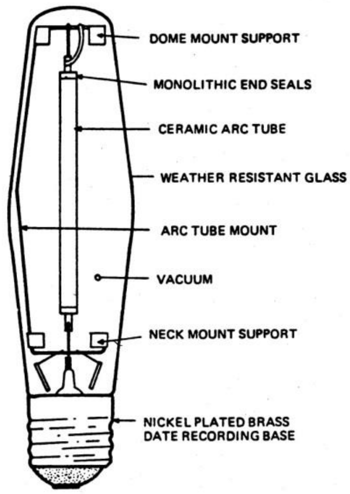
Exhibit 7-3: Fluorescent tube



High pressure sodium discharge

An electric discharge in a high pressure sodium atmosphere in an arc tube contained in a diffusing or clear outer envelope; needs control gear. Characteristics: run-up time to 90 percent of light output requires from 4 to 7 minutes, re-ignition within 1 minute if an external igniter is used; operates in any position; high pressure sodium discharge lamp family is developing rapidly (Exhibit 7-4).

Exhibit 7-4: High pressure sodium lamp



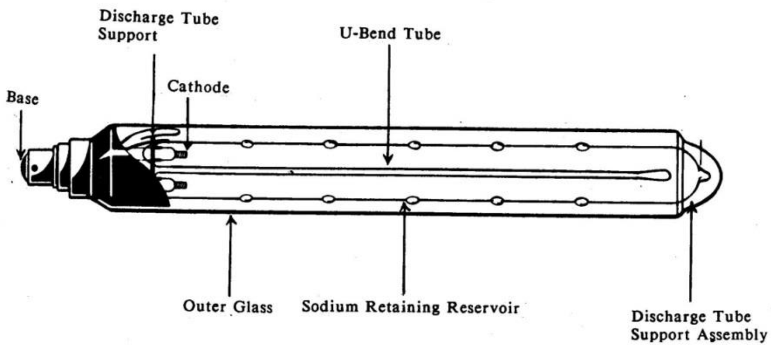
Low pressure sodium discharge

An electric discharge in a low pressure sodium atmosphere in a glass arc tube contained in a glass envelope; needs control gear. Characteristics: run-up to 90 percent of full light output requires from 6 to 12 minutes, re-ignition typically within 3 minutes; restricted operating positions (Exhibit 7-5).

Fluorescent lamps, like other discharge lamps, need some form of starting device (starters) and a means of controlling the lamp current once started (ballast or choke). A capacitor can be connected to provide power factor correction and reduce the current drawn from the mains for a given Wattage. Control gear (starter and ballast) comes in a variety of forms. The simplest equipment uses a starter and choke (from cored inductor). The starter switch may be a plug-in glow starter (which should be replaced at every second or third lamp change) or an electronic starter. Special low-loss chokes can be obtained with greater copper content to improve the efficiency of switch and choke starters. These are heavier and bulkier than standard chokes and are more expensive. Quick-start, semi-resonant start, and similar circuits do not use starters.

The final category of starters is the all-electronic and part-electronic ballasts. These are similar to the ballasts used in emergency lighting equipment. They are more efficient than conventional circuits and operate suitable lamps more efficiently. This efficiency is, however, achieved at a greater cost.

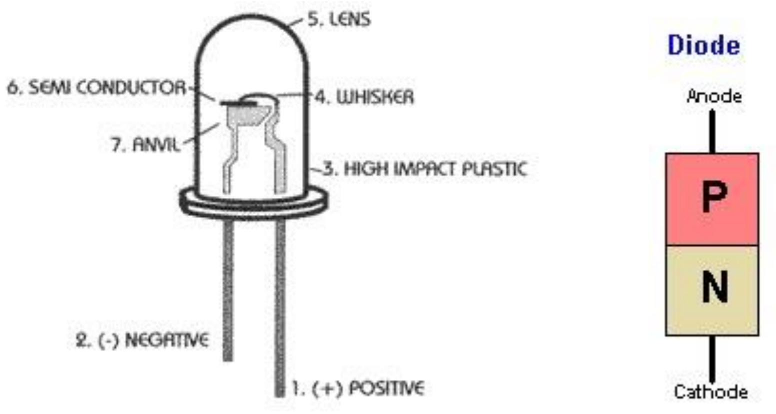
Exhibit 7-5: Low pressure sodium lamp



7.2 LED Lights

A light-emitting diode (LED) is essentially a PN junction semiconductor diode that emits light when current is applied. By definition, it is a solid-state device that controls current without heated filaments and is therefore very reliable (Exhibit 7-6).

Exhibit 7-6: LED and diode PN junction



The PN junction is one of the primary building blocks of semiconductors. It is the interface at which p-type silicon and n-type silicon make contact with each other. At this coupling point, free electrons (n-type) and holes (p-type) cancel each other and form a "depletion zone" that acts as a non-conductive barrier.

LED lights stand out due to their very long life, lumens maintainability, high energy efficiency, ecological acceptability, durable quality, zero UV emissions, operational in extreme cold and hot conditions, good light dispersion, instant lighting and frequent switching possible, and operation at low voltage. LED lights offer a very large variety of colors.

New developments are taking place at a very fast phase in improving the quality and quantity of LED lights; and they offer very bright prospects at highly efficient levels.

7.3 Lighting Levels and Control

7.3.1 Lighting Level Standards and Considerations

The standard levels of illumination common and recommended by various societies reflect current good practice. They are not the sole criteria of good lighting, for other factors such as visual comfort, the color of the light and the "atmosphere" of an installation must also be taken into account. The recommended illumination levels do, however, provide a foundation on which to base lighting design.

Common Light Levels Outdoor

Common light levels outdoor at day and night can be found in the Exhibit 7-7.

Exhibit 7-7: Outdoor light levels

Condition	Illumination	
	(foot candle)	(lux)
Sunlight	10,000	107,527
Full Daylight	1,000	10,752
Overcast Day	100	1,075
Very Dark Day	10	107
Twilight	1	10.8
Deep Twilight	0.1	1.08
Full Moon	0.01	0.108
Quarter Moon	0.001	0.0108
Starlight	0.0001	0.0011
Overcast Night	0.00001	0.0001

Common and Recommended Light Levels Indoor

The outdoor light level is approximately 10,000 lux on a clear day. In the building, in the area closest to windows, the light level may be reduced to approximately 1,000 lux. In the middle area it may be as low as 25 - 50 lux. Additional lighting equipment is often necessary to compensate the low levels.

Earlier it was common with light levels in the range 100 - 300 lux for normal activities. Today the light level is more common in the range 500 - 1000 lux - depending on activity. For precision and detailed works, the light level may even approach 1500 - 2000 lux.

Further, the following Exhibit 7-8 provides guidelines for recommended light level in different work spaces:

Exhibit 7-8: Recommended lighting levels in different work spaces

Activity	Illumination (lux, lumen/m2)
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes	250
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500
Supermarkets, Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theatres	1,000
Detailed Drawing Work, Very Detailed Mechanical Works	1,500 - 2,000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2,000 - 5,000
Performance of very prolonged and exacting visual tasks	5,000 - 10,000
Performance of very special visual tasks of extremely low contrast and small size	10,000 - 20,000

7.4 Properties of Lights

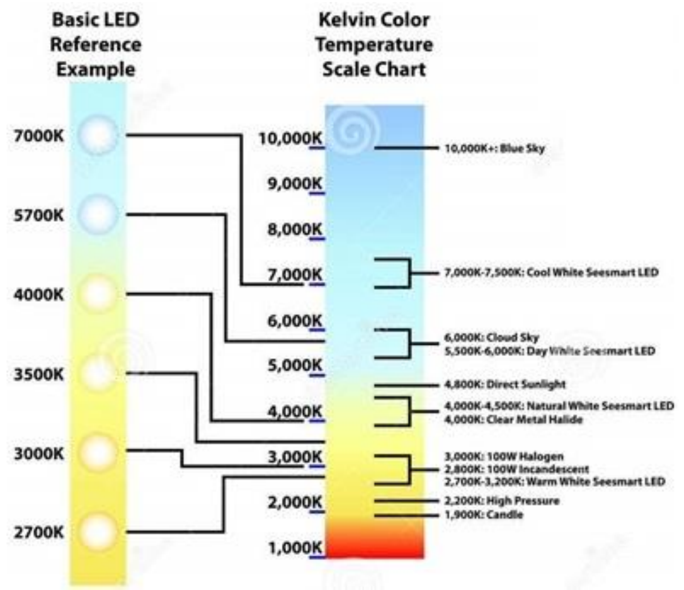
Exhibit 7-9 shows the lumens output and burning life of various types of lamps.

Exhibit 7-9: Lumen output and burning life of various lamps

	Lumen Output		Burning Life
Lamp Type	**(initial)**	**(maintained)**	**Hours**
Light Emitting Diode (LED)	150 +	150 +	60,000 +
Low-Pressure Sodium (LPS)	147	147	10,000
High-Pressure Sodium (Clear) (HPS)	105	77	12,000
Pulse Start Metal Halide (MH)	98	59	6,000
Standard Metal Halide (MH)	96	60	6,000
T8 Fluorescent (FL)	93	84	7,500
Induction Fluorescent (Sylvania Icetron) (IFL)	83	62	10,000
T12 High-Output (800 ma) Fluorescent (FL)	79	64	7,500
T12 Cool-White Fluorescent (FL)	74	59	7,500
Compact Fluorescent (PL)	68	54	5,000
Tungsten Halogen (Quartz) (TH)	19	17	2,000
Incandescent (standard) (INC)	14	12	1,000

The other important characteristic of lights is their color and color rendering properties. Color of lights is defined by the Kelvin color temperature scale (Exhibit 7-10). Natural outdoor light has a Color Rendering Index (CRI) of 100 – and therefore is the standard of comparison for any other light source. The higher the CRI .the near the light source is to the sunlight. It has relationship with the Kelvin color temperature.

Exhibit 7-10: Color scale of lighting



7.4.1 Control of Lighting Systems

Even with efficient lamps and luminaries, energy used for lighting can be wasted in several different ways. Careful monitoring studies show that, in general, people will usually turn lighting on only when they use it, but cannot be relied upon to turn it off when daylight would provide adequate conditions or when rooms are unoccupied. Exhortation can be helpful in the short term, but the ideal solution is to provide a manual switch-on and some form of control for switching off.

A further source of unnecessary use results from the common practice of controlling large areas of lighting with a small number of switches, or by confusing switch layouts, such that individual requirements can only be met by turning on many luminaries. Controls are a very effective way of reducing lighting cost, but before incurring significant capital cost occupancy patterns and behavior should be studied. This will enable the most cost effective control system to be installed (Exhibit 7-11).

Exhibit 7-11: Outline Guidance on the Application of Lighting Controls

TYPE OF SWITCHING

	User/Manual Controls		**Automatic Controls**				
TYPE OF ACCOMMODATION	Conventional Wall Switch	Individual Pull Cord on each Luminaire	Timed Bulk Off Switching	Photocell Operated Off Switching	Daylight Linked Dimmin g	Acoustic and Photocell Switching	Range of Potential Energy Saving (%) *
Open-plan Office	4	2	2	1	2	4	40 - 70
Cellular Office	4	3	2	1	4	R	40 - 70
Office with Daylight	1	4	1	4	4	R	3- - 50**
Office w/o Daylight	1	4	4(S)	4	4	4	10 - 20**
Large Storage Area	4	4	1	2	3	R	40 - 60**
Factory Area w/o Daylight	3	4	4	2	1	4(S)	40 - 60**

KEY 1 = Preferred 4 = Inappropriate
2 = Good 4(S) = Inappropriate on all luminaires for safety reasons
3 = Poor
R = Requires further investigation
* = Potential energy savings if correctly applied to suitable situation
** = Estimated savings potential

7.4.1.1 Manual Controls

Switching arrangements should at least permit individual rows of lamps parallel to window walls to be controlled separately. Controls (both mechanical and electronic) are available to permit individual lamps in a large installation to be switched on by the occupants most affected.

7.4.1.2 Automatic Controls

Photoelectric controls ensure that lighting will be turned off when daylight alone provides the required illumination. For example, a photoelectric sensor could respond to exterior illumination and be set to operate at that level which supplies the design illumination in the work place.

With fairly deep interiors having two or more rows of light running parallel with the window wall (or walls), it may be advantageous to use a separate controller for each row. If the control is of the on-off type, only the row nearest the window should be operated in this way to ensure user acceptability, although careful design with multi-lamp luminaires may be acceptable. Potential energy savings can be large (up to 50 percent of uncontrolled use has been claimed), but evaluation of particular installations is required to determine their cost effectiveness. In general, top-up or dimming control is more expensive than on-off, but it saves more energy and is more unobtrusive.

If building occupation effectively ceases at a fixed hour every working day, it may be worthwhile installing a time switch so that most of the lighting is switched off at this time. Arrangements may need to be made, however, for security lighting and individuals working late to override part of the switching, with subsequent automatic switching - off and override cycles to avoid accidentally leaving lights on after hours.

Switch control can produce considerable energy savings. A time control system that switches all selected lights off at a fixed period in the day, but with personal local override (switch on), can have a payback of one and a half to two years. If this is fitted at the time of refurbishment, payback can be one year or less. This general principle is well suited to multi - occupant spaces such as group offices, but with care it can also be applied in schools, factories, and warehouses. Commercial systems exist which enable this principle to be followed and can also offer the further option of photo - electric switching - with occupant override - to promote greater savings. The use of remote switching (e.g., by infra - red transmitters or ultrasonics) to fulfill the localized override facility is also possible.

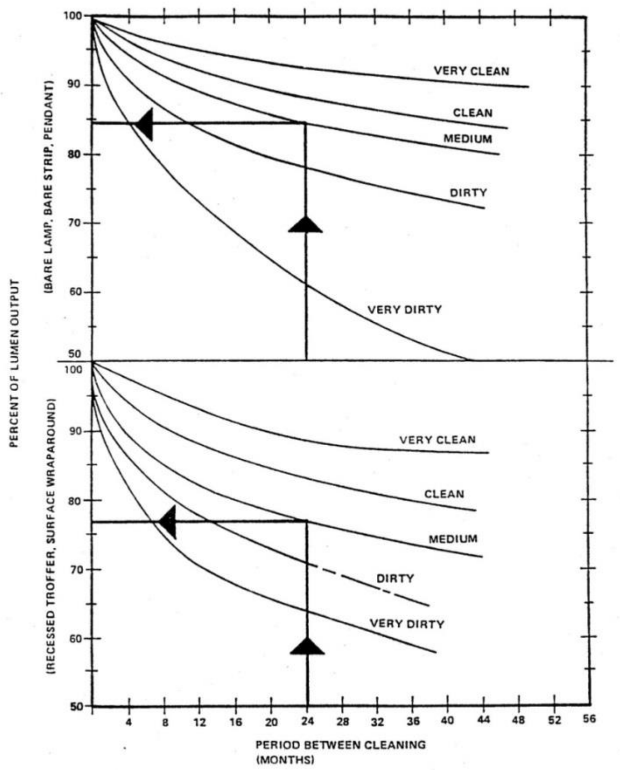
7.4.2 Proper Maintenance of Lighting Systems

In the past, there has been a tendency to "fit and forget", and replacing lamps only when they fail. One consequence is that the illumination levels fall to the extent that safety and productivity is seriously affected. Thus, the importance of regular maintenance of all forms of lighting equipment is strongly stressed. Loss of daylight from dirty windows should not be tolerated, and energy surveyors and managers must be mindful that lamps also collect dust and dirt, causing light output to fall (Exhibit 7-12).

A regular cleaning schedule should be established and, although it should occur more frequently, it can be timed to coincide with the group replacement of lamps. The individual replacement of lamps can be an expensive process, wasting the staff's time. When applied to electric lamps, "lamp life" has two distinct meanings:

- The time after which the lamp ceases to operate; and
- The time after which the light output is reduced by normal deterioration processes to such a low level that it is more economical to replace the lamp, even though it is still operating electrically. This is the economic service period.

Exhibit 7-12: Lighting fixtures cleaning cycle



7.5 The Lighting Systems ECOs

Without compromising high quality lighting, the aim of energy conservation and cost savings can be achieved by choosing and implementing the most suitable and cost effective energy conservation measures (ECMs). The ECMs, given below, are based on the following principles:-

- Choose the right light (lamp)
- Direct the light where it is needed (task lighting proper lighting design).
- Use the light when it is needed.
- Use the day light whenever and wherever practical.

7.6 The Lighting Survey

The following procedure is recommended for assessing the efficiency of a lighting installation and deciding on the action to be taken.

1. Check the date installed: Any installation that is more than 20 years old is probably due for rewiring. Lamps that are over ten years old will probably have deteriorated and in many cases versions of higher luminous efficacy will be available, making replacement a worthwhile investment.
2. Check the illumination levels. Readings should be taken with a light meter of known accuracy. Measurements should be made either at every working point or at the centers of a regular grid pattern (which does not coincide with the luminaire spacing grid) throughout the area in the horizontal working plane. The average horizontal illumination is the average of these readings. The variations in illumination over a task should not be excessive. The difference between minimum luminance and average luminance over the task area should be less than 30 percent of the average.

3. Compare observed illumination levels to standards: The average service illumination and the levels at individual work stations of the installations should be checked against those recommended in various standards and a decision should then be made as to the acceptability of the installation in respect of productivity, health, safety, and morale.
4. Calculate lighting loads and energy consumption: The lighting load should also be calculated, together with the annual energy consumption associated with the lighting system.
5. Evaluate opportunities for energy savings: By calculations, the energy surveyor can identify areas that are underlit, overlit, and where action might be taken (and with what results) to save energy. Obviously, when areas are underlit it is possible that some increase in energy use will be observed when corrective action is taken.
6. Light source and luminaire types: The reflectors are likely to have deteriorated with age and absorb a high percentage of the light. Consideration should be given to changing both lamps and reflectors, using high pressure sodium, or metal halide or high pressure sodium deluxe. In offices illuminated by tubular fluorescent lamps, discoloration of reflecting and diffusing surfaces of the luminaires may have occurred. Reflector tape may be used to increase light output from a luminaire in which the internal surface has lost efficiency over the years.
7. Check the installation wiring: In the case of old fluorescent or discharge lamp installations, apart from the deterioration due to dust and dirt, power factor capacitors may have become open circuit and consequently "Wattless" current will have increased.
8. Check flexibility of switching control: It is common practice to arrange the switching for light fittings in groups determined by ease of wiring, despite the fact that it will encourage wasteful use. In many deep plan buildings, it is better to switch groups of fittings near areas which receive natural light (near windows or lighting wells) separately so as to save electricity in daylight hours. Turning a fluorescent lamp off does shorten its life, but it also lengthens its "real time" life because it is off. The actual life in years is hardly affected in most cases.
9. Compare Cost of Lighting (existing and proposed): It is essential to assess the true cost of a lighting system when considering its performance. This is not simply a matter of comparing the individual cost of lamps and luminaires. It is easy to overlook some of the other factors involved, such as the reduced numbers of luminaires, the use of controls, the reflectance of surfaces, the amount of glazing, and the use pattern of premises. It is also useful to assess the respective advantages or disadvantages of alternative capital costs and payback periods.

7.6.1 Reduction in Lighting Levels

Some areas of the building may be overlit to levels of illumination far in excess of those appropriate to the particular tasks or functions carried out in those areas. In this case, it may be possible to remove excess luminaires or replace existing lamps with ones yielding lower illumination levels and energy consumptions.

Lighting levels can be reduced by removing or disconnecting unnecessary luminaires or by removing individual lamps. In this latter case, the energy surveyor should be careful to indicate that spare ballasts should also be removed; a ballast will still consume energy even if there is no lamp connected to it. There are two methods of "de-lamping": uniform de-lamping and task-oriented de-lamping (Exhibit 7-13).

7.6.2 Conversion to High Efficiency Lighting Systems

In many cases, it is cost - effective to convert from low efficiency lighting systems to those having higher efficiencies (based on lumens per watt). Lower wattage lamps and luminaires can provide the same amount of light with a smaller energy consumption.

In making the recommendation, the energy surveyor should carefully take into account the nature of the area served and the special requirements that the proposed higher efficiency lighting system may have. In addition, the nature of the area served by the lamps may be an important consideration. For instance, although replacement of retail display incandescent bulbs by high pressure sodium discharge lamps will save energy, the color rendition of the HPS lamps makes them unsuitable for the purpose proposed.

7.6.3 Control of Lighting Systems

As discussed earlier, control of lighting systems can be accomplished manually or through a variety of automatic means. The objective, to eliminate the number of hours that the lighting systems are used unnecessarily, can be met by any of these means.

Exhibit 7-13: Fixture delamping

Unifromly delamped space

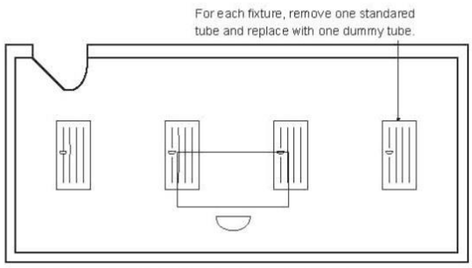
1What is Fixture Delamping?

Fixture delamping is simply the removal of selected lamps from existing fixtures to reduce power for lighting.

Fixture delamping is the easiest and least expensive means of achieving a reduction in power used for lighting. For these reasons, it is suggested that delamping be the first modification considered in any space in which too much power is being used for lighting.

2How to Delamp

Generally one of two methods will be selected, either uniform delamping or task oriented delamping.



All fixtures have undergone the same modification, the addition of a single dummy tube. Total power reduction is 184 watts or 264 watts depending upon type of dummy tube.

2.1 Uniform Delamping

Many existing lighting systems were deisgned to provide uniform illumination, resulting in a fairly even distribution of light. If it is desirable to maintain this uniform illumination, power can be reduced by delamping each fixture equally.

These uniform modifications will maintain an even distribution of light, similar to that which existed prior to delamping, although the illumination level may be lower.

2.2Task Oriented

A task oriented lighting system is designed to provide more light in work areas and less light in circulation areas. A task lighting system may also be created through non-uniform delamping of an existing lighting system with fixtures outside work area delamped to a greater extent than fixtures nearest work areas.

Task oriented lighting systems may provide a higher level of illumination at the work area than that which would be achieved through a uniform system modificiation.

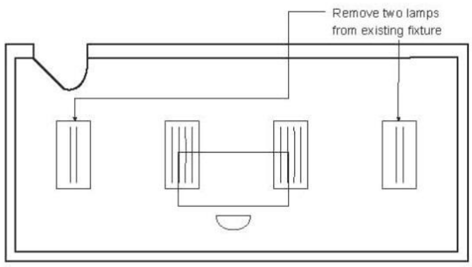
Task-oriented delamped space

3Delamping Fluorescent Fixtures

Fluorescent lamps are generally operated in pairs with a common ballast; removal of one lamp will cause the other lamp to extinguish. Therefore, often the easiest method of delamping fluorescent systems is to remove both lamps on a common ballast.

If it is desirable to remove just one lamp on a two lamp ballast, a dummy tube may be installed in place of the lamp removed. This dummy tube will keep the fixture operational by the removal of one lamp. Dummy tubes, which do not produce light, will reduce both the energy consumed by the fixture and the light output.

If both lamps on a common ballast are removed, consideration should be given to disconnecting the ballast because the ballast will continue to consume energy (approximately 4 to 7 watts). An analysis will determine if the expenditure of labor involved in disconnection of the ballasts is warranted by the potential energy savings.



fixtures furthest away from visual task have been partially delamped and fixtures nearest visual task are not modified. Total power reduction: 184 watts.

4Delamping Incandesent Fixtures

Delamping incamdescent systems is simply the removal of the selected lamps. When there is only one lamp per fixture, however, dark spots may be created with in the space. This will depend upon the light distribution characteristics and spacing of the existing fixtures.

In most instances, problems created by dark spots can be avoided by exercising judgment as to which fixtures in a space are delamped. Often rearranging work stations is a solution. A sound judgment can be made by trying alternatives.

If problems remain, however, it might be necessary to also utilize relamping or fixture modification.

7.7 Checklist to Conserve Electricity in Lighting Systems

7.7.1 How to improve Lighting Efficiency

- Design lighting for expected activity.
- Clean walls and ceilings to improve reflectivity.
- Repaint dark surfaces with paints having higher reflectance.
- Replace light transmitting plastics (that have yellowed) with glass or acrylic plastic.
- Clean light fixtures regularly.
- De-energize some light fixtures.
- Remove lamps and chokes where appropriate.
- Use lower-wattage lamps where appropriate.
- Replace incandescent lamps with more efficient fluorescent, mercury-vapor, or sodium lamps.
- Reduce indoor mounting heights where lighting levels can be maintained and number of fixtures reduced.
- Maximize the efficient use of energy through group lamp replacement and proper maintenance of lighting fixtures.

7.7.2 When to Save Lighting Energy

- Turn off lights not in use. Install reminder plates that are available for switch plates.
- Mark panels and switches so that guards/security staff can monitor lights.
- Turn off parking-area lights after last shift.
- Provide separate and convenient switches for areas that have different use patterns.
- Install photoelectric controls on lights.

7.7.3 Where to Save Lighting Energy

- Restrict parking to specific lots so lights can be kept off in unused lots.
- Put time shut-off switches on lights in closed-off areas.
- Reduce lighting in material storage areas except where required for production, safety, and security.
- Reduce lighting levels in corridors.
- Improve local/task lighting so that overall lighting can be reduced accordingly.
- Remove desk lamps where overhead lighting systems are sufficient.
- Rearrange office furniture so that desks and chairs are close to sunlight.
- Make maximum use of the sunlight by opening blinds or drapes.

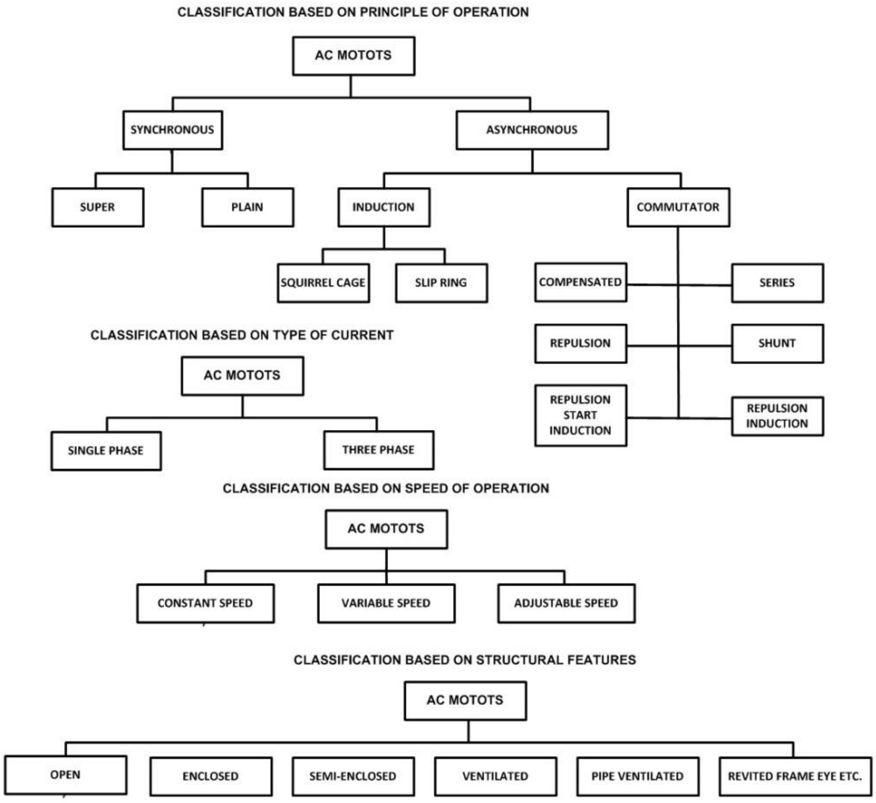
8 Electric Motors

The electric motor is by far the most common and wide spread machine used to convert electric power to mechanical output or useful work. It is estimated that more than 70% of electrical energy is used to power the motors. Over 95% of these are induction motors. Since such a great portion of electric power is consumed by the motors, their efficiency and efficient use are of utmost importance from the energy conservation standpoint.

8.1 Type of AC motors

There are numerous types of motors used for variety of services (Exhibit 8-1).

Exhibit 8-1: Classification of motors



8.1.1 Synchronous Motors

These motors have the rotor(which is connected to the load) rotating at the same speed as the speed of rotation of the stator current. In other words, these motors do not have slip with respect to the stator current. They are sometimes used no to drive the load but instead act as "synchronous condenser", to improve the power factor of the local grid to which it is connected to. This kind of motors are used even in high precision positioning devices like modern robots. They can also act as stepper motors.

8.1.2 Asynchronous Motors

The most common form of motor which is used in everyday life from pumping water up the overhead tank to power plant boiler feed pumps, these kind of motors rule. These motors are very flexible to use and matches the load demand almost for everything. The most widely used Induction Motors are very important for many industries due to their load bearing capacity and flexibility. These motors, unlike synchronous motors, slip when compared to the stator current field. They are generally used for various types of pumps, compressors and acts as prime movers for many types of machinery.

8.1.3 Single and Three Phase Motors

The AC motors can find their usage in 2 forms based on their power supply. The single phase motors are generally found their use in low power requirements/domestic appliances like ceiling fans, mixer grinders, portable power tools etc. The three phase motors are generally found for high power requirements like power drives for compressors, hydraulic pumps, air conditioning compressors, irrigation pumps and many more.

8.1.4 Constant, Variable and Adjustable Speed Motors

As already said, AC motors are highly flexible in many ways including their speed control. There are motors which should be run at a constant speed for air compressors. Certain cooling water pumps driven by AC motors can be run at two or three speeds by just switching the number of poles used. If the number of poles are changed then the speed also changes. These serve best for sea water cooling pumps in marine engine room applications and many power plants. The speed of the motors can also be varied continuously by some electronic arrangements thus this can be suited for certain applications like a ship's cargo pump, whose discharge rate has to lowered as per the terminals requirement.

8.1.5 Varied Structure Motors

These types of motors have different outer cage arrangements, depending upon the usage or any special industrial requirement. For motors used in gas and oil terminals, the casing must be of intrinsically safe, thus it may either have an enclosed casing or a pipe ventilated arrangement such that the sparks produced inside the motor do not cause a fire outside it. Also many motors are totally enclosed as it may be open to weather like those used in hydro-electric power plants.

8.2 Types of DC Motors

The direct current motors or the DC motors have a lot of applications in the field of engineering and technology. Starting from a battery operated electric shaver to parts of automobiles, in all small or medium sized motoring applications DC motors are frequently used. Because of their wide range of application different functional types of dc motor are manufactured (Exhibit 8-2). Brief introduction to major types of DC motors is given below.

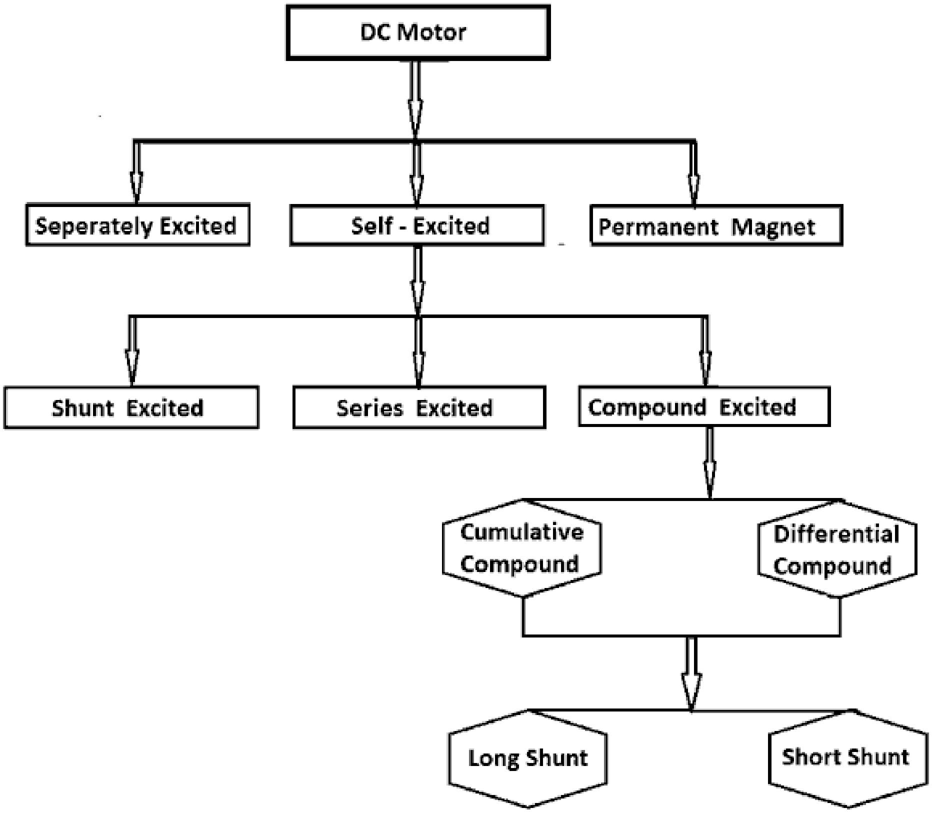
8.2.1 Separately Excited DC Motor

As the name suggests, in case of a separately excited DC motor the supply is given separately to the field and armature windings. The main distinguishing fact in these types of dc motor is that, the armature current does not flow through the field windings, as the field winding is energized from a separate external source of dc current.

8.2.2 Permanent Magnet DC Motor

The permanent magnet DC motor consists of an armature winding as in case of an usual motor, but does not necessarily contain the field windings. The construction of these types of DC motor are such that, radially magnetized permanent magnets are mounted on the inner periphery of the stator core to produce the field flux. The rotor on the other hand has a conventional dc armature with commutator segments and brushes.

Exhibit 8-2: Types of DC motors



8.2.3 Self-Excited DC Motor

In case of self-excited dc motor, the field winding is connected either in series or in parallel or partly in series, partly in parallel to the armature winding, and on this basis its further classified as: Shunt wound DC motor, Series wound DC motor, and Compound wound DC motor.

8.2.4 Servo Motors

A DC motor has a two wire connection. All drive power is supplied over these two wires. When turned on, it just starts rotating, say at 5,000 rpm. Its speed (or more accurately, its power level) is controlled using a technique named pulse width modulation (PWM). It controls the motor's power level by strobing the power on and off. The key concept here is duty cycle—the percentage of "on time" versus "off time." If the power is on only ½ of the time, the motor runs with ½ the power of its full-on operation.

If you switch the power on and off fast enough, then it just seems like the motor is running weaker—there is no stuttering. This is what PWM means when referring to DC motors.

A servo motor works on entirely different principle. The servomotor is actually an assembly of four things: a normal DC motor, a gear reduction unit, a position-sensing device (usually a potentiometer—a volume control knob), and a control circuit.

The function of the servo is to receive a control signal that represents a desired output position of the servo shaft, and apply power to its DC motor until its shaft turns to that position. It uses the position-sensing device to determine the rotational position of the shaft, so it knows which way the motor must turn to move the shaft to the commanded position. The shaft typically does not rotate freely as in the case of a DC motor, but rather can only turn 200 degrees or so back and forth.

The servo has a 3 wire connection: power, ground, and control. The power source must be constantly applied; the servo has its own drive electronics that draw current from the power lead to drive the motor.

The servo control pulse is repeated every 20 milliseconds. In essence, every 20 milliseconds, it is receiving signals to perform a specific action.

8.3 Motor nameplate information

The National Electrical Manufacturer's Association (NEMA) specifies that every motor nameplate must show these specific items:

1. Manufacturer's type
2. Rated volts and full load amps
3. Rated frequency and number of phases
4. Rated full load speed
5. Rated temperature rise or the insulation system class
6. Time rating
7. Rated horsepower
8. Locked rotor indicating code letter
9. Service Factor
10. Efficiency
11. Frame Size
12. Design Code

8.4 Insulation designation of motors

Thermal tolerance of motor winding Insulation is crucial in a motor. This is determined by the ambient temperature, the heat generated at fully loaded conditions (temperature rise), and the thermal capacity of the motor insulation. Standard classification of the thermal tolerance of the motor winding is designated by the letters A, B, E, F, and H.

IEC and NEMA use the same classification system for winding insulation. It is based on the highest temperature the material can withstand continuously without degrading or reducing motor life (motor life taken as 20,000 hours). Exhibit 8-3 compares the rises in temperature (add 45°C for total acceptable temperature), allowed under IEC and NEMA standards.

Exhibit 8-3: IEC and NEMA temperature rise for motors, °C

Insulation Class	IEC	NEMA	NEMA
		1.0 Service Factor	1.15 Service Factor
A	60	60	70
E	75	*	*
B	80	80	90
F	100	105	115
H	125	125	-

*Note that NEMA has no Class E.

Most industrial-duty motors use Class B or Class F insulation, depending on the application. IEC and NEMA 1.00 service factor ratings are nearly identical; NEMA 1.15 ratings are higher.

8.5 De-rating of Motors for High Altitude Consideration

Temperature rise for NEMA rated motors is based on operation at altitudes of 1,000 meters or less, with a maximum ambient temperature of 40 Degrees C. Altitudes up to and including 1,000 meters are considered the equivalent of sea level. One typical characteristic of high altitude locations is low air density. Low-density air does not allow a motor to cool as well as the air at sea level. However, the decrease in ambient temperature characteristic of high altitudes generally compensates for the increase in temperature rise due to low air density.

Motors with Class B or F insulation systems operate satisfactorily at altitudes above 1,000 meters if the ambient temperature is lower than 40 Degrees C. This table shows how lower ambient temperatures at high altitude make up for lower air density.

Maximum Ambient Temperature, °C, °F	Maximum Altitude, Meters, Feet
40 °C , 104 °F	1,000 m, 3,280 ft
30 °C , 86 °F	2,000 m, 6,560 ft
20 °C , 68 °F	3,000 m, 9,840 ft

This table shows how general de-rating factors apply to motors operated above 1,000 meters to maintain an ambient temperature rating of 40 °C. The de-rating of motors at higher altitudes is given in Exhibit 8-4

Exhibit 8-4: De-rating of motors at different altitudes

Altitude, Feet, Meters	Motor Service Factor (SF) 1.0	Motor Service Factor (SF) 1.15
1,000 – 2,750	93%	100%
2,750 – 3,000	91%	98%
3,000 – 4,000	86%	92%
4,000 – 5,000	795	85%
Over 5,000	Consult Manufacturer	

The de-rating factor multiplied times the motor's nameplate horsepower provides the de-rated horsepower corresponding to the given high altitude.

Example:

A 100 horsepower motor with a service factor of 1.0 is rated for 1,000 meters maximum altitude. It is to be operated at an altitude of 1,525 meters feet.

The motor de-rating factor according to the table is 0.93. Multiply 0.93 times 100 horsepower. The result is the de-rated horsepower of the motor 93 horsepower.

Overheating will not adversely affect the service life of this particular motor, as long as its output horsepower of the motor remains below 93 horsepower.

Motors having a service factor of 1.15 or higher operate satisfactorily at full load, but with an ambient temperature of 40 °C at altitudes ranging from 1,000 to 3,000 meters.

8.6 Selection of Motors

The following steps are suggested for the selection of appropriate motor for a specific duty:

Step 1: Know the load characteristics

For line-operated motors, loads fall into three general categories: constant torque, torque that changes abruptly, and torque that change gradually over time. Bulk material conveyors, extruders, positive displacement pumps, and compressors without air unloaders run at relatively steady levels of torque.

Sizing a motor for these applications is simple once the torque (or horsepower) for the application is known. Load demands by elevators, compactors, punch presses, saws, and batch conveyors change abruptly from low to high in a short time, often in a fraction of a second.

The most critical consideration for selecting a motor in these cases is to choose one whose speed-torque curve exceeds the load torque curve.

Loads from centrifugal pumps, fans, blowers, compressors with unloaders, and similar equipment tend to be variable over time. In choosing a motor for these conditions, consider the highest continuous load point, which typically occurs at the highest speed.

Step 2: Get a handle on horsepower

The rule of thumb for motor horsepower is: Select only what you need, and avoid the temptation to oversize or undersize. Calculate the required horsepower from this formula:

$$\text{kW} = \frac{\text{Tortque (N-m)} \times \text{Speed (rpm)}}{9{,}545.45}$$

$$\text{Horsepower} = \frac{\text{Tortque (lb–ft)} \times \text{Speed (rpm)}}{5{,}250}$$

Step 3: Getting started

Another consideration is inertia, particularly during startup. Every load represents some value of inertia, but punch presses, ball mills, crushers, gearboxes that drive large rolls, and certain types of pumps require high starting torques due to the huge mass of the rotating elements.

Motors for these applications need to have special ratings so that the temperature rise at startup does not exceed the allowable temperature limit. A properly sized motor must be able to turn the load from a dead stop (locked-rotor torque), pull it up to operating speed (pull-up torque), and then maintain the operating speed.

Motors are rated as one of four “design types” for their ability to endure the heat of that starting and pull up.

In ascending order of their ability to start inertial loads, NEMA designates these as design type A, B, C, and D. Type B is the industry standard and is a good choice for most commercial and industrial applications.

Step 4: Adjust for duty cycle

Duty cycle is the load that a motor must handle over the period when it starts, runs, and stops.

Continuous duty

Continuous duty is by far the simplest and most efficient application. The duty cycle begins with startup, then long periods of steady operation where the heat in the motor can stabilize as it runs.

A motor in continuous duty can be operated safely at or near its rated capacity because the temperature has a chance to stabilize.

Intermittent duty

Intermittent duty is more complicated. The life of commercial airplanes is measured by their number of landings; in the same way, the life of a motor is proportional to the number of starts it makes. Frequent starts shorten life because inrush current at startup heats the conductor rapidly.

Because of this heat, motors have a limited number of starts and stops that they can make in an hour.

Step 5: The last consideration, motor de-rating

If the motor is going to operate at altitudes that are substantially above sea level, then it will be unable to operate at its full service factor (SF) because, at altitude, air is less dense and does not cool as well. Thus, for the motor to stay within safe limits of temperature rise, it must be de-rated on a sliding scale.

Up to an altitude of 1,000 m, SF = 1.15; at 2,900 m, it declines to 1.00.

This is an important consideration for mining elevators, conveyors, blowers, and other equipment that operates at high altitudes.

Note: Using a Rewound Motor

The quality of the rewind has a big impact on operating cost. A poorly rewound motor may lose up to 3% in efficiency. It is generally cost-effective to replace motors under 10 horsepower with new high-efficiency motors rather than rewind them. When deciding whether to buy a new motor or rewind the old one, consider the cost difference between the rewind and a new high-efficiency motor, and the potential increase in energy costs of a rewound motor that is less efficient than the original.

The motors, field testing of motors, and energy conservation opportunities are discussed below.

8.7 Motor Efficiency

The efficiency of electric motor is defined as the ratio of mechanical power (output) delivered by the motor and the electrical power (input) supplied to the motor. Motor efficiency is expressed as the ratio of output power and input power:

$$\text{Motor Efficiency} = \frac{\text{Output, kW}}{\text{Input, kW}} = \frac{0.746 \times \text{Output, hp}}{\text{Input, kW}}$$

Rated input power of the motor at full load can be calculated from the motor nameplate data.

$$\text{Input Power, kW} = \frac{\text{Output, kW}}{\text{Motor Efficiency}}$$

The power absorbed by the motor itself is the losses incurred in converting the electrical energy (input) to mechanical energy (output). Therefore, to reduce the electric power consumption for a given mechanical energy output, the losses must be reduced to improve the motor efficiency. Alternatively, motor efficiency can be expressed as:

$$\text{Motor Efficiency} = \frac{\text{Intput - Losses}}{\text{Input}} = \frac{\text{Output}}{\text{Output + Losses}}$$

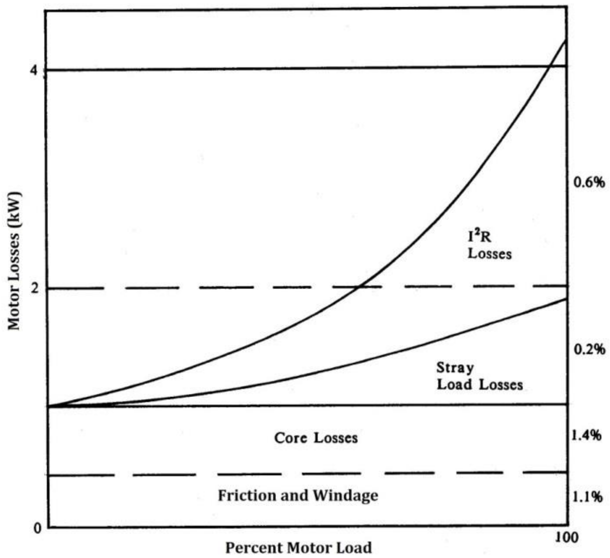
8.8 Motor Losses

The losses in an induction motor are caused by a variety of imperfections. These losses can be divided into two categories: (1) No-load losses, which occur whether the motor is operating on-load or unloaded and are independent of the motor load (i.e., they remain constant); (2) Operating Losses, which occur only when the motor is loaded, and are direct function of the motor load (Exhibit 8-5). These losses can be subdivided into as follows:

No-Load Losses : Iron (Core) Losses

	:	Friction and Windage Losses
Operating Losses	:	Primary I^2R Losses (Stator Copper Losses)
	:	Secondary I^2R Losses (Rotor Copper Losses)
	:	Stray Load Losses

Exhibit 8-5: Typical losses – 50 hp (37.5 kW) induction motor



In a very general sense, the average loss distribution for standard NEMA design B motors can be summarized as follows:

Motor Component Loss	% of Total Losses
Iron (Core) Losses	20
Friction and Windage Losses	9
Primary (Stator)Copper Losses	37
Secondary (Rotor) Copper Losses	18
Stray Load Losses	16

A more detailed description of the motor energy losses is provided below:

8.8.1 Iron (Core) Losses

The iron losses are the sum of eddy current and hysteresis losses. These losses result from the energization of the motor's magnetic circuit. The flux density in the magnetic structure is a major factor in determining these losses. The quality and thickness of lamination also affect these losses.

8.8.2 Friction and Windage Losses

These losses arise from the air friction against rotor, ventilation air paths and friction in the bearings.

8.8.3 Primary (Stator) Copper Losses

The primary losses are the ohmic losses due to the passage of current through the stator windings. The losses are a function of current flowing through the stator and the stator winding resistance, hence the term I^2R losses. The stator current is given by the following relationship:

$$\text{Stator Current, I} = \frac{\text{Input Watts}}{\text{Voltage} \times 1.732 \times \text{Power Factor}}$$

8.8.4 Secondary (Rotor) Copper Losses

These losses are the ohmic losses in the rotor conductors. The rotor losses are generally expressed as slip loss:

$$\text{Rotar Losses, W} = \frac{\text{Output Watts} + \text{FW} \times \text{S}}{1 - \text{S}}$$

Where, S = Slip = $\frac{\text{Ns} - \text{N}}{\text{N}}$

N = Output speed, RPM

Ns = Synchronous speed, RPM

FW = Friction and windage losses, Watt

These losses are often approximated by measuring output speed of an operating motor.

8.8.5 Stray Load Losses

Stray load losses are caused by the edge effects in windings and rotors. The nature of these losses is quite complex, and is a function of many elements of the design and construction of the motor. Stray load losses are defined as the difference between the total motor losses and the sum of the other four losses described above.

8.9 Determination of Motor Efficiency

Basically, electric induction motor efficiency is a difficult parameter to determine. A number of methods have been employed around the world to measure, approximate, or otherwise determine the motor efficiency. Since different manufacturers use different methods, it is worthwhile to briefly examine some of these methods. These test methods are applicable to motors on test benches only.

The accuracy of the efficiency determined depends on the test methods used and the accuracy of the losses determined by the test method. Generally, manufacturers of motors follow standards of their own countries, if they have them; however IEEE Standard Test procedure for Polyphase Induction Motors and Generators, and IEC 34-2 Methods of Determining Losses and Efficiencies of Rotating Electrical Machinery are the most commonly followed standards for declaring efficiencies.

Almost all renowned standards in the world allow for more than one method of determining motor efficiency, and they can be grouped into either direct or indirect measurement methods.

8.9.1 Direct Measurement Methods

The direct measurement methods are the clearest ways to determine the actual efficiency of the motor. They rely on the basic efficiency formula, simply measuring mechanical output and electrical input to determine efficiency. Three types of tests are described below:

Brake Test

A mechanical break is used to load the motor and the reaction force is measured to determine the motor torque. This method is usually limited to fractional horsepower motors because of the problem of dissipation of heat generated in the brake.

Dynamometer Test

A dynamometer is used to load the motor. The motor torque is measured by load cell or scale. Most dynamometers have electrical controls for setting the load torque and holding it steady while readings are being taken. This method is the most common, and applicable for efficiency measurements of motors up to 500 hp, although the cost of electrical power consumed during the measurement can become expensive with the larger motors.

Duplicate Machine Test

Two identical motors are coupled together and supplied the power from two separate power sources. One of the two sources must be an adjustable frequency source. Controlling the adjustable frequency source to operate at frequencies above and below the fixed frequency source causes each machine to operate as a motor and then as an induction generator, returning power back to line. Electrical power into and out of the two machines is measured and the difference is the combined loss of the two machines. This method has the advantage that the net power consumed is equal only to the losses of the two machines, and the majority of the power entering the system is returned to the line through the machine which is acting as an induction generator.

8.9.2 Indirect Efficiency Determination Methods

In case where load tests cannot be made for various reasons, the equivalent circuit calculation method, or input measurement and segregation method are used. For the most accurate efficiency determination, the segregation of loss method can be used. These are described below:

Equivalent Circuit Calculation

The operating characteristics of a motor can be calculated from no load and impedance data by means of an equivalent circuit diagram. Parameters of equivalent circuits are determined by performing no load and locked rotor tests and making measurement of resistance of the winding. Once the equivalent circuit constants are determined, the efficiency is calculated for any load by using an iterative technique to solve the equivalent circuit problem.

Input Measurement and Segregation of Loss

This method requires that the motor being tested should be loaded, but measuring the motor output is not required. Rather, input power is measured and output power is calculated by separately determining and subtracting the losses from the measured input at different load points. Readings on the voltage, current, electrical power input, speed, temperature and winding resistance are taken. From this data, four of the motor's five losses can be calculated. The fifth loss, the stray load loss, can be determined by difference, taken as 0.5% of the total motor input, or by performing separate tests on the stator with the rotor removed.

8.10 Field Testing of Motors

Unfortunately, the determination of the efficiency of a motor operating in service in a plant or other application is extremely difficult. The motors in use cannot easily be decoupled from their loads and taken to a test laboratory. Nor is there an inexpensive portable testing equipment available for plant use.

An adaptation for the field testing of motors has been adapted from the motor efficiency testing procedures, but even this is not a simple procedure, since it involves decoupling the motor from its load. Three measurements required in this procedure are:

1. **Load Test:** Voltage, current, power input, and shaft speed of the motor under actual load conditions are measured
2. **Stator Resistance:** With the motor turned off, stator resistance between phases is measured

3. **No-Load Test:** Voltage, current and power readings are taken with the motor turned on, but completely uncoupled from its load

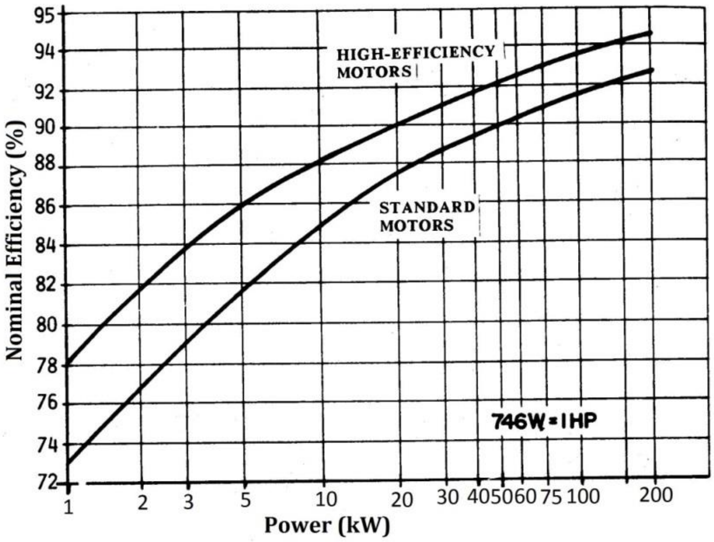
These tests are the only way to estimate the efficiency of motors in the field.

8.11 Standard and Energy-Efficient Motors

At present, the electric motors available from various motor manufacturers are being termed as "Standard" and "Energy-Efficient" motors. Standard motors refer to all motors manufactured to efficiency specifications in effect before the late 1970's. The aim of the manufacturers was to produce a reasonably efficient motor at a low selling price.

On the other hand due to increase in energy prices over the last 20 years, the energy efficiency has gained prominence. As a result of this, many motor manufacturers have brought out a new line of energy-efficient motors. While there is slight cost premium (15 to 25%) for these motors, they are on the average 5% energy efficient as compared to standard motors. A comparison of standard motor and energy-efficient motor efficiencies is presented in Exhibit 8-6.

Exhibit 8-6: Comparison of efficiencies for standard and high efficiency motors



8.12 Electric Motor Analysis

The efficiency and power factor of the motor are both direct functions of the motor loading (Exhibit 8-7). At high motor loading, both efficiency and power factor are high. At low motor loading, both efficiency and power factor are low. Hence, the motor efficiency and its power factor are directly related to each other. Power factor of a motor can be easily measured. With the help of the measured power factor of the motor, one can estimate the efficiency of the motors of various sizes operating at different power factors.

The following criteria are used to analyze a motor:

Motor is under-loaded, if

$$\frac{\text{Motor input power,kW} \times \text{Rated efficiency at full load, \%}}{\text{Rated motor output power, kW}} \triangleleft 60\%$$

Motor is overloaded, if

$$\frac{\text{Motor input power, kW} \times \text{Rated efficiency at full load, \%}}{\text{Rated motor output power, kW}} \triangleright 100\%$$

Motor power factor is low, if < 60%

Motor winding temperature is in access of rating, if Motor temperature °C - Ambient temperature °C > 80

Voltage imbalance is high, if > 4%

Current Imbalance is high, if > 15%

The voltage and current imbalance are calculated as follows:

When data of two phases is recorded:

$$\text{Voltage imbalance, \%} = \frac{2 \times (V_1 - V_2) \times 100}{(V_1 + V_2)}$$

Where, V1 and V2 are the line voltages

$$\text{Current imbalance, \%} = \frac{2 \times (A_1 - A_2) \times 100}{(A_1 + A_2)}$$

Where, A1, and A2 are the line currents.

When data of three phases is recorded:

$$\text{Voltage imbalance, \%} = \frac{100 \times \{(V_1 - V_2) + (V_2 - V_3) + (V_3 - V_1)\}}{(V_1 + V_2 + V_3)}$$

Where, V1, V2, and V3 are the line voltages.

$$\text{Current imbalance, \%} = \frac{\{(A_1 - A_2) + (A_2 - A_3) + (A_3 - A_1)\} \times 100}{(A_1 + A_2 + A_3)}$$

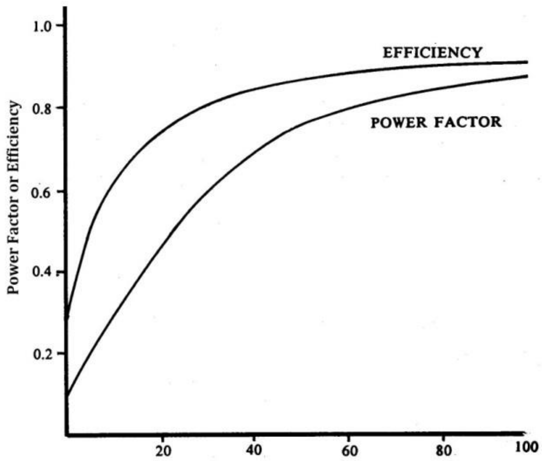
Where, A1, A2, and A3 are the line currents.

Note: In the above equations, positive numbers of differences in voltages and amperes are used.

% estimated Motor Efficiency corrected to voltage imbalance is:

% Motor Eff. corrected to Voltage = % Estimated Motor Eff. - % of voltage imbalance

Exhibit 8-7: Motor efficiency vs. load level



If the motor is under-loaded, over-loaded or has low power factor, further analysis should be carried out to determine the correct size of the motor to be recommended for replacement. And in case, the motor has temperature in excess of rating, high voltage imbalance or high current imbalance, the possible causes should be identified and recommendations should be made accordingly.

Since the exact efficiency of the motor operating in the field is not known, the approximate field test tells whether the existing motor should be replaced on the basis of incomplete test. The following data obtained from motor manufacturers may be helpful in estimating the efficiency of the existing motor:

1. No load current for different sizes
2. Stator resistance readings for different sizes
3. Currents at different loads for different sizes, preferably presented in the form of graphs
4. Efficiencies of different sizes of motors at different loads, drawn in the form of curves
5. Power factor of different sizes of motors at different loads, presented in the form of curves
6. Motor classification B, F, etc.
7. Permitted no. of startups per hour for different sizes and types of motors.

As a next step in this process, a procedure for field measurements on the driven equipment - primarily fans, pumps and compressors, should also be developed. Motor tests can provide information on the input side of these devices, and coupled with information on parameters like flow and pressure, one can evaluate energy efficient pumps, variable speed drives, etc. Field experience so far suggests much larger savings exist here (as compared to improvements in motor efficiency), but the problem is more complex as well.

A Note of Caution

Premium (energy efficient) motors are likely to have a higher design operating speed than standard ones. This increase is about 1 to 1.5 percent and would normally be insignificant, except that a great deal of industrial equipment driven by motors (fans and pumps) requires more power to run at higher speeds. This important fact can reduce the benefits of a more efficient motor - actual increase in loss can be significant and will be site specific. It may be possible to change some of the system characteristics (reduction of impeller diameter in a centrifugal pump; changes in pulley diameters for belt driven systems) to offset the effect of this increased speed, and should be taken into consideration in the motor replacement economics. This fact further highlights the importance of analyzing motor-drive-system as a whole.

Otherwise the resulting savings may overshadow the gains from motor replacement, as the higher operating speed of the premium motors can offset the efficiency gains. But, overall, the motor replacement by itself and the cost effective energy savings in motors appear promising.

8.13 Annual Cost Savings

Annual cost savings from replacement of an in-efficient existing motor are discussed as below.

Annual Power Consumption of a motor in kWh is:

$$= \left(\text{Motor input power, kW}\right) \times \left(\text{Annual operating hours}\right)$$

$$= \left(\text{Motor output power, kW}\right) \times \left(\text{Annual operating hours}\right) \times \frac{1}{E_1}$$

The annual energy cost savings and simple payback period for replacing existing inefficient motor with energy efficient motor can be calculated as:

$$= (\text{Output power}) \times (\text{Ann. operating hours}) \times (\text{Cost of electricity per kWh}) \times \left\{\frac{1}{E_1} - \frac{1}{E_2}\right\}$$

$$= (\text{Existing input power}) \times (\text{Ann. operating hours}) \times (\text{Cost of electricity per kWh}) \times \left\{\frac{E_2 - E_1}{E_2}\right\}$$

$$\text{And, Simple Payback Period (yrs.)} = \frac{(\text{Cost of Impementation})}{(\text{Annual Cost Savings})}$$

Where, E1 and E2 are % efficiencies of existing and premium motors respectively at existing load

Assumptions for the above are: (i) no change in motor size; (ii) no change in load; and (iii) no change in operating hours.

Load (loading) of a motor is defined as the ratio of actual output power of the motor and the rated motor output power. In practice, the input to the motor as a percentage of the rated output, is used as a measure of the load on the motor. (As can be seen there is a difference between load and this quantity).

8.14 Variable Frequency Drives

Typically, a Variable Frequency Drive (VFD) system involves an AC motor, controller, and operator interface. The three-phase induction motor is most commonly applied to a Variable Frequency Drive because it offers versatility and cost-effectiveness in comparison to a single-phase or synchronous motor. Though they can be advantageous in some circumstances, a Variable Frequency Drive system often utilizes motors that are designed for fixed-speed operation.

Variable Frequency Drive operator interfaces allow for the user to adjust operating speed, and start and stop the motor. The operator interface might also allow the user to switch and reverse between automatic control, or manual speed adjustment.

Advantages of a Variable Frequency Drive

- Process temperature can be controlled without a separate controller
- Low maintenance - Longer lifespan for the AC motor and other machinery
- Lower operating costs
- Equipment in the system that cannot handle excessive torque is

Exhibit 8-8: Variable frequency drives (VFDs)

8.14.1 Types of Variable Frequency Drives

There are three common Variable Frequency Drives (VFDs) that offer both advantages and disadvantages depending on the application they are used for. The three common VFD designs used include: Current Source Inverter (CSI), Voltage Source Inverter (VSI), and Pulse Width Modulation (PWM). However, there is a fourth type of VFD called Flux Vector Drive, which is emerging in popularity among end-users for its closed-loop control feature. Each VFD consists of a Converter, DC Link and Inverter section but how each one is constructed varies from drive to drive. Although the sections of each VFD are similar, they require a variation in circuitry in how they supply the frequency and voltage to the motor.

8.14.1.1 Current Source Inverter (CSI)

A Current Source Inverter (CSI) is a type of variable frequency drive (VFD) which converts incoming AC voltage and varies the frequency and voltage supplied to the AC Induction Motor. The general configuration of this type of VFD is like that of other VFDs in that it consists of a Converter, DC Link, and Inverter. The converter part of the CSI uses silicon-controlled rectifiers (SCRs), gate-commutated thyristors (GCTs) or symmetrical gate-commutated thyristors (SGCTs) to convert the incoming AC voltage to a variable DC voltage. In order to maintain the correct voltage to frequency (Volt/Hertz), the voltage must be regulated by the correct sequencing of the SCRs. The DC Link for this type of variable frequency drive uses an inductor to regulate the current ripple and to store the energy used by the motor. The inverter, which is responsible for converting the DC Voltage back to an AC sine-like waveform, comprises of SCRS, gate turn-off thyristors (GTOs) or symmetrical gate-commutated thyristors (SGCTs). These thyristors behave like switches which are turned on and off to create pulse width modulation (PWM) output that regulates the frequency and voltage to the motor. CSI variable frequency drives regulate current, require a large internal inductor and a motor load to operate. An important note about CSI VFD designs is the requirement of input and output filters which are necessary due to high harmonics in the power input and poor power factor. To work around this issue, many manufacturers implement either input transformers or reactors and harmonic filters at the point of common coupling (users electrical system connected to the drive) to help reduce the effects harmonics have on the drive system. Of the common VFD drive systems, CSI VFDs are the only type of drives that have regenerative power capability. Regenerative power capability means that power is driven back from the motor to the power supply can be absorbed.

Advantages of CSI

- Regenerative power capability
- Simple circuitry
- Reliability (Current Limiting Operation)
- Clean current waveform

Disadvantages of CSI

- Motor cogging when PWM output is below 6 Hz
- Inductor used are large and costly
- Large power harmonic generation sent back into power source
- Dependent on motor load
- Low input power

8.14.1.2 Voltage Source Inverter (VSI)

The converter section of the VSI is similar to the converter section of the CSI in that the incoming AC Voltage is converted into a DC Voltage. The difference from the CSI and VSI converter section is that the VSI uses a diode bridge rectifier to convert the AC Voltage to DC Voltage. The DC Link of the VSI uses capacitors to smooth out the ripple in the DC voltage and to also store energy for the drive system. The inverter section is comprised of insulated gate bipolar transistors (IGBTs), insulated gate-commutated thyristors (IGCTs) or injection-enhanced gate transistors (IEGTs). These transistors or thyristors behave like switches which are turned on and off to create a pulse width modulation (PWM) output that regulates the frequency and voltage to the motor.

Advantages of VSI

- Simple Circuitry
- Can be used with applications requiring multiple motors
- Not dependent on load

Disadvantages of VSI

- Large power harmonic generation into power source
- Motor cogging when PWM output is below 6 Hz
- Non-Regenerative operation
- Low power factor

8.14.1.3 Pulse Width Modulation (PWM)

The Pulse Width Modulation (PWM) Variable Frequency Drive (VFD) is among the most commonly used controllers and has proven to work well with motors that range in size from 1/2HP to 500HP. Most PWM VFDs are rated for 230V or 460V, 3-Phase operation, and provide output frequencies in the range of 2-400Hz. Like the VSI VFD, the PWM VFD uses a diode bridge rectifier to convert the incoming AC voltage to a DC voltage. The DC Link uses large capacitors to remove the ripple evident after the rectifier and creates a stable DC bus voltage. The six-step inverter stage of this driver uses high power rated IGBTs which turn on and off to regulate the frequency and voltage to the motor. These transistors are controlled by a microprocessor or motor IC which monitors various aspects of the drive to provide the correct sequencing. This produces a sine-like waveform output to the motor. So how does turning a transistor on and off help create the sine-like wave output? By varying the voltage pulse width you are obtaining an average power which is the voltage supplied to the motor. The frequency supplied to the motor is determined by the number of positive to negative transitions per second.

Advantage of PWM

- No motor cogging
- Efficiencies from 92% to 96%
- Excellent input power factor due to fixed DC bus voltage
- Low initial cost
- Can be used with applications requiring multiple motors Disadvantages of PWM
- Non-Regenerative operation
- High frequency switching may cause motor heating and insulation breakdown

Disadvantages of PWM

- Higher initial cost as compared to standard PWM drives.
- Requires special motor in most cases.
- Drive setup parameters are complex.

8.15 Guide to selecting VFDs

Finding the perfect VFD or motor controller can be a fairly daunting task as there are many variables with each application and system. However, below are some helpful tips and suggestions to help in selecting the right drive.

8.15.1 Horsepower (HP)

Although it is important to size the VSD with the FLA of the motor(s) being controlled, knowing the horsepower of the load is a great way to search for drives that may fit the application to be further narrowed down by other variables.

8.15.2 Full Load Amps (FLA)

This is perhaps one of the most critical pieces of information to gather. Using the FLA rather than horsepower ratings is the proper way to size a VSD.

8.15.3 Voltage

For three-phase input this one is easy. It is crucial to match the voltage of the VSD and motor to your available voltage on site.

In addition, if continuous operation is a must, then the following should be specified:

- +/- 10% voltage fluctuation
- +/- 3% frequency variation

8.15.4 Type of Load (Constant Torque or Variable Torque)

If the equipment being driven is centrifugal, such as a fan or pump, then a variable torque drive will be more appropriate. Energy savings are usually the primary motivation for installing variable frequency drives for centrifugal applications, and variable torque drives offer the greatest energy savings.

For example, a fan needs less torque when running at 50% speed than it does when running at full speed. Variable torque operation allows the motor to apply only the torque needed resulting in reduced energy consumption, which is one of many VSD Benefits. Conveyors, positive displacement pumps, punch presses, extruders, and other similar type applications require constant level of torque at all speeds. In which case, constant torque variable frequency drives would be more appropriate for the job.

A constant torque drive should have an overload current capacity of 150% or more for one minute. Variable torque variable frequency drives need only an overload current capacity of 120% for one minute since centrifugal applications rarely exceed the rated current. If tight process control is needed, then you may need to utilize a sensorless vector, or flux vector variable frequency drive, which allow a high level of accuracy in controlling speed, torque, and positioning.

8.15.5 Speed Range

Generally speaking, a motor should not be run at any less than 20% of its specified maximum speed allowed. If it is run at a speed less than this without auxiliary motor cooling, the motor will overheat. Auxiliary motor cooling should be used if the motor must be operated at slow speeds.

8.15.6 Control Method

With 2-wire control, only one switch is used to run the variable frequency drive. An open switch stops the drive, and a closed switch starts the drive. Two-wire control is predominately used in HVAC applications since it is able to maintain the RUN command to the drive during a loss of power, which enables variable frequency drives to automatically restart when power is restored. Plus, 2-wire control allows drives that have "power loss ride-through" to operate during a power drop that is 2 seconds or less in duration.

With 3-wire control, two switches are used to run the drive. One switch is needed to stop, and another to start the variable frequency drive. This is typical in an industrial application on a conveyor or process control where multiple stations can start/stop the VSD, but a single safety circuit must be made to allow this operation to start.

Speed Reference Alternatives

Speed Potentiometer – Allows the operator to set motor speed with potentiometer.

Digital Programming / Display Unit – Allows the operator to program and troubleshoot the drive by inputting values through a keypad with an LED or LCD display unit. Drive operation can also be monitored through this display.

Analog Signal Follower – 4-20mA or 0-10VDC; must provide variable frequency drives with an isolated input; must use a twisted/shielded pair and keep wire away from 3-phase AC.

Selector switch speed selection – Allows the operator to select from several preset speeds. Can also be used if the speed is being set via a PLC, and an analog output is not available.

Serial Communications – Allow variable frequency drives to communicate on a network, such as MODBUS, PROFIBUS, DEVICENET, or METASYS, enabling drive operation to be coordinated and monitored from a PC.

8.15.7 Special Enclosure Needs

An important aspect of selecting the right VFD for the application deals with the environment surrounding the drive. There are a few types of certifications that drives are rated in including, Ingress Protection (IP), NEMA, and UL Type Enclosures. It is important to match specific application needs to the right enclosure. This can be done by finding a stand-alone drive with the proper enclosure rating, or the VFD can be placed inside of another enclosure.

8.15.8 Inverter Duty Rated Motors

Although running a VFD is the best way to control the motor, there are some issues that arise in motors as a result of the way a VFD works. PWM VFD’s do not produce a sinusoidal waveform, but rather a digital output that can put additional stresses on the motor windings and bearings. Newer motors all use wire that has been designed to handle the high voltages that can occur due to a drive usage. Some additional recommended features of inverter rated motors include grounding rings, isolated bearings and special cooling features (such as a separate fan to cool the motor at low speeds, typically on a constant torque application).

8.16 The Motor Survey and ECOs

Motor may offer the following energy conservation opportunities:

- Replacement of energy in-efficient motors
- Replacement of over-sized motors
- Use of variable speed drives

The following procedure is recommended for assessing the ECOs in motors:

1. Determine the general condition of the motors and opportunities from improved maintenance
2. Discuss with the engineer/operations and maintenance supervisor to determine the make of the motors, motor age, inspection and maintenance procedures, and %age of rewound motors

3. Discuss and identify any operational problems with motors, such as excessive tripping/over hearing. When necessary, measure the temperature of the motors.
4. Discuss and estimate the motor burn out percentage.
5. Identify motors for testing.
6. For motors requiring further investigation/testing, identify the application of the motors and specify any energy conservation opportunities. Make appropriate recommendations such as: time of day control, shut off idling motors, interlocking with main process. Use relevant Forms and Sheets to calculate savings and simple payback for proposed measures.
7. Measure the actual kW, power factor and determine their percent loading and their operating schedule.
8. Calculate savings by replacing oversized motor with matching motors.
9. Estimate the efficiency of the motors and where the efficiency is low investigate their replacement with efficient motors. Follow the procedures outlined in appendix on motors Calculate annual savings from the replacement of the existing motor.

9 Pumps

Pumping is one of the most common applications of electric power in industry, buildings, and agriculture. Improving operating efficiency of pumps can have great effect on power consumption in these areas.

The basic types of pumps are centrifugal, axial and reciprocating, but centrifugal pumps are most common in use. The power output of a pump can be used as an indicator of pump's performance. It is the product of total dynamic head and the mass of liquid pumped in a given time. Power output (hydraulic power) is given by:

$$\text{Power output, kW} = \frac{H \times Q \times \rho}{367{,}000}$$

Where, H = total dynamic head, m of liquid

Q = capacity, $\frac{m^3}{h}$

ρ = liquid density, $\frac{kg}{m^3}$

The power input to a pump is greater than the power output because of the requirement to overcome internal losses such as friction and leakage. The pump efficiency is defined as:

$$\text{Pump efficiency, } \eta_p = \frac{\text{Hydraulic power}}{\text{Input power}}$$

9.1 Head-Capacity Curve and Pump Affinity Laws

Exhibit 9-1 shows the head capacity curve of the typical centrifugal pumps.

Centrifugal pumps follow Affinity Laws, as summarized below:

For change in impeller diameter:

$$\left(\frac{Q_1}{Q_2}\right) = \left(\frac{D_1}{D_2}\right) \qquad \left(\frac{H_1}{H_2}\right) = \left(\frac{D_1}{D_2}\right)^2 \qquad \left(\frac{P_1}{P_2}\right) = \left(\frac{D_1}{D_2}\right)^3$$

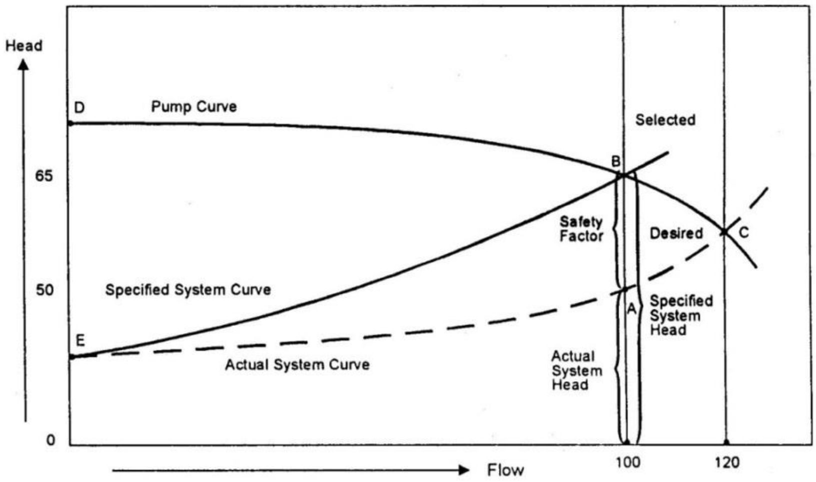
For change in pump speed:

$$\left(\frac{Q_1}{Q_2}\right) = \left(\frac{N_1}{N_2}\right) \qquad \left(\frac{H_1}{H_2}\right) = \left(\frac{N_1}{N_2}\right)^2 \qquad \left(\frac{P_1}{P_2}\right) = \left(\frac{N_1}{N_2}\right)^3$$

Where, D, N, Q, H, and P are impeller diameter, speed, flow, total head and brake horsepower respectively. Subscripts 1 and 2 indicate two different conditions.

Pump manufacturers provide pump head-capacity "curves" that predict individual pump performance. As shown in Exhibit 9-1, for a given speed and impeller diameter, a pump operates over a range of head and flows. With a change in the speed or the impeller diameter, a given pump will operate on a different "curve". It is characteristic of centrifugal pumps that as flow through the pump increases, its head decreases.

Exhibit 9-1: Centrifugal pump characteristic curves



9.2 Reducing Friction Losses

From the equation above, the first way to reduce pumping power is to reduce the total dynamic head. This is made up of the static head (pressure and/or height) to which the pump must discharge, plus the friction losses of the flow due to pipe and fittings. While the discharge condition is normally dictated by the process requirement, the friction losses offer some possibility of reduction. The friction loss component of the total head is given by:

$$Hf = F \times \left(\frac{L}{D}\right) \times \left(\frac{V^2}{2g}\right)$$

$$Hf = 0.0826 \times F \times L \times \left(\frac{Q^2}{D^5}\right)$$

Where, Hf = friction head loss, m

F = friction factor (determined by the type of pipe and fittings

Q = volumetric flowrate, $\frac{m^3}{h}$

V = velocity, $\frac{m}{s}$

D = insidediameter of the pipe, m

L = length of pipe system, m

g = accelaration due to gravity, $9.81\frac{m}{s^2}$

In fact, the friction loss is proportional to the square of the capacity (or velocity). So, the expression for the two flow conditions is:

$$\frac{Hf_1}{Hf_2} = \left(\frac{Q_1}{Q_2}\right)^2 = \left(\frac{V_1}{V_2}\right)^2$$

For constant flow rate:

$$\frac{Hf_1}{Hf_2} = \left(\frac{D_2}{D_1}\right)^5$$

Note:- Frictional pressure drop is inversely proportional to fifth power of the pipe diameter for a given flow. Thus a 5% reduction in diameter will produce a 29% increase in pressure drop and a 25% increase in pipe diameter would reduce friction losses by a factor of 3. In any application where scaling will occur, this factor the trade-off between the piping and pumping costs.

9.3 The Centrifugal Pump Systems ECOs

Centrifugal pumps are the most widely used pumps in the industry. Flow reduction is the most common and readily identifiable energy-saving measure in pumping application. As with many other equipment, pumps are often over-sized or over-designed for the application. In other instances, a careful evaluation of the process can identify potential reduction in required flows. With centrifugal pumps, flow reduction offers a variety of possible applications for energy savings.

Other ECOs may arise from reduction in operating hours, installation of level controls on over-head tanks, using the efficient pump systems, inter-locking of water pumps with the equipment (heat exchangers, compressors, etc.) using the water.

9.3.1 Flow Reduction by Throttling

By throttling, the flow is reduced, but the head is increased. The result is a decrease in power consumption, but this decrease is small, due to the extra head of the throttled valve that the pump must work against. It is an in-efficient method for controlling flow rate.

9.3.2 Flow Reduction by Changing Impeller Size

Another method of achieving a reduction in flow rate is to use a smaller impeller. To meet the wide variety of pumping needs, manufacturers produce several impellers, each with a different diameter, to be used inside a single pump casing. A separate pump curve is developed for each impeller.

A drawback of using a small impeller in the larger pump casing is that the pump efficiency is reduced. In most cases, this efficiency, however, is not much lower than the efficiency under throttled conditions, and the energy savings is nevertheless significant.

If a smaller impeller is not available, the existing impeller is sometimes trimmed or machined. This has the same basic effect as impeller replacement, except that additional loss of efficiency is suffered by trimming; thus, the energy savings may not be as great.

9.3.3 Flow Reduction by Reducing Speed

The pump laws show that the brake horsepower consumption ratio at two conditions is related to the cube of the speed ratios at the two conditions. Also, flow is proportional to pump speed. Therefore, any decrease in flow will have a cubed reduction effect on the power requirement. Thus, the most energy-efficient option of reducing the flow rate would be to reduce the pump speed.

Speed can be controlled in several ways depending on the pumping conditions and the desire for automation. Simple, semi-permanent methods involve changing pulley sized for belt-drives using manually adjustable pulley and belt systems, two-speed motors and various manually controlled or fully automatic electronic drives systems can be employed.

Note that reducing pump speed rather than trimming impeller diameter allows the use of the more efficient, full-size impeller, and at the same time provides for a quick, easy way to increase pumping capacity should that become necessary, Operation at lower speed also results in longer pump life.

9.3.4 Parallel and Series Pumping

There are two types of pump systems frequently used in many pumping applications. These systems are used to obtain certain sets of conditions not practically or economically attained by single pump application. They are systems using pumps in parallel or in series. Properly applied, they can be excellent ways of obtaining desired results; all that is required is a thorough knowledge of how and why they work.

9.3.4.1 Parallel pumps

Parallel operation is obtained by having two pumps discharging into a common header. This type of system is useful when the demand for liquid fluctuates as in condenser cooling water. When demand is light only one pump operates and the second pump is used when the fluid requirement increases beyond the capacity of the first pump. Three or four pumps can also be operated in parallel to achieve additional benefits where the operating conditions permit such arrangement.

If two pumps are placed in parallel, as shown in Exhibit 9-2, they will produce the same head, which is also the same as the system head. If the pumps are identical, they should also produce the same flow, which will be one-half of the system flow. The parallel pumps can be added together on a head-capacity diagram as shown in Exhibit 9-3.

Exhibit 9-2: Parallel pumps with system curve

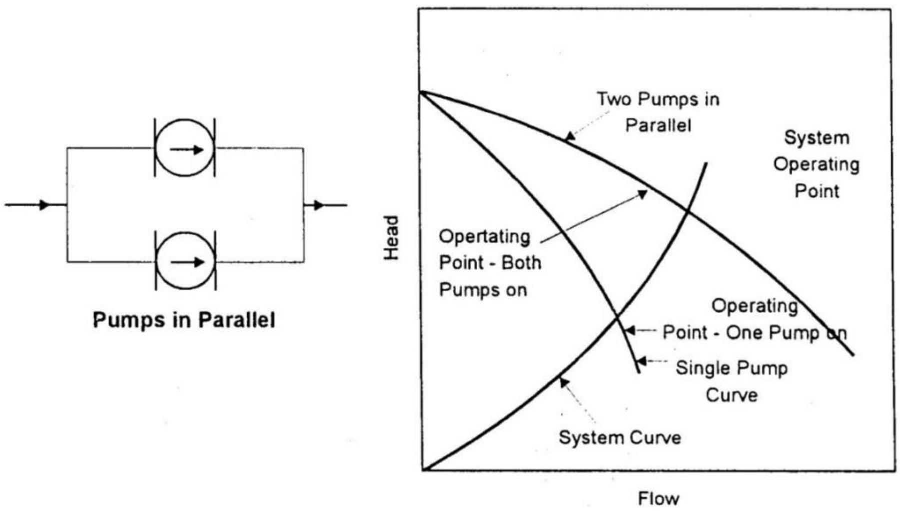
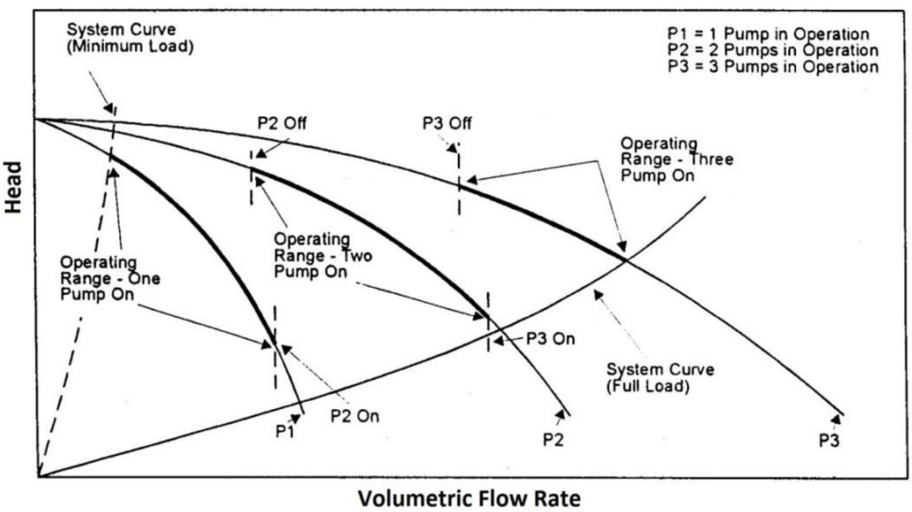


Exhibit 9-3: Operating ranges for parallel pumps energy analysis



When the system curve is graphed along with two pumps in parallel, as shown in Exhibit 9-2, operating points with one or both pumps running can be determined. If normal operation is for both to be running, one pump by itself can provide about 70-80% flow (and about 55% of pump power) can carry the whole load.

Additional backup or load control can be achieved by paralleling three or four pumps. If four pumps are placed in parallel to carry full-load flow, operating three pumps will provide over 90% of design flow. The parallel pumps can be controlled on and off by a flow sensor. This is different than with variable-speed drives, where pump speed is controlled by a pressure differential between the supply and return lines. A typical application of three pumps operating in parallel is shown in Exhibit 9-3.

Most parallel pumps are identical because it is difficult to use pumps with different pressure heads effectively. Even if the pumps are identical, the way the pumps are piped can have a great effect on how much fluid each one actually pumps. A better piping arrangement is in Exhibit 9-2.

Occasionally, pumps sized for two-third and one-third of full flow can be effective, but "run-out" flow when only the smaller pump is running means careful system design and pump selection is a must.

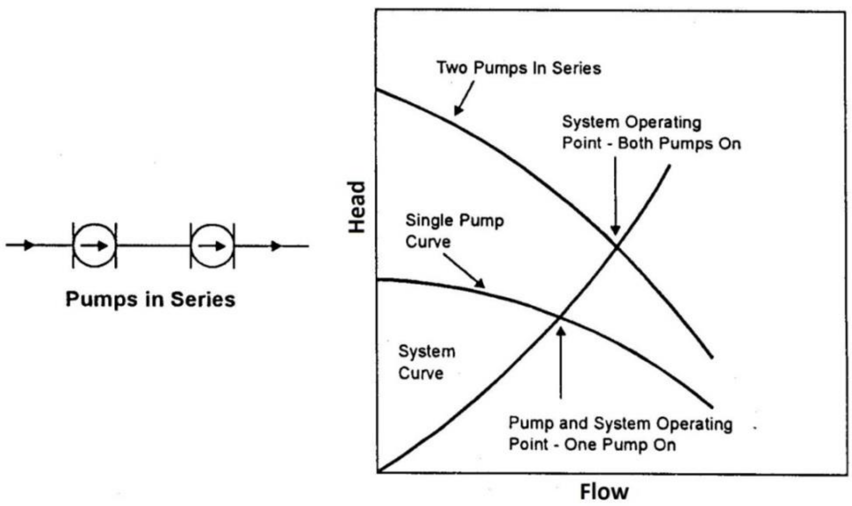
9.3.4.2 Series Pumps

Exhibit 9-4 shows how pumps are used in series. All the fluid passes through each pump, so the flow for each pump and the system is the same. For identical pumps, each pump delivers half of the total system head. A series pump arrangement can be constructed on the head-capacity diagram by adding the heads together vertically, as shown in Exhibit 9-4.

If a series pump is out of service, series pumping also provides backup capability of 70-80% of flow with the proper piping arrangements.

A difference between series and parallel pumping occurs in motor sizing. A pump motor must be sized for its largest probable load. This occurs in centrifugal pumps when a pump is allowed to "run out on its curve" as flow increases with decreasing head. For parallel pumps, this occurs when only one pump is running. For series pumps, it will occur when both pumps are running. In other words, shutting one pump off in parallel pumping increases the load on the remaining pump(s). Shutting one pump off in series pumping actually decreases the load on the remaining pump(s).

Exhibit 9-4: Pumps in series with system curves



9.4 The Pump Survey

The evaluation of operating condition, brake horsepower required, head output, and efficiency is an important part of ensuring that centrifugal pumps are operating at optimum efficiency. The following steps provide a methodology for pump evaluation.

1. From the pump nameplate, record the design heat and flow, impeller size (if listed), speed, make and model number.
2. Record the electric motor nameplate data.
3. Record the pressure gauge reading(s). Gauges are often installed with the system for balancing. Some pumps will have a gauge only on the pump discharge because the pump suction is close to atmospheric pressure (open system).
4. Walk the system to identify any problem areas in pump noise (cavitation, etc.), layout configuration, valve type and throttling, and required static lift. Possible problems with any pump or system change should be identified.
5. Obtain the pump curves. By using the pump curves a preliminary evaluation can generally be done without measuring the actual flow rate. If the pressure (head) is known, simply read the flow off the pump curve. Keep in mind that the pump curves are only representative of the model.
6. Pumps should be tested because small differences in performance can add up to large energy costs. Worn pumps will operate at a lower efficiency than the curves would suggest. These pumps should also be fully tested, or simply replaced with an efficient model pump that is appropriately sized for the task. Perform pump tests where necessary, measuring motor current to estimate brake horsepower, flow and inlet and discharge pressures. Make these measurements at different flow rates to check pump curves or develop approximate new curves. If actual pump curves are not available, compare measured data to curves for similar new pumps.
7. Evaluate the system for which the pump is working. Can the flow be reduced completely, or only part of the time? Consider and evaluate changes in the motor, pump replacement, or other system changes.
8. In case of variations in the flow rates, record the percent of time the pump operates on the reduced flow rates, method applied for reducing the flow rate, flow rates and pressures before and after (say) the throttling valve at different actual operating conditions.
    a. Develop the pump curves (also use the manufacturer's pump curves) and the system curves. The system curve (system friction curve) meets the pump curve when the pump operates at full flow conditions. the other point of the curve is the at no flow conditions. (It is numerically equal to the static pressure of the system in case of open systems, and is equal to zero in case of closed systems, e.g. , chilled water systems. The system friction loss curve varies proportional to the square of the flow rate.)

    b. When the actual operating conditions of the pump at different flow rates have been recorded, the pump curves for different pump speeds are drawn. The pump operating curve should match with the system curve. If this condition is satisfied, the pump is suitable for applying variable speed system. It can also identify the maximum and minimum speed of the pump for varying conditions. It helps in the selection of variable speed drive system.
9. Another possibility to be analyzed to meet the varied pump conditions is the use of parallel pumps in place of one. It should also be very carefully analyzed before recommending parallel pump operation. (Say three small capacity pumps are installed instead of one pump, and they are operated through proper controls

1. Pump and motor specifications, and motor rated input power

Obtain the data from the name-plates

2. Input Power, kW

Measure by Watt meter

3. **Discharge Pressure: (Head)**

Note from the pressure gauge installed at the pump outlet or by installing a pressure gauge in case gauge is not already installed. Pressure gauge be mounted at a point, nearest the pump.

Other alternative is, if pump curves are available, find out flow rate and impeller size, and read corresponding pressure developed by the pump from the pump curves.

Total dynamic head developed by a horizontal shaft centrifugal pump can be calculated from measurement of pressures immediately before and after the pump and velocities of flow in the suction and discharge pipes. Velocities of flow in discharge and suction pipes can be calculated from discharge and internal diameters of discharge and suction pipes respectively. Hence, the total dynamic head developed (H in meters of liquid) by the pump is:

$$H = \left(\frac{R_{gd}}{S_w} + \frac{V_d^2}{2g}\right) - \left(\frac{R_{gs}}{S_w} + \frac{V_s^2}{2g}\right)$$

Where R_{gd} = Pressure reading on gauge in discharge pipe, Pa

R_{gs} = Pressure reading on gauge in suction pipe, Pa

S_w = Specific weight of liquid, N/m^3

$= \text{Density}, \frac{kg}{m^3} \times \text{gravity}, 9.81 \frac{m}{s^2}$

Vd = Velocity of liquid in discharge pipe, m/s

Vs = Velocity of liquid in suction pipe, m/s

g = Acceleration due to gravity, 9.81 m/s^2

4. **Static Head**

If necessary, estimate by observing the process conditions or on shutting down the pump, the pressure gauge installed at pump outlet will show the static head of the system, on discharge side. Total static head is the sum of static heads on discharge and suction sides.

5. **Suction Pressure (Head)**

Estimate by observing the suction conditions, such as water level below or above the central line of pump; or note from the suction pressure gauge, if installed.

6. **Flow rate**

Measure by using flow meter; or estimate if operating pressure and impeller size are known and pump curves are available, corresponding flow rate can be read from the pump curve. (The estimates from the pump curves are good only when the pump is in good condition, otherwise pump will not behave according to the curves.)

7. **Operating Hours**

By interviewing the operating staff, determine the operating, daily operating schedule, weekly working days, and working weeks per year.

9.5 System Curve (Open or Closed Systems)

The system or layout in which a pump operates may be classified as open or closed. A condenser water loop to an open cooling tower would be an example of an open system. A chilled water loop, with no exposure to the atmosphere, would be a closed loop system.

For open systems, the friction head is added to the static head to determine the total static head to determine the total head required, as shown in Exhibit 9-3, Exhibit 9-4. Closed systems do not require the addition of the static head. This is because the work needed to pump the fluid against gravity is exactly negated by work done by the fluid when it drops in elevation to return to the pump. Since the actual friction head will vary approximately with the square of fluid velocity (or flow rate, Q), a system curve can be developed and overlaid on the pump curve. The intersection of the pump head-capacity curve and the system (friction) curve will be the operating point for the pump.

System curve can be constructed by using the affinity laws:

$$\frac{Hf_1}{Hf_2} = \left(\frac{Q_1}{Q_2}\right)^2 = \left(\frac{V_1}{V_2}\right)^2$$

As affinity laws are applied to the friction head, so graph of system curve is drawn for the friction head. The static head (ht) must be included in the graph but should be subtracted from the total head before using the affinity laws. So, the above equation becomes:

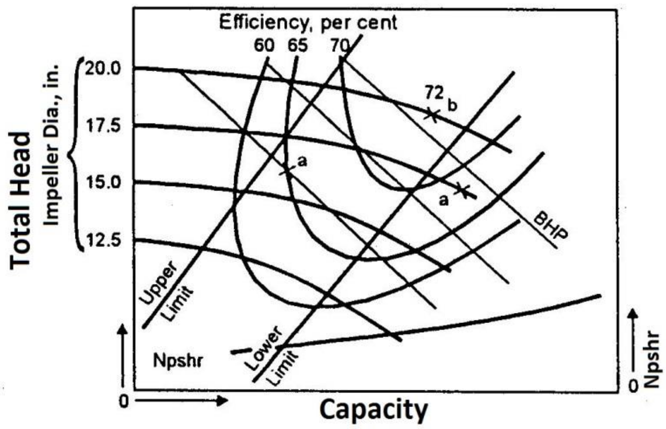
$$\frac{Hf_1}{Hf_2} = \left(\frac{H_1 - h_t}{H_2 - h_t}\right) = \left(\frac{Q_1}{Q_2}\right)^2 = \left(\frac{V_1}{V_2}\right)^2$$

9.6 Pump Selection

Pump selection should begin with an accurate assessment of system needs. Design flows should be determined without undue safety factors. Factors to be considered are a number of probable flow and load conditions to determine a range of system curves over which the pump(s) must operate. For the best selection, following factors should be considered:

- Select a pump or pump system using actual piping pressure drop data. The penalty for using "old" pipe pressure drop factors is severe in terms of both first and operating costs.
- The best selection for a typical centrifugal pump is at the best efficiency point on the head-capacity curve. As no pump company can offer an infinite number of curves, a reasonable rule for selection of pump(s) is to pick the pump in a range from 25% less than capacity at BEP (best efficiency point) to 15% greater than the capacity at BEP (Exhibit 9-5). Selection made on the above basis will generally keep the operator out of trouble and provide him with a serviceable pump unit. Another consideration when studying a pump curve is to make certain that the operating point falls below the maximum and above the minimum impeller diameters.

Exhibit 9-5: Typical pump performance curve



b = Best Efficiency Point

10 Fans and Blowers

Fans and blowers are universally used for numerous processes where circulation and supply of air is required, e.g., in air conditioning systems, combusters of boilers, and dryers. Fans, and their associated motors, are a major consumer of electricity in space conditioning processes. Fans serve two functions: they impart a motion to the air stream, and they serve to increase the static pressure of the air stream.

Industrial fans is really a generic term that could include any type of fan or blower. An industrial fan could be a centrifugal type blower or an axial type fan. Centrifugal blowers differ from axial flow fans in the way they move the air. A centrifugal blower typically has an impeller that draws the air into the inlet of the blower housing, and discharges it at 90 degrees out through the discharge of the housing. An axial flow fan uses a propeller to draw the air into it and discharges it in the same axial direction. An "air moving device" with a propeller is typically referred to as a fan, while one with a wheel is typically referred to as a Blower. The deciding factor of whether to use a centrifugal blower or an axial fan depends on a specific application.

The property that distinguishes a centrifugal fan from a blower is the pressure ratio it can achieve. A blower in general can produce higher pressure ratio. As per American Society of Mechanical Engineers (ASME) the specific ratio - the ratio of the discharge pressure over the suction pressure – is used for defining the fans and blowers.

Difference between fans and blowers

Equipment	Specific Ratio	Pressure Rise, mm WC
Fans	1.11	1,136
Blowers	1.11 -1.2	1,136 – 2,066
Compressors	Above 1.2	

10.1 Types of Fans and Blowers

10.1.1 Axial Fans

Axial fans can be categorized into three major varieties, distinguished by the applications for which they are designed rather than by blade configurations (Exhibit 10-1). The principle types of axial fans are propeller, tubeaxial and vaneaxial fans.

Propeller Fans

These are low pressure, high capacity fans that are seldom applied in applications requiring more than 0.75 in. static pressure. As compared to centrifugal fans, the horsepower required by a propeller fan is lowest at maximum air volume. Centrifugal fans are the opposite in that they require minimum horsepower at no air delivery.

Tubeaxial Fans

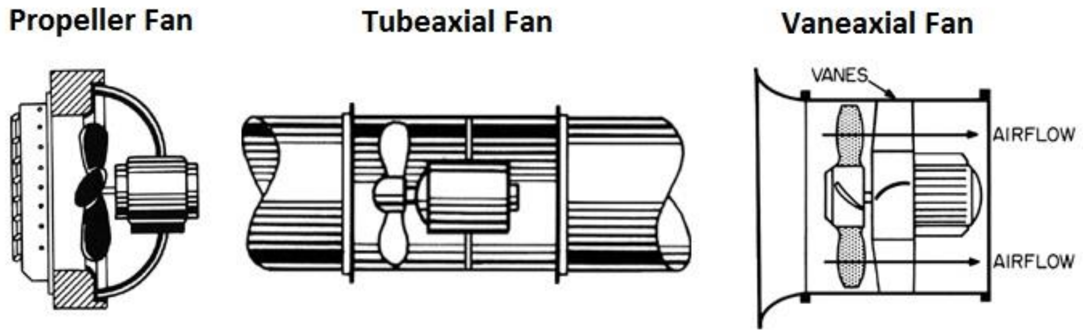
These are generally considered to be heavy-duty propeller fans. They are built for pressures in the range of 2.5 to 3 in. of water and are generally limited to industrial duty where noise considerations are unimportant.

Vaneaxial Fans

These are basically tube axial fans plus vanes. Behind the fan blades are vanes which straighten the spiral flow of air, thus increasing the static efficiency. Also available on some fans is a provision to allow adjustment of the blade angles permitting adjustment of the air volume delivered by the fan.

Because the discharge opening is inline with its entrance, and axial flow fan offers the advantage of simplified duct arrangement. This becomes important when space considerations must be taken into account.

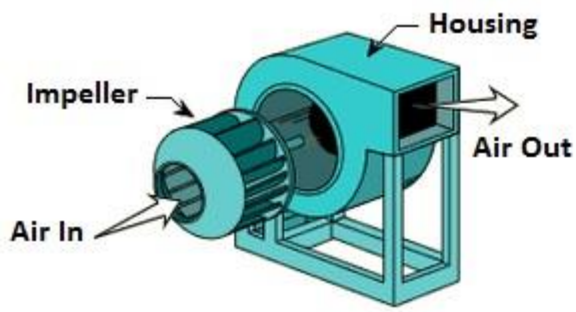
Exhibit 10-1: Types of axial fans



10.1.2 Centrifugal Fans or Centrifugal Blowers

They generally use centrifugal force to propel air forward. Inside a centrifugal air blower is an impeller with small blades on the circumference and a casing to direct the flow of air into the center of the wheel and out toward the edge (Exhibit 10-2). The design of the blades will affect how the air is propelled and how efficient the air blower is. Blade designs in air blowers are classified as forward-curved, backward-inclined, backward-curved, radial and airfoil ().

Exhibit 10-2: Model of a centrifugal fan



Forward-Curved Air Blowers

Forward-curved blowers are impulse devices with blades that are curved in the direction of rotation. The blower accelerates air to a high velocity while rotating at a low speed. Forward-curved blower wheels spin at relatively low speeds and produce high volumes of air at low static pressures. This type of blower is incapable of operating at the speeds necessary to create high static pressures because of its lightweight construction. Still, forward-curved blowers are the most common type of air blower because they propel the most air volume in relation to blower size and speed.

Backward-Inclined and Backward-Curved Air Blowers

A backward-inclined blower, operating at roughly twice the speed of a forward-curved air blower, has flat blades that slant away from the direction of travel. This type of blower is highly efficient (low horsepower requirement) and has a rugged construction suitable for high static pressure applications. This type of air blower is best used in locations where the air is either clean or mildly contaminated. Similar to this style is a backward-curved air blower. The blades of a backward-curved blower are a single thickness throughout and curve away from the direction of travel. These blades are sturdier than backward-inclined blades and can be used in corrosive and erosive environments.

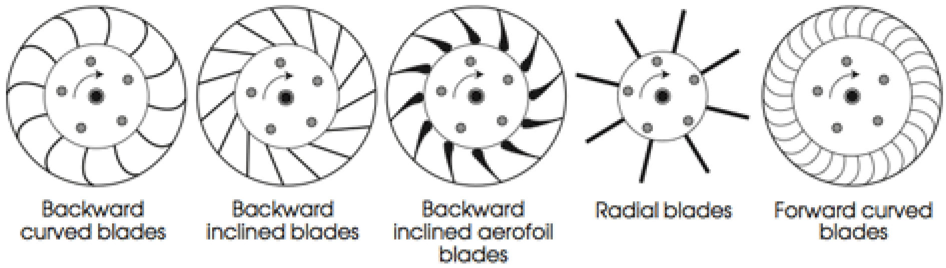
Radial Air Blowers

Radial blowers are designed for industrial use in small exhaust systems. These air blowers are capable of handling air that contains bits of dirt, grit, lint and other foreign particles while still maintaining a high-pressure supply of air for conveying and cooling. Their use in particle-laden air means that this type of blower is generally designed to be self-cleaning. Radial air blowers have the lowest efficiency levels because the blades have no curve or lean and are perpendicular to the wheel's rotation. Think of a paddleboat racing a boat with an outboard motor. No matter how fast the paddle spins, it will not catch up to the boat with the outboard motor.

Airfoil Air Blowers

Airfoil blowers have the most efficient design of all air blowers. Their blades have an airfoil shape that is wide at the center and curves down to narrow edges. Airfoil blowers are extremely efficient because they require lower horsepower levels to operate. This type of blower is used in clean air situations.

Exhibit 10-3: Impeller blade designs of centrifugal fan



Relative Characteristics of Centrifugal Fans Using Different Blade Types

	Forward Curved Blades	Radial (Straight) Blades	Backward Curved Blades
Efficiency	Medium	Medium	High
Stability of Operation	Poor	Good	Good
Space Required	Small	Medium	Medium
Tip Speed for Given Pressure Rise	Low	Medium	High
Resistance to Abrasion	Poor	Good	Medium
Noise Characteristics	Poor	Fair	Good

10.1.3 Positive displacement blowers

Positive displacement blowers do not generate pressure (Exhibit 10-4) internally. Instead, positive displacement blowers overcome line pressure when they are in operation (see Exhibit 10-5). Air enters the inlet port of the blower and is trapped as the impeller rotates beyond the limits of the port opening. There is no contact between the moving parts inside of the machine. The air is trapped by the tight tolerances between the impeller and blower casing. The air is moved around the impeller and blower casing to the opposite side of the blower towards the discharge port. Once the impeller chamber opens into the discharge port there is an equalization of pressure between the impeller chamber and the discharge line. As the rotation continues, the air is forced out the blower and the process repeats. The following illustration should help explain the process of how a positive displacement blower overcomes line pressure.

Exhibit 10-4: Cut-away of positive displacement blower

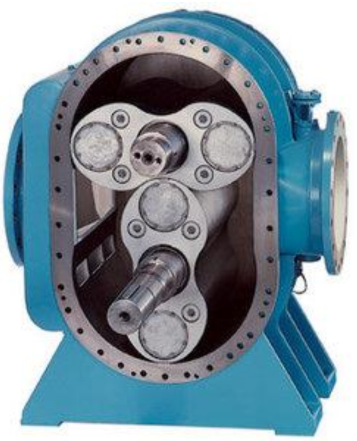
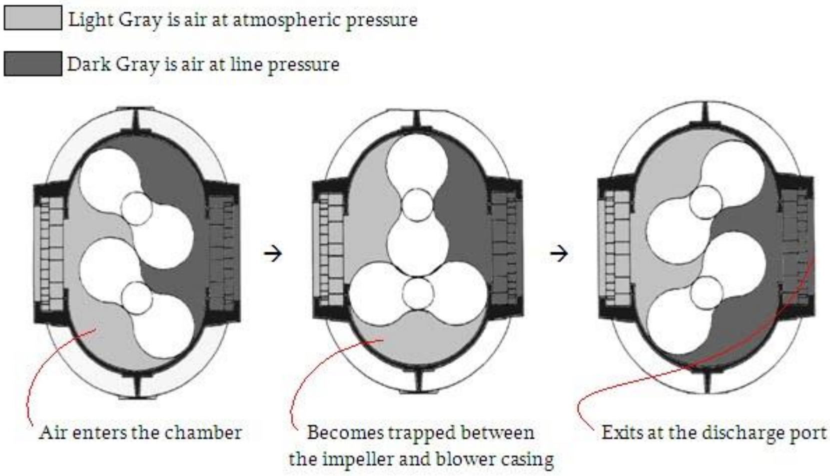


Exhibit 10-5: Function mechanism of positive displacement blower



10.2 Guidelines for selecting a fan or blower

The following parameters must be considered in the proper selection per selection of a fan or blower:

1. What is the air volume that will be required? This is rated in cubic meters per hour (m^3/h)?
2. What is the static pressure resistance through the complete system? This is rated in millimeters water gauge (mm WG)?

   Note: mm WG is the resistance to flow, or friction, caused by the air moving through a pipe or duct. Friction due to other deices should also be taken into account. Such devices may include filters, dampers, heat exchangers, etc.
3. What is the temperature of the air going through the fan?
4. What is the ambient air temperature outside the fan?
5. Will the air stream be clean, dry air?
6. Will there be any corrosive substances in the air?
7. Will there be any moisture in the air stream?
8. What is the altitude where the fan will be operating?
9. Any other special consideration.

10.3 Fan Power and Fan Laws

Equations for air horse power, i.e., output power of a fan, and other important quantities for the fans are given below:

$$\text{Air Power, watts} = \frac{Q \times p}{1,000}$$

Where, Q = Flowrate, $\frac{l}{s}$

p = Fan pressure, Pa

$$\text{Air Power, kW} = 2.724 \times 10^{-6}\ Q \times p$$

Where, Q = Flowrate, $\frac{m^3}{h}$

p = Fan pressure, mm of water column

Fan pressure or operating pressure is the sum of the static pressure and the velocity head (total fan pressure) of the air leaving the fan. Operating efficiencies of fans range from 40% to 70%.

$$\text{Fan Motor Input Power, watts} = \frac{\text{Air Horsepower, watts} \times 100}{\text{Efficiency, \%}}$$

Volume in above equations is at actual gas temperature.

Fan Total Pressure = Total pressure at discharge minus Total pressure at inlet

Fan Static Pressure = Fan Total Pressure minus Fan Velocity Pressure (at discharge)

= Fan Static Pressure at discharge minus Fan total pressure at inlet

Some properties of air are given below:

Density of dry air at standard conditions

(@ 101.325 kPa and 210C = 1.20048 kg/m^3 = 0.833 m^3/kg

(@ 14.696 psi, 700F = 0.075 lbs/ft^3 = 1.2015 kg/m^3

Under actual conditions, the density may change because of Temp., composition of gas, or altitude.

Operating efficiencies of the fans are in the range of 40 to 70%. Backward curved blade fans have commonly efficiency of 70%, while Forward curved and radial fan are commonly 50% efficient.

The fan laws relate the performance variables for any dynamically similar series of fans. The fan laws can also be used to predict the performance of a given fan under different operating conditions. The variables are: fan size; rotational speed; air density; volumetric flow rate; either static or total pressure; power; and mechanical efficiency. For fan laws see Exhibit 10-6. The fan laws in simplified form are as follows:

$$\left(\frac{Q_1}{Q_2}\right) = \left(\frac{D_1}{D_2}\right)^3 \times \left(\frac{N_1}{N_2}\right)$$

$$\left(\frac{SP_1}{SP_2}\right) = \left(\frac{D_1}{D_2}\right)^2 \times \left(\frac{N_1}{N_2}\right)^2$$

$$\left(\frac{HP_1}{HP_2}\right) = \left(\frac{D_1}{D_2}\right)^5 \times \left(\frac{N_1}{N_2}\right)^3$$

Q, SP, HP, D and N stand for flow rate, static pressure, input power, internal diameter and speed respectively; while subscripts 1 and 2 represent the operating conditions.

Friction pressure drop is inversely proportional to fifth power of the pipe diameter for a given flow:

$$\left(\frac{Hf_2}{Hf_1}\right) = \left(\frac{D_1}{D_2}\right)^5$$

Hf1 and Hf2 stand for the friction losses. Thus a 5% reduction in diameter will produce a 29% increase in pressure drop.

Characteristic curves of the fan are shown in Exhibit 10-7.

10.4 The Fan Systems ECOs

The fans offer ECOs in the areas, such as, reduction in operating hours, reduction in air flow, duty cycling, and applying time of day controls.

10.4.1 Reduce Airflow by Controlling Fan Speed

Most fans, whether forced air HVAC blowers or kiln of boiler induced draft fans, are oversized for their actual application requirements. This is because it is because it is difficult to calculate actual fan requirements in the design stage, and because allowance is often made by the designer for degradation and/or facility expansion. As a consequence, many fans are throttled by using dampers of one form or another. Dampering is a very convenient but very inefficient method of reducing airflow.

In case of air conditioning systems, additional savings from reduction in speed arise from reduction in air conditioning load.

10.4.2 Duty Cycling and Time of Day Control

Duty cycling allows fans to be cycled intermittently and in turn. For example, if there are 20 ventilating fans serving an area and it is known that two can always be shut down for 10 minutes without anyone noticing it, then a simple timer-sequencer can cycle through the fans shedding and restoring them in some selected order. Air conditioners and electric heaters of various types can be handled in the same way, thus minimizing demand level and energy consumption together, strictly on a time basis.

And through the time of day controls unneeded fans can be shut down during off hours and at any time when they are not required.

Exhibit 10-6: Fan laws

VARIABLE	CONSTANT	NO.	LAW	FORMULA
SPEED	Air Density Fan Size Distribution System	1	Capacity varies as the Speed	$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$
		2	Pressure varies as the square of the Speed	$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^2$
		3	Horsepower varies as the cube of the Speed	$\frac{Hp_1}{Hp_2} = \left(\frac{N_1}{N_2}\right)^3$
FAN SIZE	Air Density Tip Speed	4	Capacity and Horsepower vary as the square of the Fan Size.	$\frac{Q_1}{Q_2} = \frac{Hp_1}{Hp_2} = \left(\frac{D_1}{D_2}\right)^2$
		5	Speed varies inversely as the Fan Size.	$\frac{N_1}{N_2} = \frac{D_2}{D_1}$
		6	Pressure remains constant	$P_1 = P_2$
	Air Density Speed	7	Capacity varies as the cube of the Size.	$\frac{Q_1}{Q_2} = \left(\frac{D_1}{D_2}\right)^3$
		8	Pressure varies as the square of the Size.	$\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^2$
		9	Horespower varies as the fifth power of the Size.	$\frac{Hp_1}{Hp_2} = \left(\frac{D_1}{D_2}\right)^5$
AIR DENSITY	Pressure Fan size Distribution System	10	Speed, Capacity and Horsepower vary inversely as the square root of Density	$\frac{N_1}{N_2} = \frac{Q_1}{Q_2} = \frac{Hp_1}{Hp_2} = \left(\frac{W_1}{W_2}\right)^{1/2}$
	Capacity Fan Size Distribution System	11	Pressure and Horsepower vary as the Density.	$\frac{P_1}{P_2} = \frac{Hp_1}{Hp_2} = \frac{W_1}{W_2}$
		12	Speed remains constant.	$N_1 = N_2$

Where

Q = volume flow capacity (m3/s)
N = wheel velocity - revolution per minute - (rpm)
D = wheel diameter
P = pressure (m)
SP = static pressure (m, Pa)
Hp = power (bhp)
W = power (W)

Exhibit 10-7: Fan curves

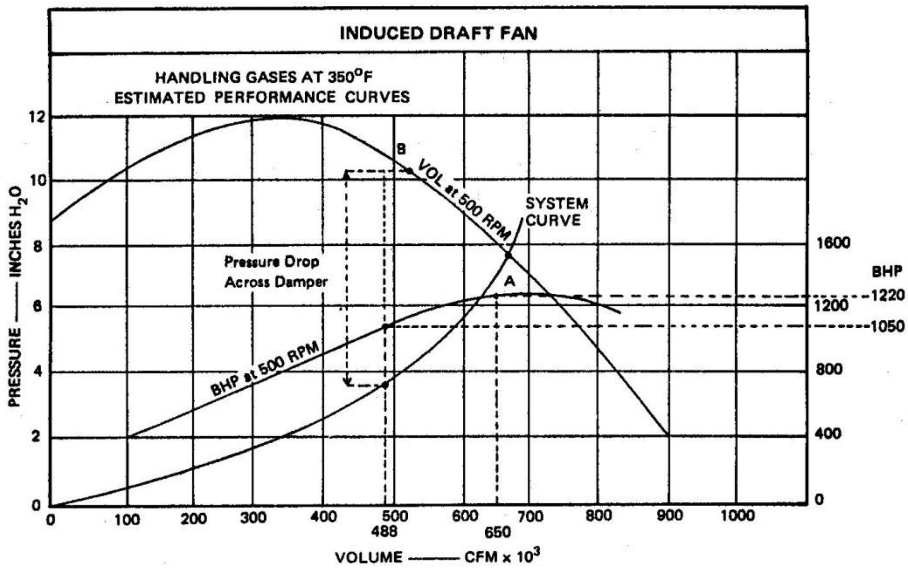


FIGURE 1

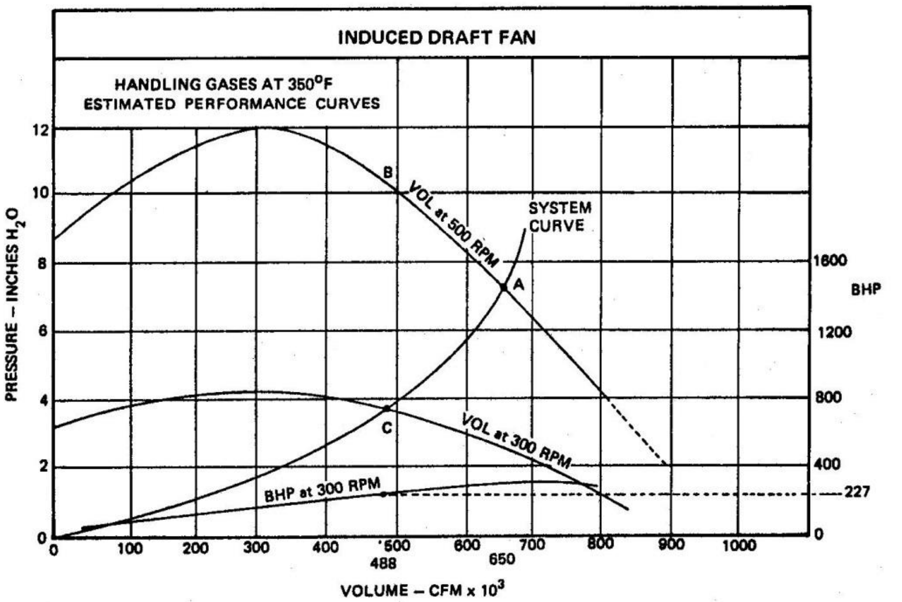


FIGURE 2

11 Compressed Air Systems

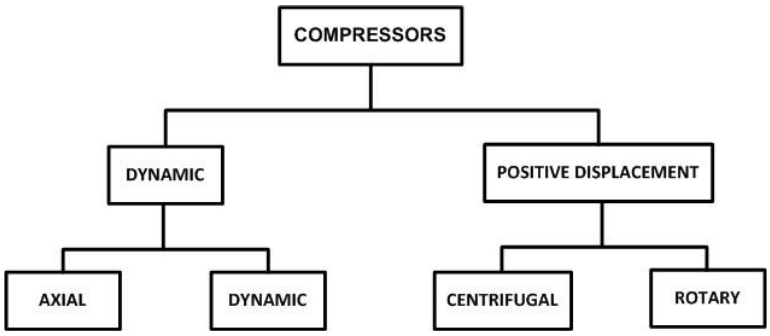
Approximately 10 per cent of all electrical power used in industry is employed in compressing air which is used as a power source particularly in unsafe or potentially dangerous situations and for operating pneumatic controls; this is proof of its widespread usage. The compressed air system in a plant can cause considerable energy loss. The factors most commonly found responsible for this energy loss are air leaks, excessive line pressure, high inlet temperature, over-sized compressor, and improper system layout. Potentially large energy savings can be achieved if the recommendations given below are put into practice.

11.1 Types of Compressors

Several types of compressors are used in the process industries (see Exhibit 11-1). However, two most common compressor types are positive displacement and dynamic. Positive displacement compressors use pistons, lobes, screws, or vanes to reduce a fixed volume of gas through compression and deliver a constant volume. Dynamic compressors use impellers or blades to accelerate a gas and then convert that velocity into pressure. Dynamic compressors are more commonly used than positive displacement compressors because they are less expensive, more efficient, have a larger capacity, and require less maintenance. Both of these types of compressors can be single- or multistage.

All compressors require a drive mechanism such as an electric motor or turbine to operate, and all are rated according to their discharge capacity and flow rate. Most compressors require auxiliary components for cooling, lubrication, filtering, instrumentation, and control. Some compressors require a gearbox between the driver and compressor to increase the speed of the compressor.

Exhibit 11-1: Major compressor types



11.1.1 Dynamic Compressors

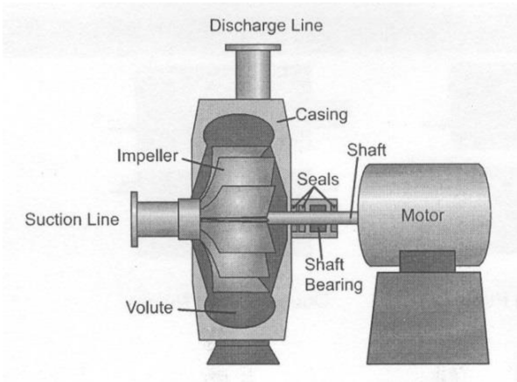
Dynamic compressors are non-positive displacement compressors that use centrifugal or axial force to accelerate and convert the velocity of the air or gas to pressure (as opposed to positive displacement compressors, which use a piston, lobe, or screw to compress air).

11.1.1.1 Centrifugal Compressors

Centrifugal compressors are a dynamic type compressor in which the gas flows from the inlet located near the suction eye to the outer tip of the impeller blade. In a centrifugal compressor, the gas enters at the low pressure end and is forced through the impellers by the rotation of the shaft. As the gas moves from the center of the impeller toward the outer tip, the velocity is greatly increased. When the gas leaves the impeller and enters the volute, the velocity is converted to pressure due to the slowing down of the molecules.

Centrifugal compressors are used throughout industry because they have few moving parts, are very energy efficient, and provide higher flows than similarly sized reciprocating compressors. Centrifugal compressors are also popular because their seals allow them to operate nearly oil-free, and they have a very high reliability. They are also effective in toxic gas service when the proper seals are used, and they can compress high volumes at low pressures. The primary drawback is that centrifugal compressors cannot achieve the high compression ratio of reciprocating compressors without multiple stages. Exhibit 11-2 shows an example of a centrifugal compressor.

Exhibit 11-2: Centrifugal compressor and volute with driver

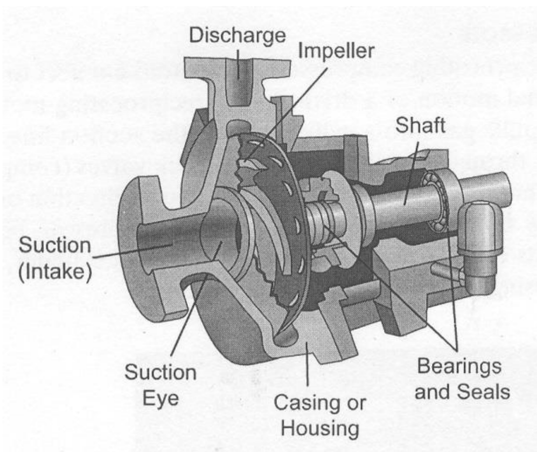


Centrifugal compressors are more suited for continuous-duty applications such as ventilation fans, air movers, cooling units, and other uses that require high volume but relatively low pressures.

In a centrifugal compressor, there is a direct relationship between impeller speed, velocity, pressure, and flow. As the impeller speed increases, velocity increases. As velocity increases, pressure increases. As pressure increases, flow increases.

Centrifugal compressors may be single-stage or multistage, and the stages may be contained in one casing or several different casings. The main components of a centrifugal compressor include bearings, a housing (casing), an impeller, an inlet and outlet, a shaft, shaft couplings, and shaft seals. Exhibit 11-3 shows another example of a centrifugal compressor and its components.

Exhibit 11-3: Centrifugal compressor with parts labeled



11.1.1.2 Axial Compressors

Axial compressors are dynamic-type compressors in which the flow of gas is axial (in a straight line along the shaft). A typical axial compressor has a rotor that looks like a fan with contoured blades followed by a stationary set of blades, called a stator.

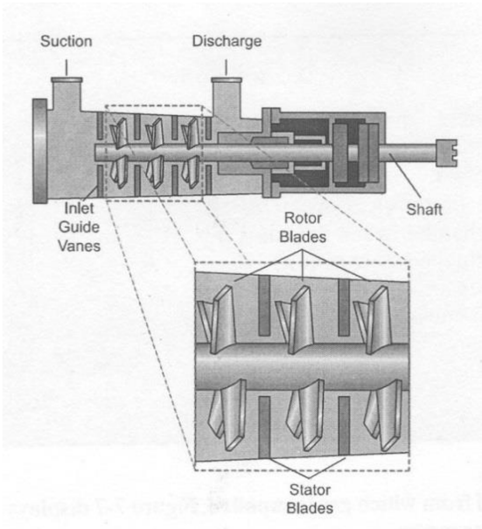
Rotor blades attached to the shaft spin and send the gas over stator blades, which are attached to the internal walls of the compressor casing. These blades decrease in size as the casing size decreases. Rotation of the shaft and its attached rotor blades causes flow to be directed axially along the shaft, building higher pressure toward the discharge of the unit.

Each pair of rotors and stators is referred to as a stage. Most axial compressors have a number of such stages placed in a row along a common power shaft in the center. Exhibit 11-4 shows an example of an axial compressor with rotor and stator blades.

The stator blades are required to ensure efficiency. Without these stator blades, the gas would rotate with the rotor blades, resulting in a large drop in efficiency. Each stage is smaller than the last because the volume of air is reduced by the compression of the preceding stage. Axial compressors therefore generally have a conical shape, widest at the inlet. Compressors typically have between nine and fifteen stages. The main components of an axial compressor include the housing (casing), inlet and outlet, rotor and stator blades, shaft, and inlet guide vanes.

Axial compressors are very efficient compressors; however, they are not as frequently used in industry as reciprocating and centrifugal compressors because of the high initial and maintenance costs. Regardless of the type, all compressors are rated by dividing the discharge pressure by the suction pressure. This is called the compression ratio.

Exhibit 11-4: Axial compressor showing rotating and stator blades



11.1.2 Positive Displacement Compressors

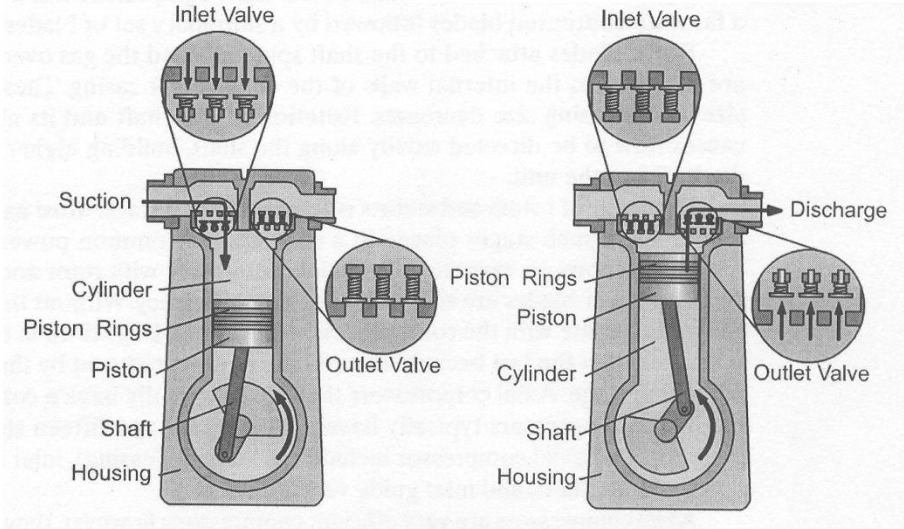
Positive displacement compressors are devices that may use screws, sliding vanes, lobes, gears, or a piston to deliver a set volume of gas with each stroke. Positive displacement compressors work by trapping a set amount of gas and forcing it into a smaller volume. The two main types of displacement compressors are reciprocating and rotary, with reciprocating being the most commonly used.

11.1.2.1 Reciprocating Compressors

The term reciprocating refers to the back-and-forth movement of the compression device (a piston or other device is positioned in a cylinder). Reciprocating compressors use the inward stroke of a piston to draw (intake) gas into a chamber and then use an outward stroke to positively displace (discharge) the gas. A common application for the reciprocating compressor is in an instrument air system.

In a reciprocating compressor, a piston receives force from a power medium (e.g., a drive shaft) and then transfers that power to the gas being compressed. In a piston type reciprocating compressor, the gas is trapped between the piston and the cylinder head and then compressed. The cylinder is the cylindrical chamber in which a piston compresses gas and from which gas is expelled. Exhibit 11-5 displays a cutaway picture of a reciprocating compressor.

Exhibit 11-5: Air / gas flow in piston-type reciprocating compressor

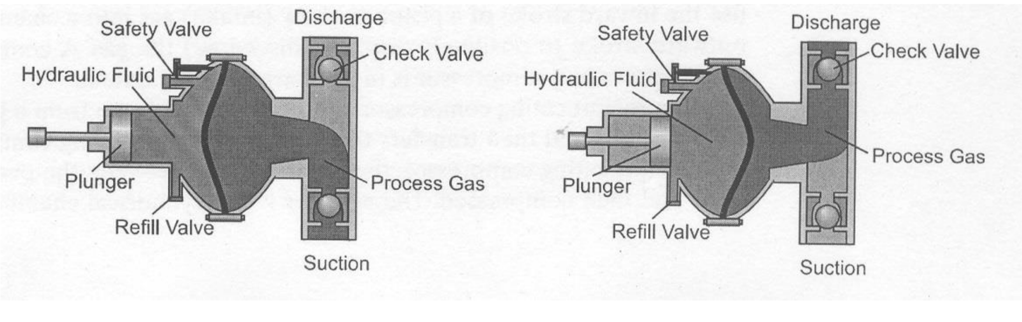


In theory, reciprocating compressors are more efficient than centrifugal compressors. They are also cheaper to purchase and install than a centrifugal compressor. However, problems with pulsation and mechanical reliability cause these compressors to be less desirable than centrifugal compressors for most industrial applications.

Another type of reciprocating compressor is the diaphragm compressor. Diaphragm compressors can be used for a wide range of pressures and flows (very low to very high). In a diaphragm compressor, a fluid is forced against one side of the diaphragm, which flexes the diaphragm into the free space above it, thereby compressing and pressurizing the gas on the other side of the diaphragm. Exhibit 11-6 displays the basic design of a diaphragm compressor with labels.

Because the process gas in a diaphragm compressor does not come in contact with the fluid, process purity is assured. This is useful in laboratory or medical applications.

Exhibit 11-6: Diaphragm compressor with parts labeled



11.1.2.2 Rotary Compressors

Rotary compressors (shown in Exhibit 11-7) move gases by rotating a set of screws, lobes, or vanes. As these screws, lobes, or vanes rotate, gas is drawn into the compressor by negative pressure on one side and forced out of the compressor (discharged) through positive pressure on the other. Rotary compressors do not require a constant suction pressure to produce discharge pressure.

In other positive displacement compressors, lobes or gears displace the gas from a cavity created between the rotors and the compressor body. If the suction pressure is lower than the original compressor design capacity, the compressor will still work, but with lower-than-design capacity results. Because of this, these compressors are appropriate for processes in which the inlet pressures change over a wider range than centrifugal compressors can operate. Exhibit 11-8 shows three diagrams of rotary compressors.

Exhibit 11-7: Rotary compressor

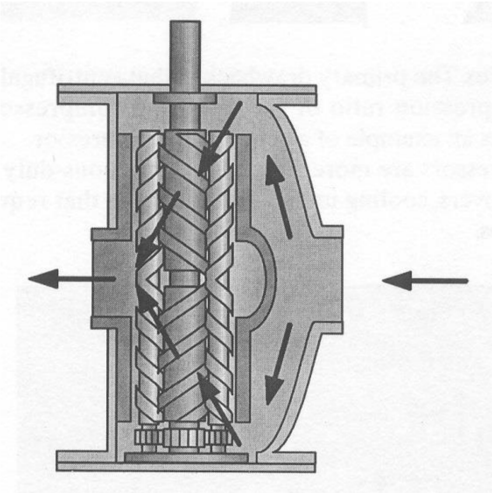
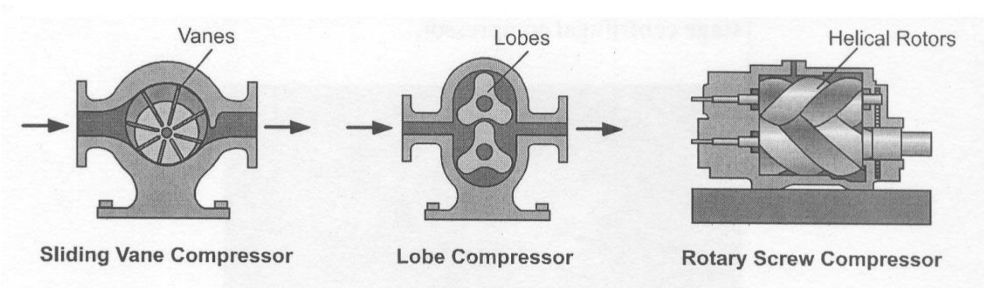
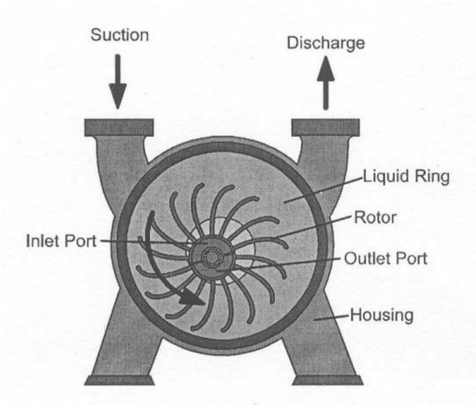


Exhibit 11-8: Examples of rotary compressors



Another kind of rotary compressor is a liquid ring compressor. A liquid ring compressor uses an eccentric impeller with vanes to transmit centrifugal force to a sealing fluid (e.g., water), driving it against the wall of a cylindrical casing. The liquid moves in and out of the vanes as the rotor turns. The liquid is used in place of a piston that compresses the gas without friction. Air or gas is drawn into the vane cavities and is expelled against the discharge pressure. Exhibit 11-9 shows an example of a liquid ring compressor.

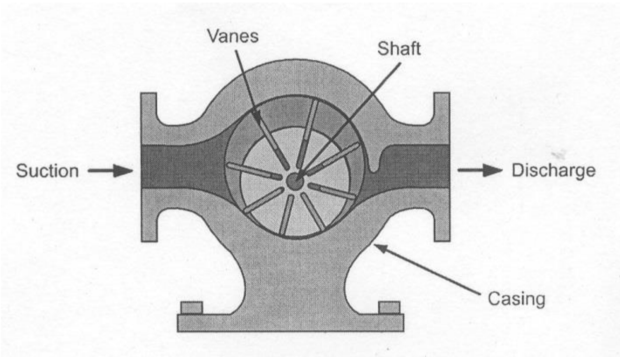
Exhibit 11-9: Liquid ring compressor



The sealing fluid in a recycling system is replenished and cooled in an external reservoir. In a once-through cooling system, the sealing fluid is removed and replaced with fresh fluid.

A sliding vane compressor employs a rotor filled with blades that move freely in and out of the longitudinal slots in the rotor. The blades are forced out against the housing wall by centrifugal force, creating individual cells of gas that are compressed as the eccentrically mounted rotor turns. As the vanes approach the discharge port, they have reduced the chamber volume and compressed the gas, which is discharged at a pressure much higher than when it entered the compressor. Exhibit 11-10 shows an example of a sliding vane compressor.

Exhibit 11-10: Sliding vane compressor



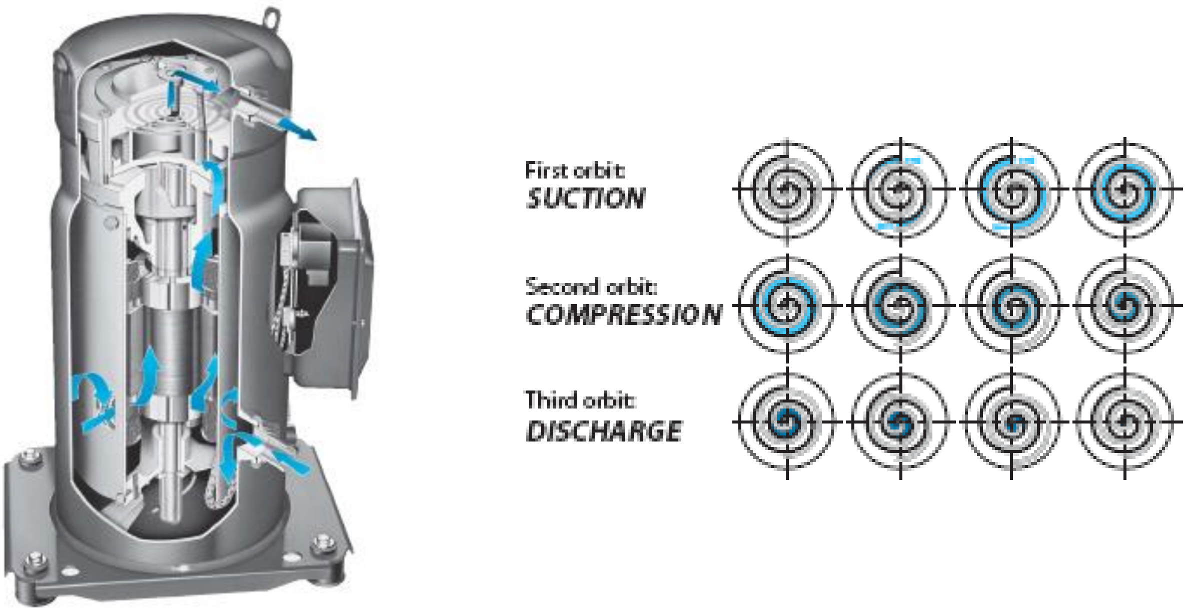
11.1.2.3 Scroll Compressors

The scroll type of rotary compressor has been the subject of extensive development in recent years, as improved machining techniques have made its production viable.

Scroll compressors are being increasingly applied to medium and small air-conditioning applications because of their quiet, low vibration operation and good efficiency. Their efficiency advantage over reciprocating compressors at lower compression ratios makes them ideal for high temperature refrigeration applications, such as beer cellar and milk tank cooling. Scroll compressors are also being developed for lower temperature applications.

In a scroll compressor, the compression is performed by two scroll elements located in the upper part of the compressor above the motor (Exhibit 11-11). Suction gas enters the compressor at the suction connection. The gas then flows around the motor and enters at the bottom side through the openings as shown. Oil droplets separate from the suction gas and fall into the oil sump. All of the suction gas passes through the electrical motor, thus ensuring complete motor cooling in all applications. After exiting the electrical motor, the gas enters the scroll elements where compression takes place.

Exhibit 11-11: Scroll compressors construction and operation



A check valve is located directly above the fixed scroll discharge port; this feature prevents the compressor from running backwards once the power has been switched off. Ultimately, the discharge gas leaves the compressor at the discharge connection.

The Exhibit 11-11 illustrates the entire compression process. The center of the orbiting scroll traces a circular path around the center of the fixed scroll. This movement creates symmetrical compression pockets between the two scroll elements. Low pressure suction gas is trapped within each crescent-shaped pocket as it gets formed; continuous motion of the orbiting scroll serves to seal the pocket, which decreases in volume as the pocket moves towards the center of the scroll set increasing the gas pressure. Maximum compression is achieved once a pocket reaches the center where the discharge port is located; this stage occurs after three complete orbits. Compression is a continuous process: when one quantity of gas is being compressed during the second orbit, another quantity is entering the scrolls and yet another is being discharged all at the same time.

11.2 Air Compressors – Power Equation

The power required by a compressor is basically proportional to the flow rate of air and increase in pressure provided. Standard industrial compressors follow a polytropic process, a compromise between an adiabatic and isothermal process in which PVn remains constant. P is the pressure, V the specific volume, and the value of n varies between 1 for isothermal and 1.4 for adiabatic compression process. Since compression occurs rapidly, with little time for heat transfer, a reasonable estimate for machines with cooling jackets and fins around the casing or cylinders is n = 1.35. The theoretical specific work input (work per unit mass) for a polytropic compression process is given by:

$$w, \frac{J}{kg} = \frac{nRT_1}{1 - n} \times \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

Assuming ideal gas behavior for air, and using SI units, this equation reduces to:

$$w, \frac{J}{kg} = 1106 \times T_1 \times \left[\left(\frac{P_2}{P_1} \right)^{0.259} - 1 \right]$$

In this equation w is the specific work input in J/kg and T_1 is the inlet temperature in ^oK, and P_1 and P_2 the inlet and outlet pressures, respectively. More relationships are given at the end of the chapter.

The efficiency of compressors, excluding the motor, ranges from 55 to 65%. The specific power consumption for various types and sizes of compressors, obtained from actual field test results performed according to BS 1571 Part 2: 1984, are summarized in Exhibit 11-12. These take into account electric drive motor inefficiencies and are a true assessment of the actual electrical input, not shaft input power which is usually stated by the manufacturers.

11.3 Air Quality

Most compressed air users need higher quality air than delivered by the compressors. The desired air quality in terms of dirt, water, oil and microbial burden is achieved by treatment after compression. Exhibit 11-13 shows the classification of air quality, and Exhibit 11-14 gives information on typical application classes required for various applications.

Exhibit 11-12: Summary of compressor configurations with relative efficiencies

Description	Capacity (l/s)	Specific power (J/L)*	Part Load efficiency**
Lubricated piston	2-25 25-250 250-1,000	510 425 361	Good Good Excellent
Non-lubricated piston	2-25 25-250 250-1,000	552 467 404	Good Good Excellent
Oil-injected vane/screw	2-25 25-250 250-1,000	510 446 404	Poor Fair Fair
Non-lubricated toothed rotor/screw	25-250 250-1,000 1,000-2,000	429 382 382	Good Good Good
Non-lubricated centrifugal	250-1,000 1,000-2,000 Above 2,000	444 382 361	Good Excellent Excellent

* 21 J/L = 1 kW/100 cfm, 1 J/L = 0.0472 kW/100 cfm

** Efficiencies are measured in specific power consumption (joules/liter (J/L).

Exhibit 11-13: Air quality classifications (ISO/DIS 8573.1)

ISO Quality Class	Contamination		Water Maximum Pressure Dew point 0C	Oil (including vapor (mg/m3)
	Particle Size (micron)	Concentration (mg/m3)		
1	0.1	0.1	-70	0.01
2	1	1	-40	0.1
3	5	5	-20	1
4	1.5	8	+3	5
5	40	10	+7	25
6	-	-	+10	-

For example: compressed air of quality class 2.2.2 (contamination: particles 1 micron and 1mg/m3, water -40 °C pdp (pressure dew point), oil 0.1 mg/m3

11.4 Criteria for selection of Compressor

A very general outline of criteria for selecting a particular type of compressor or certain model may be drawn along the following lines to meet the specific requirements:

- How much compressed air (in m^3/min or m^3/s) is consumed, at what pressures and in what periods of time? Are higher or lower air flows or pressures needed? Must reserve capacity be available?
- What are the environmental conditions for operation of the compressor? Intake temperatures? Site altitude, intake pressure? Coolant? Quality of intake air? Noise protection required? Indoor or outdoor installation? Protected by roof?
- How is compressor to be used? Continuous full-load or variable operation? Start-stop or continuous control? One, two or three shifts? Total running time (in years)? Stationary or portable?
- How is compressor to be driven? Electric motor or diesel engine? Speed? Driver cooling?
- What qualifications do operating, maintenance and service personnel have? How important are long intervals between routine maintenance? Total running time desired prior to overhaul? Is field repair desirable or essential? Required extent of protection against mal-operation, poor maintenance or failure due to wear?
- What legal regulations are to be observed?

Exhibit 11-14: Typical Air Quality Requirements for Various Processes

	Typical Classes		
Application classes	**Oil**	**Dirt**	**Water**
Air agitation	3	5	3
Air bearings	2	2	3
Air gauging	2	3	3
Air motors	4	4	5
Brick and glass machines	4	4	5
Cleaning of machine parts	4	4	4
Construction	4	5	5
Conveying, granular products	3	4	3
Conveying, powder products	2	3	2
Fluidics, power products	4	4	4
Fluidics, power circuits	2	2	2
Foundry machines	4	4	5
Food and beverages	2	3	1
Hand operated air tools	4	5	5
Machine tools	4	3	5
Mining	4	5	5
Micro-electronics manufacture	1	1	1
Packaging and textile machines	4	3	3
Photographic film processing	1	1	1
Pneumatic cylinders	3	3	5
Pneumatic tools	4	4	4
Process control instruments	2	2	3
Paint spraying	3	3	3
Sand blasting	-	3	3
Welding machines	4	4	5
General workshop air	4	4	5

11.5 De-rating of Compressors

Changes in ambient conditions dictate the necessity of de-rating of compressors. Altitude, ambient temperature, and humidity are the major factors having direct impact on the performance of the compressors. The following Exhibit 11-15 will assist in the assessment of de-rating and performance of the compressors under varying conditions, reproduced from different sources. The designed rating of the compressor is divided by the de-rating factor given in the table to calculate the actual rating under the actual operating conditions.

Exhibit 11-15: General compressor de-rating factors

Compressor De-rating Factors

ALTITUDE	COMPRESSOR INLET TEMPERATURE, Deg C					
meters	**20**	**25**	**30**	**35**	**40**	**45**
1	**2**	**3**	**4**	**5**	**6**	**7**
0	1.00	1.02	1.03	1.05	1.07	1.08
500	1.06	1.08	1.09	1.11	1.13	1.14
1,000	1.12	1.14	1.15	1.17	1.19	1.20
1,500	1.19	1.21	1.22	1.24	1.26	1.27
2,000	1.26	1.28	1.29	1.31	1.33	1.34
2,500	1.33	1.35	1.36	1.38	1.40	1.41
3,000	1.41	1.43	1.44	1.46	1.48	1.49
3,500	1.49	1.51	1.52	1.54	1.56	1.57
4,000	1.58	1.60	1.61	1.63	1.65	1.66

11.6 The Compressed Air Systems ECOs

Compressed air systems offer various ECOs. These are discussed below.

11.6.1 Distribution System

To avoid excessive energy loss in the distribution systems, maximum velocity in the pipes should not exceed 6 meters per second. The distribution should be designed to cause no more than 0.1 to 0.2 bar pressure drop at full demand at the usage points. The nomogram (Exhibit 11-16) is a very useful method of arriving at pipe sizes. Exhibit 11-17 gives the equivalent pipe length for valves and fittings of various types. The equivalent lengths should be added to the actual pipe length to be used and the total length then be used with the nomogram shown in Exhibit 11-16 for finalizing the pipe diameter.

Notes on Exhibit 11-16:

The compressed air distribution network is divided into:

- Main pipe (MP),
- Distribution pipes (DP), and
- Connecting pipes

With an optimum layout of the pipe network, the pressure loss is assumed to be:

- 0.03 bar for the main pipe (MP)
- 0.03 bar for the distribution pipe (DP)
- 0.04 bar for the connecting pipe (CP)

The total pressure loss of the system, including filters, separators, dryers, maintenance units and connection hoses, should not exceed 1.0 bar.

To realize an operation pressure of 6 bar at the point of use, it will therefore be necessary to produce a pressure of 7 bar at the compressor station.

To determine pipe diameter:

- Select the maximum permissible pressure drop on scale line G
- Select the actual working pressure on scale line E. Draw a line between these two points to locate the intersection on reference line F
- Knowing the pipe length and free airflow (output of compressors or demand), draw a line between these values on scale lines A and B, respectively
- Extend the line to reference line C
- Draw a line to connect the two points that are located on the reference lines (E and C). The point at which this line crosses scale D will give the required pipe diameter.

To determine pressure drop:

- Draw a line connecting the pipe length (on scale line A) with the airflow (on scale line B), and extend it to reference line C
- Draw a second line from the intersection on C to the pipe diameter (on scale line D) and extend it to reference line F
- Using the intersection on F as a pivot, draw a line from the actual working pressure on scale line E across to scale line G
- Read off the pressure drop from scale line G. The nomogram is derived from the following equation:

$$dP = \frac{1.6 \times 10^{8} \times V^{1.85} \times L}{d^{5} \times P}$$

Where:

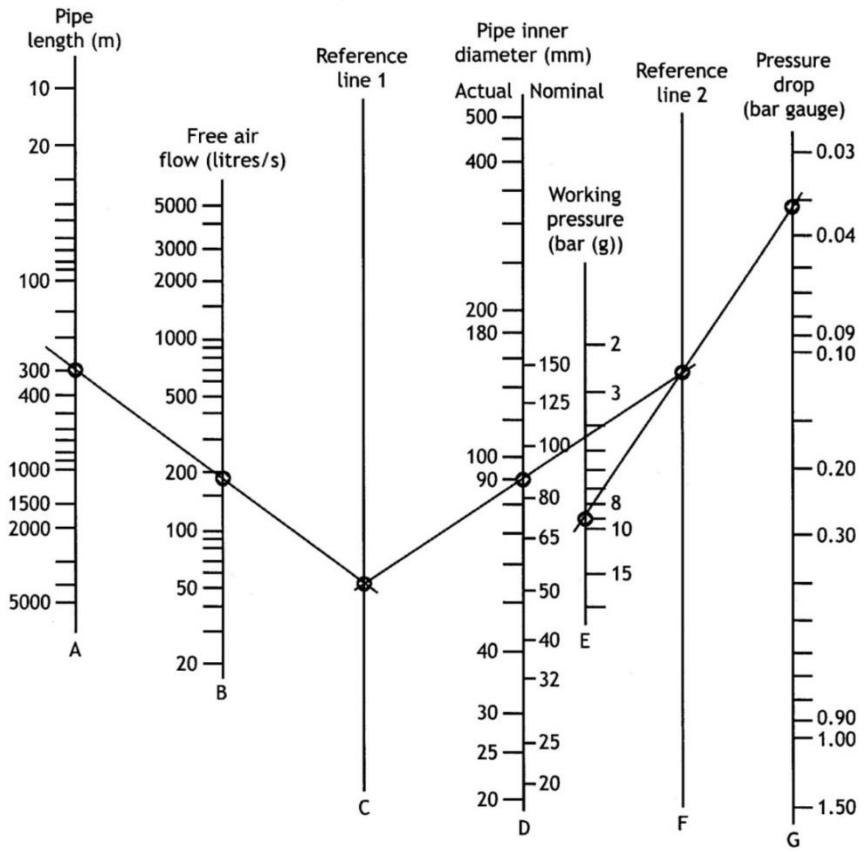
dP = Pressure drop in bar
V = Free air flow in m^3/s (liters/s x 10^{-3})
L = Pipe length in meters

d = Inside pipe diameter in mm

P = Initial pressure in bar absolute

This equation can be used if accurate figures are required for pressure drop. Alternatively, if the parameters fall outside the scales shown in the nomogram, then the equation to calculate pipe size can be used.

Exhibit 11-16: Determining pipe diameter and pressure drop for compressed air systems



11.6.2 Misuse of Compressed Air

Compressed air is usually used by the operators for cooling purposes. Such type of practices should be eliminated.

11.6.3 Air Leaks

One of the major opportunities to save energy is in the prevention of leaks in the compressed air systems. In most cases air leaks are due to poor maintenance rather than improper installation. Air leaks are odorless and invisible and therefore often difficult to find. Also, the hissing sound that accompanies a leak is often difficult to hear because of plant noise. Under such conditions one should conduct the inspection of the compressed air system either at night or on a weekend when the plant noise is at a minimum.

After having located and repaired the large leaks, one should inspect the pipeline, air hoses, valves and fittings for small leaks. A good method for locating these harder-to-find leaks is to swab the line of fitting with soapy water and then look for soap bubbles. Even the smallest leak will usually be apparent.

The energy cost associated with an air leak is a function of the size of the hole, the line pressure and the cost of energy used to drive the compressor. Exhibit 11-18 gives the approximate power wastage due to air leaks. Cost analysis will yield that cost of repair of leaks has a very attractive simple payback period.

Exhibit 11-17: Equivalent pipe length for fittings and valves

Item	Equipment pipe lengths in meters Inner pipe diameter (mm)									
	15	20	25	40	50	80	100	125	150	200
Gate valve - Fully open	0.1	0.2	0.3	0.5	0.6	1	1.3	1.6	1.9	2.6
Gate valve - Half closed		3.2	5	8	10	16	20	25	30	40
Diaphragm valve - Fully open	0.6	1	1.5	2.5	3	4.5	6	8	10	
Angle valve - Fully open	1.5	2.6	4	6	7	12	13	18	22	30
Globe valve - Fully open	2.7	4.8	7.5	12	15	24	30	38	45	60
Ball valve (full bore) - Fully open	0.5	0.2	0.2	0.4	0.3	0.4	0.3	0.5	0.6	0.6
Ball valve (reduced bore) - Fully open	3.4	4.9	2.4	2.2	5	2.6	4.1	3.3	12.1	22.3
Swing check Valve - Fully open		1.3	2	3.2	4	6.4	8	10	12	16
Bend R = 2d	0.1	0.2	0.3	0.5	0.6	1	1.2	1.5	1.8	2.4
Bend R = d	0.2	0.3	0.4	0.6	0.8	1.3	1.6	2	2.4	3.2
Mitre bend 90	0.6	1	1.5	2.4	3	4.8	6	7.5	9	12
Run of tee	0.6	0.3	0.5	0.8	1	1.6	2	2.5	3	4
Side outlet tee		1	1.5	2.4	3	4.8	6	7.5	9	12
Reducer		0.3	0.5	0.7	1	2	2.5	3.1	3.6	4.8

It is obvious that the air leaks should be repaired as soon as possible. However, it may be necessary to wait for the plant shutdown. In such instances perhaps some temporary measures can be taken to plug the large leaks.

Exhibit 11-18: Power loss through air leaks

Hole diameter (true size), mm	Air leakage at 6 bar (g) 600 kPa (g), liters / s	Power loss at the compressor, kW
0.5	0.2	0.06
1.0	1.2	0.36
1.5	2.7	0.81
3.0	10.8	3.24
5.0	30.0	9.00
6.0	43.2	12.96
10.0	120.0	36.00

It is estimated that compressing 1 liter of air to 7 bar (g) requires 300 W; while compressing 1m^3 of air to 6 bar (g) requires 0.075 kWh.

11.6.4 Operating Pressure

It is wasteful to allow the supply pressure to greatly exceed the pressure required by the process. In some cases the required pressure may not be known and some experimentation may be needed to establish the minimum required. In other cases one or two process users who require very high pressure may have established the line pressure for the entire plant. These are situations to be avoided. It is often less expensive in the long run to purchase a small separate compressor to operate at the higher pressure and to operate the balance of the plant at the lower pressure.

Practicality of reducing the air pressure on the existing compressor: In some cases a simple adjustment of the pressure control is all that is necessary. On other compressors modifications may be necessary and the compressor manufacturer should be consulted. The manufacturer can also provide the performance data for the installed compressor and inform of any limitation on lowering the compressor discharge pressure.

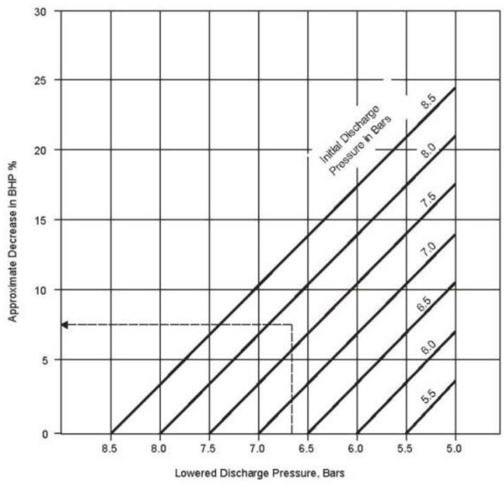
Exhibit 11-19 shows the percent energy savings which can be achieved from reduction in operating pressure.

11.6.5 Intake Air

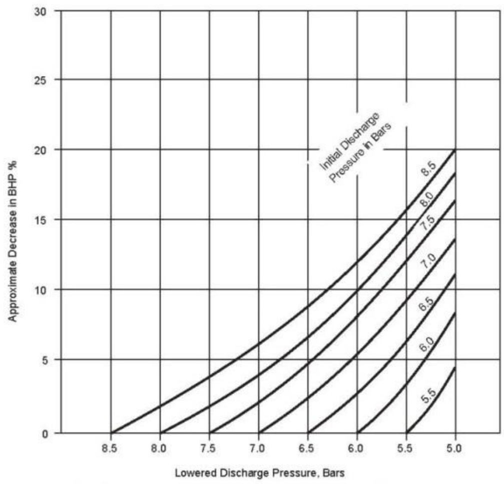
Another effective measure for reducing the energy consumption of the compressed air system is to locate the intake duct in a cooler location. The ECO arises from the fact that a given weight of air occupies less volume at lower temperature as compared to higher one (Volume of given air decreases with decrease in temperature). Thus, for a given volume at a particular pressure and temperature in the main air line, an air compressor would be required to handle a lower volume of cool air than warm air. This reduction in volume is reflected in an energy saving as shown in Exhibit 11-20.

In plants the air compressors are located in the boiler rooms where the temperature is usually above the ambient. To complete the evaluation of this ECO, the cost of running an intake line from the air compressor to a cooler location should be estimated. Preferably air should be taken from outside the building because its temperature will be lower and thus compressor will work more efficiently. A sheltered inlet protected from rain on a wall not facing the equator is thus desirable. Ducting between air intake and the compressor should be short, straight and of generous diameter.

Exhibit 11-19: Compressor power savings by decreasing discharge pressure



(a) Single-stage reciprocation and rotary screw compressors



(b) Two-stage reciprocating and centrifugal compressors

The condition of the air entering the compressor cannot be over-emphasized. The savings are given by the following equation:

$$\% \text{ Savings} = \frac{(T_e - T_p) \times 100}{(273 - T_e)}$$

where T_e and T_p are existing and proposed temperatures of the inlet air in °C.

Exhibit 11-20: Savings from cool intake air

Temperature of Intake Air °C	% Power Savings or Increase Relative to 25 °C Intake
10	+5.03
15	+3.36
20	+1.68
25	-
30	-1.68
35	-3.36
40	-5.03
45	-6.71
50	-8.39

11.6.6 In-efficient Compressor

The performance of the compressor should be checked to estimate its existing efficiency. The existing efficiency may be estimated by measuring the following quantities comparing the actual performance number of the compressor with the ideal performance numbers given below:

$$\text{Actual Performance Number, } N_a = \frac{V \times (P_2 - P_1)}{P_a \times t \times MR}$$

Where V is the volume of the receiver tank which is filled from initial pressure, P_1 to final pressure P_2 in time t seconds. MR is the compressor motor rating in kW. The values of P_1 and P_2 are chosen in such a way that there average is closer to the actual/designed operating pressure of the compressor and coincide with any of the numbers given in the table below.

The value of N_a obtained for the Compressor is compared with the values of the following N_i, ideal numbers, given for single and two stage compressors, which are the most likely to be obtained in practice:

(P1 + P2) ÷ 2 bars abs.	Ni, Single Stage Compressor	Ni, Two Stage Compressor
4.46	3.92	4.36
6.53	2.97	3.42
7.91	2.59	3.04

Percent saving may be estimated as follows:

$$\% \text{ Savings} = \frac{(N_i - N_a) \times 100}{N_i}$$

Exhibit 11-1 also provides useful information on specific energy consumption for various types and sizes of compressors.

11.6.7 Compressor Size

A compressor running at part-load is generally less efficient than when it is running at full-load.

The capacity of compressor should match with the actual consumption of the air. This is particularly important for the compressors fitted with idling type of controls. For example, if the actual consumption of compressed air is 50% of the capacity of installed compressor, then the compressor will meet the air requirements in 50% of the time, and for the remaining 50% of the time it will be idling. The electricity consumed during idling period will be wasted. This type of situation can be avoided by selecting a compressor of matching size with appropriate design factor, say 10 - 15%. For the already installed compressor, one should look into the possibility of reducing the capacity of installed compressor or replacing the idling controls by on/off type controls. In case of belt-drive reciprocating compressors, the compressor capacity can easily be reduced by decreasing the compressor RPM through changing the size of pulley of compressor or motor

It is advised that before making changes in the pulley size or the compressor controls the manufacturer's advice must be sought.

11.6.8 Energy Conservation Checklist

- Locate and repair all compressed-air leaks. (An ultrasonic leak detector can be used.)
- Locate the compressor to a cooler place.
- Size the compressor properly.
- Operate at the lowest required air pressure.
- Eliminate the use of compressed air for cooling equipment or personnel.
- Survey air tools and spray equipment; upgrade to reduce usage of compressed air.
- Study the feasibility of using heat from the after-cooler for supplementing the plant space heat.

11.7 The Compressed Air Survey

The survey is conducted as follows:

11.7.1 Delivered free Air Capacity of the Existing Compressor Q, l/sec, or m³/h

Obtained: (i) From manufacture's technical data/literature, or, (ii) By measurement.

Procedure for the measurement method is:

a) Note the volume of compressed air reservoir (a) from name plate data or (b) calculate from the size of the reservoir. VR is the volume of reservoir in m^3.

b) Shut off the outlet (discharge) valve of the reservoir

c) Operate the compressor and bring initial pressure of the reservoir to (P_1) say 2 bars abs. Also note temp. T_1 of compressed air

d) Again operate the compressor and note time required for pressure to increase to operating pressure (P_2) bars abs., or above P_2. Note on-load time = t min. and temperature T_2 of compressed air

Selection of maximum and minimum pressure should be such that the best estimate of the compressor capacity is obtained at the actual operating conditions.

Delivered capacity, Q in m^3/min, of compressor at STP conditions, is calculated by the following equation, taking P_a the absolute atmospheric pressure in bars absolute.

$$Q\ \frac{m^3}{min} = \frac{VR \times 298}{P_a \times t} \times \left(\frac{P_2}{T_2} - \frac{P_1}{T_1}\right)$$

Units must be consistent.

11.7.2 Actual requirement of Compressed Air (as Free Air)

a. Calculate from noted "On load" and "Off load" time of compressor

Record by using stop watch, Off-load and On-load time of the Compressor , during normal operation of the plant

The Off-load and On-load time are noted as described in estimating "air leaks", but in the present case, compressed air operated equipment is operating as normal. Also, it is assumed that there are no air leaks in the distribution system.

b. Alternately collect the data of the compressed air requirements of the different processes/equipment, and calculate total compressed air required.

1. Input Power during On load:

   Measure the input power to the compressor during on-load by using Watt meter

2. Input power during Off-load (Idling):

   Measure the input power of the compressor during off-load by using watt meter.

3. Motor Rating:

   Note the nameplate rating of the compressor

4. Existing Operating hours:

   Calculate operating hours from the operating schedule of the compressor, through interviewing the operating staff and observation. Annual operating hours are calculated as:

5. Suggested Operating hours:

   Estimate by observing the daily operating hours of the Compressor and operating hours of the processes/equipment which use the Compressed Air. Estimate is made through survey/ interviewing/ observation.

6. Existing inlet temperature:

   Measure by using a suitable thermometer, the temperature of the area where the Compressor is installed. (If in that area, there is such equipment which releases heat, the surrounding temperature will surely be higher than normal.)

7. Temperature of the suggested place:

   With the help of the thermometer, measure the temperature of the proposed place.

8. Type of duty:

   Note from interviewing/ observation, whether the duty is intermittent or continuous.

9. Existing Operating Pressure:

   Note the pressure from the pressure gauge installed on the compressor. In case there is no pressure gauge, install one gauge with appropriate range at a suitable point nearest the compressor and note the operating pressure.

10. Proposed Operating Pressure:

    Find the proposed operating pressure from the operating pressure data of the compressed air operated equipment. It will depend on max. operating pressure required by any equipment, and pressure drop in the distribution lines.

In case, most of the air requirement is at low pressure and small air requirement is at substantially high pressure; instead of supplying compressed air to whole system at highest required operating pressure, the possibility of using separate compressors for low pressure and high pressure requirements should be explored.

11. Existing Storage Capacity for Compressed Air, including vol. of distribution network

a) Note volume of storage tank from the literature.

Estimate volume of piping from the pipe sizes and length of piping of the distribution system.

(Tables for pipe size and volume per unit length can be used for these calculations.)

b) or Calculate as free air from the following measurements:-

(i) Capacity of the Compressor, Q, m^3/min

(ii) On load time, T, min

(iii) Off load time, t, min

The formulae is, when the time intervals are noted for one atmosphere change in pressure :

Storage volume, SV, m^3 (including System Volume) as free air: $SV = \frac{Q \times T \times t}{(T + t)}$

11.7.3 Suggested off-load interval

Basis of recommending increased off load time will be:

a) Type of duty should be intermittent/unsteady type and process conditions may demand additional storage.

b) Max. number of motor startings per hour should not exceed, than the recommended limit.

c) Calculate suggested additional storage volume to increase Off load time of compressor by using the following equation:

Suggested additional storage volume (as free air):

ASV = SSV - ESV

$$ASV = \frac{Q \times ET \times (St - Et) \times P_a}{(ET + Et) \times (P_2 - P_1)}$$

ESV = Existing Storage Volume, m^3

SSV = Suggested Storage Volume, m^3

ASV = Additional Storage Volume, m^3

Q = Capacity of the Compressor, m^3/min

ET = Existing On-load time, min

Et = Existing Off-load time, min

St = Suggested Off-load time, min

P_1 = Initial (lower) Storage Pressure, bars abs

P_2 = Final (higher) Storage Pressure, bars abs

P_a = Absolute atmospheric pressure, bars abs

Required additional storage volume is less, if the differential between cut-in and cut-out pressures is large.

- 15. Air Leaks

a) Procedure for Reciprocating Compressors

1. Shut off all air operated equipment
2. Run the compressor, until the system reaches full line pressure and compressor off-loads. Note the time.
3. Due to air leaks the system pressure will fall and compressor will come on-load again. Note the time.
4. Note the intervals for which the compressor "On-loads and "Off-loads".
5. Take at least four measurements to get an average value of the intervals.

Off-load	On-load	Off-load	On-load	Off-load	On-load	Off-load	Off-load
1	1'	2	2'	3	3'	4	4'

Average On load time, t min. =

Average Off load time, T min. =

b) Procedure for rotary vane and screw compressors

1. Shut off all air operated equipment
2. Run the compressor to reach desired pressure and stop the compressor.
3. Let the pressure drop by one bar due to leaks. Note the Off load time.
4. Restart the compressor. Note time to recover 1 bar pressure. (On load time)

Use appropriate equations to calculate the quantity of air leaks from the above data.

c) Procedure for calculating from air holes:-

1. Note and tag the no. of holes/leaks in the compressed air distribution system, and their respective sizes.
2. Note the operating pressure of air in the system
3. Calculate the quantity of air leaks by using graphs/equations provided for this purpose.
4. Note operating hours

16. Compressor Pulley Diameter

If required, actually measure the diameter, or note from literature

17. Motor Pulley Diameter

If required, measure the diameter or note from literature

18. Compressor RPM

Note by using tachometer

19. Motor RPM

Note by using tachometer or from the nameplate of the motor

Relationship between RPM and pulley diameter is:

20. Estimate the quantity of air leaks

(i) Use approximate formulae for calculating rate of air leaks (volume at STP conditions) assuming nozzle coefficient as 0.65. Air leak (for hole of D mm dia)

$m^3/hr = 0.3475 \times (D\, mm^2) \times (barg + 1)$

(ii) Use graph of pressure vs. air leak rates for hole of different sizes.

Some important air compressor equations are:

For air compression:

k = 1.4 for adiabatic compression
k = 1.0 for isothermal compression
k = 1.35 for polytropic compression
Had = pressure head for adiabatic compression, meters
p1 = absolute inlet pressure, kiloPascals, kPa = bars abs. × 102
p2 = absolute discharge pressure, kPa = bars abs. × 102
m' = mass flow rate, kg/s
Q1 = volumetric flow rate, m3/h
kWad = adiabatic power, kW
Hpt = polytropic head, meters
kWpt = polytropic power, kW
Molecular weight of air = 29

$R = \text{gas constant}, = \frac{8314}{\text{mol.wt.}}, \frac{J}{kg\ °K}$

$$Had = \frac{k}{k - 1} \times \frac{RT_1}{9.806} \times \left\{ \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right\}$$

$$kWad = \frac{k}{k - 1} \times \frac{m'RT_1}{10^3} \times \left\{ \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right\}$$

$$kWad = 2.78 \times 10^{-4} \times \frac{k}{k-1} \times Q_1 p_1 \times \left\{ \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right\}$$

$$Hpt = 112.768 \times T_1 \times \left\{ \left(\frac{p_2}{p_1} \right)^{0.259} - 1 \right\}$$

$$kWpt = 1.106 \times m' \times T_1 \times \left\{ \left(\frac{p_2}{p_1} \right)^{0.259} - 1 \right\}$$

$$kWpt = 1.0723 \times 10^{-3} \times Q_1 \times p_1 \times \left\{ \left(\frac{p_2}{p_1} \right)^{0.259} - 1 \right\}$$

12 Refrigeration

It is convenient to classify the applications of refrigeration into the following categories: domestic, commercial, industrial, and air conditioning. Commercial refrigeration is used in retail stores, restaurants, and institutions, for the same purposes as those in the household. Industrial refrigeration is needed in processing, preparation, large-scale preservation and many other applications.

Refrigeration is also widely used in both comfort air conditioning for people and in industrial air conditioning. Industrial air conditioning is used to create the air temperatures, humidity, and cleanliness required for manufacturing processes.

12.1 Coefficient of Performance

The refrigeration capacity is usually expressed in terms of the amount of heat that can be removed from the heat source in a unit time. A common expression is kilo Joules (kJ) per hour. Another common unit of refrigeration capacity is the ton. This is a term from the days when ice was the principle means of refrigeration and reflects the cooling capacity of 910 kg of ice melting during a 24 hour period. One ton of refrigeration is equivalent to 12,658 kJ of heat removal per hour or about 3.5 kW.

The effectiveness of a refrigeration system is known as the coefficient of performance (COP) and is expressed by the dimensionless ratio:

$$\text{COP} = \frac{\text{Useful refrigerating effect, Q}}{\text{Net external work, W}} \qquad \text{Q and W are expressed in same units.}$$

It is common to express the performance of a mechanical compression system in terms of the number of horsepower (hp) required per ton of refrigeration (TR). By manipulation of the above equation, we can express this as:

$$\text{hp} / \text{TR} = \frac{12{,}000}{(2545) \times (\text{COP})} = \frac{4.72}{\text{COP}} \qquad \frac{\text{kW}}{\text{TR}} = \frac{3.517}{\text{COP}}$$

In most publications, this ratio is reported in the form of kW/TR. According to ASHRAE, the approximate power inputs, kW/TR of various systems are:

	SYSTEM	COMPRESSOR, kW/TR	AUXILIARIES, kW/TR	TOTAL, kW/TR
1.	Window Units	1.46	0.32	1.78
2.	Packaged Units, Air-Cooled	1.49	0.14	1.63
3.	Central, Air-Cooled (3 to 25 TR) (25 to 100 TR)	 1.20 1.18	 0.20 0.21	 1.4 1.39
4.	Central, Water-Cooled			
	(25 to 100 TR)	0.94 0.79	0.17 0.20	1.11 0.99

It is also known that recent development in the design of chiller have improved their performance tremendously to as low as 0.60 kW/TR.

Yet, another way of expressing the performance, which is quite similar to COP is the Energy Efficiency Ratio (EER). It is defined as:

$$EER = \frac{\text{Useful cooling capacity, Btu / h}}{\text{Power input, Watts}}$$

The ratio of cooling load in kWR (sometimes kWc) and power input in kW is also called the energy efficiency ratio.

Vapor compression and absorption refrigeration systems are both widely used for producing refrigeration. They are discussed below.

12.2 Methods of Refrigeration

Refrigeration, commonly spoken of as a cooling process, is more correctly defined as the removal of heat from a substance to bring it to or keep it at a desirable low temperature, below the temperature of the surroundings. The most wide-spread method of producing mechanical refrigeration is called the vapor compression system. In this system a volatile liquid refrigerant is evaporated in an evaporator; this process results in the removal of heat (cooling) from the substance to be cooled. A compressor and condenser are required to maintain the evaporation process and to recover the refrigerant for reuse.

Another widely used method is called the absorption refrigeration system. In this process a refrigerant is evaporated (as with the vapor compression system), but the evaporation is maintained by absorbing the refrigerant in another fluid.

Basic principle in both is: A liquid boils and condenses -- the change between the liquid and gaseous states -- at a temperature which depends upon its pressure. In boiling it must obtain the latent heat of evaporation and in condensing the latent heat must be released again. The basic refrigeration cycle makes use of the boiling and condensing of a working fluid at different temperatures and, therefore, at different pressures. In a refrigeration cycle heat is removed from a fluid (typically air or water) to boil a working fluid (refrigerant) with the end result being that the first fluid is cooled.

12.2.1 Vapor Compression Refrigeration System

A schematic flow diagram showing the basic components of the vapor compression refrigeration system is shown in Exhibit 12-1. To aid in understanding it, some typical temperatures for air conditioning applications are indicated. Refrigerant fluid circulates through the piping and equipment in the direction shown. There are four processes (changes in condition of the fluid) that occur as it flows through the system.

PROCESS 1-2: At point (1), the refrigerant is in the liquid state at a relatively high pressure and high temperature. It flows to (2) through a restriction called the flow control device or expansion device. The refrigerant loses pressure going through the restriction. The pressure of (2) is so low that a small portion of the refrigerant flashes (vaporizes) into a gas. But in order to vaporize it must gain heat (which it takes from that portion of the refrigerant that did not vaporize), thus cooling the mixture and resulting in a low temperature at (2).

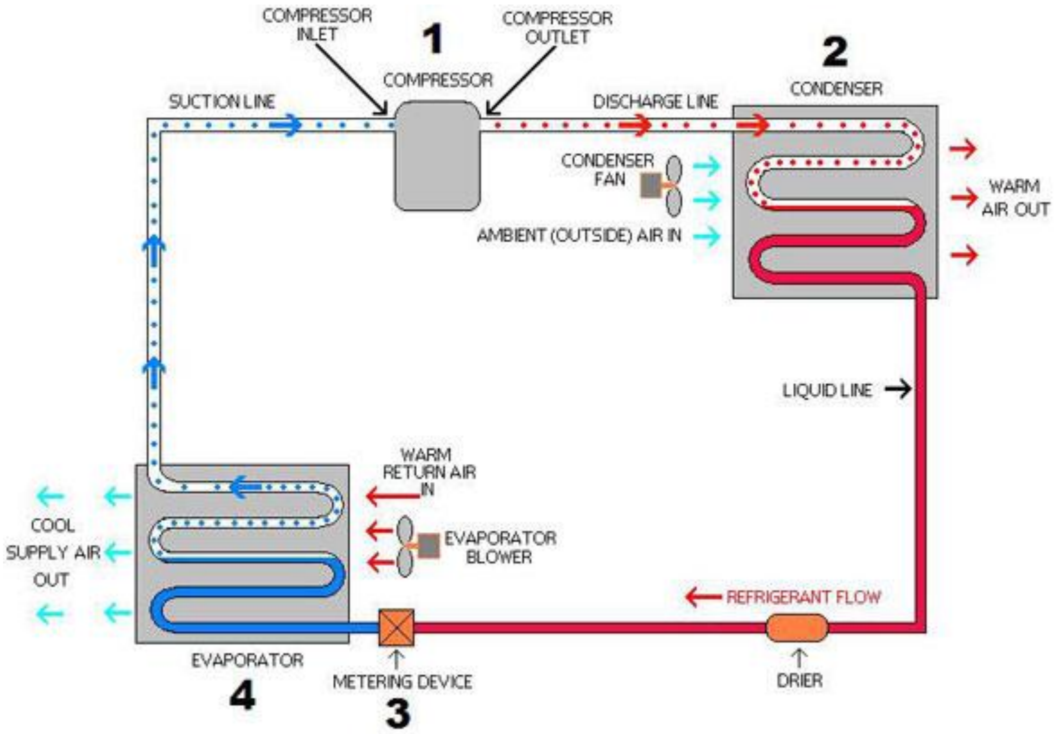
PROCESS 2-3: The refrigerant flows through a heat exchanger called the evaporator. This heat exchanger has two circuits. The refrigerant circulates in one, and in the other the fluid to be cooled (usually air or water) flows. The fluid to be cooled is at a slightly higher temperature than the refrigerant, therefore heat is transferred from it to the refrigerant, producing the cooling effect desired. The refrigerant boils because of the heat it receives in the evaporator. By the time it leaves the evaporator (4) it is completely vaporized.

PROCESS 3-4: Leaving the evaporator, the refrigerant is a gas at a low temperature and low pressure. In order to be able to use it again to achieve the refrigerating effect continuously, it must be brought back to the conditions at (1) - a liquid at a high pressure. The first step in this process is to increase the pressure of the refrigerant gas by using a compressor. Compressing the gas also results in increasing its temperature.

PROCESS 4-1: The refrigerant leaves the compressor as a gas at high temperature and pressure. In order to change it to a liquid heat must be removed from it. This is accomplished in a heat exchanger called the condenser. The refrigerant flows through one circuit in the condenser. In the other circuit a cooling fluid flows (air or water), at a temperature lower than the refrigerant. Heat therefore transfers from the refrigerant to the cooling fluid and as a result, the refrigerant condenses to a liquid (1).

The refrigerant has returned to its initial state and is now ready to repeat the cycle. Of course the processes are actually continuous as the refrigerant circulates through the system.

Exhibit 12-1: Flow diagram of the refrigeration system



12.2.2 Absorption Refrigeration Systems

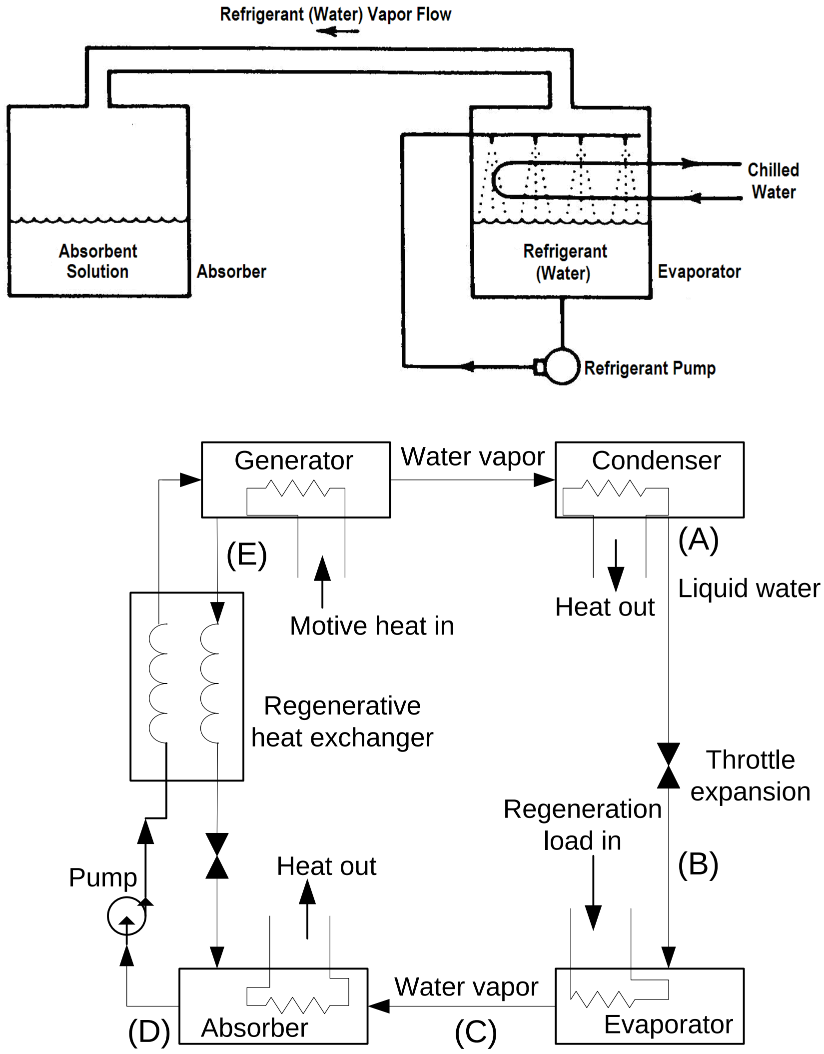
The absorption system uses the principle that some gases will be absorbed by certain other substances. There are many pairs of substances that have this affinity for one another. We are all aware of how table salt absorbs water vapor from the air, thus making it difficult to pour. Another combination is lithium bromide (LiBr) and water. Lithium bromide will absorb large quantities of water. This pair is used in many absorption systems.

Consider a tank partially filled with a concentrated liquid solution of lithium bromide (concentrated means that it contains very little water) as shown in Exhibit 12-2. The space above the liquid is evacuated of any gas, as much as possible, leaving a very low pressure. Water is sprayed into the tank. Because of the low pressure some of the water will evaporate, requiring heat needed for the evaporating spray, and is thereby chilled. The temperature at which the spray water evaporates will depend on the pressure in the tank, according to the saturation pressure-temperature relation of water.

The lithium bromide absorbs the water as both solutions make contact. The lithium bromide eventually absorbs all of the water it can hold, however, and no longer is effective. The water vapor quantity will build up in the tank, raising its pressure, and therefore increasing its evaporating temperature above useful refrigeration temperatures.

In order to have a practical absorption refrigeration system that will operate continuously, the diluted solution of lithium bromide must be reconcentrated and used again. The actual system function is explained, as shown in Exhibit 12-2. Typical operating temperatures and pressures are indicated on the diagram.

Exhibit 12-2: Flow diagram of Lithium Bromide-Water absorption refrigeration system



The evaporator operation is as described previously. Spray water (the refrigerant) evaporates in a tank where the pressure is very low, thus extracting heat form water circulating in a coil. The water that is chilled in the coil is distributed to air conditioning equipment as required. The spray water does not evaporate fully, so the liquid water is recirculated by the refrigerant pump.

To prevent the pressure from building up in the evaporator the water vapor must be absorbed by lithium bromide. A concentrated solution is stored in a tank called the absorber. This solution is sprayed into the absorber and recirculated by the absorber pump. The lithium bromide absorbs and draws water vapor from the evaporator space and a low pressure is maintained there. However, the solution gradually becomes too dilute to absorb enough water. To solve this problem diluted solution is pumped to the concentrator (also called generation) by concentrator pump. Here it is heated to a temperature that will evaporate some of the water, which has a lower boiling point than the lithium bromide. The re concentrated solution is then returned to the absorber steam or hot water is used as a source of heat in the concentrator.

The water vapor from the concentrator flows to the condenser, where it is condensed to a liquid by giving up heat to water from a cooling tower or natural body of water. The condensed water is then returned to the evaporator, completing the cycle.

Two refinements to this cycle, which improve the system's efficiency, and are shown in Exhibit 12-2 require explanation. The absorption process generates heat that would raise the temperature of the absorbing solution, making it less effective. The heat removed by cooling water is then used in the condenser, as shown.

The second refinement to the cycle is the inclusion of a heat exchanger between the absorber and concentrator. The solution from the absorber is preheated by hot solution returning from the absorber is preheated by the solution returning from the concentrator, thereby saving some of the heat needed in the concentrator.

Another pair of fluids often used in absorption systems is ammonia and water. in this case water is the absorbent and ammonia is the refrigerant. Because of its volatility some water boils off with the ammonia in the generator of the aqua-ammonia absorption system. This requires additional equipment (a rectifier) to separate the ammonia from the water. Another disadvantage of this system is that it operates at much higher pressures in the generator (about 300 psi) compared with about 30 psi for the LiBr system.

Small capacity lithium bromide-water absorption units (3 to 25 tons) with direct-fired generators are also available. They are popular in areas where natural gas is plentiful and inexpensive.

12.3 Refrigeration Systems and Equipment

12.3.1 Prime Movers Mechanical Vapor Compression

Mechanical vapor compression refrigeration systems rely on compressors to increase the pressure and temperature of a working fluid, the refrigerant, so that heat may be rejected to a high temperature sink. Compressors can be driven by electric motors, reciprocating engines, or by steam or gas turbines.

Various types of compressors used are reciprocating, rotary, screw and centrifugal types. Selection of compressor type is a function of economics and is dependent on refrigeration load, available condenser (ambient) and evaporator temperatures.

12.3.1.1 Reciprocating Compressors

The ability of a reciprocating compressor to pump refrigerant vapor, or its volumetric efficiency, decreases as the compression ratio increases.

Constant operation of the reciprocating compressor makes regulation of refrigeration output difficult under varying load conditions. Intermittent operation can be used with small compressors, but the frequent starting and stopping of large compressors is not desirable. Capacity control on large reciprocating compressors is usually accomplished with cylinder unloaders and external gas bypass. Cylinder unloading, gas bypassing within the compressor (internal gas bypass), is the most common capacity control method in use. When the suction valve of a cylinder is held open so that the charge of refrigerant gas merely surges back and forth in the cylinder, the cylinder is inoperative. Such unloaders can be operated by a solenoid mechanism built into the compressor or act under the action of suction-pressure reduction.

12.3.1.2 Centrifugal Compressors

The second most widely used compressor is of the centrifugal type. This type of compressor has vaned impellers rotating inside a casing, similar to a centrifugal pump. The impellers increase the velocity of the gas, which is then converted to a pressure increase by decreasing the velocity. The nature of the centrifugal compressor makes it suitable for applications in very large refrigeration systems, up to 35,000 kWR. The impellers can rotate at speeds up to 20,000 RPM, enabling the compressor to handle large quantities of refrigerant.

Centrifugal refrigeration units of smaller than 250 kWR capacity are rarely seen, and units of up to 35,000 kWR capacity are available. At capacities above about 5500 kWR, however, the physical size required makes hermetic units prohibitive. Above this size, open units are used. As such, package centrifugal units are generally not available, and they must be field erected.

Because the driver speed is kept constant in a centrifugal compressor, capacity control is commonly achieved by imparting a swirl to the refrigerant that is about to enter the turbine. This is done with adjustable inlet guide vanes, also known as prerotation vanes. Setting the vanes to cause a swirl in the direction of the impeller motion produces a reduction in compressor capacity. Controlled positioning of the vanes can be accomplished by electric, hydraulic or pneumatic means. External refrigerant gas bypass of the compressor can also be used to achieve capacity control.

For centrifugal compressors which are driven by variable speed drives, speed reduction is a convenient method of capacity reduction. Both inlet guide vane and variable speed drive are relatively efficient methods of capacity control, with power input decreasing significantly with capacity. Below 50 percent capacity, however, efficiency falls off rapidly. This is one reason why it is desirable to use multiple (parallel), centrifugal machines in large applications, if practical.

12.3.2 Other Equipment

12.3.2.1 Condensers

The condenser rejects from the system the energy gained in the evaporator and the compressor. Atmospheric air or water are the two most convenient heat sinks to which the heat can be rejected.

In the air cooled condenser the refrigerant circulates through a coil and air flows across the outside of the tubing. The air motion may be caused by natural convection effects when the air is heated, or the condenser can include a fan to increase the air flow rate, resulting in greater capacity. Air-Cooled condensers are normally installed outdoor. They are available in sizes up to about 175 kWR (50 TR).

Water-Cooled condensers are usually of shell and tube construction, similar to shell and tube evaporators. Water is recirculated through a cooling tower and reused.

Evaporative condensers reject heat to the atmosphere as do air cooled condensers, but by spraying water on the coils some heat is transferred to the water as well as the air, increasing the capacity of the condenser. A pump, piping, spray nozzles, and collection sump are required for the water circulating system. Fans are used to force the air through the unit. Evaporative condensers can be installed indoor as well as outdoor, by using ductwork to discharge the exhaust air outside.

12.3.2.2 Evaporators and Chillers

The purpose of an evaporator is to provide a continual and efficient transfer of heat from the medium to be cooled to the refrigerant fluid. The medium to be cooled may be a gas, liquid, or solid. Air and water are the most common substances cooled by evaporators. In the most familiar evaporator refrigerant flows through tubes while air to be cooled flows across the outside of the tubes. The tubes, often constructed in a coil configuration, are called the heat transfer surface. The following explanation of evaporator function will refer to this particular arrangement, for simplicity. However it should be understood that many other arrangements and constructions of evaporators exist, and that the method of heat transfer is the same in all of them.

These may be classified into two types - dry expansion (DX) evaporators or flooded evaporators. In the dry expansion type, refrigerant flows through tubing and there is no liquid storage of refrigerant in the evaporator. In the flooded type of evaporator, a liquid pool of refrigerant is maintained. Dry expansion (DX) evaporators exist in two types - DX cooling coils or DX chillers. Cooling coils are used for cooling air and chillers for cooling water or other liquids. Flooded evaporators are called flooded chillers. Evaporators for cooling water or other liquids are called chillers.

When cooling air, dry expansion (DX) cooling coils are used. The tubing is arranged in a serpentine coil form, and is finned to produce more heat transfer from a given length.

In the shell and tube type chillers, bundle of straight tubes is enclosed in a cylindrical shell. The chiller may be either the flooded type, with water circulating through the tubes and refrigerant through the shell or dry expansion, with the reverse arrangement. The shell may be made in one piece or can be constructed with bolted removable ends, called heads. In the latter case mechanical cleaning and replacement of individual tubes is possible. This construction is more expensive, however. Flooded chillers are generally used on the larger systems.

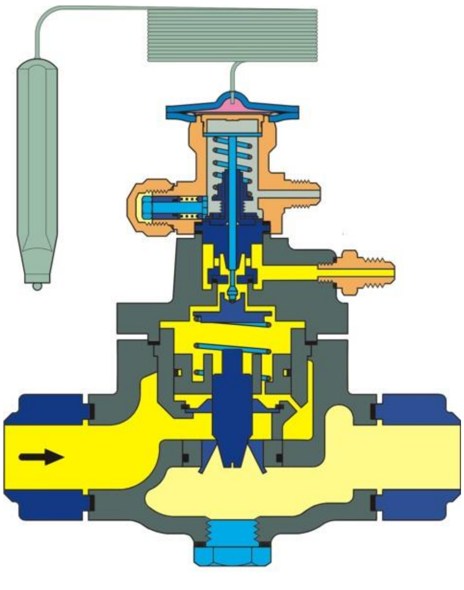
12.3.2.3 Flow Control Devices

The restricting device that causes the pressure drop of the refrigerant also regulates the refrigerant flow according to the load. The most common devices used are the capillary tube and thermostatic expansion valve. The flow control process in the refrigeration cycle is an adiabatic process; i.e., enthalpy of the refrigerant remains the same before and after expansion.

The capillary tube is a very small diameter tube of considerable length. It is used often in small units (e.g., domestic refrigerators and window air conditioners) because of its low cost and simplicity.

The thermostatic expansion valve (TEV), shown in Exhibit 12-3Exhibit 12-3, is widely used in dry expansion systems. The small opening between the valve seat and disc results in the required pressure drop. It also does an excellent job of regulating flow according to the need. The operation of a TEV is shown in Exhibit 12-3. A bulb filled with a fluid is strapped to the suction line, and thus senses the suction gas temperature. This bulb is connected to the valve by a tube in a manner so that the pressure in the fluid in the bulb tends to open the valve more, against a closing spring pressure. If the load in the system increases, the refrigerant in the evaporator picks up more heat and the suction gas temperature rises. The pressure of the fluid in the bulb increases as its temperature rises, and it opens the valve more. This increases the refrigerant flow needed to handle the increased load. The reverse of all these events occurs when the refrigeration load decreases.

Exhibit 12-3: Thermostatic expansion valve



12.3.2.4 Distribution Systems

Depending on the specific refrigeration application, refrigeration must be distributed to a load in the form of a low temperature heat transfer media. Refrigeration can be provided to some applications with no distribution system, such as room air conditioners. In most applications, the load is removed from the chiller system and cooling is supplied by either chilled water, brine or air. These distribution systems are often referred to as secondary refrigeration equipment.

12.4 Refrigeration Equipment Measurement and Analysis

The field performance of refrigeration equipment is difficult to measure. Direct measurement of refrigerant conditions with portable instruments is almost impossible to perform because of the lack of access while the equipment is operating. Often, the energy surveyor must rely on installed instrumentation on larger installations. In the absence of this instrumentation, which is generally the case with smaller systems (particularly package direct expansion units), the energy surveyor has to rely on simple measurements of temperatures and energy consumption of compressor motor. In the absence of detailed performance measurements taken during equipment operation, the energy surveyor is generally limited to making recommendations for improved equipment operation and maintenance.

12.4.1 Improved Refrigeration Equipment Operation and Control

Refrigeration equipment are complex machines and should be operated and maintained according to manufacturer's recommendations to remain at optimum operating conditions. Startup of chillers should always follow the procedure dictated by the manufacturer in the operations manual.

Before starting up, the refrigerant and oil levels should always be checked. Levels below manufacturer's recommendations may indicate a leak in the system and will result in reduced operating efficiency at best and complete system failure at worst.

During the cooling season, the following operating checks should be made:

- Check the oil level regularly
- Check the flow of refrigerant through the sight glass; the flow should be smooth and without bubbles: the presence of bubbles may indicate a refrigerant leak which can be located with the use of a leak detector
- Check the appearance of the machine and the floor under and around the machine for oil spots, which may indicate leaks
- Where pressure and temperature instrumentation is provided by the manufacturer or installed later, log readings on a regular basis and compare to normal ranges established by the manufacturer; deviation from these normal ranges may indicate equipment problems
- Check alignment and tension of any belts
- lubricate motors as per manufacturer's recommendations
- Check proper operation of chilled water and condenser water pumps; clean strainers of filters on a regular basis
- Air cooled condensers and direct expansion evaporators generally use finned coils for heat transfer; the exterior of the these coils should be cleaned regularly to eliminate clogging by dust or dirt
- Direct expansion evaporator and condenser fans should be checked and adjusted according to manufacturer's recommendations, including the adjustment of fan belt alignment and tension

- At the end of the cooling season, the following procedures should be followed:
    - Check entire system for refrigerant leaks
    - Inspect condenser and evaporator for scaling, fouling or leaks in tubes; repair or replace as necessary, but try to avoid capping tubes as this will reduce effective heat transfer area and reduce machine efficiency
    - After cleaning, the condenser should be filled with treated water to prevent corrosion

A trouble shooting guide is generally provided by the equipment manufacturer.

The most important aspect of absorption machine maintenance is maintaining the tightness of the system in respect to leaks. Absorption machines are operated under partial vacuum conditions, and leaks could lead to infiltration of air into the system. Units must be purged regularly by either manual or automatic purge systems furnished with the equipment to prevent air and other non-condensable gases from accumulating within. Such accumulation has an adverse effect on refrigeration capacity, permits internal parts to corrode over time, and can cause crystallization of the lithium bromide. The crystallized lithium bromide forms a slush that can plug pipelines and fluid passages within the unit, and make it inoperable.

The concentration of the lithium bromide in the machine should be checked by analysis on at least yearly basis. If necessary, the solution should be drained from the machine and refilled to the proper specifications.

12.5 The Refrigeration Systems ECOs

As noted earlier, measurements of refrigeration system efficiency and performance are difficult to make in the field. Generally the types of measurements needed to establish these parameters cannot be made while the machine is in operation and refrigeration machine manufacturer-installed instrumentation may not be available. Many of the recommendations for improving machine efficiency must be made by qualitative analysis of the state of the existing equipment.

The energy surveyor must take into account the qualitative information obtained during the survey:

- The age of the refrigeration equipment: absorption chillers have a useful life of up to about 25 years, while the useful life of a mechanical vapor compression machine may range from 15 to 25 years.
- Normal maintenance procedures employed: the surveyor should determine if the machines are maintained according to manufacturer's recommendations, including maintenance of refrigerant levels, lubrication, cleaning of evaporator and condenser heat exchangers, and other factors. To a large extent, a visual examination of the machine may reveal whether any maintenance is carried out. Lack of maintenance will severely reduce the operating life of the equipment.
- Repair and overhaul history: have any of the major components of the machine been repaired or replaced during its lifetime, and if so, were the parts repaired or replaced (especially motors). Rewound motors may be substantially less efficient than new replacement motors. In addition, it is difficult to maintain the integrity of hermetic motors unless proper instruments are used to re-seal the equipment.
- Comments from operating staff: consider comments concerning the ability of the equipment to carry the refrigeration load required, comments concerning observed degradation in equipment performance, and comments concerning replacement needs or plans for replacements.

Calculation of potential energy savings through modification in refrigeration equipment or changes in operating procedures are generally performed using computer simulation models. These models take into account the load on the refrigeration machine on an hourly basis, and use hourly weather data. While this type of calculations cannot be done manually (without a large amount of time), rough estimates of potential energy savings may be obtained using the manual calculation procedures.

12.5.1 Vapor Compression Air Conditioning Systems

12.5.1.1 Replacement of Inefficient Refrigeration System

In the case of an old and inefficient vapor compression refrigeration system, outright replacement of the equipment may be called for. The energy savings depend on the number of hours that the system is used annually, and the difference in coefficients of performance between the present system and the replacement system.

12.5.1.2 Reducing Refrigeration Machine Operating Hours

Often, refrigeration machines are started several hours before the areas served are to be occupied. Although the rationale is to pre-cool the areas, the number of hours that the chiller operates may be much more than actually required. In addition, it may be possible to shut down the refrigeration system up to one hour prior to the end of occupancy of the area served without a discernible degradation in comfort conditions.

12.5.1.3 Economizing Controls

A rough estimate of the potential energy savings can be obtained using the relevant calculation sheet. The exact savings are a strong function of the building cooling load pattern and a hand calculation cannot easily take this into account. The savings in the calculation are based on an average of 7.5 percent increase in machine efficiency. This may vary with the type and manufacturer of control employed. In this case, the savings are based on the use of controls which reset chilled water temperature based on a combination of outdoor temperature and the temperature of the chilled water returned to the chiller. Potential savings from adjusting chilled water temperature on the higher side is given in Exhibit 12-4, and Exhibit 12-5Exhibit 12-5.

Exhibit 12-4: Chiller C.O.P. relationship with chilled water temperature

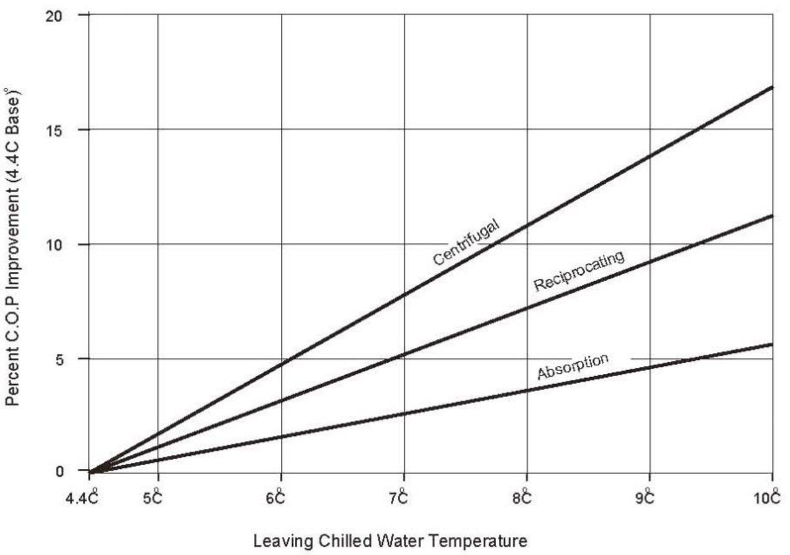
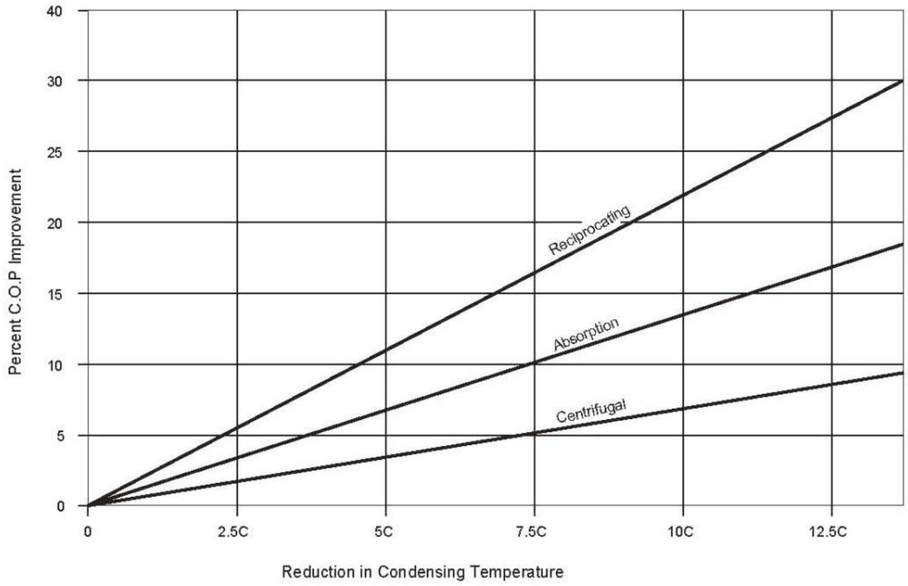


Exhibit 12-5: Energy savings from reset of condenser water temperature



12.5.2 Absorption Chiller Systems

12.5.2.1 Replacement of Inefficient Refrigeration System

The surveyor should keep in mind that modern absorption refrigeration machines consume substantially less energy than the old machines, and the marginal cost and savings attributable to the use of the latest machines should be considered in the energy survey recommendations.

12.5.2.2 Reducing Refrigeration Machine Operating Hours

The discussion for vapor compression machines also applies here.

12.5.2.3 Economizing Controls

Use the same principles as discussed above for vapor compression machine.

12.5.2.4 Cooling Tower Filtration Systems

The use of cooling tower filtration systems improves the condenser performance. The calculation procedure to estimate energy savings is given in the relevant calculation sheet.

13 Cooling Towers

Most industrial processes and refrigeration systems use cooling water cooled in the cooling towers. In this way heat generated by the processes and from the refrigeration systems is dissipated through the circulating water of the cooling towers. While it is possible to use a steady stream of cool water for once-through condenser cooling this practice is wasteful and can be expensive.

Air cooled condensers are used on smaller sized direct expansion air conditioners, but for larger sized central refrigeration systems the first cost and operating cost of the fans to provide the flow of air over the condenser coil is very high and not economical. In addition, air cooled condensers with condenser water as the medium being cooled, cannot provide the cooling effect required: the condenser water can be cooled to about 11 °C higher than the ambient air economically. This temperature is generally too high for the condenser cooling water of most refrigeration systems.

Cooling towers overcome these problems and are more commonly used. The water consumption rate of a cooling tower is about 5 to 10 percent of that for a once-through cooling system. The primary advantage is the ability of the cooling tower to cool water to within 3 to 6 °C of the ambient wet-bulb temperature, or about 19 °C lower than air-cooled systems of reasonable sizes.

13.1 Cooling Tower Principles

Cooling towers cool water by a combination of heat and mass transfer. The water to be cooled is distributed in the tower by spray nozzles and splash bars of filming-type fill. The objective is to expose a very large water surface area to atmospheric air. The air is circulated by fans, convective currents, natural wind currents, or inductive effect from sprays.

A portion of the water in the cooling tower absorbs heat to transform from a liquid to a vapor. The heat of vaporization at atmospheric pressure is transferred from the water remaining in the liquid state to the air stream.

The thermal capability of any cooling tower may be defined by the following parameters:

- Entering and leaving water temperatures
- Entering air wet bulb temperature or entering air wet bulb and dry bulb temperatures
- Water flow rate

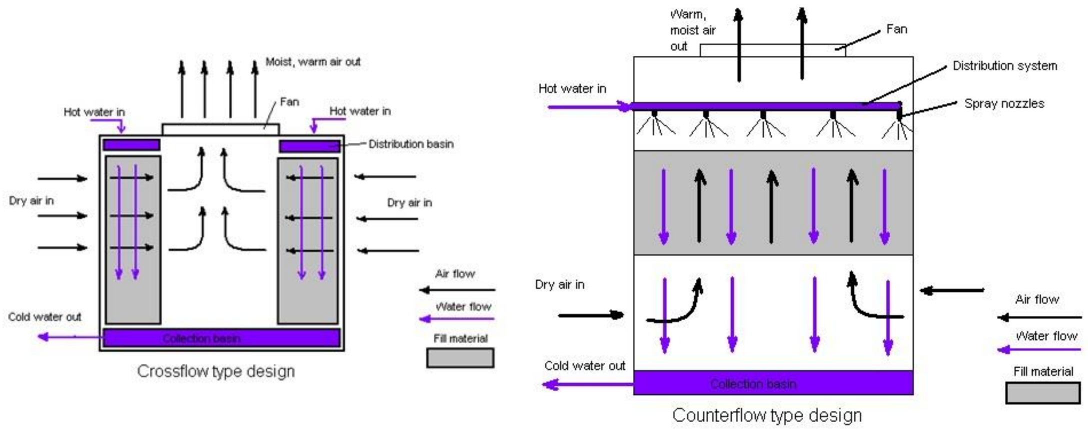
The thermal capability of cooling towers for air conditioning is generally expressed in nominal tonnage, (TR) based on a heat dissipation of 1.25 kWR per kW of condenser heat and a water circulation rate of 0.054 liters per second per kWR, cooled from 35 °C to 29.4 °C at 25.6 °C wet bulb temperature.

13.2 Mechanical Draft Cooling Towers

There are two basic types of evaporative cooling devices used: those involving direct contact between the heated water and the atmosphere and those where the heated water and atmosphere do not come into direct contact (indirect or "dry" cooling towers). There are a number of different types of direct contact cooling towers, but the mechanical draft cooling tower is the most common for air conditioning purposes.

Mechanical draft cooling towers use a fan to introduce a flow of air into contact with the water to be cooled. The fans on mechanical draft towers may be on the inlet air side (forced draft) or the outlet side (induced draft). A number of different cooling tower configurations, based on air flow, are available (Exhibit 13-1). Air may enter from the bottom of the tower (counterflow configuration) or may enter from a single side of the tower or from two sides (crossflow). Water always flows from the top of the tower to the bottom by gravity.

Exhibit 13-1: Crossflow and counterflow type cooling towers



13.3 Cooling Tower Capacity Control

Cooling towers encounter substantial changes in ambient wet bulb temperature and load conditions during the normal operating season. Hence, some form of capacity control is desirable.

The simplest method of providing this capacity control is the cycling of forced or induced draft fans. Mechanical draft cooling towers may be configured as multiple cells sharing a common basin. The basin acts as a sump for the cooled water. Each cooling tower cell is equipped with its own fan. When the cooling load is high, all of the cells are operating; when the cooling load drops, individual fans may be turned off as needed. This type of control may be effected either manually (e.g. operation of individual fans with individual chillers), or the control may be achieved automatically. In this latter case, the temperature of the condenser water returned from the cooling tower is monitored. If the temperature exceeds preset limits, one or more cooling tower fans are energized. If the condenser water temperature drops, fans may be shut off.

Another option is the use of two-speed motors. During low cooling tower load conditions, the fans may be shut down or operating at half speed. As the load increases, fans may be energized or shifted from half speed to full speed operation. This type of control can be achieved manually, but to obtain the minimum use of fan energy, automated controls are preferable.

Exhibit 13-2 presents an example of this type of control for a typical cooling tower. The exhibit presents graphically the cooling outlet water temperature versus wet bulb temperature for a number of ranges. Consider the case where a design cooling water temperature of 30oC must be provided. At decreasing wet bulb temperatures, the cooling tower can meet this condition at half speed. For a range of 11 °C, the cooling tower can meet this condition when the wet bulb temperature is below about 17.5 °C. Theoretically, operating the fan at half speed decreases fan energy requirements to one eighth of full speed requirement[2]. In other words, a 100 kW motor operating at half speed would have a demand

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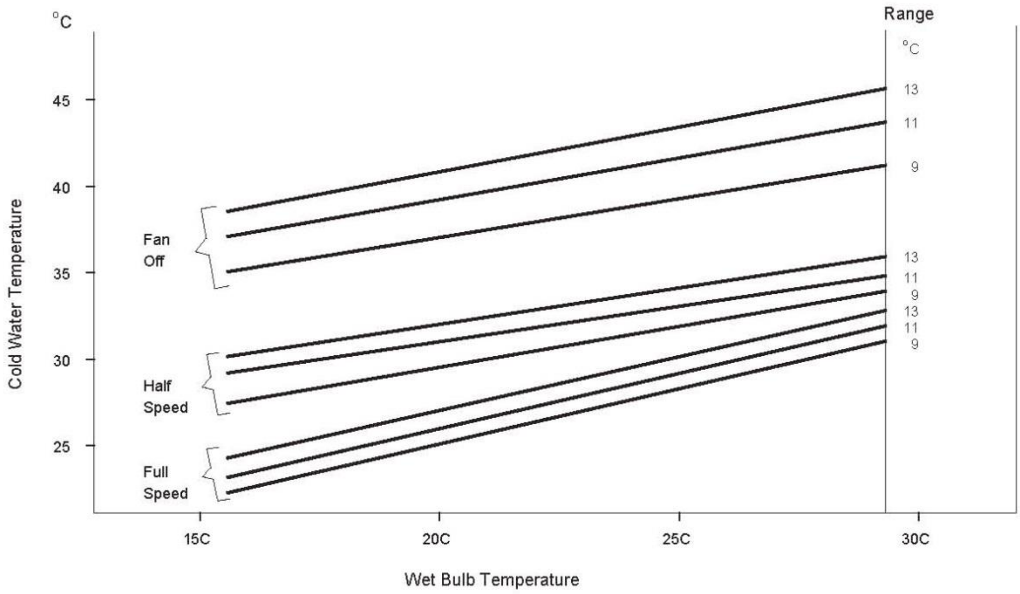
the air flow results in a reduction in a power requirements of (1/2)3, or 1/8 of maximum.

of only about 12.5 kW. There may be times when sufficient condenser water cooling can be provided with the cooling tower fan off, and the condenser water simply circulated through the cooling tower.

According to the fan laws, fan power requirements are directly proportional to the cube of the air flow. Hence, halving the air flow results in a reduction in a power requirements of (1/2)3, or 1/8 of maximum.

In actual practice, half speed operation would reduce fan energy demand to about 17 percent instead of 12.5 percent; this is because of inherent motor losses at lower loads

Exhibit 13-2: Use of two-speed motors in mechanical draft cooling towers



Another approach to cooling tower capacity control is the use of variable pitch blades on the cooling tower fans (when propeller fans are used). Automatically varying the pitch of the fans at a constant motor speed can provide an infinite range of air flows through the cooling tower in response to cooling load requirements, and cooling load requirements can be met precisely by the cooling tower with little or no excess energy use.

A comparison of cooling tower capacity control methods and relative energy consumption is presented in the table below. This comparison is based on the computer simulation of a mechanical cooling tower which is required to meet a fixed hourly cooling load (industrial cooling). The simulation was conducted using actual hourly weather data for Houston Texas for a full year of continuous cooling tower operation (comparable to Karachi for certain times of the year). The results of the simulation are as follows:

Method of Control	Relative Energy Use
No control	1.00
Automatic on-off control	0.63
Automatic on-off control with dual speed fans	0.59
Automatic variable pitch fans	0.50

The figures in the table are very sensitive to ambient condition.

For cooling tower systems where centrifugal blower fans are employed, another option for capacity control is with the use of modulating dampers to control air flow. Often, modulating dampers are combined with two speed motors to provide more precise control when the cooling tower load is a modulating one.

13.4 Performance Measurement

Cooling tower performance curves are generally provided by the manufacturer. The comparison of actual operating conditions to the manufacturer's performance curve is a relatively simple procedure. The temperature of the condenser water entering the cooling tower is measured, as is the temperature of the cooled condenser water leaving the cooling tower. The surveyor also measures the ambient air dry bulb and wet bulb temperature at a point adjacent to the cooling tower but far enough so that the higher local relative humidity conditions due to evaporation of water in the cooling tower is not reflected in the readings.

The range is computed as the difference between entering and leaving condenser water temperature. On the performance curve (Exhibit 13-3), the energy surveyor marks the point plotted on the curve which represents the wet bulb temperature and the range (the point which predicts cooling tower performance):

- If the cooling tower is operating near design capacity, the two points should be very close or coincident
- If the point which represents actual operation is higher (on the cold water temperature axis) than the point which represents the predicted cooling tower performance, the cooling tower is providing less than the correct amount of cooling
- If the point which represents actual operation is lower (on the cold water temperature axis) than the point which represents the predicted cooling tower performance, the cooling tower is providing more cooling than predicted.

When conducting such tests, the energy surveyor should keep in mind that the results reflect only a snapshot of cooling tower performance at a single operating condition. Performance varies simultaneously with ambient wet bulb temperature and with the temperature of the entering condenser water. Unless there is a great difference between the predicted and actual values, the energy surveyor must be careful when drawing conclusions. Even if a log is kept of entering and leaving condenser water temperatures, the energy surveyor should keep in mind that these values taken at the refrigeration machine may vary significantly from the values that may be recorded at the same time at the cooling tower due to heat gains and losses in the condenser water pipework. He should also keep in mind that the manufacturer's curves are based on design flow rates of condenser water through the cooling tower. Unless it can be verified that these rates are maintained at the condenser water pump, the conclusions drawn from this testing may also be misleading.

13.5 The Cooling Tower Systems ECOs

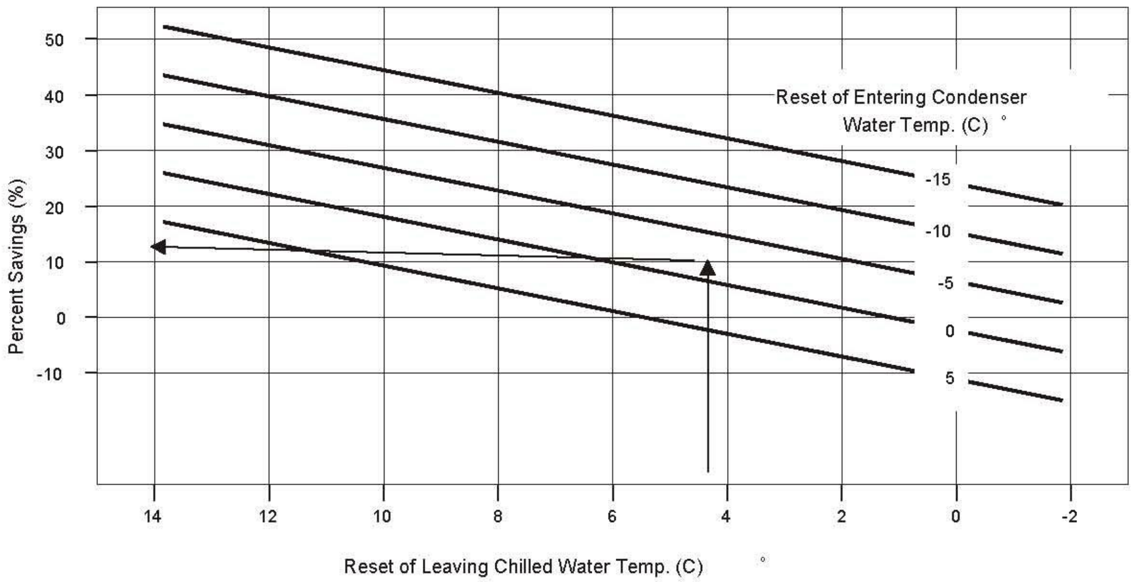
During the cooling season, the following checks of the cooling tower system should be made on a regular basis:

- Check fan by visual inspection for proper belt alignment; there should be no unusual noise or vibration in the motor or the fan; lubricate fan bearings as required
- The water basin level should be checked; the proper operation of the float valve providing make up water to the basin should be verified
- Cooling tower water blowdown (bleed) rate should be checked by measuring basin water TDS levels; it is important to realize that high TDS levels will not only have impact on the cooling tower, but can also have a significant impact on the heat transfer at the condenser itself
- Inspect the nozzle spray for clogging by scale or algae; inspect the tower baffles or packing for contamination by algae or bacterial slime; clean and flush the system and the water treatment system if needed
- Inspect the tower basin for mud, slime, silt, etc.; drain, clean and refill the basin to prevent these deposits from entering the condenser water system

- Perform urgent repairs as required and schedule other repairs for end of cooling season
- At the end of the cooling season, the following shut down procedures should be followed:
- Clean and flush out tower; leave drain open to eliminate accumulation of rain water
- Remove belts from the fan assembly and store them in a place safe from extreme weather
- Repair any rusted areas and repaint areas where there is need; use a marine - type paint over a suitable primer

Exhibit 13-3 presents saving potential from reduction in condenser water temperature.

Exhibit 13-3: Energy savings from reset of chilled water and condenser water temperature



14 Heating, Ventilating and Air Conditioning Systems

14.1 Physiological Comfort Conditions

Space conditioning in buildings can be defined as the employment of those processes which provide the effective control of the physical and chemical properties of air to provide a condition most suitable for human comfort and health. The four factors which affect human comfort are, in order of importance:

- Temperature
- Humidity
- Air motion and distribution
- Air purity (the quality of air with regard to odor, toxic gases, dust, and bacteria).

Simultaneous control of all four of these factors is required to produce a fully satisfactory human environment. However, many systems do not control all of the factors and still maintain surroundings that are pleasant and conducive to comfort.

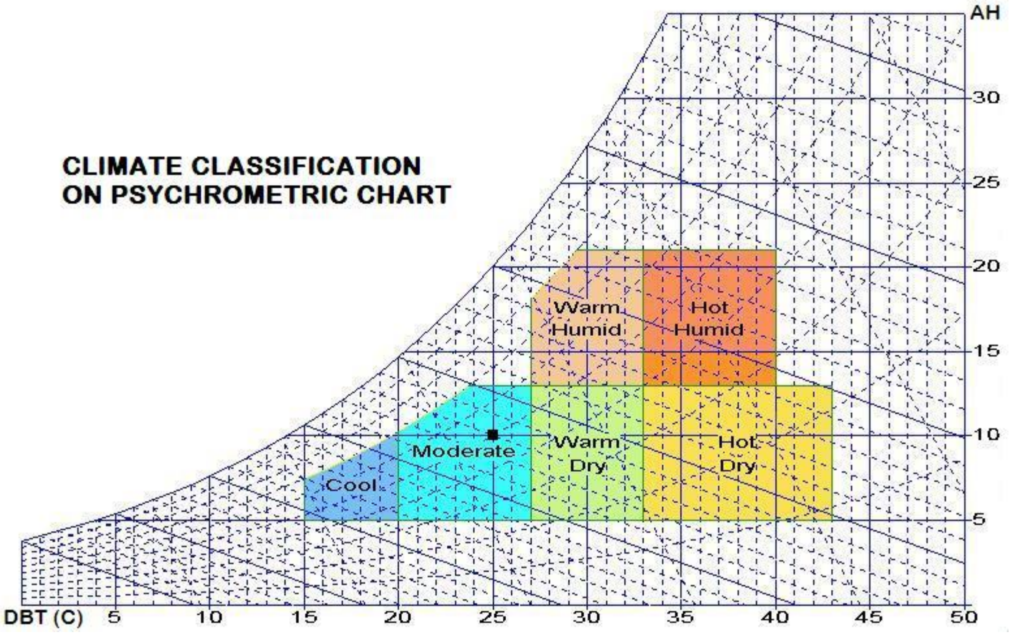
The objective of space conditioning is to provide an atmosphere having such characteristic under which people occupying the space loose enough body heat to permit proper functioning of the metabolic system, yet do not lose this heat at so rapid a rate that the body becomes chilled. As is commonly known, the normal body temperature, 37 °C, is normally above the temperature maintained in a building. This body temperature, produced by the heat released from the combustion of food, is maintained by a complex regulating mechanism. The processes of heat control within the body are not fully understood, but they are thought to operate in two general directions:

- To decrease or increase internal heat production (metabolism) as the body temperature rises or falls; and
- To control the rate of heat dissipation by changing the rate of blood flow under the surface of skin and by changing the rate of perspiration.

At first thought, this objective of human comfort would appear to be an easy task; however, what may be considered to be comfortable conditions to one person may be intolerable to another.

From all of this research, the ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) comfort zone, has been developed (Exhibit 14-1). In it, the comfort zone is shown superimposed upon a psychometric chart. The comfort zone is based on a number of assumptions: sedentary or near sedentary activity, average weight of indoor clothing, and air movement of less than about 6 meters per minute. The overall comfort zone is seen to be broken down into summer and winter zones, with an overlap. Combinations of temperature and humidity falling into these zones should result in the optimum comfort for the occupants of a space.

Exhibit 14-1: Comfort zones defined by ASHRAE



14.2 Types of Air Handling Units

Air handling units (AHUs) provide conditioned air to a given space. Space conditioning systems can be divided into two broad categories: constant air volume systems, and variable air volume systems. As could be inferred from their names, constant air volume systems provide a fixed amount of conditioned air into a space while variable air volume systems have the ability to vary the amount of conditioned air depending on requirements.

Both of these types of systems can be configured in a number of ways. Description of the more common air handling units is presented below.

14.2.1 Constant Air Volume Systems

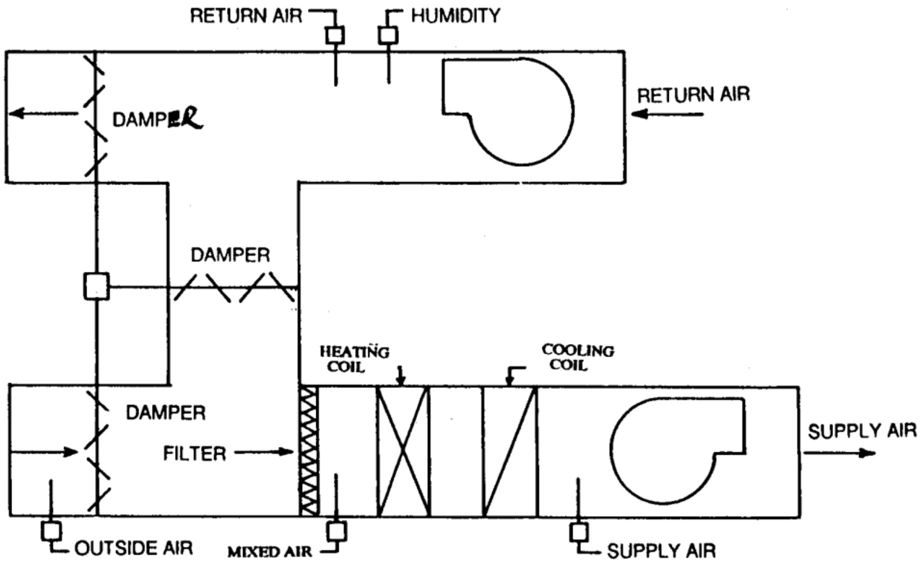
In this section, five commonly used constant air volume systems will be described: single zone heating and cooling units, make-up air units, and multiple zone heating and cooling units and dual units. The discussion continues with a description of commonly encountered terminal units.

14.2.1.1 Single Zone Heating and Cooling Units

These units are the most basic of the air handling units encountered (Exhibit 14-2). They are applied to provide conditioned air to a single area within a building, or to multiple areas having the same environmental requirements.

Single zone units may be encountered which operate on 100 percent fresh air and the return air ductwork is not provided. Instead of the return air ductwork and fan, a separate exhaust fan is employed to extract the air from the space at about the same rate at which conditioned air is provided to the space; this extracted air is exhausted directly to the environment. This is generally the case in areas where space conditioning is required but is not desirable to return the conditioned air to the air handling unit. Such a situation may be found in certain areas of hospitals where high ventilation rates are desired for hygienic reasons, or in restaurants where recirculation of food odors is not desired. The separate exhaust fan is generally interlocked to the air handling unit supply fan; the exhaust fan cannot operate unless the air handling unit is providing conditioned air into the space.

Exhibit 14-2: Constant volume single zone heating and cooling system

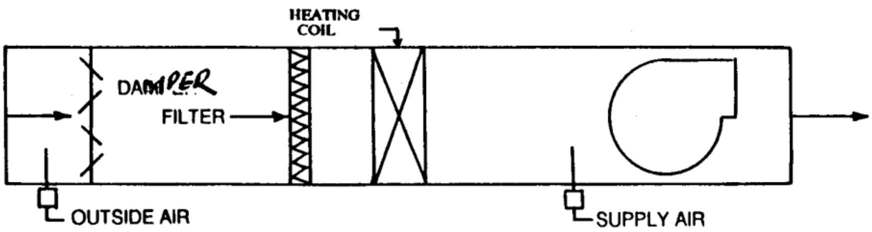


Some small package air handling units (up to about 175 kW of cooling) incorporate direct expansion vapor compression refrigeration machines, and are generally located on a rooftop or adjacent to the building. In very rare cases, the heat is rejected from the condenser to a small cooling tower (which may serve multiple units) or directly to a stream of running water. Other units may be "split" units, with the evaporator and compressor located inside the building and heat may be rejected by a condenser unit located remotely from the air handling unit itself (generally on a rooftop or adjacent to the building).

14.2.1.2 Make-up Air Units

A make-up air unit is a variation on the single zone heating and cooling unit (Exhibit 14-3). Make-up air units are applied in situations where large ventilation requirements are encountered and it is not desirable to recirculate any of the air in the conditioned space. Examples of applications are kitchens, where food odors have to be extracted or workshops where dust or chemical fumes need to be removed from the air. As such, these units operate on 100 percent outside air and are generally associated with an exhaust fan (or range hood in the case of a commercial kitchen) which is interlocked to the air handling unit supply air fan. Make-up air units are sometimes fitted with heating coils to temper the fresh air. They are rarely found fitted with cooling coils.

Exhibit 14-3: Constant volume make air unit

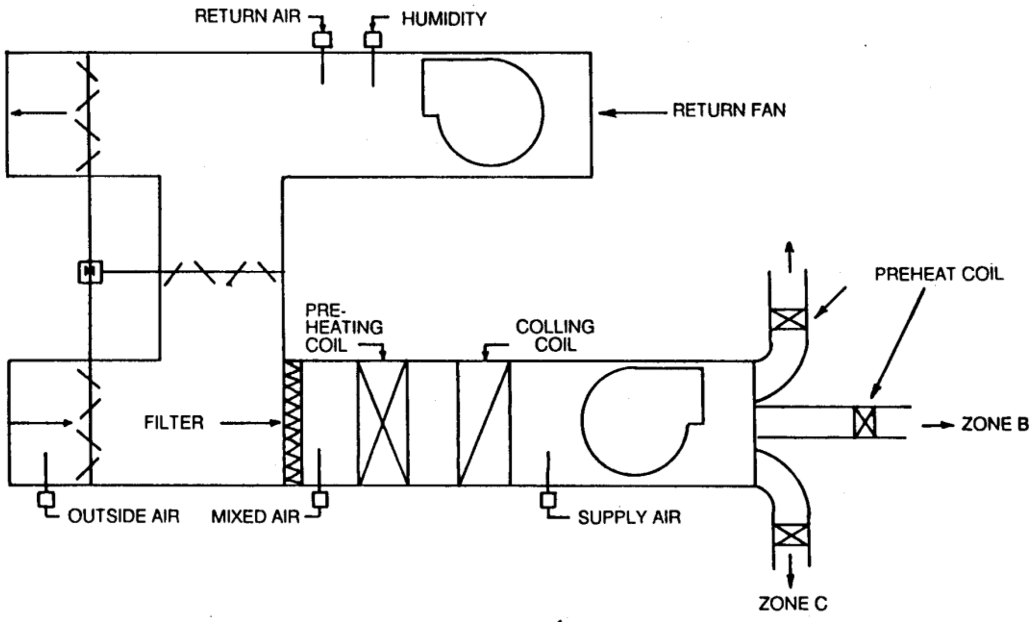


14.2.1.3 Multiple Zone Heating and Cooling Unit with Reheat

The simplest type of constant air volume air handling unit that can serve multiple zones is the type of unit fitted with reheat coils in each zone duct (Exhibit 14-4). This type of unit serves a number of spaces in the building, providing each area some control over the temperature of the conditioned air.

This unit is similar in configuration to the single zone unit. Return air from all of the individual spaces is induced into the unit by a return air fan. The outside air is filtered to remove airborne dust, and is then mixed with the return air in the mixing area behind the filter.

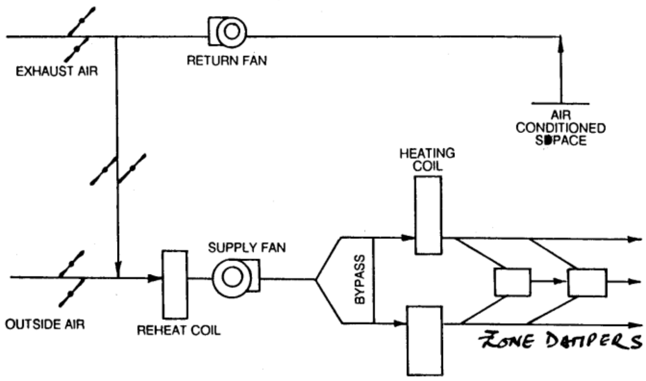
Exhibit 14-4: Multiple zone heating and cooling unit with reheat



14.2.1.4 Multiple Zone Dual Duct Heating and Cooling Units

Dual systems (Exhibit 14-5) are used to provide space conditioning to multiple building zones having wider differences in environmental conditioning requirements than the type of units previously discussed. Indeed, dual duct systems are capable of providing heating to one building zone while simultaneously cooling another zone.

Exhibit 14-5: Multiple zone dual duct heating and cooling unit



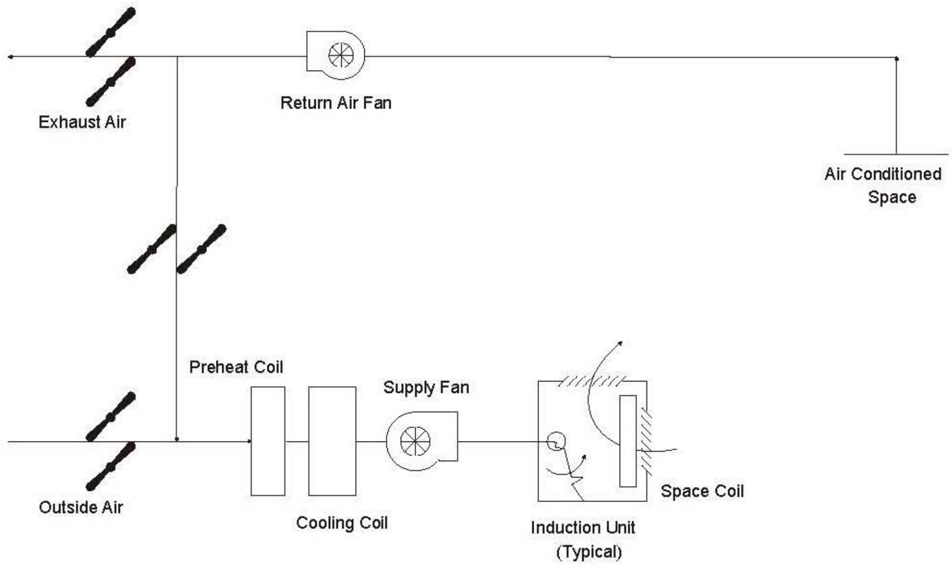
14.2.1.5 Air Handling Systems Incorporating Terminal Units

Where a large number of individual spaces or zones are to be space conditioned, and where individual control of temperature in each of the spaces is desired, constant volume air handling units of the single zone type serving terminal units are employed. Examples of buildings where this type of individual control might be required include hotels (guest rooms), hospitals (private or semi-private patient rooms and offices), and commercial office buildings (private offices).

The air handling unit itself provides preheating or precooling of the air to be supplied to each space; the terminal units, which are located in each space, provide the final heating or cooling of the air to achieve the desired condition. Two commonly used terminal unit systems are fan coil units (Exhibit 14-6) and induction units (Exhibit 14-7).

Exhibit 14-6: Typical fan coil unit

Exhibit 14-7: Typical induction unit



Pre-conditioned air from the air handling unit enters the fan coil unit. The velocity of the air is increased by a small fan within the unit. The fan also serves to recirculate part of the air from the space through the fan coil unit; the air provided from the air handling unit to the fan coil unit generally satisfies fresh air and ventilation requirements.

The fan of fan coil unit is often a multiple speed fan, and its rating is generally in the range of 0.05 HP. The air is heated or cooled by the coil in the unit and is discharged into the space. The desired space temperature is controlled by a thermostat located in the space. The thermostat modulates the amount of chilled water or hot water provided to the coil within the fan coil unit by controlling a valve on the coil.

The second type of commonly used terminal unit is the induction unit. Induction units are always used in conjunction with air handling units, and the air handling units are of the high velocity (high pressure) type.

The induction unit is generally fitted with a single coil (analogous to the two - pipe fan coil unit) which provides either heating or cooling depending on the season. The amount of heating or cooling provided is modulated by a zone thermostat.

Induction units are generally vertical in configuration and located at the building perimeter. In the heating season, the air flow to the units can be turned off during periods of low or no occupancy, while maintaining the flow of hot water to the unit. In this way, the units operate as convectors and provide night setback heating of the space.

14.2.2 Variable Air Volume Systems

Variable air volume systems are relatively new compared to constant air volume systems, and provide a similar level of space comfort control while operating with reduced energy requirements. They are applied in situations where a single air handling unit serves multiple building zones having differing comfort conditions.

One major difference between variable and constant air volume systems is that variable air volume systems have the ability to change total air flow in response to changing heating or cooling loads. Reducing air flow significantly reduces fan energy consumption and power requirements. A second major difference is that variable air volume systems generally operate at a fixed supply air temperature (constant air systems modulate supply air temperature), controlling the space temperature by modulating the volumetric flow of supply air into that space.

Advantages of variable air volume (VAV) systems over constant volume systems are as follows:

- The VAV concept, when combined with separate perimeter heating, results in inexpensive temperature control for multiple zones and a high degree of heating - cooling flexibility
- VAV systems, which are sized on simultaneous peaks rather than the sum of the peaks for constant volume systems, take advantage of changing loads from lights, occupancy, solar radiation and equipment; first cost savings may be realized for fans, refrigeration, heating, and auxiliaries, as well as for ductwork, insulation and piping systems
- VAV systems are self - balancing. Manual adjustment of air flows into individual zones is not required as is with constant volume systems
- VAV systems allow subdivision of the served spaces into new zones with more flexibility than constant volume systems
- Operating costs are typically lower for VAV systems as compared to constant volume systems because of reduced fan operating speeds, and reduced refrigeration and heating requirements

Variable air volume systems may be configured as simple cooling systems (Exhibit 14-8) with or without zone reheat or as dual duct systems (Exhibit 14-9). The simplest type of VAV system is a cooling only system relying on perimeter radiation systems or an independent constant volume variable air temperature system to provide heating for the space. The fan system is sized to handle the largest simultaneous load (not the sum of the individual peak loads). Each zone served by the VAV system will have its peak cooling load at a different time of the day; the VAV system "borrows" the extra air needed to meet the zone peak requirements from off - peak zones.

Exhibit 14-8: Simple cooling only variable volume system

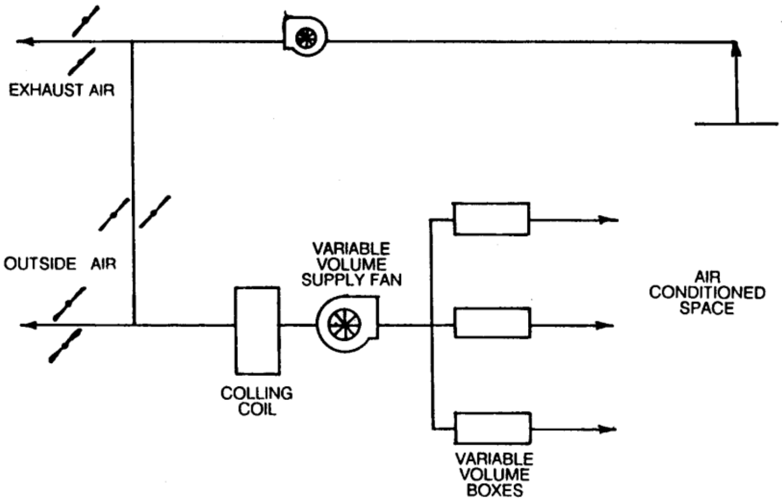
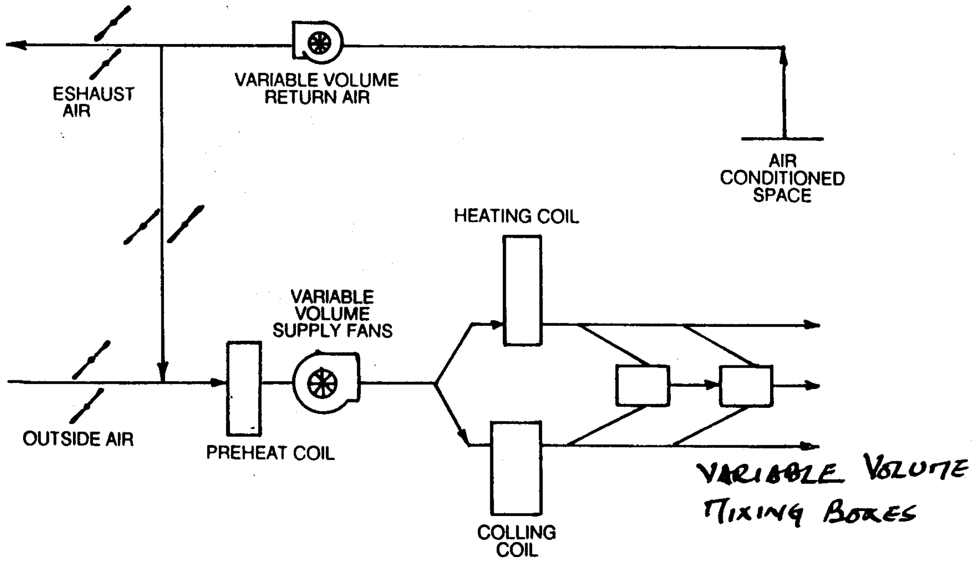


Exhibit 14-9: Typical dual duct variable air volume system



14.3 Types of HVAC Controls

14.3.1 Control system Elements

Controls for HVAC systems are used to perform a variety of functions, including the regulation of temperature, ventilation, humidity, and fire management. HVAC control systems are complicated, but even the most complex system can be reduced to a few fundamental functions that can be considered separately.

A basic HVAC control system consists of a power supply, a means of transferring the power to the controller, the controller itself is a means of communication between the controller and the controlled device.

Automatic HVAC controls operate on a cause and effect relationship. A sensing device monitors the condition to be controlled and the controller acts based on the information received from the sensing device (e.g., a room thermostat). This type of control is commonly called "feedback" control.

Control actions may be accomplished through the use of a number of different power sources. In large commercial buildings with multiple HVAC systems, the most commonly encountered controls are of the pneumatic type. Packaged HVAC systems generally have integral electric controls. The levels of control afforded by pneumatic and electric controls are roughly equivalent. Newer control systems, including those tied into energy management systems, use electronic controls (sometimes in conjunction with pneumatic controls). These electronic control systems provide a much higher degree of control and control flexibility than either simple electric or pneumatic controls; including the ability of the controller to "learn" and anticipate conditions.

Exhibit 14-10 presents various types of control elements and systems.

14.3.1.1 Pneumatic Control Systems

Pneumatic controls use low pressure compressed air for transmitting control instructions. The air is generally provided by a central air compressor to multiple systems. Pneumatic controls are generally powered by compressed air at 1 to 1.3 bar. The sensor provides a pressure signal of between 0.2 to 1 bar to the controller; the pressure transmitted depends on the value of the variable being monitored. The controller similarly varies the pressure of the output signal between 0.2 to 1 bar to cause changes in the operation of the controlled device.

14.3.1.2 Electric Control Systems

Electric control systems provide control by starting and stopping the flow of electricity or by varying the voltage and/or current. The nominal voltage of the control signal may vary from low voltage (6 to 24 volts) to building line voltage (120 to 220 volts) depending on the manufacturer of the control systems and the types of devices to be controlled.

Electric control systems make use of four major types of components: switches, relays and solenoids, two - position motors, and modulating motors.

Switches are used to turn power on and off to a load. In an HVAC system, the load may be an actuator, relay or motor. The switch may be a sensor. A simple example is an electric thermostat using a bimetallic sensor element. The bimetallic may be a straight metal strip, or it may be arranged in a spiral fixed at one end and attached to a mercury switch at the other.

Relays and solenoids use the principles of electromagnetism to overcome a resistance (generally a spring - similar to the pneumatically actuated valve described above). When wire is formed into a coil and electricity flows through the coil, a magnetic field is set up. A solenoid consists of an iron plunger placed in proximity to the end of a hollow coil. A spring acts to keep the plunger out of the coil. When electricity is allowed to flow through the coil, the magnetic force overcomes the tension of the spring and draws the plunger inside the coil. The position of the plunger (inside or outside of the coil) determines the action that the controller takes. Similarly, a relay uses the electromagnetic force to energize or de-energize another electric circuit.

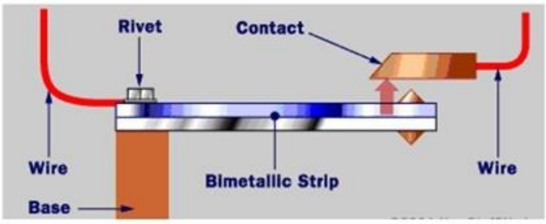
Two - position motors are used to operate dampers or valves that need to open and close more slowly than is possible with a solenoid or relay. These motors may be of two types:

- Unidirectional: the motor operates in one direction only, and the controlled device is returned to the "rest" position by the force of a spring
- Directional: the motor (generally a DC motor) has two "directional" wires and a common return wire. When electricity is applied to one of the directional wires, the motor turns in one direction and when electricity is applied to the other directional wire, the motor turns in the other direction. The choice of directional wire may be made by a relay or solenoid. These motors may be either of the two - position type (the motor will come to rest fully in one direction or the other), or fully proportional (the motor can come to rest at any point between its limits)

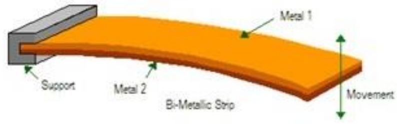
Electronic systems use low voltages (15 volts or less) and currents for sensing and transmission. Electronic circuits provide output to the devices to be controlled. New devices employing digital equipment are known as direct digital control (DDC) systems.

Exhibit 14-10: Control elements and systems

Thermostat with Open Electric Contacts to Transmit Signal

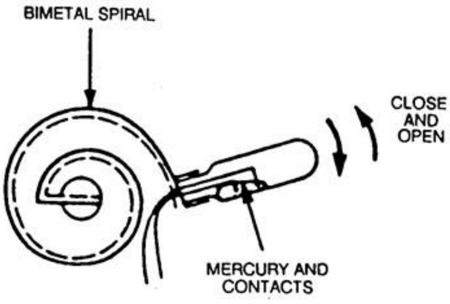


Bi-metallic Temperature Sensor

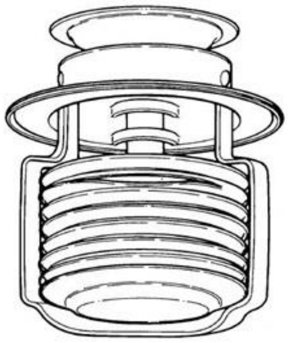


Remote Thermostat with Fluid Filled Bulb Type Sensor

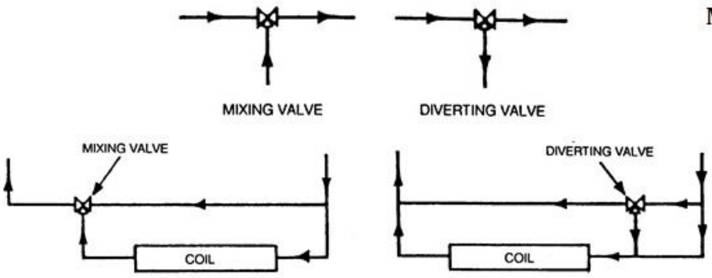
Mercury Switch



Bellows Type Thermostat

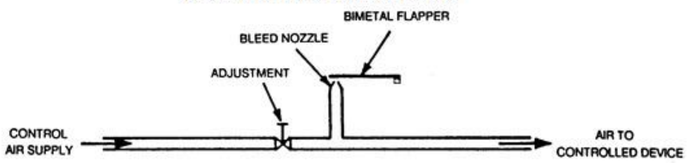


Use of Three-Way Valve to Control Flow

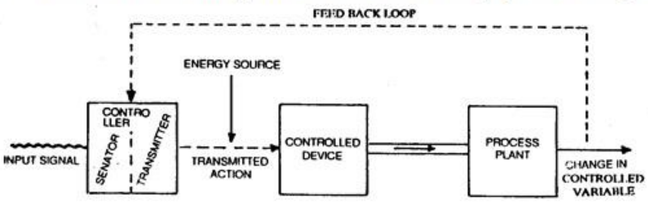


Multi-Blade Damper Arrangements

Peneumatic Thermostat



Functional Block Diagram for a Closed Loop (Feed-back) Control System



14.3.1.3 Thermostats

Thermostats are the most commonly encountered types of control elements in HVAC systems. They are used most visibly to monitor and control the temperature of a room or space. They are also used to monitor and help control (through the use of a controller) the flow of chilled water or steam to heat transfer coils, and adjust the position of outside, return air and mixed air dampers.

A bimetallic thermostat employs a spiral bimetallic element. The expansion or contraction of the spiral causes the steel blade to pivot toward and away from the terminal electrode at the top of the thermostat. When the steel blade touches the terminal, the circuit is closed; when the steel blade does not touch the terminal, the circuit is open.

Another type of thermostat control is the bellows switch. The bellows is filled with a fluid that reacts by expanding with increased temperature and contracting with decreased temperature. The change in volume of the fluid is accommodated by the bellows, which in turn expands or contracts with the fluid. As the temperature drops, the bellows contracts to the right and the blade pivots to the right until contact is made with the terminal at the top of the thermostat. A circuit is closed and the controller takes the necessary action. As the temperature increases, the bellows expands to the left and the contact between the blade and terminal is broken.

14.4 Measurement and Analysis of HVAC System Performance

This activity consists primarily of developing an inventory of the HVAC systems with as much detail about operating parameters as possible. The equipment inventory should be supplemented by a visual inspection of the equipment. This visual inspection serves to help the energy surveyor qualitatively assess the condition of the equipment. Things, which should be checked, are, such as:

- Existence and visual condition of controls
- Condition and cleanliness of air handling unit filters
- Whether damper positions are reflective of indoor and outdoor temperatures and the mode of operation of the air handling unit
- Condition of motors, belts and pulleys serving the air handling unit or exhaust fan
- Whether the air handling unit or exhaust fan is operating while the area served is unoccupied
- Condition of steam and chilled water pipework (e.g. leaks insulation, properly operating control valves)
- Condition of heating and cooling coils (fouled spaces between coil fins, improperly draining of condensate from cooling coil, simultaneous use of heating and cooling coil)
- Condition of ductwork (e.g. presence of insulation, leaks, breaks)
- Condition of air handling unit envelope/housing (improperly seated or open access doors, holes and major air leaks)

14.5 The HVAC Systems ECOs

14.5.1 Adjustment of Space Temperatures

The most basic energy saving opportunity encountered is that of space temperatures which are maintained at too low a level for the cooling season and too high a level during the heating season. There are many potential causes (and solutions) to this problem, including:

- Thermostats for heating or cooling units are vulnerable to unauthorized occupant adjustment: reset the thermostats to correct settings and install or replace locking screws to prevent tampering; consider relocating thermostat or installing a ventilated and locked enclosure.
- Thermostat settings have not been adjusted for a change in seasons from heating to cooling (or vice versa): thermostats should not be located in areas subject to extreme temperature fluctuation (e.g. near windows or over a heating or cooling unit) and should be relocated if this is the case.
- Unoccupied or little used areas are heated or cooled unnecessarily: reduce thermostat set point to 13.5oC in winter or turn off heating to the space altogether if nothing can freeze; turn off cooling to the area in the summer; consider the use of spot heaters in large areas that are occasionally occupied.
- Building temperatures are not adjusted for unoccupied periods: reduce thermostat set point by a minimum of 10oC at night during the heating season, or shut off heating system altogether at night if possible; shut down all air conditioning systems during unoccupied hours; consider the use of automatic time clocks or other controls (e.g. energy management system) to control the operating hours of HVAC systems.
- Heating or cooling equipment is operated to serve lobbies, corridors, vestibules or other public areas: reduce HVAC services to those areas to minimum level or eliminate services entirely; remove electric heaters from vestibules.
- Space temperatures are higher or lower than thermostat settings: re-calibrate thermostat; blow out moisture, dirt, or oil from pneumatic control lines; clean contacts on electrical controls; ensure that control valves and dampers are operating correctly; limit excessive outdoor air intake during the cooling season when economizer cycle is not operating.

14.5.2 Adjustment of Operating Hours

Another basic energy savings measure for air handling units is adjustment of operating hours. Obviously, the air handling unit (and the primary systems serving it) will consume less energy if the period of operation is reduced. There are a number of common reasons given for AHU operating schedules by building operations personnel. The most common reason given for operation long before the arrival of occupants into the space is the desire to ensure that the area is comfortable for the occupants when they arrive. While this is a valid reason, the operating schedule is not adjusted on a seasonal basis and the units are left on all of the time because of the forgetfulness of the operating staff, or because of the remote location of the units.

Some practical suggestions for adjusting operating hours are:

- Experiment with start-up times to determine latest start-up time that will result in no loss of comfort to occupants
- Start-up time can be varied as a function of outdoor temperature or time of year
- Reduce or turn off HVAC systems during last hour of occupancy
- Consider the use of energy management systems with optimum start-stop control feature

14.5.3 Adjustment and Modification of Controls and Settings

HVAC controls are, as noted earlier, complex devices which perform a number of simple functions. The complexity arises from the integration of the simple functions into a fairly rapidly responding control system. A number of commonly encountered energy control problems and their solutions are given below:

- Excessive amounts of outside air are used for ventilation: reduce outside air quantity to the minimum practicable; adjust or replace air handling unit dampers and ensure proper operation (dampers should close tightly); consider replacement of old style dampers with newer blade types for better close-off.
- Outdoor dampers are open when building is unoccupied: implement a program to close manual dampers at the end of the day; check the operation of automatic dampers and repair associated control mechanisms if required; if not already in place, install controls which will close outside air dampers when air handling unit is shut down.
- Ventilation systems are not utilized for natural cooling capability: whenever possible, use outside air for cooling instead of refrigeration; consider the installation of economizer or enthalpy controls on air handling units; flush the building with outside air for one or two hours prior to starting the refrigeration system (early morning hours are best) in order to remove the residual heat in building.
- Exhaust system operates unnecessarily: discontinue the use of unnecessary exhaust fans or reduce exhaust volume by fan pulley adjustment; consider automatic interlocking of exhaust fans with air handling units through the motor starters to ensure that the supply and exhaust fan operating schedules coincide; consider the use of time locks to schedule non-interlocked exhaust fan operation; install controlled or gravity dampers in exhaust ducts to close ducts when fan is not operating and eliminate outside air infiltration.
- Return air, outdoor air, and exhaust air dampers are not sequencing properly: adjust or replace the damper linkages; make sure that the damper motors or pneumatic controllers are operating properly; reset the linkages to ensure that damper blades close tightly.
- Controls are not inspected and adjusted on a regular basis: routinely inspect and adjust all controls including time clocks for proper operation and programming, including set points.

14.6 Room Air Conditioners

Room air conditioners generally serve a single room, a relatively small area in a house, or a single office in a commercial building. They are easily installed in a window. No ductwork is required for this type of air conditioner (Exhibit 14-11).

Exhibit 14-11: Room air conditioner and split package air conditioner

Improper installation and maintenance of the air conditioner can severely reduce its ability to maintain comfort levels. In this section the information presented is about the operation and maintenance of new and old room air conditioning units and direct expansion mini-split systems.

14.6.1 Window Type Room Air Conditioners

A room air conditioner's basic function is to provide comfort by cooling, dehumidifying, filtering and circulating room air. It may also provide ventilation by introducing outside air into a room or by exhausting room air to the outside. Room air temperature is generally controlled by means of a thermostat located on the air conditioner's control panel.

The air conditioner itself consists of two heat exchange coils (which resemble a car radiator), a fan (located on the outdoor side on the unit) and a blower (located on the indoor side of the unit), and a refrigeration compressor. The heat exchange coil located on the indoor side of the air conditioner is called the cooling coil or evaporator. The coil located on the outdoor side of the air conditioner is called the condenser. Warm room air is circulated over the cooling coil by the blower and is cooled and dehumidified. The conditioned air is then recirculated to the room.

The room air conditioner control panel usually has at least two sets of switches or knobs. One of these controls the fan speed while the compressor is operating; in most cases at least two fan speeds are provided. This control also allows the operation of the fan without the compressor, for ventilation. The second control is a thermostat. This control cycles the compressor on and off when a predetermined room air temperature is reached. The air conditioner compressor does not operate at different speeds, hence, contrary to what is sometimes thought, turning the thermostat to its coolest setting does not cool the room down faster. The thermostat is generally not calibrated with room temperature, but it is a simple job to calibrate the thermostat. Room air conditioner energy efficiency is usually expressed as the ratio of air conditioning cooling capacity (in kW) and energy input (in kW). This ratio is called the Energy Efficiency Ratio or EER:

$$\text{EER} = \frac{\text{Cooling Capacity in kW}}{\text{Energy Input in kW}}$$

In some countries, air conditioner manufacturers are required by law to measure air conditioner EER using a standardized test procedure and to display the EER prominently on the air conditioner. If there are no such labels the unit's EER can be determined from its nameplate. From the air conditioner nameplate, determine the total input wattage of electricity required. If the wattage is not indicated explicitly the unit's amperage is generally provided. Multiplying the unit's amperage by voltage will yield the wattage. The nameplate generally states the cooling capacity of the air conditioner, either in BTU/h or in kW. 12,000 Btu/hr equals 3.5 kW.

The higher the EER the more energy efficient the air conditioner. Generally, more efficient air conditioners cost more than less efficient ones. However, the price differential is quickly recovered through reduced electricity charges for air conditioner operation.

If at all possible, do not install air conditioners on the sides of the building exposed to direct sun. Sunlight will heat the outside portion of the air conditioner making it more difficult for the unit to reject heat from the room to the outdoors. If it is necessary to install an air conditioner on the walls under direct exposure to sun, install a simple awning over the top of the air conditioner to protect it from the heat of the sun's rays. However, care must be taken to make sure that the awning does not restrict the air flow into the air conditioner's condenser.

Set the air conditioner thermostat to maintain as high a temperature as possible. The air conditioner should not be operated if the temperature in the room is less than about 26 °C. The cost of operating a room air conditioner increases by about 10% or more for every 1 °C that the room temperature is maintained below that level (i.e. at lower temperature).

Conversely, the cost of running an air conditioner is reduced by as much as 10% for every 1 °C that the thermostat is maintained above 26 °C (i.e., at higher temperature).

Room air conditioner can be supplemented by the use of small electric fans or ceiling fans in the air conditioned space. These fans increase the air circulation in the room and increase comfort through the evaporation of perspiration. When these additional fans are used the thermostat setting on the air conditioner can be adjusted upward because of this "wind-chill" effect.

Proper maintenance is important for both old and new air conditioners. A few minutes spend each month to clean the unit will ensure that the air conditioner operates at its optimum efficiency. The most important item that the owner can maintain in a room air conditioner is its air filter. This filter is located behind the air intake grill in the front of the air conditioner. The filter serves a dual purpose: it not only cleans the air that is being cooled, but it also removes dust and dirt from the air that could foul the cooling coil surfaces. If the cooling coil surfaces become very dirty the effective cooling capacity of the air conditioner could be reduced substantially.

The filter should be removed at least once a month and washed or cleaned according to the manufacturer's instructions. If the filter is very dirty and cannot be cleaned it should be replaced. The air conditioner should never be operated without the filter in place.

14.6.2 Direct Expansion Mini-Split Systems

Direct expansion mini-split systems utilize a split refrigeration circuit, with the refrigeration compressor and condenser located in a condensing unit, and the direct expansion (DX) coil located in the air handling unit. The condensing unit and air handling unit are physically separated from each other, connected by refrigerant piping. This enables the air handling portion of the system to be located indoors, while the condensing unit (if air cooled) is located outdoors. Exhibit 9-3 shows a split-system air conditioner.

The applications for split systems include virtually the same broad range as unitary equipment. Capacities cover a similar range, from about 5 to 100 kWR (1.5 to 30 tons) for standard equipment, although field engineered systems of much greater capacity have been installed, including central VAV systems for retail stores and office buildings. The benefits of split systems over unitary systems include improved serviceability and reduced energy and air losses as a result of the indoor location of the air handling components. The major disadvantage is the potential for problems in the refrigeration circuit resulting from improperly designed or installed refrigerant piping systems or failure to properly clean and evacuate field refrigerant piping, which can lead to premature compressor failure.

The condensing unit of a split system may be air-cooled or water-cooled, although air-cooled is the most common arrangement. Air-cooled heat pump split systems are also popular, and offer excellent operating efficiency. The air handling side of the system may take a variety of forms, including constant volume single zone, variable volume, or multi-zone. Where air flow across the cooling coil may be variable, as with variable volume and multi-zone systems, some means of capacity reduction must be provided in order to avoid excessive compressor cycling. This is usually accomplished with cylinder unloading, possibly supplemented with hot gas bypass at very low loads. The use of hot gas bypass for capacity reduction is extremely inefficient and should be minimized.

14.6.3 Room Air Conditioners ECOs

Aside from the operating and maintenance guidelines given in the above section, there is little that can be done to improve the operating efficiency of room air conditioners. Hence, only an inventory of the existing equipment and their cooling ratings can be developed. Instrumented testing of this equipment is not called for, since changes in operating characteristics can not be made by in such field testing. Some simple energy saving measures are as under:

- Turn off air conditioners when the space is unoccupied: When a space is to be unoccupied for more than just a few minutes, there is no need to continue to provide cooling. It does not take a long time for a properly sized room air conditioner to cool down the space it serves, even if the space is very warm.
- Set thermostats and controls to provide the maximum comfortable space temperature: The occupants of the space should avoid the tendency to run the air conditioner at the coolest thermostat setting. It is a relatively easy task to "calibrate" the air conditioner's thermostat with the use of a thermometer. The thermostat setting that results in a maximum acceptable room temperature should be maintained when the air conditioner is used.
- Reduce drafts and outside air infiltration into the space: As described earlier, all possible sources of warm air infiltration into cooled space should be eliminated. This includes leaks from windows and window frames, from around through-the-wall air conditioner itself, and from uncooled spaces in the building. Doors between cooled and uncooled spaces should be kept closed, and doors to the outside should have weather-stripping to prevent drafts coming in from under or over the door.
- Minimize solar heat gain into an air conditioned room: Draw curtains or shades to reduce the amount of heat from sunlight that enters the air conditioned space. Consider building an awning to shade the part of the air conditioner that is outside of the room. For both of these items, make sure that the free flow of air in and around both the indoor and outdoor sections of the air conditioner is not blocked.
- Maintain air conditioners properly: Filters should be cleaned at least once a month (or according to manufacturer's recommendations) and the air conditioner should not be operated without a filter in place. If air conditioner performance seems to be deteriorating, consult a trained air conditioner mechanic to recharge the refrigerant or identify leaks.

14.7 Hot Water Systems

Hot water is used in a building in the kitchen and toilets. It is produced by two major methods: through heat exchange with steam in larger commercial buildings having steam boilers, and through the use of gas or electric fired hot water heaters.

For hot water systems employing a storage tank with a steam coil, the principle of operation is as follows:

A thermostat measures the temperature of the hot water. If the thermostat indicates that the hot water temperature is below the setpoint, a valve of the steam side is allowed to open and the steam flows through the coil to heat the water. When the hot water temperature has achieved the setpoint condition, the thermostat signals the automatic valve to close. As hot water is consumed from the storage tank, a float valve allows city water to enter the tank as makeup.

The causes of heat losses in hot water systems are similar in nature to those encountered in steam distribution systems: missing or damaged thermal insulation, leaks, excessive temperatures, and other uncontrolled use.

14.7.1 Hot Water Systems ECOs

The energy surveys of the hot water generation and distribution systems are carried out by looking specifically for such easily identified problems as hot water leaks, improperly closing faucets and taps, and areas where thermal insulation is missing.

14.7.1.1 Insulation of Hot Water Generation and Distribution System

The inventory of missing or damaged thermal insulation on hot water generation and distribution systems is prepared and the energy savings potential is quantified for this measure.

Insulation of hot water pipe work may result in marginal savings which are not cost-effective. This is due to the generally low temperatures involved. Before beginning the more rigorous calculation method, it is recommended that the energy surveyor make a quick estimate of savings potential. If the energy and energy cost savings are significant, then the next step should be to carry out the more rigorous analysis.

14.7.1.2 Repairing Hot Water Leaks

Hot water leaks represent a loss of both the energy that is used to heat the water, and of the water itself, since a quantity of makeup water has to be introduced into the hot water system in excess of that consumed through normal hot water consumption.

14.7.1.3 Reducing Hot Water Temperature

Hot water at the tap or faucet should not exceed about 38 °C. Above this temperature, the person using the hot water will be forced to mix the hot water with cold stream to lower the temperature for avoiding discomfort or scalding. Aside from the risk of personal injury, the practice of having to reduce the hot water temperature is wasteful of both energy and water.

Generally, the temperature reduction can be accomplished by adjustment of the hot water generator's thermostat. In some cases the thermostat may be found to be faulty or need to be replaced. Another common cause of abnormally high hot water temperature may be a leaking or otherwise malfunctioning (e.g. stuck in the open position, not properly seating) steam valve. The energy surveyor should attempt to identify the cause of the problem and estimate the cost of the remedy.

In buildings where hot water is required in certain areas (e.g. dish washing or laundry) at temperatures above the recommended 38 °C, the use of instantaneous hot water heaters should be considered to serve those functions. Hot water can be supplied to those areas at the recommended 38 °C, and raised to the higher temperature required. The cost-effectiveness of implementation of such a system will depend on the relative quantities of hot water required at different temperatures and a best possible attempt should be made to determine this relative split at different temperatures.

14.7.1.4 Install Flow Restrictors

When a person turns on a tap, he tends to create a rate of water flow in excess of the needs. Hence, some of the water is wasted. For hot water system, this is doubly wasteful since both energy used to heat the water and the water itself are wasted. Flow restrictors can help reduce this waste. Flow restrictors are devices that fit into the faucet, tap or shower head to reduce the amount of water flow by introducing a restriction to the free flow. These devices can be purchased commercially or fabricated from small pieces of sheet metal at little cost. A properly fitted flow restrictor can reduce water consumption by as much as 50 percent.

15 Buildings

Buildings can be easily classified on the basis of their use as given below:

- Domestic or residential buildings;
- Industrial buildings;
- Institutional buildings (schools, universities, hospitals, etc.); and
- Commercial buildings.

Commercial buildings can be termed as buildings which are used for commercial activities, such as offices; hotels; shopping malls; and restaurants etc.

This chapter deals with heat flow through the envelope of a building, thermal insulation of the building envelope, infiltration of outside air, and discussion on energy conservation opportunities based on reducing heat flow across the building structure.

15.1 Building Envelope

The building structure provides a barrier, shielding the occupants from the ambient weather conditions, and providing an "envelope" of conditioned (heated or cooled, humidified or dehumidified) air. Building envelopes are not perfect, and do allow the transfer of heat between the building's interior and the outdoors. Building HVAC systems are designed to match this heat transfer, providing heating or cooling to overcome any discomfort caused by this heat transfer.

15.2 Heat Transfer Principles

Heat transfer takes place when there is a temperature difference or temperature gradient between two locations (or bodies). There are three basic mechanisms by which heat is transferred: conduction; radiation; and convection. This section describes some of the basic theories relating to each type of heat transfer and discusses how practical problems may be solved.

15.2.1 Conduction

When a temperature gradient (difference) exists in a solid body, there is a transfer of heat from the high-temperature region to the low temperature region. This heat is transferred by conduction and the rate of heat transfer per unit area is proportional to the temperature difference:

$$\frac{Q}{A} \propto \frac{(t_1 - t_2)}{x}$$

where,	Q	=	Rate of heat transfer per unit of time
	A	=	Area
	t1 - t2	=	Temperature gradient (difference)
	x	=	Thickness

15.2.2 Convection

A hot body will cool faster when placed in front of a fan than when it is exposed to still air. The air velocity enhances the heat transfer process by convection. Convection is the transmission of heat through a fluid. The warmer fluid travels to cooler fluids to warm them.

15.2.3 Radiation

Radiation is emitted by a body by virtue of its temperature. Thermal radiation is similar to visible light, X-rays, and radio waves, the difference between them being their wavelengths. In radiation, heat is transmitted by electromagnetic rays.

All solids and liquids, as well as certain gases, emit thermal radiation. The calculation of thermal radiation is based on the Stefan-Boltzman law, which relates the energy flux emitted by an ideal radiator to the fourth power of the absolute temperature:

$$Q = \sigma \times T^4$$

Where, Stefan-Boltzman constant $\sigma = 5.670 \times 10^{-8} \dfrac{W}{m^2\ K^4}$

When radiant energy strikes a material surface, part of the radiation is reflected (R), part is absorbed (A), and part is transmitted (T). In general:

$$R + A + T = 1$$

Most opaque solids do not transmit thermal radiation, in which case:

$$R + A = 1$$

15.2.4 Resistance and Conductance

In most steady state heat transfer problems, more than one heat transfer mode (mechanism) may be involved. Various heat transfer coefficients can be combined into an overall heat transfer coefficient so that the total heat transfer can be calculated from the temperatures of the two extreme boundaries of the materials through which heat is flowing. For this purpose, the concept of thermal resistance is often employed.

To explain the concept of thermal resistance, consider the transfer of heat from one fluid to another with an interposing solid wall between the fluids. An example of this is two streams of liquid flowing in a heat exchanger, separated by the heat exchanger tube. An overall coefficient of heat transfer, U, based on the difference in the bulk temperatures of the two fluids t_1-t_2 is defined by:

$$Q = U \times A \left(t_1 - t_2\right)$$

Here, U is the overall hear transfer coefficient. Its inverse (1/U) is the overall resistance denoted as R.

15.3 Thermal Insulation

15.3.1 Insulation Fundamentals

Thermal insulation materials are such materials or combination of materials that retard the flow of heat energy by conduction, convection or radiation. Thermal insulation are available in a variety of forms, and can be composed of a number of types of materials. Thermal insulation retards the heat flow and serves one or more of the following functions:

- Conserve energy by reducing the heat loss or gain of piping, vessels, or structures
- Control the surface temperature of equipment and structures
- Help control the interior temperature of a piece of equipment or structure
- Prevent vapor condensation on the surface of a body with a temperature below the dew point of the surrounding air
- Reduce temperature fluctuations within an enclosure when no heating or cooling is provided or available
- Reduce temperature variations within a conditioned space for increased comfort

Thermal insulation normally consists of the following types of materials and composites:

- Organic fibrous materials, such as cotton, animal hair, wood, pulp, cane or synthetic fibers
- Cellular organic materials such as cork
- Foamed rubber
- Inorganic fibrous, or cellular materials, such as glass, rock or slag wool; calcium silicate, bonded perlite, vermiculite, ceramic products and asbestos
- Synthetic materials, such as polystyrene, polyurethane and other polymers

15.3.2 Common Building Insulation Materials

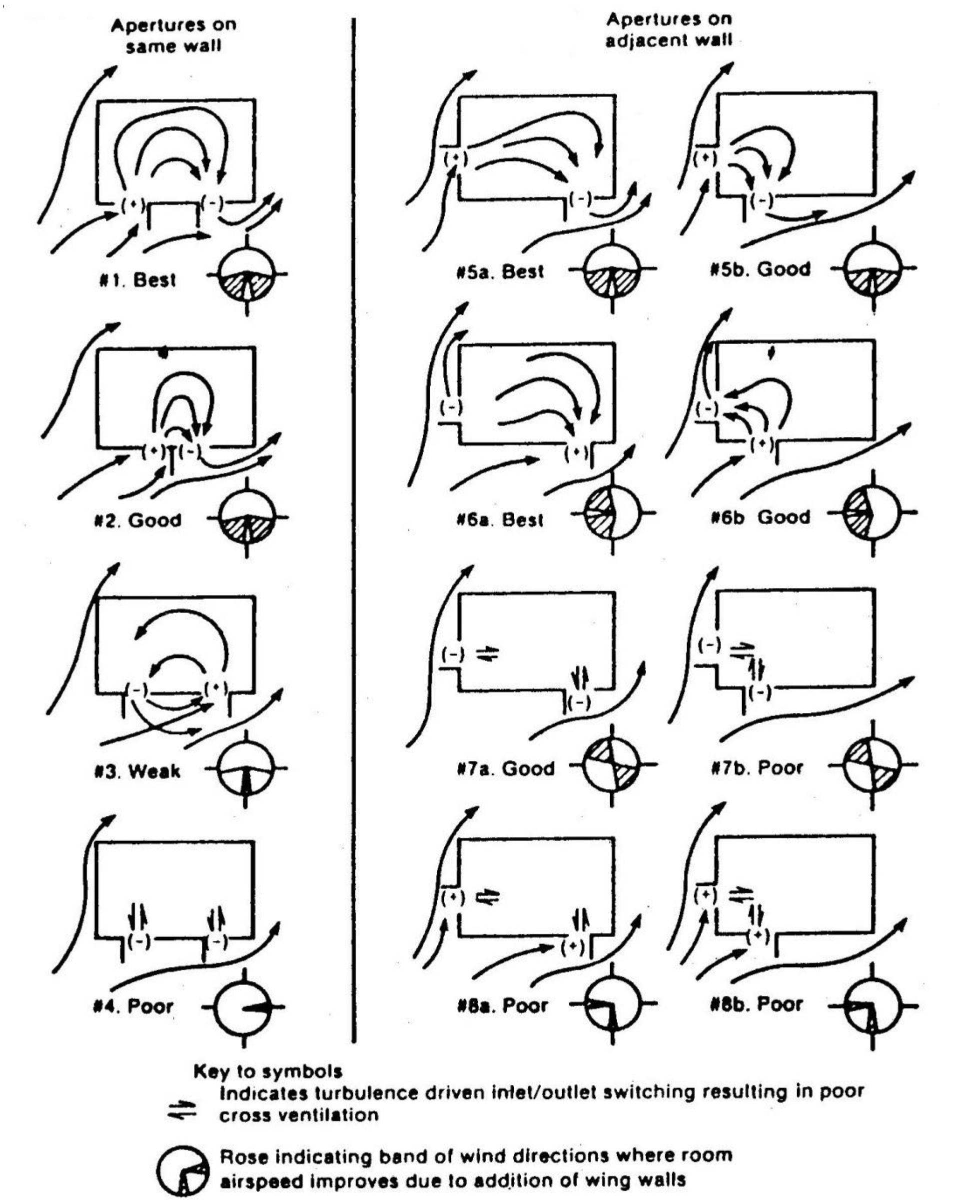
The following are some of the basic physical forms of thermal insulation materials for building applications:

- Loose-fill insulation: It consists of fibers, powders, granules or nodules that are poured or blown into walls or other spaces.
- Insulating cement: It is a loose material (generally in powder form) that is mixed with water or other binders to obtain plasticity and adhesion. It is applied wet to a surface and allowed to dry in place. Insulating cement is generally used to cover irregular spaces.
- Flexible and semi - rigid insulation: It consists of organic or inorganic materials with or without binders and with varying degrees of compressibility and flexibility. These materials may be available in blanket or bat form, in either sheets or rolls. Coverings or facings may be applied to one or both sides of the insulation material to serve as either reinforcement or a vapor barrier.
- Rigid materials: These are available as rigid blocks, boards, or sheets. These materials are pre-formed during manufacture to standard sizes, widths and thicknesses. Insulation for pipes and other curved surfaces are supplied as sections or segments of suitable radius.
- Reflective materials: They are available as sheets or rolls of single or multiple layer construction.
- Formed-in-place insulations: They are available as liquid components or expandable pellets which are poured, frothed, or sprayed in place to form rigid or semi - rigid foam insulation. Fibrous materials mixed with liquid binders can also be sprayed in place.

15.4 Infiltration and Natural Ventilation Mechanisms

Natural ventilation and infiltration occur due to temperature and pressure differences between indoor and outdoor air, and the operation of such equipment as combustion devices and mechanical ventilation systems. The pressure difference at a location depends on the magnitude of these driving mechanisms as well as on the characteristics of the openings in the building envelope (Exhibit 15-1).

Exhibit 15-1: Design strategies using wing walls



15.4.1 Air Flow through Openings

When wind impinges on a building, it creates a distribution of static pressure on the building's exterior surface. The magnitude of the pressure depends on the wind direction relative to the building surface and is independent of the pressure inside the building. If there are openings, wind would blow inside through them. In the absence of these openings it would still get through various cracks and spaces around window/door frames.

The building envelopes of large commercial buildings are often considered to be quite air tight. Tests and measurements have indicated that this is not the case. Typical air leakage rates per unit wall area at 0.75 cm water gauge in volume per unit time per unit area are:

For "tight" construction $= 4.72 \times 10^{-4} \dfrac{m^3}{s \times m^2}$

For “average” construction $= 14.16 \times 10^{-4} \dfrac{m^3}{s \times m^2}$

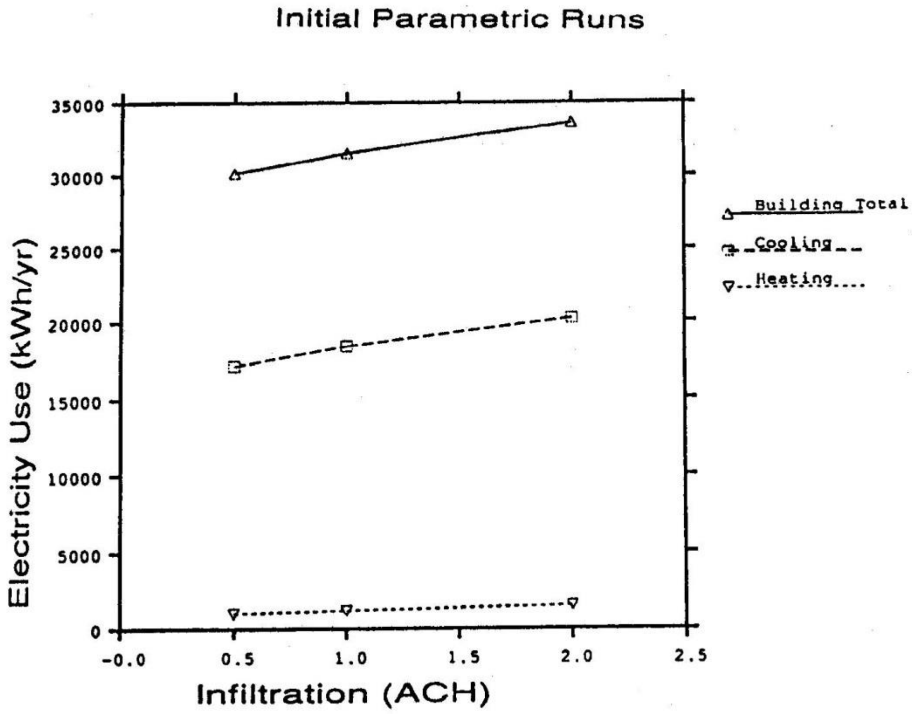
For “leaky” construction $= 28.32 \times 10^{-4} \dfrac{m^3}{s \times m^2}$

Where, m is for meters and s for seconds.

Another consideration in large buildings is air leakage associated with internal partitions, such as: elevator shafts; stairwells; service shafts; and other interior partitions.

Unnecessary Infiltration/exfiltration of air is not energy efficient (Exhibit 15-2) and must be controlled.

Exhibit 15-2: Infiltration



15.4.2 Controlling Infiltration

In existing buildings, air leakage sites must be located in order to tighten the envelope of the building. Air leakage is not caused only through windows and doors, but also through a wide range of unexpected and unobserved construction defects, or to aging of the building. While some sources of infiltration are visible and obvious, it is often difficult to identify all of the air leakages by visual inspection alone. Among the more obvious sources of air leakages are the following:

- Cracks in walls, ceilings or roof structure, which can be repaired with mortar, plaster, or other sealants
- Gaps around through-the-wall or window air conditioners, which can be sealed with closed - cell foam rubber or caulking material
- Gaps around windows and door frames, which can be sealed with caulking material, window putty or bitumen
- Entry doors or roof access doors left open, which can be remedied by installing door closers, removing doorstops, or installing vestibules for high traffic areas

15.5 The Buildings Insulation ECOs

Energy conservation opportunities related to improvements of the building envelope are generally easy to identify, but difficult to quantify in terms of potential energy savings. The reason being that buildings are dynamic structures, experiencing transient rather than steady-state heat flows.

An additional problem occurs in trying to estimate savings through reduction in infiltration or exfiltration, as these sources of energy waste depend heavily on prevailing wind direction and speed and are variable from moment to moment.

One should, however, identify building envelope energy savings opportunities even if they cannot be easily quantified. The energy surveyor should make a careful examination of the building envelope during the surveys to identify potential savings opportunities and at least make a very rough estimate of potential savings.

During the course of the survey, the surveyor should collect the following data on the building envelope:

- Building dimensions (width and height) and orientation (compass direction of the walls) for each face
- Number of stories of the building
- Materials of construction and dimensions (thickness) of construction layers of the building walls, from the outside to the inside (including internal air spaces between layers of construction), color and approximate emissivity of the exterior of the building
- Percent of the gross area of building walls that are glazed (alternately, a detailed count of windows and glazed areas).
- Material of construction and dimensions (thickness) of construction layers of the building roof, from the outside to the inside (including internal air spaces between layers of construction), color and estimated emissivity of the roof deck, orientation of the roof deck (if it is not horizontal).
- Overall condition of the building shell (walls and roof deck), examine for presence of cracks, loose mortar between courses of brick, missing or damaged brickwork, loose or missing shingles or roof tiles, evidence of water leaks or roof flooding
- Inspection for tightness of building construction by searching for gaps which allow excessive infiltration of outside air or exfiltration of conditioned inside air, poorly sealed or constructed window and door frames, gaps around window or through-the-wall air conditioners, exterior doors left open, broken windows or windows left open in conditioned spaces, gaps around doors or windows in their frames.

15.5.1 Low Cost ECOs

There are many energy conservation opportunities that can be implemented by simple changes in operation, maintenance and administrative procedures. In conducting the energy survey, a number of these measures can be identified. One should be on the lookout for these types of opportunities and point them out to the building's owner or operator. A number of these measures and the procedures required to achieve savings are described below:

- Improper alignment of windows and doors allows excessive infiltration: re-align or re-hang windows and doors to permit proper closure; make sure that automatic door closers are working properly and adjust as required for faster return; install vestibules or revolving doors at major entrances (if required).

- Ceiling/roof insulation is inadequate or has been water damaged: repair roof before replacing water damaged insulation; verify that vapor barrier faces the conditioned space and is intact; consider addition of insulation if the roof needs to be replaced.
- Weather-stripping or caulking around windows, doors, conduits, etc., is worn, missing or broken or damaged mortar allows infiltration of outside air: repair or replace damaged parts to ensure that proper sealing is maintained; air gaps around through-the-wall air conditioners should be eliminated and units should be covered in the winter.
- Excessive expanses of glass areas exist on exterior walls: use curtains and drapes to minimize solar heat gain in summer and night heat losses during winter; consider replacing glazed areas with walls; consider adding solar film or replacing windows with thermal barrier windows.
- Outside air leaks through mechanical ventilation system: a potential source of outside air infiltration is through improperly sealed dampers on air handling units, when the air handling units or exhaust fans are not in use. Adjust or replace ineffective outside air or exhaust fan dampers to minimize the infiltration of air into the building.

15.5.2 Higher Capital Cost ECOs

Higher capital cost energy conservation measures related to improvements in the building envelope include those which are major modifications or improvements to the building structure. Included in this category are the following measures:

- Applying insulation to roof surfaces: Adding a layer of insulation to an existing flat roof deck can be accomplished by building up a suitably protected insulation layer (or layers) above the existing roof deck. The insulation can take a number of forms, including layers of concrete (or foam concrete), polystyrene panels covered by light colored gravel ballast, addition of layers of fiber glass bats (protection from the weather elements is critical here) or by other means. While this higher capital cost approach is relatively easy to accomplish, it is essential that the installing contractor be experienced in the application of the insulating material and the required vapor barrier. If the insulation and vapor barrier are not installed correctly, premature aging, degradation in performance, or failure of the insulating material is likely.
- Replacement of window and door frames: Where it is not possible or desirable to seal existing window and door frames to eliminate air infiltration and exfiltration, another systems should incorporate double or triple glazing and the frames should incorporate a thermal break (to reduce conduction through the window frames). Metal door frames should also incorporate a thermal break; if glass doors are used, these should be double glazed.
- Applying insulation to existing walls: Because of the prevailing solid wall construction it is not easy to insulate existing walls. The simplest approach is to apply insulating material to the interior surface of the wall, but this may damage the appearance of the walls. A false inside wall system may be used (e.g., a layer of insulation on the inside wall covered by decorative wooden panels), but this may not always be possible or desirable on walls where there are windows. It is easier to install outside insulation on blank walls.

15.6 Fenestration/Windows

Fenestration refers to any glazed opening in the building envelope. The term "windows" will also be used to refer to glass doors or other glass areas of a building. Windows provide the following in a building.

- Satisfy the human need for visual communication with the outside world

- Allow the entrance of solar radiation to provide daylight and heat
- Enhance the aesthetics of the exterior and interior of a building
- Provide a secondary means of escape from low - rise buildings in the event of fire or other emergencies

In this section the concept of solar heat gain, computing solar heat gain, solar heat gain through windows, how solar heat gain affects building energy consumption for heating and the use of shading devices and energy efficient windows to reduce solar heat gain, will be presented.

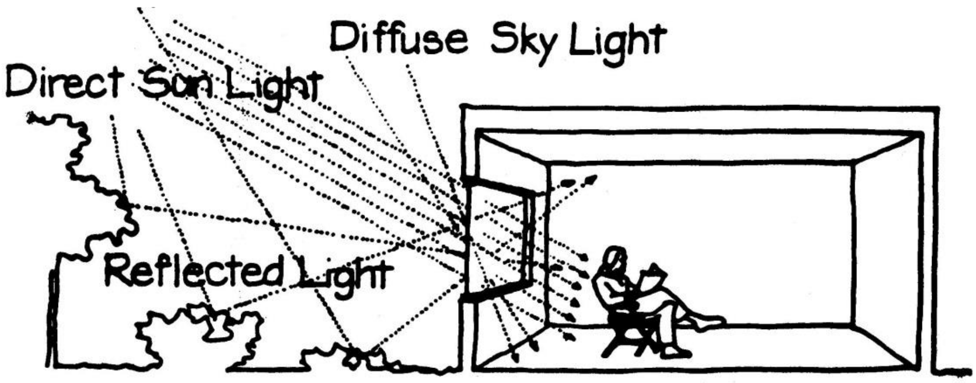
15.6.1 The Sun's Position and Solar Angles

The energy radiated by the sun and received on the surface of the earth is variable, depending on the time of the year and the local atmospheric conditions. A more or less standard figure for the intensity of solar radiation, the solar constant Isc, defined as the energy received on a surface perpendicular to the sun's rays beyond the earth's atmosphere at the mean earth-sun distance is 4933.53 kJ/h-m^2. This figure represents an average for the entire year. Since the earth's orbit is elliptical, the actual value varies from 5107.46 kJ/h-m^2 in January when the earth is closest to the sun to 4770.06 kJ/h-m^2 in July when the earth-sun distance is greatest.

15.6.2 Direct, Diffused and Reflected Solar Radiation

There are three components of solar radiation, namely: direct, diffused and reflected (Exhibit 15-3).

Exhibit 15-3: Sources of daylight



The direct component impinges directly on a given surface, while the reflected component is reflected, scattered or absorbed in the atmosphere, thus not impinging a given surface.

The diffused solar radiation falling on any surface consists of two components: radiation from the sky and part of the reflected solar radiation from the ground lying south of the surface for northern hemisphere and north of the surface for southern hemisphere. The radiation does not come uniformly from all parts of the sky.

15.6.3 Solar Heat Gain through Windows

This section describes transfer of heat through windows, absorption of solar radiation by windows, overall heat transfer co-efficient for glazing systems and the description of methods for predicting heat transfer through windows.

15.6.3.1 Absorbed Solar Radiation

When windows are irradiated by sunshine both inside and outside surfaces of the glazing material can become hotter than the temperature of the ambient air. Heat flows by radiation and convection in two directions:

- From the outer surface to the atmosphere and surrounding environment, and
- From the inner surface to room air and interior surfaces,

15.6.3.2 Coefficient of Heat Transfer: U-Value

In the absence of other heat transfer mechanisms (e.g. solar radiation, air infiltration, and moisture condensation) the rate of heat transfer through a window system is proportional to the inside - outside air temperature difference. Heat is transferred by the combined effects of radiation, conduction and convection. The normal heat flow path is parallel through the center of glass, edge of glass, and window framing members (Exhibit 15-4).

Estimation of the rate of heat transfer through the framing members of a window system is complicated by the variety of frame configurations for operable windows, the different combinations of materials used for sash and frames, and difference in sizes of windows.

15.6.3.3 Predicting Heat Transfer through Windows

The ability of glazing materials to transmit solar radiation depends to a large extent on the physiochemical properties of the material and the wavelength distribution of the impinging radiation. Tests of different types of glazing materials have indicated that, on average, the transmission of total incident solar radiation for clear float glass ranges from 86% (0.225 cm thickness) to 84% (0.3 cm thickness). The actual transmission varies with the iron content of the glass. As a comparison, bronze, gray or green heat absorbing glasses (all 0.225 cm thickness) transmit from 45% to 49% of the total incident solar radiation.

Almost all glass used in buildings is opaque to longwave radiation emitted by surfaces at temperatures below 120 0C. This characteristic is responsible for the "greenhouse effect". Solar radiation passes through a window and is absorbed by surfaces within the room. It is re-emitted from those surfaces as longwave radiation, and cannot escape back through the window, since it is opaque to the longwave radiation.

The most significant environmental factors affecting heat transmission through windows are:

- Solar radiation intensity and incident angle
- Outdoor - indoor temperature difference
- Velocity and direction of air flow across exterior and interior window surfaces
- Low temperature radiation exchange between the window surfaces and the surroundings

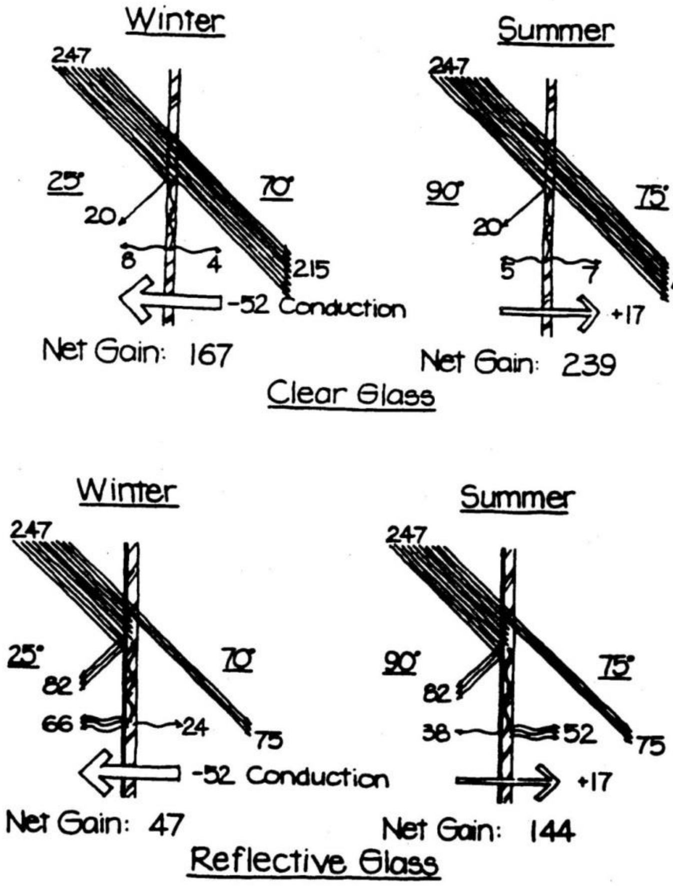
15.7 Shading Devices and Energy Efficient Windows

Most window systems are fitted with some sort of internal shading to provide privacy and aesthetic effects, as well as to give some degree of sun control. The effectiveness of any internal shading device depends on its ability to reflect incoming solar radiation back through the window before it can be absorbed and converted into heat within the building. The effectiveness of external shading devices is dependent upon their orientation in relation to the sun's path and the surface to be shaded. In this section, various types of shading devices and their effectiveness in reducing solar heat gain through windows are described.

15.7.1 Venetian Blinds and Shades

Venetian blinds and shades act to reduce solar heat gain by introducing an opaque or translucent surface between the window and the interior of the room. The solar radiation is either reflected back out of the window or absorbed by the blind or shade.

Exhibit 15-4: Heat gain through window glass



15.7.2 Draperies

Depending on the type and use of the draperies, they have been found capable of reducing both heating and cooling load in buildings by as much as 5 to 20 percent. The solar optical properties of drapery fabrics can be determined accurately through laboratory tests and manufacturers may be able to provide solar transmittance and reflectance values.

Another useful property is the openness factor, which is the ratio of the open area of the weave to the total area of the fabric. This factor can be measured exactly through laboratory measurements, or can be estimated by visual inspection.

Fabric reflectance is directly related to the ability of the fabric to reduce solar heat gain. Based on their appearance, drapery fabrics can be classified by yarn color as being light, medium, or dark. Similarly, they can be classified by inspection as being open weave, semi - open weave or closed weave.

15.7.3 Exterior Shading

The effectiveness of an exterior shading device depends on its orientation with respect to the sun and to the surface to be shaded. As the earth travels around the sun during the course of a year, the orientation of the fixed surface with respect to the sun changes. During the summer months, the sun appears to be higher in the sky than during the winter months, and rises and sets further to the north than during the winter months (In the northern hemisphere). During the summer months, the sun is farther to the south in the southern hemisphere.

At a given time from day to day, the sun's position in the sky is only slightly different. However, over the course of a few months these small daily differences add up to make a significant change. Hence, any fixed object will have a different shadow length and direction at different times during the year.

As described earlier in this section, the sun's position in the sky is defined by two angles. The altitude angle is the angle subtended by the sun perpendicular to the horizon and represents the height of the sun in the sky. The azimuth angle is the angle between due south and the sun parallel to the horizon. In designing exterior shading devices, it is important to know the sun's position in the sky during the summer and winter solstices, as this represents the extremes of the sun 's path. It is also helpful to know the sun's position during the equinoxes, as this is a middle value, and also during the hottest months of the year, when the solar shading is most required.

There are a number of types of external shading devices. The choice of the type or combination of types to employ depends on the amount of shading from direct sunlight required, and on architectural and aesthetic consideration. In addition, some choices of exterior shading devices are easier to incorporate into existing buildings than others.

15.7.4 Overhangs, Fins, and Recessed Windows

Overhangs are horizontal projections either from a building roof or from the wall above a window. Some overhangs may be slanted downward from the roof or wall surface. It is the overhang's length component which is perpendicular to the wall surface that is used to determine shading. Roof eaves, or other projections, and balconies can also perform the same function as overhangs.

Overhangs are particularly effective for the south side of a building in the northern hemisphere (and for the north side for the southern hemisphere), as they prevent the rays of the summer sun, which is high in the sky, from coming through the window. Properly placed overhangs provide the additional advantage of allowing the sun to shine into the window during the winter, when the sun is lower in the sky.

Fins are vertically oriented projections that are placed at the sides of the windows. They are useful in blocking the direct rays of the sun from entering the window when the sun is low in the sky and at an oblique angle to the window.

The benefits of overhangs and fins can also be achieved by the use of recessed windows. The window is recessed from the outside wall of the building, and the wall surfaces to the sides and above the window provide the equivalent protection of externally positioned overhangs and fins.

15.8 The Fenestration ECOs

There are many energy conservation measures that can be applied to reduce solar heat gain through windows. However, they all fall under the same general strategy: reduce the amount of sunlight entering the space through the glazed portions of the building envelope.

15.8.1 Window Inventory

In determining the potential for energy savings through reduction in solar heat gain, an inventory of the windows and other glazed areas in the building must be developed. The inventory itself is fairly simple to organize, although it can be time consuming. Data collected during a window survey includes the following:

- Orientation of window or group of windows (compass direction)
- Dimensions of windows (length, width, sash length)
- Window configuration (number of panes, single or double glazed and type of glass, type of framing material, presence or absence of storm windows)

- Presence of overhangs, balconies, fins, other external shading devices (and their dimensions) and internal shading devices

A sketch of typical window types used in the building is useful and should be included as part of the inventory. Any convenient form or worksheet can be developed during the survey to aid in data collection and organization.

15.8.2 Energy Savings Measures

In keeping with the general principle behind reducing solar heat gain, the following measures can be applied:

- Adjust existing blinds, drapes, shutters, or other shading devices to prevent penetration of solar radiation into the building.
- Install blinds, drapes, shutters, or other shading devices on the south, east, and west windows in the northern hemisphere (north, east and west windows for the southern hemisphere. If north - facing windows are subject to large amounts of reflected solar radiation (e.g. these exposures face open expanses of land, bodies of water, etc.) consider the use of interior shading devices.
- Where the use of interior shading devices is not appropriate or desired for aesthetic or other considerations, similar savings can be obtained through the use of solar reflective films applied to the glass surfaces.
- Consider the attachment of fixed or removable awnings or other overhangs on south facing windows where these are not currently installed to block the sun. Exterior fins can be installed on east and west facing glass. The solar control devices should provide 100 percent shading during the hottest months of the year.

The computation procedure for determining the energy savings through the installation of devices which reduce solar heat gain is a complex one. It needs to take into account the movement of the sun in the sky, shading of the building by other buildings and landscaping, details for the location in question, and numerous other factors. Generally, the most accurate method of computing the energy savings through implementation of such measures is through the use of computerized building energy simulation models, which take all of these factors into account. However, a discussion of the use of such models is not necessary here.

Hand computations are lengthy and time consuming. The general procedure is to determine the annual solar heat gain into the space through the windows with and without the solar barrier. The difference between these figures is the annual reduction in solar heat gain, which can be considered to be a reduction in building cooling load. This can then be translated into energy savings by dividing by the efficiency of the building cooling system (e.g. dividing by the chiller efficiency and boiler efficiency for absorption refrigeration equipment; by the chiller efficiency for cooling by electric refrigeration equipment; or by the COP of window air conditioner).

16 Financial Analysis

Electrical energy is expensive and undoubtedly will become more so in future. Thus it is necessary for every electricity consumer to use electrical energy as efficiently as possible. But this is not as simple as it sounds since there is much more to using electrical energy efficiently than just using less of it, although, of course, lower consumption is one important ingredient in saving electricity and reducing the electricity bill.

16.1 Economics of electrical energy conservation

Electrical energy conservation measures can be grouped into three categories, relative to their economic attractiveness, and thus their attractiveness to the plant management:

- No cost/low cost measures
- Medium and acceptable cost measures
- High cost measures

A variety of economic and financial analysis are used by different organizations to evaluate financial viability of the projects. For most no cost/low cost or medium cost projects calculations of simple payback is considered sufficient.

No cost/low cost measures

Switching of lights, idle running equipment, insulation of chilled or electrically heated process fluid, better control of process variables and process equipment fall under this category. These measures often require little or no investment, and should obviously be the first choice for implementation. A plant energy conservation awareness/information campaign can also be considered a low/no cost measure. Creating interest in energy awareness also helps in consideration of projects which require larger funds for implementation.

Medium cost measures

In a number of cases the investment made in efficiency improvement can be recovered within a year or slightly more. Most organizations would consider such a payback as very attractive, and where the capital required for implementation is not high, these projects may get approved along with the no cost/low cost measures. The financial returns from no cost/low cost and medium cost measures can be used to invest in higher cost energy conservation measures if justified.

High cost measures

These are the opportunities which either pay in a matter of few years or even if the payback is a year, require substantial investment from the management's point of view. These measures should be considered for detailed feasibility studies and costing. Often, measures involving replacement of equipment with more efficient models fall in this category. Such equipment replacement may be delayed until new purchases are required anyway, at which time the net additional cost for higher efficiency can be easily justified.

There are many methods employed for measuring the financial attractiveness of any investment. Energy conservation investments can and should be judged on the same basis as any other company project to increase production or productivity. The more common methods used to perform financial analyses are reviewed below.

16.2 Simple Payback Period

The easiest and most basic measure of financial attractiveness of a project is the simple payback period. The simple payback period reflects the length of time required for a project to return its investment through net savings (gross annual savings and other benefits less any additional annual operating and maintenance expenses due to the project). Savings generated after that time are considered to be "unburdened" savings: these savings do not have to be used to repay the cost of the project. In cases where the annual savings are constant, the simple payback period can be computed from the following formula:

$$\text{Simple Payback Period (years)} = \frac{\text{Total Implementation Cost}}{\text{Net Annual Savings}}$$

A more attractive investment is one with a shorter simple payback period. In order to express the simple payback period in terms of months instead of years, the expression above is simply multiplied by 12. The simple payback period can be expressed in terms of before tax or after tax savings by substitution of the appropriate figure in the denominator of the above expression.

A similar measure of financial profitability is known as percent rate of return, or return on investment (ROI). This is simply the reciprocal of simple payback, multiplied by 100 percent:

$$\text{Percent Rate of Return} = \frac{\text{Net Annual Savings} \times 100}{\text{Total Capital Cost}}$$

The higher the percent rate of return, the more attractive the investment opportunity.

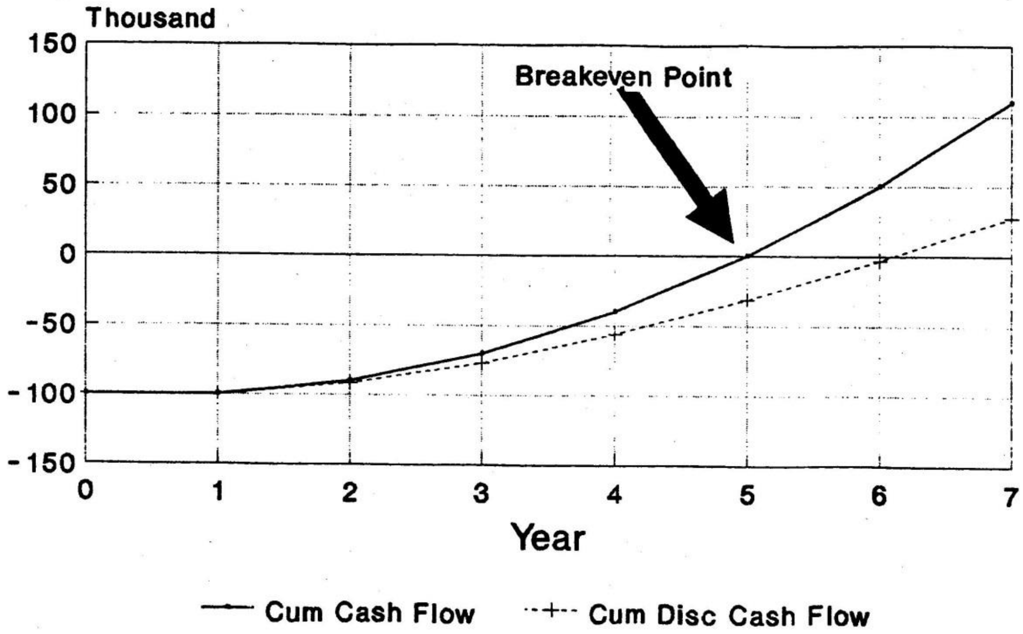
In cases where the net annual savings are not constant from year to year (e.g. a project which has different maintenance requirements from year to year), the simple payback period can be determined graphically. An example of this technique is shown in Exhibit 16-1. For this example, the cash flows from project A in Exhibit 16-2 are used.

Exhibit 16-1: Comparison of cash flows of two projects

Year	Project A Annual Cash Flow (PKR)	Project A Cumulative Cash Flow (PKR)	Project B Annual Cash Flow (PKR)	Project B Cumulative Cash Flow (PKR)
0	(100,000)	(100,000)	(100,000)	(100,000)
1	0	(100,000)	50,000	(50,000)
2	10,000	(90,000)	30,000	(20,000)
3	20,000	(70,000)	20,000	0
4	30,000	(40,000)	10,000	10,000
5	40,000	0	0	10,000
6	50,000	50,000	0	10,000
7	60,000	110,000	0	10,000
Total		**110,000**		**10,000**
Simple Payback		**5 years**		**3 years**

As can be seen in Exhibit 16-1, the simple payback period is the time after project implementation when the cumulative net savings are equal to the total capital cost or where the cumulative cash flow is zero. This is also known as the break-even point.

Exhibit 16-2: Simple payback period vs. discounted payback period



There are, however, some problems with this technique which may lead to incorrect comparisons of project alternatives. For instance, the simple payback period does not take into account the net profits or net savings achieved after the break-even point has been achieved. As an example, consider the two projects shown in Exhibit 16-2. Both projects have an initial investment of 100,000. On the basis of payback period, project A reaches its break-even point after 5 years, while project B's break-even point is reached after 3 years. However, a comparison of the cumulative cash flows of the two projects indicates that project A yields a cumulative cash flow of 110,000 while project B yields a cumulative cash flow of only 10,000. Project A is obviously much more profitable than project B. Hence, the simple payback period on its own can lead to erroneous decision making.

Other disadvantages of the simple payback method include:

- It ignores the time value of money.
- It does not reflect changing energy prices.
- It usually ignores the effect of taxation.
- It usually assumes a continuation of the status quo in terms of production and other relevant variables.
- It ignores any residual value of capital assets.

Despite its limitations, simple payback period has some advantages. There are several situations in which the simple payback method might be particularly appropriate:

- A rapid payback may be the prime criterion for judging an investment when financial resources are available to the investor for only a short period of time.
- The speculative investor who has a very limited time horizon will usually desire rapid recovery of the initial investment.
- Where the expected life of the assets is highly uncertain, the break-even point is helpful in assessing the likelihood of achieving a successful investment.
- Simple payback may be used for rapid screening of a large number of projects with, for example, those projects showing paybacks under 4 years retained and subjected to more sophisticated analysis.

16.3 Discounted Payback Period

This method is a variation on the simple payback analysis, but only taking the time value of money into account. In this approach, the net annual savings for each year is discounted back to the year of implementation using the cost of capital to the company:

$$\text{Discounted Annual Savings}_n = \frac{\text{Net Annual Savings}_n}{(1 + i)^n}$$

Where, i = the interest rate or cost of capital

n = the year from project implementation.

The factor $1/(1 + i)^n$ is called the discount factor, and can be calculated for any number of years n based on the interest rate i. It is the interest rate that determines the time value of money. Discount rates can be read off a table such as provided in Exhibit 16-3.

As managers who have to deal with financial matters are aware, money has a value that is related to time. The purpose of investments is to set aside a sum of money now in expectation of receiving a larger sum in the future. By using the discounted cash flow approach, and assigning a value to the cost of capital, it becomes apparent that the cash flows in the early years of a project have a greater value at the present time than the same amounts in the later years of a project. The following example illustrates this point:

Example:

Assuming that the cost of capital is 10% per year, what is the present value of 100,000 if it is to be received in two years? What is the present value of the same sum if it is to be received in six years?

The easiest way to calculate this is by using the discount factors of Exhibit 16-3. Multiplying the appropriate factor by 100,000, we find that the present value of the sum to be paid in two years is 82,600, while if it is to be paid in 6 years, the present value is only 56,400.

Therefore, it pays to receive money as soon as possible, and to delay paying out money for as long as possible. Assuming a discount rate of 10%, and applying the discount factors to the same project A in Exhibit 16-2, we obtain Exhibit 16-4.

The discounted payback period is generally determined graphically. As can be seen in Exhibit 16-2 , the discounted payback period is slightly over 6 years, as compared to the 5 year simple payback period for the same project.

While the discounted payback period approach has some advantage over the simple payback period approach, it still neglects cash flows generated after the break-even point.

Exhibit 16-3: Discounted factor for future payments

DISCOUNT FACTOR - How much 1 at a future date is worth today

Year	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	16%	17%	18%	19%	20%
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893	0.885	0.877	0.870	0.862	0.855	0.847	0.840	0.833
2	0.980	0.961	0.943	0.925	0.907	0.890	0.873	0.857	0.842	0.826	0.812	0.797	0.783	0.769	0.756	0.743	0.731	0.718	0.706	0.694
3	0.971	0.942	0.915	0.889	0.864	0.840	0.816	0.794	0.772	0.751	0.731	0.712	0.693	0.675	0.658	0.641	0.624	0.609	0.593	0.579
4	0.961	0.924	0.888	0.855	0.823	0.792	0.763	0.735	0.708	0.683	0.659	0.636	0.613	0.592	0.572	0.552	0.534	0.516	0.499	0.482
5	0.951	0.906	0.863	0.822	0.784	0.747	0.713	0.681	0.650	0.621	0.593	0.567	0.543	0.519	0.497	0.476	0.456	0.437	0.419	0.402
6	0.942	0.888	0.837	0.790	0.746	0.705	0.666	0.630	0.596	0.564	0.535	0.507	0.480	0.456	0.432	0.410	0.390	0.370	0.352	0.335
7	0.933	0.871	0.813	0.760	0.711	0.665	0.623	0.583	0.547	0.513	0.482	0.452	0.425	0.400	0.376	0.354	0.333	0.314	0.296	0.279
8	0.923	0.853	0.789	0.731	0.677	0.627	0.582	0.540	0.502	0.467	0.434	0.404	0.376	0.351	0.327	0.305	0.285	0.266	0.249	0.233
9	0.914	0.837	0.766	0.703	0.645	0.592	0.544	0.500	0.460	0.424	0.391	0.361	0.333	0.308	0.284	0.263	0.243	0.225	0.209	0.194
10	0.905	0.820	0.744	0.676	0.614	0.558	0.508	0.463	0.422	0.386	0.352	0.322	0.295	0.270	0.247	0.227	0.208	0.191	0.176	0.162
11	0.896	0.804	0.722	0.650	0.585	0.527	0.475	0.429	0.388	0.350	0.317	0.287	0.261	0.237	0.215	0.195	0.178	0.162	0.148	0.135
12	0.887	0.788	0.701	0.625	0.557	0.497	0.444	0.397	0.356	0.319	0.286	0.257	0.231	0.208	0.187	0.168	0.152	0.137	0.124	0.112
13	0.879	0.773	0.681	0.601	0.530	0.469	0.415	0.368	0.326	0.290	0.258	0.229	0.204	0.182	0.163	0.145	0.130	0.116	0.104	0.093
14	0.870	0.758	0.661	0.577	0.505	0.442	0.388	0.340	0.299	0.263	0.232	0.205	0.181	0.160	0.141	0.125	0.111	0.099	0.088	0.078
15	0.861	0.743	0.642	0.555	0.481	0.417	0.362	0.315	0.275	0.239	0.209	0.183	0.160	0.140	0.123	0.108	0.095	0.084	0.074	0.065
16	0.853	0.728	0.623	0.534	0.458	0.394	0.339	0.292	0.252	0.218	0.188	0.163	0.141	0.123	0.107	0.093	0.081	0.071	0.062	0.054
17	0.844	0.714	0.605	0.513	0.436	0.371	0.317	0.270	0.231	0.198	0.170	0.146	0.125	0.108	0.093	0.080	0.069	0.060	0.052	0.045
18	0.836	0.700	0.587	0.494	0.416	0.350	0.296	0.250	0.212	0.180	0.153	0.130	0.111	0.095	0.081	0.069	0.059	0.051	0.044	0.038
19	0.828	0.686	0.570	0.475	0.396	0.331	0.277	0.232	0.194	0.164	0.138	0.116	0.098	0.083	0.070	0.060	0.051	0.043	0.037	0.031
20	0.820	0.673	0.554	0.456	0.377	0.312	0.258	0.215	0.178	0.149	0.124	0.104	0.087	0.073	0.061	0.051	0.043	0.037	0.031	0.026
25	0.780	0.610	0.478	0.375	0.295	0.233	0.184	0.146	0.116	0.092	0.074	0.059	0.047	0.038	0.030	0.024	0.020	0.016	0.013	0.010
30	0.742	0.552	0.412	0.308	0.231	0.174	0.131	0.099	0.075	0.057	0.044	0.033	0.026	0.020	0.015	0.012	0.009	0.007	0.005	0.004
35	0.706	0.500	0.355	0.253	0.181	0.130	0.094	0.068	0.049	0.036	0.026	0.019	0.014	0.010	0.008	0.006	0.004	0.003	0.002	0.002
40	0.672	0.453	0.307	0.208	0.142	0.097	0.067	0.046	0.032	0.022	0.015	0.011	0.008	0.005	0.004	0.003	0.002	0.001	0.001	0.001
50	0.608	0.372	0.228	0.141	0.087	0.054	0.034	0.021	0.013	0.009	0.005	0.003	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000

Exhibit 16-4: Discounted cash flow for Project A

Year	Annual Cash Flow (PKR)	Discounted Cash Flow (PKR)
0	(100,000)	(100,000)
1	0	0
2	10,000	8,264
3	20,000	15,026
4	30,000	20,496
5	40,000	24,837
6	50,000	28,224
7	60,000	30,789

16.4 Discounted Cash Flow

The discounted cash flow approach (sometimes referred to as the net present value approach) uses the time value of money to convert a stream of annual cash flows generated by a project to a single value: the net present value. The discounted cash flow approach also allows one to incorporate depreciation, income tax implications, and other cash flows that may vary from year to year.

The discounted cash flow or net present value method takes a stream of cash flows over a period of time and "discounts" the cash flows to yield their cumulative present value. This cumulative present value may be thought of as the amount of money that needs to be invested today at an interest rate equal to the discount rate (time value of money) in order to generate the amount of revenue equal to the cash flow in each of the years of the project.

An example of this approach is shown in Exhibit 16-4. Naturally, the net present value of a stream of cash flows depends heavily on the time value of money assumed. Generally the time value of money is taken to be that annual rate of interest that can be achieved through the safest investment possible (generally, leaving the money in the bank) where the possibility of achieving a fixed rate of return is as close to a surety as possible.

The higher the cost of capital, the lower the net present value of a future sum of money. This can be seen in Exhibit 16-4. For instance, in year 10 a sum of 320,000 is expected to be received. The present value of that sum, assuming a cost of capital of 10% is seen to be 123,374; at 15% cost of capital, the present value is reduced to 79,099 and at 20%, the present value of that same sum is only 51,682.

The same principle applies to a stream of cash flows and its cumulative value. The cumulative value (not discounted) of the cash flows is seen to be 2,140,000 (the cumulative cash flow in the last year, year 14, in Exhibit 16-4). Applying the appropriate discount rates to these cash flows, we see that the cumulative net present value of the individual cash flows is reduced to 558,106 at 10%, to 231,927 at 15%, and to 42,113 at 20%.

When comparing alternative investment opportunities, the net present value approach is a useful tool. As might be expected, when comparing alternative investments, the project having the highest cumulative net present value is the most attractive. However, the net present value approach has one serious limitation. It should not be used to compare projects having unequal lives. For these types of project comparisons, a useful alternative is the annualized cost, or life cycle cost approach.

16.5 Internal Rate of Return (IRR)

The internal rate of return and the net present value approaches are very similar. As stated previously, the cumulative net present value can be thought of as the amount of money we must invest at an interest rate equivalent to the discount rate in order to be able to draw off revenues equal to the non-discounted cash flows in each of the years of the project. In the IRR approach, we seek to determine that interest rate at which the cumulative net present value of the project is equal to zero. This means that the cumulative net present value of all project costs would exactly equal the cumulative net present value of all project benefits, if both are discounted at the internal rate of return.

This computed IRR is compared to the company's actual cost of capital. If the IRR exceeds the company's cost of capital, the project is considered to be financially attractive. The higher the IRR compared to the cost of capital, the more attractive the project. On the other hand, if the IRR is less than the company's cost of capital, then the project is not considered to be financially attractive.

The manual computation of IRR is generally an iterative process. Many personal computer spreadsheet programs and some hand-held financial calculators have the ability to compute IRR from a stream of cash flows. Manually, one starts with a "guess" of the IRR and computes the cumulative net present value of the cash flow stream. If the cumulative net present value is positive, repeat the process with a higher assumed IRR. If the cumulative net present value is negative, repeat the process with a lower assumed IRR. Repeat the iterative process until the cumulative net present value is close to zero.

Using the annual cash flow data from Exhibit 16-5, compute the internal rate of return of the project.

Exhibit 16-5: Discounted and cumulative discounted cash flows at various interests

	Not Discounted		Discounted at 10%		Discounted at 15%		Discounted at 20%	
Year	Cash Flow	Cummulative Cash Flow	Cash Flow	Cummulative Cash Flow	Cash Flow	Cummulative Cash Flow	Cash Flow	Cummulative Cash Flow
0	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)
1	(30,000)	(40,000)	(27,273)	(37,273)	(26,087)	(36,087)	(25,000)	(35,000)
2	(60,000)	(100,000)	(49,587)	(86,860)	(45,369)	(81,456)	(41,667)	(76,667)
3	(750,000)	(850,000)	(563,486)	(650,346)	(493,137)	(574,593)	(434,028)	(510,694)
4	(150,000)	(1,000,000)	(102,452)	(752,798)	(85,763)	(660,356)	(72,338)	(583,032)
5	200,000	(800,000)	124,184	(628,613)	99,435	(560,920)	80,376	502,657
6	300,000	(500,000)	169,342	(459,271)	129,698	(431,222)	100,469	(402,188)
7	400,000	(100,000)	205,263	(254,008)	150,375	(280,847)	111,633	(290,555)
8	400,000	300,000	186,603	(67,405)	130,761	(150,087)	93,027	(197,528)
9	360,000	660,000	152,675	85,270	102,334	(47,752)	69,770	(127,757)
10	320,000	980,000	123,374	208,644	79,099	31,347	51,682	(76,075)
11	280,000	1,260,000	98,138	306,782	60,184	91,531	37,685	(38,391)
12	240,000	1,500,000	76,471	383,254	44,858	136,389	26,918	(11,473)
13	240,000	1,740,000	69,519	452,773	39,007	175,396	22,431	10,958
14	400,000	2,140,000	105,333	558,106	56,531	231,927	31,155	42,113

The manual computations, performed with the aid of a microcomputer, are shown in Exhibit 16-6. The starting point for the calculation was an assumed IRR of 15%. This yielded a cumulative discounted cash flow that was too high. Since cumulative discounted cash flow decreases with increasing cost of capital, the next iteration assumed a value of 20% for the IRR. The cumulative discounted cash flow was still positive, so the calculation was repeated with a higher IRR of 25%, giving a negative cumulative discounted cash flow. The next guess was 22.5%, and the iterations are repeated until the cumulative net present value was as close to zero as possible. The last column shows the estimated IRR at 21.625% (see Exhibit 16-6).

Exhibit 16-6: Internal Rate of Return (IRR)

Year	Actual Cash Flow	Discounted at 15%	at20%	at 25%	at 22.5%	at 21.5%	at 21.75%	at 21.625%
0	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)
1	(30,000)	(26,087)	(25,000)	(24,000)	(24,490)	(24,691)	(24,641)	(24,666)
2	(60,000)	(45,369)	(41,667)	(38,400)	(38,983)	(40,644)	(40,477)	(40,561)
3	(750,000)	(493,137)	(434,028)	(384,000)	(407,993)	(418,150)	(415,580)	(416,862)
4	(150,000)	(85,763)	(72,338)	(61,440)	(66,611)	(68,831)	(68,268)	(68,549)
5	200,000	99,435	80,376	65,536	72,502	75,535	74,763	75,148
6	300,000	129,698	100,469	78,643	88,778	93,253	92,110	92,680
7	400,000	150,375	111,633	83,886	96,929	102,335	100,874	101,601
8	400,000	130,761	93,027	67,109	78,881	84,227	82,853	83,537
9	360,000	102,334	69,770	48,318	57,953	62,390	61,247	61,815
10	320,000	79,099	51,682	34,360	42,052	45,644	44,716	45,177
11	280,000	60,184	37,685	24,052	30,037	32,871	32,137	32,502
12	240,000	44,858	26,918	16,493	21,017	23,190	22,625	22,905
13	240,000	39,007	22,431	13,194	17,157	19,086	18,583	18,833
14	400,000	56,531	31,155	17,592	23,343	26,181	25,439	25,807
Cumulative Discounted Cash Flow	**2,140,000**	**231,927**	**42,113**	**(68,657)**	**(20,728)**	**2,396**	**(3,621)**	**(633)**

The exact IRR, calculated by the computer software is 21.5987%. The iterative estimate of 21.625% is quite sufficient.

The internal rate of return approach has its advantage in that it provides a single number that can be compared to a standard or fixed cost of capital to the company. In many cases, the IRR is used alone to decide on investment priorities. The IRR represents the effective interest rate that will be received on the investment after repayment of the original investment, plus any interest due on borrowed funds, plus all taxes and expenses.

However, the IRR does not give the decision maker a perspective on the magnitude of the expected return or of the original investment. For instance, a project with an original investment of 100,000 and annual cash flows of 10,000 per year for 5 years has the exact same IRR as an investment of 1 million and annual cash flows of 100,000 per year for 5 years. Hence, the IRR method should not be used by itself. It is often convenient to compute the IRR of the investment and the cumulative net present value at the cost of capital to the company. For each project under consideration comparisons should be made on the two measures of financial attractiveness, rather than on only one or the other of the measures.

16.6 Annualized or Life Cycle Costs

The life cycle cost approach is a particularly useful method for comparing the financial attractiveness of investment opportunities having different lives and varying cash flows during those service lives. It involves finding the cumulative net present value of the series of cash flows, at the cost of capital to the company, and transforming the total into a stream of equal cash flows. The cash flow for each year represents the expected annual cash flow, including the cost of the original investment. In effect, the life cycle cost can be thought of as the uniform annual amount that the present value of the individual cash flows can be expected to yield over the life of the project at the cost of capital chosen.

The computational procedure is a bit more complex than either of the methods previously discussed. It involves determining the annualized value of the investment over the life of the project. The uneven cash flows generated over the life of the project also need to be transformed into a uniform stream of annual cash flows. This is done by finding the present value of each of the annual cash flows, and then determining the value of a uniform series of cash flows that is equivalent to that present value. The sum of the annualized value of the investment and the uniform annual cash flow is the annualized cash flow of the investment.

Using the annual cash flow data from Exhibit 16-5, compute the uniform annual value of the investment if the cost of capital is 10%.

The data and calculation are shown in Exhibit 16-7. The second column of the table in the Exhibit 16-7 shows the actual cash flows in each year. Each of the individual yearly cash flow is transformed into its net present value by applying the following relationship:

Present value = future value^n x present worth factor^n

Exhibit 16-7: Annualized or life-cycle cost method

Year	Actual Cash Flow	10% Present Worth Factor	Present Worth	10% Capital Recovery Factor	Annualized Equivalent Cash Flow
0	(10,000)	1.0000	(10,000)	0.1357	(1,357)
1	(30,000)	0.9091	(27,273)	0.1357	(3,702)
2	(60,000)	0.8264	(49,587)	0.1357	(6,731)
3	(750,000)	0.7513	(563,486)	0.1357	(76,491)
4	(150,000)	0.6830	(102,452)	0.1357	(13,907)
5	200,000	0.6209	124,184	0.1357	16,858
6	300,000	0.5645	169,342	0.1357	22,988
7	400,000	0.5132	205,263	0.1357	27,864
8	400,000	0.4665	186,603	0.1357	25,331
9	360,000	0.4241	152,675	0.1357	20,725
10	320,000	0.3855	123,374	0.1357	16,748
11	280,000	0.3505	98,138	0.1357	13,322
12	240,000	0.3186	76,471	0.1357	10,381
13	240,000	0.2897	69,519	0.1357	9,437
14	400,000	0.2633	105,333	0.1357	14,298
	Net Worth of Investment		**558,106**	**0.1357**	**75,761**
			Total Annualized Cash Flow		**75,761**

The present worth factor is the same as the discount factor defined previously. The computed present worth factors are shown in the third column of Exhibit 16-7. The computed present worth of each of the yearly cash flows are shown in the fourth column.

To transform the individual present worth to the equivalent uniform series of cash flows at a cost of capital of 10% and a 14 year project life, the appropriate capital recovery factor must be used. The capital recovery factor is defined as:

$$\text{Capital Recovery Factor} = \frac{i\,(1 + i)^n}{(1 + i)^n - 1}$$

Where: i = the interest rate or cost of capital

n = the number of years of the project.

The capital recovery factor is the inverse of the annuity factor, which is tabulated in Exhibit 16-8. The annuity factor at 10% for a project with a life of 14 years is 7.367. Hence, the capital recovery factor at 10% cost of capital and 14 year project life is equal to 0.1357; this figure is shown in fifth column of Exhibit 16-7. The net present worth of the individual years' cash flows are multiplied by the capital recovery factor to yield the equivalent uniform annual cash flow for each of the individual cash flows. These are shown in the last column. Finally, the annualized equivalent cash flows of each of the individual annual cash flows are summed to yield the total annualized cash flow. This sum, 75,761, is shown at the bottom of the last column.

Instead of performing the multiplication of capital recovery factor by individual annual cash flow present value, we can sum the present values of all of the individual cash flows (which we recall is the cumulative net present value) and apply the capital recovery factor to this single value. The cumulative net present value is shown at the bottom of the fourth column of the table, and the multiplication operation is shown across that row, yielding (as it should) the same result for annualized cash flow of 75,761.

16.7 Specific Energy Consumption

Another quantity that is commonly monitored is the specific energy consumption SEC, the energy used per unit of output:

$$SEC = \frac{E}{P}$$

For the ideal factory, with no services and no standing losses:

$$SEC = \frac{E}{P} = m \text{ (that is, a constant)}$$

In most real industrial facilities, the actual relationship between energy used e and production p is a combination of those described in the two Exhibits described above. This is shown in Exhibit 16-9, where the energy consumption has two components, namely:

mp = energy related to production

e = energy not related to production

Where m is a constant (equal to the gradient of the line).

For example, in one factory, "mp" could be the electricity used usefully by machinery, while "e" could be the electricity used for various purposes which are unrelated to the level of production, such as:

- Lighting
- Producing compressed air
- Running office typewriters, computers, etc.
- Running ventilation fans
- Powering machine tools in the workshop
- Unnecessary idling of production equipment
- Compressors and pumps running to compensate air and water leaks.

Ideally, if there were no such "services", the energy used would be directly related to production, e would be equal to zero, and e = mp. At the other extreme, a very inefficient factory may use the same energy whether production is going on or not (e = e). The greater that e is, relative to e (i.e., the smaller the slope m of the line) the greater the possibility of energy savings waiting to be made.

In the typical industrial case illustrated in Exhibit 16-9, the specific energy consumption is given by:

$$C = \frac{E}{P} = \frac{e}{p} + m$$

Exhibit 16-8: Present worth of an annuity

PRESENT WORTH OF AN ANNUITY
How much 1 received or paid annually for X years is worth today

Year	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	16%	17%	18%	19%	20%
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893	0.885	0.877	0.870	0.862	0.855	0.847	0.840	0.833
2	1.970	1.942	1.913	1.886	1.859	1.833	1.808	1.783	1.759	1.736	1.713	1.690	1.668	1.647	1.626	1.605	1.585	1.566	1.547	1.528
3	2.941	2.884	2.829	2.775	2.723	2.673	2.624	2.577	2.531	2.487	2.444	2.402	2.361	2.322	2.283	2.246	2.210	2.174	2.140	2.106
4	3.902	3.808	3.717	3.630	3.546	3.465	3.387	3.312	3.240	3.170	3.102	3.037	2.974	2.914	2.855	2.798	2.743	2.690	2.639	2.589
5	4.853	4.713	4.580	4.452	4.329	4.212	4.100	3.993	3.890	3.791	3.696	3.605	3.517	3.433	3.352	3.274	3.199	3.127	3.058	2.991
6	5.795	5.601	5.417	5.242	5.076	4.917	4.767	4.623	4.486	4.355	4.231	4.111	3.998	3.889	3.784	3.685	3.589	3.498	3.410	3.326
7	6.728	6.472	6.230	6.002	5.786	5.582	5.389	5.206	5.033	4.868	4.712	4.564	4.423	4.288	4.160	4.039	3.922	3.812	3.706	3.605
8	7.652	7.325	7.020	6.733	6.463	6.210	5.971	5.747	5.535	5.335	5.146	4.968	4.799	4.639	4.487	4.344	4.207	4.078	3.954	3.837
9	8.566	8.162	7.786	7.435	7.108	6.802	6.515	6.247	5.995	5.759	5.537	5.328	5.132	4.946	4.772	4.607	4.451	4.303	4.163	4.031
10	9.471	8.983	8.530	8.111	7.722	7.360	7.024	6.710	6.418	6.145	5.889	5.650	5.426	5.216	5.019	4.833	4.659	4.494	4.339	4.192
11	10.368	9.787	9.253	8.760	8.306	7.887	7.499	7.139	6.805	6.495	6.207	5.938	5.687	5.453	5.234	5.029	4.836	4.656	4.486	4.327
12	11.255	10.575	9.954	9.385	8.863	8.384	7.943	7.536	7.161	6.814	6.492	6.194	5.918	5.660	5.421	5.197	4.988	4.793	4.611	4.439
13	12.134	11.348	10.635	9.986	9.394	8.853	8.358	7.904	7.487	7.103	6.750	6.424	6.122	5.842	5.583	5.342	5.118	4.910	4.715	4.533
14	13.004	12.106	11.296	10.563	9.899	9.295	8.745	8.244	7.786	7.367	6.982	6.628	6.302	6.002	5.724	5.468	5.229	5.008	4.802	4.611
15	13.865	12.849	11.938	11.118	10.380	9.712	9.108	8.559	8.061	7.606	7.191	6.811	6.462	6.142	5.847	5.575	5.324	5.092	4.876	4.675
16	14.718	13.578	12.561	11.652	10.838	10.106	9.447	8.851	8.313	7.824	7.379	6.974	6.604	6.265	5.954	5.668	5.405	5.162	4.938	4.730
17	15.562	14.292	13.166	12.166	11.274	10.477	9.763	9.122	8.544	8.022	7.549	7.120	6.729	6.373	6.047	5.749	5.475	5.222	4.990	4.775
18	16.398	14.992	13.754	12.659	11.690	10.828	10.059	9.372	8.756	8.201	7.702	7.250	6.840	6.467	6.128	5.818	5.534	5.273	5.033	4.812
19	17.226	15.678	14.324	13.134	12.085	11.158	10.336	9.604	8.950	8.365	7.839	7.366	6.938	6.550	6.198	5.877	5.584	5.316	5.070	4.843
20	18.046	16.351	14.877	13.590	12.462	11.470	10.594	9.818	9.129	8.514	7.963	7.469	7.025	6.623	6.259	5.929	5.628	5.353	5.101	4.870
25	22.023	19.523	17.413	15.622	14.094	12.783	11.654	10.675	9.823	9.077	8.422	7.843	7.330	6.873	6.464	6.097	5.766	5.467	5.195	4.948
30	25.808	22.396	19.600	17.292	15.372	13.765	12.409	11.258	10.274	9.427	8.694	8.055	7.496	7.003	6.566	6.177	5.829	5.517	5.235	4.979
35	29.409	24.999	21.487	18.665	16.374	14.498	12.948	11.655	10.567	9.644	8.855	8.176	7.586	7.070	6.617	6.215	5.858	5.539	5.251	4.992
40	32.835	27.355	23.115	19.793	17.159	15.046	13.332	11.925	10.757	9.779	8.951	8.244	7.634	7.105	6.642	6.233	5.871	5.548	5.258	4.997
50	39.196	31.424	25.730	21.482	18.256	15.762	13.801	12.233	10.962	9.915	9.042	8.304	7.675	7.133	6.661	6.246	5.880	5.554	5.262	4.999

When production is very high, e/p becomes very small and the value of c approaches m. But if orders fall off and p becomes small, then "e", which is the energy not related to production, becomes very important and c increases rapidly.

Exhibit 16-9: Energy vs. production (typical factory)

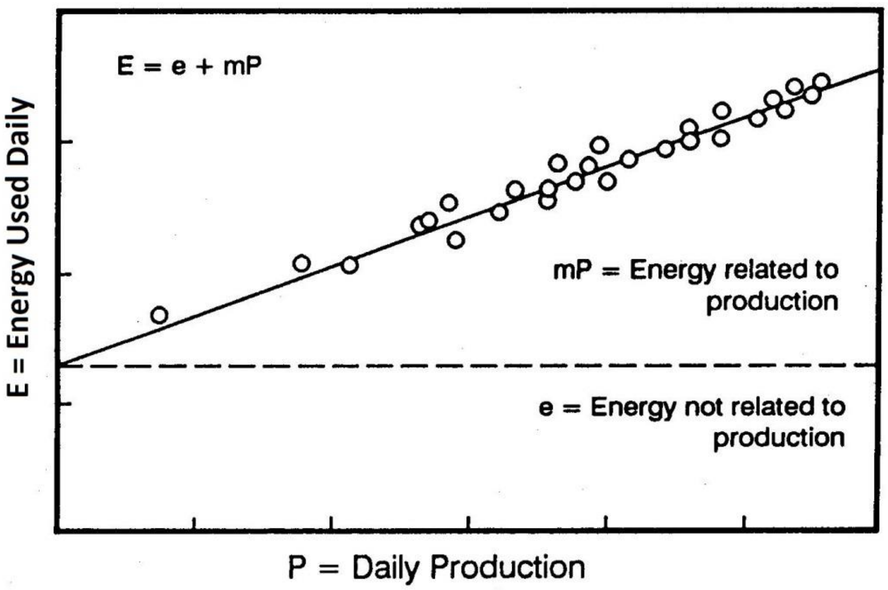
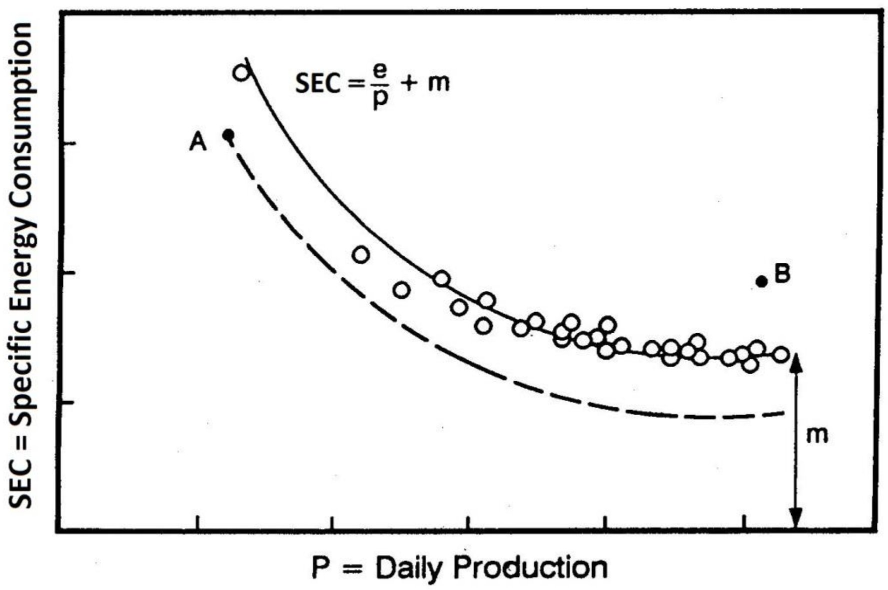


Exhibit 16-10 shows how the specific energy consumption SEC varies with production p. It will be noted that a point lying below the line represents improved efficiency energy usage. Over a period of time, each establishment should be trying to bring performance curve lower and lower.

16.8 Plant energy performance

Plant energy performance (pep) is the measure of whether a plant is now using more or less energy to manufacture its products than it did in the past; a measure of how well the energy management program is doing. It compares the change year to year in a plant's energy use considering production output. Plant energy performance monitoring compares plant energy use of a reference year and the subsequent years to determine the improvement that has been made.

Exhibit 16-10: Specific energy consumption vs. production



However, the plants' production output varies from year to year and the production output has a significant bearing on plant's energy use. For a meaningful comparison it is necessary to determine the energy that would have been required to produce this year's production output had the plant operated in the same way as it did during the reference year. This calculated value can then be compared with the actual value to determine the improvement or deterioration that has taken place since the reference year.

Production factor

Production factor is used to determine the energy that would have been required to produce this year's production output if the plant has operated in the same way as it did in the reference year. Production factor is the ratio of production in the current year to that in the reference year.

$$\text{Production factor} = \frac{\text{Current year's production}}{\text{Reference year's production}}$$

Reference year equivalent energy use

The reference year's energy use that would have been used to produce the current year's production output may be called the "reference year energy use equivalent" or "reference year equivalent for short. The reference year equivalent is obtained by multiplying the reference year energy year use by the production factor (obtained above).

$$\text{Reference year's equivalent \%} = \frac{\text{Reference year energy use X}}{\text{production factor}}$$

Plant energy performance

The improvement or deterioration from the reference year is called "energy performance" and is a measure of the plant's energy management progress. It is the reduction or increase in the current year's energy use over the reference year equivalent expressed as a percentage. Energy performance is calculated by subtracting the current year's energy use from the reference year's equivalent. The result is divided by the reference year equivalent and multiplied by 100 to obtain a percentage.

$$\text{Reference energy performance \%} = \frac{\text{Reference year equivalent - Current year's energy X 100}}{\text{Reference year equivalent}}$$

The energy performance is the percentage of energy saved at the current rate of use compared to the reference year rate of use. The greater the improvement, the higher the number will be.

Company energy performance

Company energy performance combines the performance of several plants to provide a total company energy performance. It provides company management with an overview of the total company energy management effectiveness. Each plant can have different production processes with the plant energy performance totaling method. This allows for complete flexibility at the plant level in choosing the best production processes for each specific plant.

The plant energy performance described earlier compared the plant's reference year equivalent to energy use to the plant' current year energy use. To find the company's total performance, the reference year equivalent energy use for each of the company's plants is totaled. This is the company's reference year equivalent. Next, the current year's energy use for each of the company's plants is totaled. This is the company's current year energy use.

The company's energy performance is now calculated the same way a plant's performance was calculated. The company's current year energy use is subtracted from the company's reference year energy equivalent.

The result is divided by the company's reference energy equivalent, and multiplied by 100 to provide the percentage performance change.

Company energy performance (CEP) is then:

$$\text{CEP} = \frac{\left(\text{company's reference year equivalent - company's current year equivalent}\right) \times 100}{\text{company's reference year equivalent}}$$

Plant energy performance (pep) and/or company energy performance (cep) are the starting points for evaluating energy performance and controlling energy consumption. Plant energy performance does not require detailed calculations of the energy used by every price of equipment, the energy use of every process or the energy use of buildings. It utilizes the most effective measure of energy savings, the actual measurement of energy consumption compared to production output. Yearly comparisons minimize seasonal effects.

17 Conducting an Electrical Energy Survey

Electrical energy is the most expensive form of purchased energy. For this reason, its use must be confined to the minimum for efficient operation. This chapter outlines procedures for evaluating electrical energy use and electricity consuming systems. The procedures assume that most facilities use AC power, either single-phase or three-phase.

The electricity bill cannot be controlled by managing consumption alone, because energy use is only one of several factors that affect the bill. To test electricity systems and identify conservation opportunities during an electrical energy survey, the energy surveyor should take the steps described below.

- Development of energy consumption/cost data base for a facility
- Objective evaluation of plant condition
- Identification of major energy - using systems
- Understanding of company's decision - making for energy - related projects
- Collection of data through actual measurements
- Analysis of data for identifying energy conservation opportunities
- Preparation of survey report

Steps in Conducting an Energy Audit: The survey generally has five steps, as listed below:

1. Organize resources

- Manpower/time frame
- Instrumentation

2. Identify data requirements

- Data forms

3. Collect data

a. Conduct informal interviews

- Senior management
- Energy manager/coordinator
- Plant engineer
- Operations and production management and personnel
- Administrative personnel
- Financial manager

b. Conduct plant walk through/visual inspection

- Material/energy flow through plant
- Major functional departments
- Any installed instrumentation, including utility meters
- Energy report procedures
- Production and operational reporting procedures
- Conservation opportunities

c. Carry out actual measurements

- Energy consumption of plant/sections/departments
- Energy consumption of selected equipment
- Lighting levels
- Operating conditions

4. Analyze data

a. Develop data base

- Historical data for total electrical energy consumption
- Self-generation of electricity
- Other related data
- Process flow sheets
- Energy - consuming equipment inventory

b. Evaluate data

- Energy use - consumption, cost, and schedules
- Energy consumption indices
- Plant operations
- Energy savings potential
- Plant energy management program

5. Prepare Survey Report

- Conclusions and Recommendations
- Descriptive Part
- Findings and Calculations:
- Recommendations
- Annexures and Exhibits

The survey outline presented assumes that the energy surveyor has no prior knowledge of the structure of the facility to be energy surveyed and has no details of any energy management program that may exist. It does assume, however, that the energy surveyor knows the physical size and main function of the plant before starting to collect data.

17.1 Step 1: Organize Resources

17.1.1 Manpower/Time Frame

A survey is usually done by at least two experienced energy surveyors. The time required to complete a survey depends on several factors, including:

- Experience of the energy surveyor
- Physical size of the facility
- Complexity of operations within the facility
- Availability and completeness of data
- Depth of analysis of available data
- Awareness of energy matters within the facility.

17.1.2 Instrumentation

To help collect technical data during the survey, the energy surveyor can use instrumentation. The contents of a basic instrument kit that should be carried by an energy surveyor are listed below:

- Thermal Imager
- Volt-Ampere-Ohm Meter
- Watt meter
- Power Factor Meter

- Stopwatch
- Power and Demand Analyzer
- Light Meter
- Digital Temperature Indicator and probes
- Mechanical Psychrometer
- Photo/Contact Tachometer
- Infrared Thermometer
- Slack-tube Manometer
- Inclined Manometer Set with Pitot Tubes
- Measuring tapes
- Safety equipment
- Flash light

17.2 Step 2: Identify Data Requirements

Before an energy surveyor begins a survey, he must know what data he needs to analyze for making energy conservation recommendations. Without data requirements, he may not collect the right information and as a result, the survey will not be useful.

Information must be collected on everything that affects electricity use in the facility. Such information includes, but is not necessarily limited to the following:

- Electricity consumption in the facility
- Self-generation of electricity
- Energy cost and prevailing rate schedules
- Operational schedules for the facility
- Product or function of the facility
- Location of the facility
- Electricity consuming equipment within the facility

In addition to the above technical information, the energy surveyor will obtain information on the company's decision - making criteria (e.g., maximum payback, minimum internal rate of return), as this information will be critical to present a realistic action plan to management.

17.2.1 Data Forms

Data forms are used to collect data on consumption and costs of energy, including rate schedules; to compile data on production; to prepare details of energy-consuming equipment; and to record actual measurement.

The energy surveyor should develop line diagram for the distribution system and the process flow diagram through the facility on a blank sheet, taking care to include all relevant information such as:

- Flow rate of energy/material
- Operating conditions of any system, including time of operation, temperature, pressure
- Desired goals of operation
- Ideal operating conditions, if known
- Design rating of equipment, if known.

17.3 Step 3: Collect Data (Conduct of Survey)

About three days prior to the date, the surveyor should contact the company to confirm the following:

- Operating conditions are expected to be normal during the period the survey is to be conducted.
- Confirmation of the concerned plant staff/contact person.

Prior to the conduct of survey, the surveyor should also check the instruments for their proper operation.

17.3.1 Conduct Informal Interviews

When starting a survey in a new facility, the energy surveyor should first familiarize himself with its operation and organization. The best way to do that is to meet and talk informally with those people responsible for running the facility. An energy surveyor rarely goes to plant without an invitation from someone within the facility. The invitation may come from a number of people, but the first contact is usually the person to whom the energy surveyor would direct his initial inquiries. That contact should be able to identify the people responsible for the information that the energy surveyor needs to prepare his survey.

There are several people that the energy surveyor should seek out to ensure that he gets a full picture of energy affairs within the organization. These people include:

- Senior management with direct responsibility for energy
- Energy manager/coordinator
- Plant engineer
- Operations and production management and personnel
- Administrative personnel.

The structure and complexity of the organization will dictate how many people are interviewed and how much time is spent interviewing. In many instances, some of the functions described above are combined into one job. In facilities with a well - designed and established energy management program, the information that the energy surveyor needs may be very easy to get. Other companies may not be fully aware of all implications of energy management and may have no energy program.

The type of information that an energy surveyor should seek is indicated blow.

17.3.1.1 Senior Management

In talking with senior management, the energy surveyor should learn:

- Outline of company's attitude to energy management
- Whether an in - house energy management program exists
- Personnel responsible for administering the Total Energy Management program - the energy coordinator
- Decision - making criteria for capital expenditures in productivity improvement projects.

17.3.1.2 Energy Manager/Coordinator

This position may not exist within a facility. In some cases, a company will have only a part-time energy manager. If there is an energy manager, he is the person from whom the energy surveyor should obtain most of his information (e.g., mechanical or electrical engineer).

Information that the energy surveyor should seek includes:

- Structure of in-house energy management or total energy management (TEM) program including:
  - Chain of command and position of energy manager within the facility's corporate organization
  - Goals of energy management program
  - Status of energy management program
  - Work completed to date under energy management program, including energy monitoring and reporting procedures
  - Whether a survey was conducted previously, and if so, when
  - Whether an energy management data base exists
  - Whether an action plan for conservation exists
  - Conservation opportunities identified and implemented
  - Whether a full energy survey has been completed, and if so, when
  - Conservation opportunities identified but not implemented because of (a) insufficient study, (b) lack of interest, (c) lack of capital, (d) no economic viability, (e) lack of resources, time, or manpower to implement
  - Whether an adequate energy monitoring and reporting procedure exists
  - Whether the energy manager uses external as well as internal resources for implementation
  - What ongoing actions are taken to maintain and improve energy efficiency and to implement new opportunities
- Available information on energy-related matters, including:
  - Physical layout of facility - floor plan, if available
  - Fuels used, electricity bills, consumption, rate schedules, costs
  - Energy use within the facility
  - Operating function and schedule of the facility.
- Specification of the facility, including:
  - Size
  - Age of building and equipment
  - Names and locations of operating departments
  - Schedule of operating hours for each department
  - Function of each department
  - Energy used with each department for production and environmental services
  - Major energy - consuming systems within each department and the facility as a whole
  - Line diagrams for major systems, if available
  - Installed instrumentation, including utility meters
  - Original equipment ratings and any changes, such as fuel switch or increased capacity
  - Production indicator
  - Production reporting procedures
  - Maximum capacity of plant and its relation to energy consumption: (a) maximum kW demand, (b) electrical load factor, (c) fossil fuel load factor.

If the energy manager is unable to answer the above questions, then the energy surveyor must determine who can answer the questions. Quite often, gaps will exist in the information collected that will impact on the evaluation that can be made. Where these gaps can be completed by further interview, then the energy surveyor should be prepared to meet with other individuals who can supply the information.

17.3.1.3 Plant Engineer

Because the plant engineer is involved in all aspects of equipment and operation maintenance, he is very aware of what goes on throughout the facility. He should be able to supply information on the plant's physical details that the energy manager did not provide.

Other information he can supply includes:

- Condition of equipment and any operating problems
- Control systems
- Instrumentation
- Maintenance procedures.

Often, the plant engineer serves as the energy manager/coordinator because of his unique insight into the operations within a facility.

17.3.1.4 Operations and Production Management and Personnel

These people should supply missing information on how production equipment is run and the operating conditions required to meet production targets. This information includes:

- Actual operating conditions, including production rates, quality, temperatures, pressures, and cycle times
- Ideal operating conditions
- Optimum conditions and problems encountered in meeting them
- Specification of materials before and after the production process
- Final product specifications

This information should be gathered at two levels - management and operator level. Often, equipment is operated under conditions different from those that management specifies.

17.3.1.5 Administrative Personnel

Any lack of information on costing of energy, operating schedules, production reports, etc., can usually be obtained from the appropriate administrative personnel. They often supply the economic criteria by which the facility makes its decisions. This knowledge is important

when the energy surveyor is evaluating conservation opportunities.

17.3.2 Conduct Survey

A general inspection of the electrical system should be conducted to develop a familiarity with the layout. Starting from the electric meter, the distribution system and main items of process equipment using electricity should be covered.

The energy surveyor tours the facility to objectively evaluate the plant conditions and operating procedures, and to gain understanding of the process flow. The key steps in completing a walk through/visual inspection are given as follows:

Key Steps in Conducting the Survey

1. Select facility person to accompany auditor on inspection
2. Obtain plant layout
    - Use available print or develop sketch with facility personnel
3. Mark sketch with material/energy flows, including:
    - Material receiving and storage areas
    - Prime energy inputs, meter location, storage areas

- Major production areas, with materials/energy used
- Warehouse and shipping departments for final products
- Resource recycling systems
- Waste disposal systems

4. Mark sketch with major functional areas/departments
5. Identify and evaluate major energy - consuming systems by system of analysis:
    - Electrical distribution system
    - Process systems
    - Building envelope
    - Lighting
    - Ventilation
    - Heating
    - Cooling
    - Water systems, including process pumps
    - Transformers, motors
    - Distribution systems such as compressed air, thermal fluids
6. Identify and check operation of instrumentation associated with energy
    - Utility meters
    - Process operations - related instruments
7. Identify energy reporting procedures
    - Charts, logs
    - Analysis conducted
8. Identify production and reporting procedures
    - Production charts
    - Operational logs
    - Operating conditions
9. Identify conservation opportunities and take measurements. Typical areas include:
    - Leaking systems
    - Equipment running when not required
    - Equipment schedules not matching occupancy/production systems
    - Improperly adjusted or malfunctioning control systems
    - Input power to fans, pumps, compressors
    - Maximum demand profile
    - Lighting levels and controls
    - Other process equipment
    - To achieve his goals, the energy surveyor must personally collect information and measurements on the following:
    - Material/energy flow through the plant
    - Major functional departments
    - Major energy - consuming systems
    - Any installed instrumentation, including utility meters
    - Energy reporting procedures and any inadequacies
    - Production and operational reporting procedures
    - Energy conservation opportunities.

Information on some of the above can be collected using appropriate data collection forms. Other information can be collected through sketches made by the energy surveyor during his inspection. To obtain maximum information from the survey, the energy surveyor should be accompanied on his visual inspection by someone from the plant who is familiar with the plant operations, systems, and procedures and, if possible, all aspects of the functions of each department. This person can be the energy manager, the plant engineer, or someone from the maintenance department.

Before starting his visual inspection, the energy surveyor should obtain a layout of the facility that identifies the major functional departments. This layout can be sketched by the energy manager or the person who will accompany the energy surveyor on the tour, if no printed floor plan is available.

17.3.2.1 Electricity Flow through Plant

The first element of the analysis is to determine how materials and energy flow through the facility. This can be sketched before starting the visual inspection. The following areas must be located:

- Transformer, electrical metering points, and substations, distribution voltages, sections/departments, major electricity equipment

These areas should be marked on the layout of the facility.

17.3.2.2 Major Functional Departments

At the same time, the major functional departments in the facility should be established and marked on the layout.

17.3.2.3 Major Energy - Consuming Systems (Inventory)

The energy surveyor should start the visual inspection at the point where either the material or energy inputs into the facility begin. In general, it is preferable to start with the energy metering and storage facilities and follow their use through the facility.

Because the time available for the survey is normally limited, the energy surveyor must concentrate on the major energy consumers within the facility. To do this, he should consider a facility and its major functional departments as a combination of several energy - consuming systems as follows:

- Process systems such as dryers, boilers, and furnaces
- Large motors
- Building envelope
- Lighting
- Ventilation
- Heating
- Cooling
- Water systems, including steam and condensate distribution
- Distribution systems, such as compressed air and thermal fluids.

These systems interact to a certain extent, but each can be examined by the energy surveyor on a stand - alone basis.

For each system, the energy surveyor should inspect:

- Nameplate data
- Physical appearance
- Associated instrumentation

- Control systems
- Operating conditions
- External structure
- Internal structure, if possible.

The energy surveyor should not conduct his analysis in isolation, but should talk with others to obtain information on potential operational improvements and problems.

The time examining each system should be based on the relative amount of electricity consumed.

17.3.2.4 Instrumentation, Including Utility Meters

The energy surveyor should check installed instrumentation for correct operation and to determine relative flows, pressures, and temperature cycles. All utility meters should be examined.

When specific consumption data are not available, the energy surveyor can estimate the importance by asking either the person accompanying him or the operator of the system.

The energy surveyor can estimate lighting loads by examining one fixture to determine type and rating and then adding up the number of fixtures.

17.3.2.5 Energy Report Procedures

If instruments are installed to measure energy use, there is usually a procedure for monitoring the readings. The energy surveyor should find out what is done with the available information; if it is collated, he should examine the records.

17.3.2.6 Production and Reporting Procedures

Major production processes are usually monitored, and the energy surveyor should determine what information is reported for each major product. This information is usually collected from some form of production report. Operational data collection sheets and logs are often used by production personnel. By examining them and by analyzing operation conditions at the time of the survey, the energy surveyor can identify possible conservation opportunities.

17.3.2.7 Conservation Opportunities

A through visual inspection of all parts of the facility will usually indicate obvious areas for energy efficiency improvement. It should follow actual measurements to quantify the energy conservation opportunities. Following are the typical examples of EC opportunities found during the surveys. - found during a survey - represent opportunities for conservation:

- Missing or damage insulation on heating and air-conditioning surfaces
- Equipment operating when not required
- Improperly adjusted or malfunctioning control systems
- Lighting systems when not required
- Equipment schedules not matched to occupancy/production schedules.
- Maximum demand control
- Power factor improvement
- Replacement of in-efficient motors
- Replacement of over-sized motors
- Proper operation of compressors
- Reduction in speed of fans

- Reduction in impeller dia of over-sized pumps
- Reduction in lighting levels
- Proper operation of refrigeration systems

The above list is by no means exhaustive; rather, it indicates the types of opportunities that generally exist and can easily be captured.

17.4 Step 4: Analyze Data

Once data are gathered, they must be analyzed. The steps in the analysis are:

- Develop an energy consumption - related data base for the facility
- Evaluate data base
- Prepare energy consumption indices
- Consider energy use in light of other factors, such as production and environmental conditions
- Quantify the identified energy conservation opportunities
- Review the overall facility energy management program.

17.4.1 Data Base Development

The major analysis step is the development of a data base on energy - related matters. The data base will be used many times in the course of energy management programs, and it must be as complete and accurate as possible. However, the data base will be continually refined as the energy management program progresses.

There are several items that should be included in an energy management data base:

- Historical data on consumption and cost of all energy supplies over a given time frame
- Historical production and other related data for the same time period as energy supplies
- Process flow diagrams
- Energy - consuming equipment inventory.

17.4.1.1 Historical Data for All Energy Supply

The energy surveyor should collect data for all forms of energy on a periodic basis. That basis is usually either a month or the periodic billing cycle of the energy supplier. In a survey, it is normal to use data from the preceding 12 months of facility operation.

However if more than 1 year of data is incorporated in the data base, the picture of energy use will be more complete. The data on energy consumption and costs must be converted to the same units of energy, which can be done by using appropriate data collection forms.

Because energy suppliers do not all bill on the same day, the facility should take its own readings from the meters. Where this can be done, all data will cover the same time period. Personnel should be encouraged to standardize the time and method of collecting these data.

17.4.1.2 Historical Production and Other Related Data

The energy surveyor must determine how energy is used by the facility. To do this, he must compile a historical record of production for the same period as that for energy consumption and cost. Similarly, he can use other data that may affect the use of energy.

He can use two sources to obtain the data. One source is the facility's production records, operating schedules, scrap records, operating parameters, etc. The other source is records from external agencies, such as weather stations that contain information on prevailing climatic conditions, or local energy suppliers. The energy surveyor should not dismiss any potential factor that could significantly affect energy use.

Process Flow Diagrams

The visual inspection enables the energy surveyor to identify the significant energy consumers within a complex. During the inspection, the energy surveyor should try to produce a series of line diagrams for the flow of materials and energy through the facility.

Prior to his evaluation, the energy surveyor should combine these notes and sketches into a series of process flow diagrams. He should mark details of physical size, instrumentation, and capacities, together with the data and operating conditions at the time of the inspection, on the process flow sheets. He should also note flow rates of materials and energy, if known.

The energy surveyor should prepare the diagrams carefully so they can be used on recurring basis to monitor operations.

If ideal or target conditions can be determined, they should be marked on the diagram.

17.4.1.3 Energy Consuming Equipment Inventory

Because the time spent on a survey is limited, it is not possible to compile a complete inventory of energy-consuming equipment within the facility. However, if the energy surveyor has done his work thoroughly, he should have identified 80% of the consumers of energy within a facility.

The energy surveyor should compile an inventory of the various equipment on the basis of the type of energy used. The rating or capacities of the equipment for the various energy sources should be totaled and compare with actual energy usage as found from the consumption data base.

17.4.2 Evaluate Data and Prepare Report

Next, the energy surveyor evaluates the data collected in the data base. The evaluation should permit him to draw conclusions and make recommendations for improving energy efficiency.

He can evaluate the data to determine the following:

- Energy use- consumption, cost, and schedules
- Energy consumption indices
- Plant operations
- Energy savings potential
- Plant energy management program

i) Conclusions and Recommendations

- These should contain identified opportunities for energy conservation, improving efficiency of specific energy consuming processes, inter-fuel substitution, and opportunities for co-generation if any. It should also contain summary on technical and economic evaluation of no cost/low cost measures and recommend "optimal package" with costs and payback periods, as well as an action plan for implementation of these measures.

ii) Descriptive Part

- This part should include a brief description of industrial/commercial enterprise including product, capacity utilization, operating hours, floor area, annual electricity consumption for the past three years, annual electricity bills compared to other operating expenses. It should include, description of main end-use categories (lighting, heating, cooling etc.) and their characteristics, and single line diagram etc.

iii) Findings and Calculations

This part should consist of calculations used to quantify, where ever possible during the time available, current electricity consumption total and per end-use, such as, lighting, cooling, ventilation, heating, electric equipment, and analysis of energy consumption/savings potential.

iv) Recommendations

On the basis of survey results and the above calculations, specific EC measures should be identified. These measures will be analyzed for their financial viability using the NPV or Payback technique. Projects requiring further study will also be identified.

v) Annexures and Exhibits

The report must contain calculation sheets and completed questionnaire as appendix. A separate appendix containing the tables, graphs etc. used to quantify savings should be included in the report.

18 ISO 50001 – Energy Management Standard

As a new member of international standards family, ISO 50001 has been developed based on the common elements shared by other major ISO management system standards, ensuring a high level of compatibility with them. It is notably aligned with ISO 9001 quality management system and ISO 14001 environmental management system standards.

ISO 50001 - Energy Management System

ISO 50001 is based on the ISO management system (EnMS) model familiar to more than a million organizations worldwide who implement standards such as ISO 9001 (quality management), ISO 14001 (environmental management), ISO 22000 (food safety), ISO/IEC 27001 (information security).

Energy Management Systems (EnMS) offer a systematic approach and a recognized framework to monitor and reduce the energy consumption in all types of organizations including industrial, commercial, hospitality and health care. ISO 50001 is based on a **Plan--Do--Check--Act** cycle, with requirements for: establishing an energy policy with measureable objectives, taking actions to monitor and reduce energy use, verifying energy savings and planning improvements. ISO 50001 has a similar structure to ISO 14001 and can integrate into an existing quality, safety and/or environment management system.

Implementation of EnMS

As described earlier, the energy management system (EnMS) of ISO 50001 follows the **Plan-Do-Check-Act** process for continual improvement of the energy management system.

ISO 50001 provides a framework of requirements enabling organizations to:

- Develop a policy for more efficient use of energy
- Fix targets and objectives to meet the policy
- Use data to better understand and make decisions concerning energy
- use and consumption
- Measure the results
- Review the effectiveness of the policy
- Continually improve energy management.

ISO 50001 can be implemented individually or integrated with other management system standards.

These characteristics enable organizations to integrate energy management now with their overall efforts to improve quality, environmental management and other challenges addressed by their management systems.

Benefits of implementing an EnMS

Implementing an energy management system certified to ISO 50001 aids in the reduction of energy consumption through a structured approach to monitoring the energy use, identifying areas for improvement and then implementing action plans to improve the energy performance. Its major benefits are listed below:

- Significant financial savings and profitability can be achieved through energy efficiency and reduced operational and overhead costs
- Increase understanding of energy use and consumption through defined methods and processes of data collection
- Demonstrate to stakeholders your commitment to environmental preservation, as well as cost reduction and profitability
- Raise your staff's awareness on the importance of energy consumption and reduction

- Positive contributions toward depletion of energy resources
- Mitigate worldwide effects of energy use
- Utilize a single, harmonized standard for implementation across multiple locations, including international locations
- Provide a framework for promoting energy efficiency throughout the supply chain
- Easily integrate with other organizational management systems such as environmental, health and safety
- Reduce air emissions such as GHG's
- Enhance marketing capabilities
- Ensure best practice energy management systems are in place
- Allocate cost/CO_2 across all manufacturing processes
- Benchmark for continuous process improvement
- Prioritize/verify energy efficiency measures

Appendix-A: Cable Sizing Calculations

All cables have resistance, and when current flows in them it results in a volt drop. Hence, the voltage at the load is lower than the supply voltage by the amount of this volt drop.

The volt drop may be calculated using the basic Ohm's law formula

V = I x R

where V is the cable volt drop (V)

I is the circuit current (A), and

R is the circuit resistance Ω (Ohms)

Unfortunately, this simple formula is seldom of use in this case, because the cable resistance under load conditions is not easy to calculate.

Cable sizing calculations will be illustrated taking into account the following two essential features, with examples:

- Cable rating, and
- Volt drop

Cable rating calculations

The Regulations indicate the following symbols for use when selecting cables:

Iz is the current carrying capacity of the cable in the situation where it is installed

It is the tabulated current for a single circuit at an ambient temperature of 30°C

Ib is the design current, the actual current to be carried by the cable

In is the rating of the protecting fuse or circuit breaker

I2 is the operating current for the fuse or circuit breaker (the current at which the fuse blows or the circuit breaker opens)

Ca is the correction factor for ambient temperature

Cg is the correction factor for grouping

Ci is the correction factor for thermal insulation.

The correction factor for protection by a semi-enclosed (rewirable) fuse is not given a symbol but has a fixed value of 0.725.

Under all circumstances, the cable current carrying capacity must be equal to or greater than the circuit design current and the rating of the fuse or circuit breaker must be at least as big as the circuit design current. These requirements are common sense, because otherwise the cable would be overloaded or the fuse would blow when the load is switched on.

To ensure correct protection from overload, it is important that the protective device operating current (I2) is not bigger than 1.45 times the current carrying capacity of the cable (Iz). Additionally, the rating of the fuse or circuit breaker (In) must not be greater than the cable current carrying capacity (Iz) It is important to appreciate that the operating current of a protective device is always larger than its rated value. In the case of a back-up fuse, which is not intended to provide overload protection, neither of these requirements applies.

To select a cable for a particular application, take the following steps: (note that to save time it may be better first to ensure that the expected cable for the required length of circuit will not result in the maximum permitted volt drop being exceeded the prescribed limits.

1. Calculate the expected (design) current in the circuit (Ib)
2. Choose the type and rating of protective device (fuse or circuit breaker) to be used (In)
3. Divide the protective device rated current by the ambient temperature correction factor (Ca) if ambient temperature differs from 30°C
4. Further divide by the grouping correction factor (Cg)
5. Divide again by the thermal insulation correction factor (CI)
6. Divide by the semi-enclosed fuse factor of 0.725 where applicable
7. The result is the rated current of the cable required, which must be chosen from the appropriate Tables-4, 5, 6 and 7.

{Tables-4, 5, 6, and 7 give current ratings and volt drops for some of the more commonly used cables and sizes. The Tables assume that the conductors and the insulation are operating at their maximum rated temperatures. They are extracted from the Regulations Tables shown in square brackets e.g. [4D1A]

The examples below will illustrate the calculations, but do not take account of volt drop requirements.

Cable volt drop calculation

BS 7671 [525-01-03] indicates that the voltage at any load must never fall so low as to impair the safe working of that load, or fall below the level indicated by the relevant British Standard where one applies.

BS 7671[525-01-02] indicates that these requirements will be met if the voltage drop does not exceed 4% of the declared supply voltage. If the supply is single-phase at the usual level of 240 V, this means a maximum volt drop of 4% of 240 V, which is 9.6 V, giving (in simple terms) a load voltage as low as 230.4 V. For a 415 V three-phase system, allowable volt drop will be 16.6 V with a line load voltage as low as 398.4 V.

The volt drop for a particular cable is calculated by using Tables-4, 5, and 7. Each current rating table has an associated volt drop column or table. For example, multicore sheathed non-armoured PVC insulated cables are covered by Table-5 for current ratings, and volt drops. The exception in the Regulations to this layout is for mineral insulated cables where there are separate volt drop tables for single- and three-phase operation, which are combined here as Table-7.

Each cable rating has a corresponding volt drop value in millivolts per ampere per meter of run (mV/A/m). Strictly this should be mV/(A-m), but here we shall follow the pattern adopted by BS 7671: 1992. To calculate the cable volt drop:

1. Take the value from the volt drop table (mV/A/m)
2. Multiply by the actual current in the cable (NOT the current rating)
3. Multiply by the length of run in meters
4. Divide the result by one thousand (to convert millivolts to volts).

For example, if a 4 mm^2 PVC sheathed circuit feeds a 6 kW shower and has a length of run of 16 m, we can find the volt drop thus:

From Table-5, the volt drop figure for 4 mm^2 two-core cable is 11 mV/A/m. Cable current is calculated from:

$$I = \frac{P}{V} = \frac{6000W}{240V} = 25A$$

Volt drop is then:

$$VD = \frac{vd(mV\ /\ A - m) \times I(A) \times l(m)}{1000} = \frac{11 \times 25 \times 16}{1000} = 4.4V$$

Since the permissible volt drop is 4% of 240 V, which is 9.6 V, the cable in question meets volt drop requirements. The following examples will make the cable sizing calculations clear.

Example-1

An immersion heater rated at 240 V, 3 kW is to be installed using twin with protective conductor PVC insulated and sheathed cable. The circuit will be fed from a 15 A miniature circuit breaker type 2, and will be run for much of its 14 m length in a roof space which is thermally insulated with glass fibre. The roof space temperature is expected to rise to 50°C in summer, and where it leaves the consumer unit and passes through a 50 mm insulation-filled cavity, the cable will be bunched with seven others. Calculate the cross-sectional area of the required cable.

Cable current rating calculations:

First calculate the design current Ib:

$$Ib = \frac{P}{V} = \frac{3000W}{240V} = 12.5A$$

Ambient temperature correction factor from Table-1 = 0.71.

The circuit in question is bunched with seven others, making eight in all.

Group correction factor from Table-2 = 0.52..

Thermal insulation correction factor has already been taken into account in the current rating table (4D2A ref. method 4] and need not be further considered. This is because we can assume that the cable in the roof space is in contact with the glass fiber but not enclosed by it.

However, the point, where the bunched cables pass through the insulated cavity, is to be considered.

From Table-3, correction factor for thermal insulation = 0.89.

The correction factors must now be considered to see if more than one of them applies to the same part of the cable. The only place where this happens is in the insulated cavity behind the consumer unit. Factors of 0.52 (Cg) and 0.89 (CI) apply. The combined value of these (0.463), which is lower than the ambient temperature correction factor of 0.71, and will thus, be the figure to be applied. Hence, the required current rating is calculated:

$$Iz = \frac{In}{Cg \times Ci} = \frac{15A}{0.52 \times 0.89} = 32.4A$$

From Table-5, 6 mm^2 PVC twin with protective conductor has a current rating of 32 A. This is not quite large enough, so 10 mm^{2}with a current rating of 43 A is indicated. Not only would this add considerably to the costs, but would also result in difficulties due to terminating such a large cable in the accessories.

A more sensible option would be to look for a method of reducing the required cable size. For example, if the eight cables left the consumer unit in two bunches of four, this would result in a grouping factor of 0.65 (from Table-2). Before applying this, it must be checked that the combined grouping and thermal insulation factors (0.65 × 0.89 = .0.58) are still less than the ambient temperature factor of 0.71, which is the case.

Note that in (Tables-6 and 7) PVC sheath means bare and exposed to touch or having an over-all covering of PVC or LSF and bare' means bare and neither exposed to touch nor in contact with combustible materials. This leads to a cable current rating:

$$CableCurrentRating, Iz = \frac{In}{Cg \times Ci} = \frac{15A}{0.65 \times 0.89} = 25.9A$$

This is well below the rating for 6 mm^2 of 32 A, so a cable of this size could be selected.

Cable volt drop calculations:

Proceed to find out maximum length of the selected cable, which would allow the installation to comply with the volt drop regulations.

The table-5 is used here, which shows a value of 7.3 mV/A/m for 6 mm^2 twin with protective conductor PVC insulated and sheathed cable. The actual circuit current is 12.5 A, and the length of run is 14 m.

$$CableVoltDrop = \frac{7.3 \times 12.5 \times 14V}{1000} = 1.28V$$

$$Max.PermissibleVoltDrop = \frac{240 \times 4\%}{100} = 9.6V$$

If a 14 m run has 1.28 V volt drop, the length of run for a 9.6 V drop will be:

Example-2

The same installation as in Example-1 is proposed. Here, attempt is made to make the cable size smaller, the run in the roof space is to be kept clear of the glass fiber insulation. Find out, whether, there is any difference to the selected cable size.

Cable current rating calculations:

There is no correction factor for the presence of the glass fiber, so the calculation of Iz will exactly be the same as Example-1 at 32.4 A.

$$Iz = \frac{In}{Cg \times Ci} = \frac{15A}{0.52 \times 0.89} = 32.4A$$

This time reference method I (clipped direct) will be applied to the current rating (Table-5). A two core cable, 4.0 mm^2, will be selected, since it has a rating of 36 A.

It is interesting to note how quite a minor change in the method of installation, in this case clipping the cable to the joists or battens clear of the glass fiber, has reduced the acceptable cable size.

Cable volt drop calculations:

Proceed to find out maximum length of the selected cable, which would allow the installation to comply with the volt drop regulations.

Refer to Table-5. It shows a volt drop value of 11mV/A/m for 4.0 mm^2 cable. Cable current rating and length of run remain at 12.5 A. and 14 m respectively.

$$Cable\,VoltDrop = \frac{11 \times 12.5 \times 14V}{1000} = 1.93V$$

$$Max.Permissible\,VoltDrop = \frac{240 \times 4\%}{100} = 9.6V$$

If a 14 m run has 1.93 V volt drop, the length of run for a 9.6 V drop will be:

$$Max.\,\mathrm{Run\,for\,9.6\,V\,volt\,drop} = \frac{9.6 \times 14m}{1.93} = 70meters$$

Example-3

Assume that the immersion heater indicated in the two previous examples is to be installed, but this time with the protection of a 15 A rewirable (semi-enclosed) fuse. Calculate the correct cable size for each of the alternatives, that is where firstly the cable is in contact with glass fiber insulation, and secondly where it is held clear of it.

Cable current rating calculations:

This time the value of the acceptable current carrying capacity Iz will be different because of the need to include a factor for the rewirable fuse as well as the new ambient temperature and grouping factors for the rewirable fuse from Tables-1 and 2.

$$CableCurrentRating, Iz = \frac{In}{Cg \times Ci \times 0.725} = \frac{15A}{0.52 \times 0.89 \times 0.725} = 45.7A$$

When the cable is in contact with the glass fiber, the first column of Table-5 of current ratings will apply. In this case, the acceptable cable size is 16 mm^2 which has a current rating of 57 A.

This cable size is too large, therefore is not acceptable due to high cost of cable and difficulties associated with installation.

If the cables leaving the consumer unit are re-arranged in two groups of four, this will reduce the Cg (grouping factor) to 0.65, so that the newly calculated value of Iz will be:

$$CableCurrentRating, Iz = \frac{In}{Cg \times Ci \times 0.725} = \frac{15A}{0.65 \times 0.87 \times 0.725} = 36.6A$$

This means using 10 mm^2 cable with a current rating of 43A (from Table-5), since 6 mm^2 cable is shown to have a current rating in these circumstances of only 32 A.

By further rearranging the cables leaving the consumer unit to be part of a group of only two, Cg is increased to 0.8, which reduces Iz to:

$$CableCurrentRating, Iz = \frac{In}{Cg \times Ci \times 0.725} = \frac{15A}{0.8 \times 0.87 \times 0.725} = 29.72A$$

Cable current rating of 29.72A enables selection of a 6 mm^2 cable.

If it is possible to bring the immersion heater cable out of the consumer unit on its own, no grouping factor would apply and Iz would be:

$$CurrentRating, Iz = \frac{In}{Ci \times 0.725} = \frac{15A}{0.87 \times 0.725} = 23.78A$$

Now, cable current rating of 23.78A allows the selection of a 4 mm^2 cable with current rating of 36 A.

When the cable is not in contact with fiber glass there will be no need to repeat the calculation of Iz, which still has a value of 29.7 A provided that it is possible to group the immersion heater cable with only one other where it leaves the consumer unit.

$$CableCurrentRating, Iz = \frac{In}{Cg \times Ci \times 0.725} = \frac{15A}{0.8 \times 0.87 \times 0.725} = 29.72A$$

This time the 'Reference Method 1 (clipped direct)' column of the current rating (Table-5) is used, which shows that 4 mm^2 cable with a current rating of 36 A.

Therefore, cable current rating of 29.72 A allows the selection of a 4 mm^2 cable with current rating of 36 A.

Examples-1, 2 and 3 show the necessity of proper planning for calculating a more economical and practical cable size to be used than would appear necessary at first. It is, of course, important that the design calculations be recorded and retained properly.

Volt drop calculations:

Calculate the volt drop for the cases of for each of the alternative installations. What maximum length of cable would allow the installation to comply with the volt drop regulations in each case?

In neither case is there any change in cable sizes, the selected cables being 6 mm^2 in the first case and 4 mm^2 in the second. Solutions are thus the same as those in Examples-1 and 2 respectively.

Example-4

A 415 V 50 Hz three-phase motor with an output of 7.5 kW, power factor 0.8 and efficiency 85% is the be wired using 500 V light duty three-core mineral insulated PVC sheathed cable. The length of run from the HBC (high breaking capacity) protecting fuses is 20 m, and for about half this run the cable is clipped to wall surfaces. For the remainder it shares a cable tray, touching two similar cables across the top of a boiler room where the ambient temperature is 50°C. Calculate the rating and size of the correct cable.

Cable current rating calculations:

The first step is to calculate the line current of the motor.

$$Input = \frac{Output}{Efficiency} = \frac{100 \times 7.5kW}{85} = 8.82kW$$

$$LineCurrentIb = \frac{P}{\sqrt{3} \times V \times PF} = \frac{1000 \times 8.82kW}{1.73 \times 415 \times 0.8} = 15.3A$$

In this situation, as per BS 88 the fuse of 16 A size should be the most suitable. Part of the run is subject to an ambient temperature of 50°C, where the cable is also part of a group of three, so the appropriate correction factors must be applied from Tables-1 and 2).

$$Iz = \frac{In}{Cg \times Ci} = \frac{16A}{0.70 \times 0.67} = 34.2A$$

Note that the grouping factor of 0.70 has been selected because where the cable is grouped it is clipped to a metallic cable tray, and not to a non-metallic surface. Next, the cable must be chosen from {Table 4.8}.bWhilst the current rating would be 15.3 A if all of the cable run were clipped to the wall, part of the run is subject to the two correction factors, so a rating of 34.2 A must be used. For the clipped section of the cable (15.3 A), reference method I could be used which gives a size of 1.0 mm^2 (current rating 16.5 A).

However, since part of the cable is on the tray (method 3) the correct size for 34.2 A will be 4.0 mm^2, with a rating of 37 A.

Volt drop calculation

Calculate the volt drop and maximum length of run for the motor circuit.

Since, a mineral insulated PVC sheathed cable is being used, therefore, volt drop values will come from {Table 4.9}. This shows 9.1 mV/A/m for the 4 mm^2 cable selected, which must be used with the circuit current of 15.3 A and the length of run which is 20 m.

$$Cable\,VoltDrop = \frac{9.1 \times 15.3 \times 20V}{1000} = 2.78V$$

Maximum volt drop (4% if 415 V)

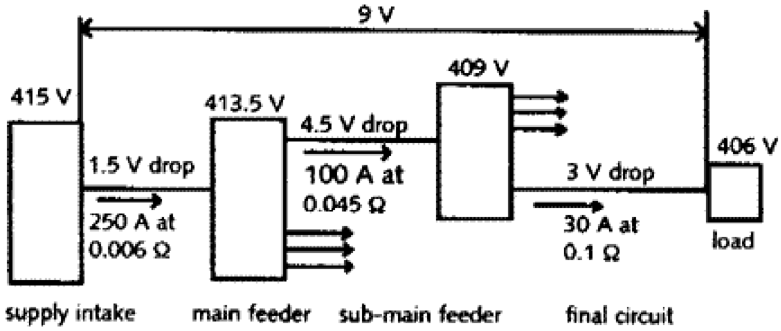
$$Max.Permissible\,VoltDrop = \frac{415 \times 4\%}{100} = 16.6V$$

Maximum length of run for this circuit with the same cable size and type will be:

$$Max.\,\mathrm{Run\,for\,16.6\,V\,volt\,drop} = \frac{16.6 \times 20m}{2.78} = 119\,meters$$

The "length of run" calculations carried out in these examples are often useful to the electrician when installing equipment at greater distances from the mains position.

It is important to appreciate that the allowable volt drop of 4% of the supply voltage applies to the whole of an installation. If an installation has mains, sub-mains and final circuits, for instance, the volt drop in each must be calculated and added to give the total volt drop as indicated in the following figure.



All the calculations in these examples so far has assumed that cable resistance is the only factor responsible for volt drop. In fact, larger cables have significant self-inductance as well as resistance.

Table 1: Correction factors to current rating for ambient temperature

(Ca) (from [Tables 4C1 and 4C2] of BS 7671: 1992)				
Ambient temperature	**Type of insulation**			
(°C)	**70°C p.v.c**	**85°C rubber**	**70°C m.i**	**105°C m.i**
25	1.03 (1.03)	1.02 (1.02)	1.03 (1.03)	1.02 (1.02)
30	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
35	0.94 (0.97)	0.95 (0.97)	0.93 (0.96)	0.96 (0.98)
40	0.87 (0.94)	0.90 (0.95)	0.85 (0.93)	0.92 (0.96)
45	0.79 (0.91)	0.85 (0.93)	0.77 (0.89)	0.88 (0.93)
50	0.71 (0.97)	0.80 (0.91)	0.67 (0.86)	0.84 (0.91)
55	0.61 (0.84)	0.74 (0.88)	0.57 (0.79)	0.80 (0.89)
Figures in brackets apply to semi-enclosed fuses used for overload protection				

Table 2: Correction factors for groups of cables

Number of circuits	**Correction factor Cg**		
-	**Enclosed or clipped**	**Clipped to non-metallic surface**	
-	-	**Touching**	**Spaced***
2	0.8	0.85	0.94
3	0.7	0.79	0.9
4	0.65	0.75	0.9
5	0.6	0.73	0.9
6	0.57	0.72	0.9
7	0.54	0.72	0.9
8	0.52	0.71	0.9
9	0.5	0.7	0.9
10	0.48	----------	0.9
* 'Spaced' means a gap between cables at least equal to cable diameter.			

Table 3: : De-rating factors (Ci) for cables up to 10mm² in cross-sectional area buried in thermal insulation

Length in insulation (mm)	**De-rating factor (Ci)**
50	0.89
100	0.81
200	0.68
400	0.55
500 or more	0.5

Table 4: Current ratings and volt drops for unsheathed single core p.v.c. insulated cables

Cross sectional area	In conduit in thermal insulation	In conduit in thermal insulation	In conduit on wall	In conduit on wall	Clipped direct	Clipped direct	Volt drop	Volt drop
(mm²)	**(A)**	**(A)**	**(A)**	**(A)**	**(A)**	**(A)**	**(mV/A/m)**	**(mV/A/m)**
-	**2 cables**	**3 or 4 cables**	**2 cables**	**3 or 4 cables**	**2 cables**	**3 or 4 cables**	**2 cables**	**3 or 4 cables**
1	11	10.5	13.5	12	15.5	14	44	38
1.5	14.5	13.5	17.5	15.5	20	18	29	25
2.5	19.5	18	24	21	27	25	18..0	15
4	26	24	32	28	37	33	11	9.5
6	34	31	41	36	47	43	7.3	6.4
10	46	42	57	50	65	59	4.4	3.8
16	61	56	76	68	87	79	2.8	2.4

Table 5: Current ratings and volt drops for sheathed multi-core p.v.c.-insulated cables

Cross sectional area	In conduit in thermal insulation	In conduit in thermal insulation	In conduit on wall	In conduit on wall	Clipped direct	Clipped direct	Volt drop	Volt drop
(mm²)	**(A)**	**(A)**	**(A)**	**(A)**	**(A)**	**(A)**	**(mV/A/m)**	**(mV/A/m)**
-	2 core	3 or 4 core	2 core	3 or 4 core	2 core	3 or 4 core	2 core	3 or 4 core
1	11	10	13	11.5	15	13.5	44	38
1.5	14	13	16.5	15	19.5	17.5	29	25
2.5	18.5	17.5	23	20	27	24	18	15
4	25	23	30	27	36	32	11	9.5
6	32	29	38	34	46	41	7.3	6.4
10	43	39	52	46	63	57	4.4	3.8
16	57	52	69	62	85	76	2.8	2.4

Table 6: Current ratings of mineral insulated cables clipped direct

Cross-sectional area	Volt	p.v.c. sheath 2 x single or twin	p.v.c. sheath 3 core	p.v.c. sheath 3 x single or	Bare sheath 2 x single	Bare sheath3 x single
(mm²)		**(A)**	**(A)**	**(A)**	**(A)**	**(A)**
1	500v	18.5	16.5	16.5	22	21
1.5	500v	24	21	21	28	27
2.5	500v	31	28	28	38	36
4	500v	42	37	37	51	47
1	750v	20	17.5	17.5	24	24
1.5	750v	25	22	22	31	30
2.5	750v	34	30	30	42	41
4	750v	45	40	40	55	53
6	750v	57	51	51	70	67
10	750v	78	69	69	96	91
16	750v	104	92	92	127	119

Table 7: Volt drops for mineral insulated cables

Cross-sectional area	Single-phase p.v.c. sheath	Single-phase bare	Three-phase p.v.c. sheath	Three-phase bare
(mm^2)	**(mV/A/m)**	**(mV/A/m)**	**(mV/A/m)**	**(mV/A/m)**
1	42	47	36	40
1.5	28	31	24	27
2.5	17	19	14	16
4	10	12	9.1	10
6	7	7.8	6	6.8
10	4.2	4.7	3.6	4.1
16	2.6	3	2.3	2.6

Appendix-B: Net Positive Suction Head (NPHS)

Centrifugal Value with Centrifugal Pumps

General

There are many detailed publications on the subject of the NPSH value. In practice, however, mistakes are made repeatedly, with pump damage or even complete system failure as a result.

This simple guideline is therefore intended to indicate where and how the system NPSH value can be rendered more favorable using various parameters, and the criteria, which are important for pump selection.

NPSH can be defined as two parts:

NPSH Available (NPSHA): The absolute pressure at the suction port of the pump.

AND

NPSH Required (NPSHR): The minimum pressure required at the suction port of the pump to keep the pump from cavitating.

NPSHA is a function of your system and must be calculated, whereas NPSHR is a function of the pump and must be provided by the pump manufacturer. NPSHA MUST be greater than NPSHR for the pump system to operate without cavitating. Put another way, you must have more suction side pressure available than the pump requires.

NPSH means "Net Positive Suction Head." A system from which, for instance, cold water flows to a pump from a height of 1 m without a pressure drop has an NPSH value of aprox 11 m (not 1m).

NPSH = 11 m

A = available

Here, only one pump with an NPSHR value of 10.5 m or less can normally be used, in order that a safety margin of at least 0.5 m is available.

NPSHR = 10.5 m

R = required

NPSHA Value of the System

Here, a customary formula which is fully adequate for practice is provided. The latest symbols in accordance with DIN 24 260 Part 1, September 1986 edition, are used here.

$$NPSHA = \frac{10\,(\rho_1 + \rho_{amb} - \rho_v)}{\varrho} + \frac{v_1^2}{10}$$

NPSHA in m
(previously $NPSH_{avail.}$) Net positive suction $head_{avail.}$

ρ_1 in bar
(previously ρ_s) Gauge pressure in suction nozzle directly upstream the pump (in case of underpressure, this value is used with a negative "=" sign).
in bar

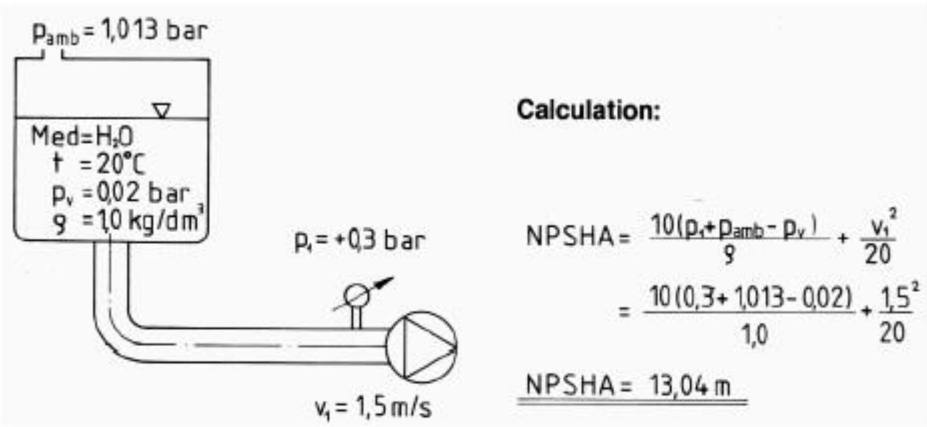
ρ_{amb} in bar abs
(previously ρ_B) Air pressure (normally 1.013 bar abs).

ρ_v in bar abs
(previously ρ_D) Vapor pressure of the fluid at working temperature.

ϱ in kg/dm^3
Density of the fluid at working temperature.

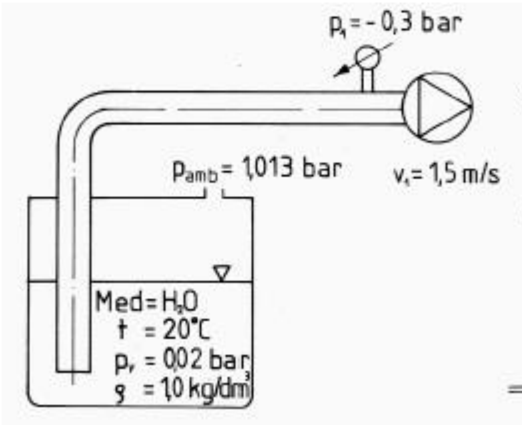
V_1 in m/s
(previously V_S) Velocity of fluid conveyed in the suction nozzle.

This data is referred directly to the center point of the suction nozzle. For the sake of simplicity, gravitational acceleration has been assumed not at 9.81 m/s2 but instead at 10.0 m/s2.



In case, NPSHA is less than NPSHR - What can be done? Referring to the system, the individual formula values can be adhered to.

ρ_1	Increase pressure at the suction nozzle, i.e. feed more fluid, which is to say, raise the fluid level in the feed reservoir, raise the intake reservoir to a higher level or lower the pump, e.g., one floor down. On the other hand, the nominal diameter of the suction line should be adequately dimensioned, and it should be ensured that the valves/fittings in the suction line have the minimum possible friction loss coefficient in order that ρ_1 is as high as possible at the pump. Ball valves with a fully open cross-section, for instance, are particularly suitable.
ρ_{amb}	No opportunities for change.
ρ_v	In few cases, the fluid can be cooled before its entry to the pump, in order to reduce vapor pressure.
ϱ	No opportunities for change.
V_1	Since this value accords with that of the pump's suction nozzle, it is of no significance for this observation. V_1 should, naturally, be as small as possible, as already mentioned with respect to ρ_v.



$$NPSHA = \frac{10(p_1 + p_{amb} - p_v)}{\varrho} + \frac{v_1^2}{20}$$

$$= \frac{10(-0{,}3 + 1{,}013 - 0{,}02)}{1{,}0} + \frac{1{,}5^2}{20}$$

$$NPSHA = 7{,}04\ m$$

The following remedies can be applied to the pump:

Reduce Delivery Rate The NPSHR value will generally become smaller, and the NPSHA value greater. If necessary, split delivery to several pumps, e.g., operate standby pump as well.

Install Larger Impeller In many cases, the NPSHR is better, but power consumption is, of course, also greater.

Reduce Speed Pumps running at lower speeds have better NPSHR values. In many cases, however, a larger pump also becomes necessary.

Install Larger Impeller And Reduce Speed If a relatively small impeller is installed in the pump, this solution is ideal from a hydraulic view point (smoother running, less wear).

Operate Pump With Cavitation In individual cases, the pump supplier and the operator of the system can agree, that total delivery head drop should be not 3%, but more. This must be determined carefully, however, in order that delivery does not collapse completely.

Select Pumps with better NPSH Value Larger pumps in many cases have better NPSH values at the same delivery rate. If necessary, special impellers designed specifically for good suction can be installed.

Miscellaneous

Plastic pumps are, generally, relatively insensitive to cavitation. It is also difficult to hear this phenomenon, since plastic is a good sound insulator.

Magnetic pumps can be treated like pumps with single mechanical seals. The temperature of the fluid should be at least 20°C below its boiling point.

The Influence of Vapor Pressure

In this context, the significance of vapor pressure on the reliable operation of the pump should again be emphasized:

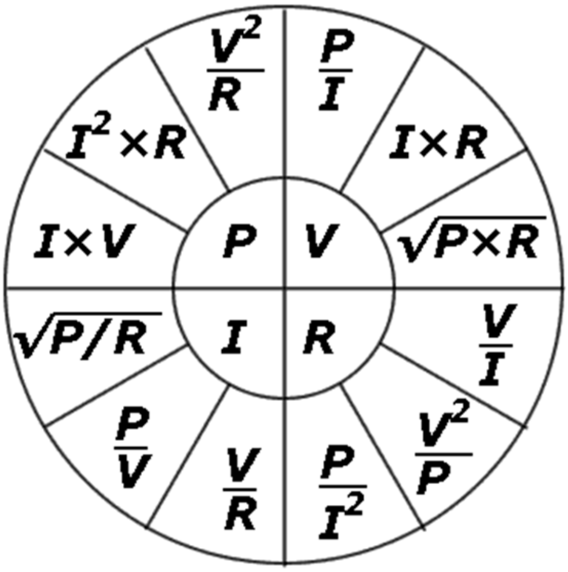
Vapor pressure is a function of temperature. Fluids which are pumped close to vapor pressure are a particular hazard, since even slight increases in temperature can cause evaporation. Not only the temperature fluctuations in general, but also obstructed cooling or an uncontrolled input of heat can trip this off. Inadequate heat dissipation can, for instance, be due to an excessively low delivery rate. Heat input may occur due to increased friction in a mechanical seal, increased bearing friction in magnetic pumps, and also particularly due to heat losses (eddy currents) in metal cans on seal less pumps.

Pumps with double mechanical seals are the least susceptible, since the contact surfaces are lubricated by a separate circuit.

Reference:

- Centrifugal pumps and centrifugal pump systems, DIN 24 260 Part 1
- NPSH in centrifugal pumps, Europump, 1981 edition

Appendix-C: Electrical Rules of Thumb



Useful three phase formulae

$\text{kW} = \text{kVA x power factor}$

$\text{kW} = \frac{\text{hp x 746}}{\text{1000 x Efficiency}}$

$\text{kW} = \frac{\text{Line amps x Line volts x 1.73 x pf}}{1000}$

$\text{kVA} = \frac{\text{kW}}{\text{pf}}$

$\text{kVA} = \frac{\text{hp x 746}}{\text{1000 x Efficiency x pf}}$

$\text{kVA} = \frac{\text{Line amps x Line volts x 1.73}}{1000}$

$\text{Line amps} = \frac{\text{kW x 1000}}{\text{Line volts x 1.73 x pf}}$

$\text{Line amps} = \frac{\text{kVA x 1000}}{\text{Line volts a 1.73}}$

$\text{Line amps} = \frac{\text{hp x 746}}{\text{Line volts x 1.73 x Efficiency x pf}}$

$\text{hp} = \frac{\text{kW x 1000 x Efficiency}}{746}$

$\text{hp} = \frac{\text{kVA x 1000 x Efficiency x pf}}{746}$

$\text{hp} = \frac{\text{Une amps x Line volts x 1.73 x Efficiency x pf}}{746}$

Cable Current Carrying Capacity

For Cu Wire Current Capacity (Up to 30 Sq.mm) = 6 × Size of Wire in sq.mm

Example

For 2.5 sq.mm = 6×2.5 = 15 Amperes

For 1 sq.mm = 6×1 = 6 Amperes

For 1.5 sq.mm = 6×1.5 = 9 Amp

For Cable Current Capacity = 4× Size of Cable in sq.mm

Example

For 2.5 sq.mm cable = 4×2.5 = 9 Amperes

Current Capacity of Equipment

- 1 Phase Motor draws Current = 7Amp per HP.
- 3 Phase Motor draws Current = 1.25Amp per HP.
- Full Load Current of 3 Phase Motor = HPx1.5
- Full Load Current of 1 Phase Motor = HPx6
- No Load Current of 3 Phase Motor = 30% of FLC
- KW Rating of Motor = HPx0.75
- Full Load Current of equipment = 1.39xkVA (for 3 Phase 415Volt)
- Full Load Current of equipment = 1.74xkW (for 3 Phase 415Volt)

Minimum Cable Bending Radius

- Minimum Bending Radius for LT Power Cable = 12 x Dia of Cable.
- Minimum Bending Radius for HT Power Cable = 20 x Dia of Cable.
- Minimum Bending Radius for Control Cable = 10 x Dia of Cable.

Diesel Generator

- Diesel Generator Set Produces = 3.87 Units (KWH) in 1 Litter of Diesel.
- Requirement Area of Diesel Generator = for 25KW to 48KW = 56 Sq. meter, 100KW = 65 Sq .meter.
- DG less than or equal to 1000kVA must be in a canopy.
- DG greater 1000kVA can either be in a canopy or skid mounted in an acoustically treated room
- DG noise levels to be less than 75dBA at 1 meter.
- DG fuel storage tanks should be a maximum of 990 Litter per unit. Storage tanks above this level will trigger more stringent explosion protection provision.

Quick Electrical Calculation

1hp = 0.746KW

1kW = 1.36HP Line

1Watt = 0.846 Kla/Hr

1Watt = 3.41 BTU/Hr

1KWH = 3.6 MJ

1cal = 4.186 J

1Tonne of refrigeration= 3.517 kW = 12,000 Btu per hour

1Kcal = 4186 Joule

1cal = 4.183 Joule

1kWH = 860 Kcal

Star Connection

Voltage = √3 Phase Voltage

Line Current = Phase Current

Delta Connection

Line Voltage = Phase Voltage

Line Current = √3 Phase Current

Bus Bar Copper - Construction detail and current carrying capacity at 35 deg C

Size in mm (height x width)			Area in mm2	Weight in Kg / meters	Current carrying capacity in Amps							
					AC (No of Bus)				DC (No of Bus)			
					I	II	III	II II	I	II	III	II II
12	X	2	24	0.209	110	200			115	205		
15	X	2	30	0.262	140	200			145	245		
15	X	3	45	0.396	170	300			175	305		
20	X	2	40	0.351	185	315			190	325		
20	X	3	60	0.529	220	380			225	390		
20	X	5	100	0.882	295	500			300	510		
25	X	3	75	0.663	270	460			275	470		
25	X	5	125	1.	350	600			355	610		
30	X	3	90	0.796	315	540			320	560		
30	X	5	150	1.	400	700			410	720		
40	X	3	120	1.	420	710			430	740		
40	X	5	200	2.	520	900			530	930		
40	X	10	400	4.	760	1350	1850	2500	770	1400	2000	
50	X	5	250	2.	630	1100	1650	2100	650	1150	1750	
50	X	10	500	4.	920	1600	2250	3000	960	1700	2500	
60	X	5	300	3.	760	1250	1760	2400	780	1300	1900	2500
60	X	10	600	5.	1060	1900	2600	3500	1100	2000	2800	3600
80	X	5	400	4.	970	1700	2300	3000	1000	1800	2500	3200
80	X	10	800	7.	1380	2300	3100	4200	1450	2600	3700	4800
100	X	5	500	4.	1200	2050	2850	3500	1250	2250	3150	4050
100	X	10	1000	9.	1700	2800	3650	5000	1800	3200	4500	5800
120	X	10	1200	11.	2000	3100	4100	5700	2150	3700	5200	6700
160	X	10	1600	14.	2500	3900	5300	7300	2800	4800	6900	9000
200	X	10	2000	18.	3000	4750	6350	8800	3400	6000	8500	10000

Bus Bar Aluminum - Construction detail and current carrying capacity at 35 deg C

Size in mm (height x width)			Area in mm2	Weight in Kg / meters	Current carrying capacity in Amps							
					AC (No of Bus)				DC (No of Bus)			
					I	II	III	II II	I	II	III	II II
12	X	2	24	0.0633	80	140			80	145		
15	X	2	30	0.0795	95	170			95	175		
15	X	3	45	0.12	115	210			115	220		
20	X	2	40	0.107	120	220			125	225		
20	X	3	60	0.161	145	270			150	280		
20	X	5	100	0.268	195	350			200	370		
25	X	3	75	0.201	180	330			185	340		
25	X	5	125	0.335	230	430			235	440		
30	X	3	90	0.242	205	385			275	520		
30	X	5	150	0.503	270	500			220	400		
40	X	3	120	0.323	280	500			285	525		
40	X	5	200	0.538	350	650			360	660		
40	X	10	400	1.08	515	975	1350	1800	540	1000	1420	
50	X	5	250	0.673	425	780	1120	1500	445	815	1220	
50	X	10	500	1.35	625	1150	1600	2160	655	1220	1730	
60	X	5	300	0.808	500	900	1300	1730	530	960	1420	1850
60	X	10	600	1.62	730	1330	1900	2500	770	1430	2030	2600
80	X	5	400	1.08	680	1170	1630	2230	700	1250	1850	2400
80	X	10	800	2.16	940	1700	2360	3150	985	1840	2640	3400
100	X	5	500	1.35	820	1440	2000	2600	855	1550	2220	2900
100	X	10	1000	2.7	1150	2050	2800	3700	1200	2240	3200	4200
100	X	15	1500	4.04	1450	2500	3350	4400	1500	2750	4000	5200
120	X	10	1200	3.24	1350	2400	3250	4300	1420	2700	3900	5100
120	X	15	1800	4.36	1650	2900	3900	5000	1750	3250	4800	6300
160	X	10	1600	4.32	1750	3000	4150	5300	1850	3450	5000	6500
160	X	15	2400	6.47	2100	3600	4850	6250	2300	4000	6200	8100
200	X	10	2000	5.4	2150	3650	4950	6400	2300	4300	6200	8100
200	X	15	3000	8.09	2550	4200	5600	7300	2850	5250	7650	10100

Appendix-D: Useful Equations and Relationships

Air:	
1. $Q = AV$	Q = Quantity, m^3/s
2. $V = 1.3\sqrt{V_p\left(\frac{1.2}{d}\right)}$	A = Area, m^2
3. $V = 1.3\sqrt{V_P}$ for standard air	V = Velocity, m/s
4. $V_P = \left(\frac{V}{1.3}\right)^2$ for standard air	V_p = Velocity pressure, Pa
5. $V = V_m\sqrt{\frac{1.2}{\rho}}$ other than standard air	ρ = Air density, kg/m^3
6. $T_p = V_p + S_p$	V_m = Measured velocity, m/s
	T_p = Total pressure, Pa
	V_p = Velocity pressure, Pa
	S_p = Static pressure, Pa
Fan Laws:	
7. $Q_2 = Q_1\left(\frac{rps_2}{rps_1}\right)$	Q = Air quantity, m^3/s
8. $Sp_2 = Sp_1\left(\frac{rps_2}{rps_1}\right)^2$	rps = Revolutions per second
9. $kW_2 = kW_1\left(\frac{rps_2}{rps_1}\right)^3$	S_p = Static pressure, Pa
	kW = kilowatts
Pulley Laws:	
10. $R = r\left(\frac{d}{D}\right)$	R = Revolutions/sec, driven pulley
11. $r = R\left(\frac{D}{d}\right)$	r = Revolutions/sec, driver pulley
12. $D = d\left(\frac{r}{R}\right)$	D = Diameter driven pulley, metres
13. $d = D\left(\frac{R}{r}\right)$	d = Diameter driver pulley, metres
Gas Laws:	
14. $V_2 = V_1\frac{P_1}{P_2}$	V_1 = Initial volume, m^3
	V_2 = Final volume, m^3
15. $V_2 = V_1\frac{T_2}{T_1}$	T_1 = Initial temperature, absolute, K
	T_2 = Final temperature, absolute, K
16. $P_2 = P_1\frac{T_2}{T_1}$	P_1 = Initial absolute pressure, Pa
	P_2 = Final absolute pressure, Pa

Heat Transfer: Air: 17. $H = C\rho Q \Delta T$ simplified for standard air; 18. $H, \text{sensible} = 1.206 Q \Delta T$ 19. $H, \text{latent heat} = 3 Q \Delta W$ 20. $H, \text{total} = 1.2 Q \Delta h$	H = Heat flow, watts C = Specific heat, $kJ/kg\,°C$ ΔT = Temperature difference, ^oC ΔW = Humidity ratio, g H_2O/kg dry air Δh = Enthalpy difference, kJ/kg dry air Q = Airflow rate, litres per second ρ = Density of air, kg/m^3
Heat Transfer: Water: 21. $H = 1000 \times 4.2\ Q \Delta T$ simplified for standard water; 22. $H = 4200\ Q \Delta T$	H = Heat flow, watts Q = Water flow, liters per second 4.2 = Specific heat of water, $kJ/kg, K$ 1000 = Density of water, kg/m^3 ΔT = Temp. differ. between inlet and outlet water, ^oC
Heat Transfer: Solid Materials: 23. $H = A\,U\,\Delta T$	H = Heat flow, watts A = Area, m^2 U = Overall heat transfer coefficient, $W/m^2 \cdot {}^oC$ ΔT = Temperature diffenence of the two sides, ^oC
Fan Duty: Air: 24. $W = \left(\frac{QP}{1000}\right)\frac{1}{\eta_f}$ Where the efficiency is not known assume 62.8% or simplified; 25. $W = \frac{QP}{628}$ 26. $\text{Fan total efficiency}, \% = \frac{QP_T}{10W}$ 27. $\text{Fan static efficiency}, \% = \frac{QPs}{10W}$ 28. $Ts = \frac{\pi D Rpm}{1000}$	W = Fan power, watts Q = Air quantity, liters per second P = Fan pressure, Pa 1000 = a constant η_f = Fan efficiency, as fracion of 1 (one) P_T = Total pressure, Pa P_S = Static pressure, Pa D = diameter of impeller, mm Rpm = Revolutions per min. Ts = Tip speed, meters per minute
Pump Duty: Water: 29. $W = \left(\frac{Qh}{1000}\right)\frac{1}{\eta_p}$ Where the efficiency is not known assume 70% or simplified; 30. $W = \frac{Qh}{700}$	W = Pump power, watts Q = Water flow, liters per second h = Head, Pa η_p = Pump efficiency, as fraction of 1 (one) 1000 = a constant
Control Valve: 31. $\Delta p = \left(\frac{Q}{Cv}\right)^2$ 32. $Q = Cv\sqrt{\Delta p}$	Δp = Pressure difference, Pa Q = Water flow, liters per second Cv = Control valve constant

Appendix-E: Typical Data Collection Forms

GENERAL INFORMATION : **Form No. 1**

Prepared By: ____________ Date: ____________

Company: ____________

Fac. Address: ____________

Tel: ____________ Fax: ____________

Head Office: ____________

Tel: ____________ Fax: ____________

Contact Name: ____________

Designation: ____________

Year Factory Established: ____________ No. of Employees: ____________

Classification of Industry: ____________

(Mining, Textiles, Food Processing, Chemicals, Paper, Oil Refining, Construction Materials, Mechanical/Electrical, Other)

Processing Activities:

Attach Flowchart (Block Diagram) of Plant indicating Major Operations: Yes / No

Estimated Floor Area of the Production Premises, sq. m : ____________

MONTHLY PRODUCTION DATA: **Form No. 2A**

Fiscal Year:

A. Monthly Production Data

Month	Year	Product 1	Product 2	Product 3	Product 4
		Units ( )	Units ( )	Units ( )	Units ( )
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
Annual Production Capacity:					
Annual Production:					
Avg. Monthly Prod. Capacity:					
Average Monthly Production:					
Annual Sale Price, PKR:					
Sale Price per Unit, PKR:					
Remarks:					

If the plant is not being operated at full capacity, state Constraints/Reasons: (e.g., non-availability of: raw materials, technical staff, electricity; low market demands; operational problems, any other reasons)

Fill in any one of the forms 2A, 2B, and 4, which is most appropriate.
Preferably fill in the form 2. Fill in forms for the last 3 years.

MONTHLY PRODUCTION DATA: **Form No. 2B**

Fiscal Year: [ ]

B. Monthly Production Data

Month	Year	Product Units ( )			
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
Annual Production Capacity:					
Annual Production:					
Avg. Monthly Prod. Capacity:					
Average Monthly Production:					
Annual Sale Price, PKR:					
Sale Price per Unit, PKR:					
Remarks:					

If the plant is not being operated at full capacity, state Constraints/Reasons: (e.g., non-availability of: raw materials, technical staff, electricity; low market demands; operational problems, any other reasons)

Fill in any one of the forms 2A, 2B, and 4, which is most appropriate.
Preferably fill in the form 2. Fill in forms for the last 3 years.

A. Annual Production Data

	Product 1	Product 2	Product 3	Product 4
	Units ( )	Units ( )	Units ( )	Units ( )
Annual Production Capacity:				
Annual Production:				
Avg. Monthly Prod. Capacity:				
Average Monthly Production:				
Annual Sale Price, PKR:				
Sale Price per Unit, PKR:				
Remarks:				

B. Annual Production Data

	Product			
	Units ( )			
Annual Production Capacity:				
Annual Production:				
Avg. Monthly Prod. Capacity:				
Average Monthly Production:				
Annual Sale Price, PKR:				
Sale Price per Unit, PKR:				
Remarks:				

If the plant is not being operated at full capacity, state Constraints/Reasons: (e.g., non-availability of: raw materials, technical staff, electricity; low market demands; operational problems, any other reasons)

Fill in any one of the forms 2A, 2B, and 3, which is most appropriate.
Preferably fill in the form 2. Fill in forms for the last 3 years.

SELF-GENERATION **Form No. 4**

Fiscal Year:

A. Monthly Data:

Month	Year	Generation	HSD	Steam	Other Fuel
		kWh	Consumption	Tons	
			Liters		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
Annual Quantities:					
Average Per Month:					

B. How much electricity was generated annually by the plant in previous 3 years?

Year:				
Electricity Generated, kWh:				

Fill 3 Forms for the last 3 years, if self-generation is done.

If data is not available for the last 3 years, fill in the data for the latest year.

If monthly data is not available, give the following annual data.

SELF-GENERATION EQUIPMENT **Form No. 5**

Unit No.:		Location:			
Generator Manufacturer:					
Year When Installed:			Installed As ?:	New / Old	
Generator Capacity:		kW			
Driver Manufacturer:					
Type:	HSD	Steam Turb.	Other	Waste Heat Boiler	
Rating:		HP			

Are there plans to install self-generation plant or to increase the capacity of existing system? Yes / No

Give details:

Unit No.: ____ Location: ____

Equipment Manufacturer: ____

Year When Installed: ____ Installed As ?: New / Old

Generation Capacity: ____ kW

Year	Energy	Heat	Steam	Electricity
	Source	Production		Production
		(Units)	(Units)	
		GJ	Tons	kWh
1.				
2.				
3.				

Uses ?

Type of Equipment:

Are there plans to install cogeneration systems or to increase the capacity of an existing system? If yes, give details:

Person Responsible for Energy Management:

Name: ____________________

Position: ____________________

Responsibility: Full time / Part time

Qualifications:
Experience:

Is there an energy team? Yes / No If yes, how many? ______

Is there an energy committee? Yes / No

If yes, list the members of the committee and their titles:

Name	Position/Title

The tasks and responsibilities of the energy committee:

Examination of energy consumption and controls:

0 By senior management only?
0 By each section/plant within the company?
0 As a routine matter, or from time to time?
When was the last complete review performed? ______

Note: Pls. provide only the information which is applicable.

Summarize the major energy problems as viewed by plant management:

What constraints to improvement of energy efficiency exist?

What studies have been performed in relation to improving energy efficiency?

Summarize major energy conservation activities already initiated or planned and specify timing:

What is the potential for using non-conventional energy forms or renewable resources (e.g. wood, solar, wind, biomass, biogas)?

INVENTORY

(For Sections/Departments of the Plant/Company) **Form No. 9**

Section/Department: ____________________

	1	2	3	4	5
Equipment					
# of Equipment					
Use/Application					
Duty *					
Installed Power, kW					
Amps.					
Voltage					
Operation: Shift I, 8A					
Shift II, 8B					
Shift III, 8C					
Daily Operating Hrs.					
Annual Operating Days					
Operation, Cont./Intermittent					
Remarks:					

* Duty: Essential / Non-Essential, or stand-by etc.

Please group together the equipment of identical size and duty

Please use as many forms as required.

This Forms is for the installed load of the plant.

INVENTORY

(Total per Sections/Departments of the Plant/Company) **Form No. 10**

	1	2	3	4	5
Section/Dept..					
Installed/Nominal Load, kW					
Measured/Actual Load kW					
Amps					
Voltage					
Power Factor					
Essential Load, kW					
Non-Essential Load, kW					
Operating Schedule					
Shift I, 8A					
Shift II, 8B					
Shift III, 8C					
Daily Operating Hrs.					
Operation, Cont./Intermittent					
Designed Production Rate *					
Actual Production Rate *					
Remarks:					

Prepare and attach Single Line Diagram

* Units be specified of the Production Rate, (daily, weekly, monthly, annual, etc.)

This form shall be completed on the basis of section/department-wise information in the previous form.

Data	Transf. 1	Transf. 2	Transf. 3	Transf. 4	Transf. 5
1. Location					
2. Use/Application					
Duty *					
Nameplate Data Make					
Type					
kVA Rating					
Amp					
Primary Voltage					
Secondary Voltage					
Power Factor					
Efficiency					
Core Losses, %					
Copper Losses, %					
Daily Operating Hrs.					
Annual Operating Hrs					
Ambient Temp. Deg. C					
Operating Conditions					
kW					
Amps					
Volts					
kVA					
Power Factor					
Remarks:					

* Duty may be termed as Essential/non-Essential and Continuous/Intermittent, or stand-by

LIGHTING **Form No. 12**

Data	Area 1	Area 2	Area 3	Area 4	Area 5
Area Served (Identification)					
Principal Use of Area					
Floor Area					
Type of Lamps					
No. of Fixtures					
Lamps per Fixture					
Ballasts (Chokes) per Fixture					
Watts per Lamp					
Watts per Ballast (Choke)					
Measured Lumens					
Method of Control					
Oper. Hrs per Wk					
Oper Wk per Year					
Total Wattage of Lamps					
Lumens per Sq. M					
Remarks:					

Data	Area 6	Area 7	Area 8	Area 9	Area 10
Area Served (Identification)					
Principal Use of Area					
Floor Area					
Type of Lamps					
No. of Fixtures					
Lamps per Fixture					
Ballasts (Chokes) per Fixture					
Watts per Lamp					
Watts per Ballast (Choke)					
Measured Lumens					
Method of Control					
Oper. Hrs per Wk					
Oper Wk per Year					
Total Wattage of Lamps					
Lumens per Sq. M					
Remarks:					

Total: (Form Type: A)

Area:

Data	Lamp Type	Lamp Type	Lamp Type	Lamp Type	Lamp Type
Principal Use of Area					
Floor Area					
No. of Fixtures					
Lamps per Fixture					
Ballasts (Chokes) per Fixture					
Watts per Lamp					
Watts per Ballast (Choke)					
Measured Lumens					
Method of Control					
Oper. Hrs per Wk					
Oper Wk per Year					
Total Wattage of Lamps					
Lumens per Sq. M					
Remarks:					

Area:

Data	Lamp Type	Lamp Type	Lamp Type	Lamp Type	Lamp Type
Principal Use of Area					
Floor Area					
No. of Fixtures					
Lamps per Fixture					
Ballasts (Chokes) per Fixture					
Watts per Lamp					
Watts per Ballast (Choke)					
Measured Lumens					
Method of Control					
Oper. Hrs per Wk					
Oper Wk per Year					
Total Wattage of Lamps					
Lumens per Sq. M					
Remarks:					

Total: (Form Type: B)

	1	2	3	4	5
Location/Identification					
Use/Application					
Duty *					
Nameplate Data Type **					
Stages ***					
Free Air Capacity, cu.m/Hr.					
Max. Operating Pressure, bars					
Motor Rating, kW					
Motor RPM					
Compressor RPM					
Cooling System					
Method of Operation					
Measured Data					
On-Load Input Power, kW					
Off-Load Input Power, kW					
Cut-out (Max) Pressure, bars					
Cut-in (Min) Pressure, bars					
On-Load Time, minutes					
Off-Load Time, minutes					
Inlet Air Temp., oC					
Motor Pulley Dia, mm					
Compressor Pulley Dia, mm					
Daily Operating Hrs					
Annual Operating Hrs					
Proposed Operating Conditions					
Cooler Intake Air at oC					
Oper. Pressure, bars					
Annual Oper. Hrs					
% On-Load Time					
Remarks:					

* Duty may be continuous/Intermittent
** Type may be reciprocating/screw
*** Stages may be single/double/multi-stage
**** Method of control may be on/off, unload, etc.

Tag No.					
Location					
Pressure, bars					
Size of Leak, mm					
Loss Rate, Cu. M / Hr.					
Annual Oper. Hrs					
Annual Loss, Cu m.					
Annual Energy Loss, kWh					
Total Annual Loss, Cu m.		Total Annual Energy Loss, kWh			

Tag No.					
Location					
Pressure, bars					
Size of Leak, mm					
Loss Rate, Cu. M / Hr.					
Annual Oper. Hrs					
Annual Loss, Cu m.					
Annual Energy Loss, kWh					
Total Annual Loss, Cu m.		Total Annual Energy Loss, kWh			

	Motor 1	Motor 2	Motor 3	Motor 4	Motor 5
1. Location					
2. Use/Application					
Duty *					
Nameplate Data Make					
Type					
kW					
Amp.					
Volts					
Power Factor					
RPM					
Physical Condition					
Vibration					
Daily Operating Hrs.					
Annual Operating Hrs					
Ambient Temp. Deg. C					
On-Load Measurements					
Motor Temp., oC					
Measured Voltage					
L1-L2 (V1), Volts					
L2-L3 (V2), Volts					
L3-L1 (V3), Volts					
L1, Amps					
L2, Amps					
L3, Amps					
kWs					
Power Factor					
RPM					
No-Loads Measurements					
L1-L2 (V1), Volts					
L2-L3 (V2), Volts					
L3-L1 (V3), Volts					
L1, Amps					
L2, Amps					
L3, Amps					
kWs					
Power Factor					
RPM					
Stator Resistance, Ohms					
L1-L2 (R1)					
L2-L3 (R2)					
L3-L1 (R3)					
Remarks:					

* Duty may be termed as Essential/non-Essential and Continuous/Intermittent or stand-by etc.

PUMPS DATA **Form No.17**

	Pump 1	Pump 2	Pump 3	Pump 4	Pump 5
Location					
Use/Application					
Duty *					
Physical Condition					
Vibration					
Nameplate Data Make					
Model					
Flow rate, cu. m/h					
Total Head, m					
Pump RPM					
Impeller Dia, mm					
Motor Size, kW					
Arrangement **					
Designed/Actual Requirements					
Flow rate, cu.m/Hr.					
Total Head, m					
Operation *****					
Overhead Tank ****					
Daily Filling Frequency					
Actual Data					
Flow rate, Cu. m/Hr.					
Static Head, m					
Discharge Head, m					
Suction Head, m					
Input Power, kW					
Throttled? ***					
% Throttle					
Controls					
Comments					

* Duty : May be Essential/Non-Essential and Continuous/Intermittent, stand-by
** Arrangement : May be Direct Coupled/Belt Driven
*** Throttled : Yes of No as the case may be
**** Overhead Tank : Yes or No as the case may be
***** Operation : May be of Constant or Variable Flow

FAN DATA **Form No. 18**

	Fan 1	Fan 2	Fan 3	Fan 4	Fan 5
Location					
Use/Application					
Duty *					
Physical Condition					
Vibration					
Nameplate Data Model					
Make					
Type					
Air Flow Capacity, cu.m/min.					
Motor Rating, kW					
Motor RPM					
Fan RPM					
Fan Pulley Dia, mm					
Motor Pulley Dia, mm					
Daily Operating Hrs.					
Annual Operating Hrs					
Designed Air Requirements					
Constant Air. cu. m/min.					
Maximum, cu. m/min.					
Minimum, cu. m./min.					
Actual Air Requirements					
Constant Air. cu. m/min.					
Maximum, cu. m/min.					
Minimum, cu. m./min.					
Actual Data Input, kW					
Velocity Head, mm water					
Total Head, mm water					
Static Head, mm water					
Air Temp., oC					
Flow rate, cu. m/min.					
% Fan Throttled					
Remarks:					

* Duty : may be Essential/Non-Essential and Continuous/Intermittent, stand-by

Data	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Location					
Use/Application					
No. of Units					
Physical Condition					
Nameplate Data Model					
Type					
Make					
Tonnage					
Compressor Stages					
Capacity					
RPM					
Condensing Mode					
Capacity Control					
Motor Nameplate Data Amps					
Motor Rating, kW					
Voltage					
RPM					
Arrangement/Coupling					
Power Factor					
Daily Operating Hrs					
Annual Operating Days					
Annual Oper. Hrs					
Designed Opening. Conditions					
Suction Temp., Deg C					
Suction Pressure, bars					
Discharge Temp. Deg C					
Discharge Pressure, bars					
Temp. Control Limits					
Maximum					
Minimum					
Actual Operating Conditions					
Suction Temp., Deg C					
Suction Pressure, bars					
Discharge Temp. Deg C					
Discharge Pressure, bars					
Temp. Control Limits					
Maximum					
Minimum					
Actual Measurements					
Input Power, kW					
Power Factor					
Volts					

Finding Actual Requirement of Compressed Air (as Free Air) — Form No. 20

a) From Equipment Data

	Capacity cu.m./Hr.	Existing Oper. Press. bars	Proposed Oper. Press. bars
1			
2			
3			
4			
5			
6			

or, b) From actual measurements of on-load and off-load time of compressor and total system volume:

a) Storage tank volume is taken from the compressor literature or estimated using the dimensions of the tank =

b) System Volume:

	Pipe dia mm	Length m	Volume liters
1			
2			
3			
4			
5			
6	Total Volume		

(Storage + System Volume)

FORM NO.	USED	# USED	FORM NO.	USED	# USED
Form No. 1	Y N		Form No. 21	Y N	
Form No. 2	Y N		Form No. 22	Y N	
Form No. 3	Y N		Form No. 23	Y N	
Form No. 4	Y N		Form No. 24	Y N	
Form No. 5	Y N		Form No. 25	Y N	
Form No. 6	Y N		Form No. 26	Y N	
Form No. 7	Y N		Form No. 27	Y N	
Form No. 8	Y N		Form No. 28	Y N	
Form No. 9	Y N		Form No. 29	Y N	
Form No. 10	Y N		Form No. 30	Y N	
Form No. 11	Y N		Form No. 31	Y N	
Form No. 12	Y N		Form No. 32	Y N	
Form No. 13	Y N		Form No. 33	Y N	
Form No. 14	Y N		Form No. 34	Y N	
Form No. 15	Y N		Form No. 35	Y N	
Form No. 16	Y N		Form No. 36	Y N	
Form No. 17	Y N		Form No. 37	Y N	
Form No. 18	Y N		Form No. 38	Y N	
Form No. 19	Y N		Form No. 39	Y N	
Form No. 20	Y N		Form No. 40	Y N	

Forms Prepared By:

Prepared Date:

Signatures: ______________________________

Revised by Mr. Iftikhar Ahmad Raja in collaboration with
Mr. Asad Mahmood - Manager Technical ECF and
Mr. Muhammad Umar - Research Associate ECF

ENERCON
National Energy Conservation Centre
ENERCON Building, G-5/2, Islamabad
Tel: 051-2272649
Email: enercon.pakistan@gmail.com