ELECTRICAL ENERGY CONSERVATION AND AUDITING

[REL5D002]

LECTURE NOTES

B. TECH 3RD YEAR – VI SEM (2024-25)

DEPARTMENT OF ELECTRICAL ENGINEERING

MODERN ENGINEERING

&

MANAGEMENT STUDIES

Module I: (12 Hours)

Electrical energy conservation: **Energy economics- discount rate, payback period, internal rate of return, net present value, and life cycle cost. Energy generation, energy distribution, energy usage by processes, technical and economic evaluation, understanding energy costs, classification of energy conservation measures, plant energy performance, benchmarking and energy performance, matching energy usage to requirement, maximizing energy system efficiency, optimizing the input energy requirements, fuel and energy substitution, and energy balancing.**

EB billing- **HT and LT supply, transformers, electric motors- motor efficiency computation, energy efficient motors, pumps, fans, blowers, compressed air systems, refrigeration and air conditioning systems, cooling towers, electric heaters (space and liquid), DG-sets, illuminating devices, power factor improvement, and harmonics.**

Electrical energy conservation

Electrical energy is the most common and widely used type of energy in the world. The subject of energy conservation is a concern for most energy users particularly industry. Energy conservation (ECON) becomes even more important for the third world, developing countries, where the rising energy costs and the use of efficient energy apparatus are of significant concern to both the industry and the utility.

In this Module, the application of the ECON techniques by which electrical energy can be saved and made cost efficient from the industrial perspective are presented for a Thermal Power Plant

Areas of application of Energy Conservation are Power Generating Station, Transmission & Distribution system, Consumers premises. Steps are to be taken to enhance the performance efficiency of generating stations.

Energy Conservation technology adopted in Transmission & Distribution system may reduce energy losses, which were in tune of 35% of total losses in Power system. Acceptance of Energy conservation technology will enhances the performance efficiency of electrical apparatus used by end users.

Implementation of Energy conservation technology will lead to energy saving which means increasing generation of energy with available source.

1.0 Need of energy conservation:

Fossil fuels like coal, oil that has taken years to form is on the verge of depleting soon. In last 200 years we have consumed 60% of all resources. For sustainable development we need to adopt energy efficiency measures. Today 85% of primary energy sources come from non-renewable and fossil sources. These reserves increasing consumption and will exist for future generations.

Energy survey conducted by Ministry of Power in 1992 reveled that there is requirement of improvement in energy generation efficiency, improvement in energy transportation (transmission & distribution systems) and enhancing the performance efficiency of use end apparatus. Study of 'Energy strategies for Future' evolved two things - efficient use of energy, energy conservation and use of Renewable Energy. Energy conservation emerges out to be the first and least cost option.

1.1 Important terms and definitions

The formal definition of the basic terms are given below

The formal definitions of the basic terms are given below:
Energy Policy

Energy Policy defines the overall guidelines for the efforts to achieve greater energy efficiency. It is established and maintained by the top management of the company.

Energy Planning

Energy Planning involves setting of concrete energy targets complying with the overall energy policy and elaborate action plans to achieve the targets in a given time frame. Planning of several activities includes, forecast, budget, infrastructure, material, equipment, technology, financial resource, human resource and R & D planning.

Energy management

Energy management can be defined in many ways. One way of defining it is: "The judicious and effective use of energy to maximize profit and enhance competitive positions" another comprehensive definition is: "The strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total cost of producing the output from these systems"

The objective of energy management is to achieve and maintain optimum energy procurement and utilization throughout the organization and to: (i) minimize energy cost/energy waste without affecting production and quality, (ii) minimize environmental effects.

Energy Audit

Energy audit is an inspection, survey and analysis of energy flows for energy conservation in a building, process or system to reduce the amount of energy input into the system without negatively affecting the output(s). It also includes submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan

to reduce energy consumption. In commercial and industrial real estate, an energy audit is the first step in identifying opportunities to reduce energy expense.

The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a "benchmark" (reference point) for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization.

Energy conservation

Energy conservation means reduction in growth of energy consumption and is measured in physical terms.

Energy conservation is the practice of decreasing the quantity of energy used while achieving a similar outcome of end use. (This practice may result in increase of financial capital, environmental value, national security, personal security and human comfort.)

Energy conservation also means reduction or elimination of unnecessary energy used and wasted.

Energy Efficiency

Energy Efficiency is define saving energy, but keeping the same level of service. For example, replace an inefficient incandescent light bulb with a more efficient compact fluorescent lamp for an LED lamp. On the other hand, if you turn off the lights when you leave a room, you are practicing energy conservation

Energy Conservation vs. Energy Efficiency: What is the difference?

Energy conservation and efficiency may be related, but they have distinct definitions in the energy world. Energy conservation involves using less energy by adjusting your behaviours and habits. Energy efficiency, on the other hand, involves using technology that requires less energy to perform the same function. Energy-saving light bulbs, large household appliances, smart thermostats, and smart home hubs like Constellation Connect are all examples of technology that can be energy efficient.

Energy intensity

Energy intensity is a measure of the energy efficiency of a nation's economy. It is calculated as the amount of energy consumed for generating one unit of Gross Domestic Product.

Energy elasticity

Energy elasticity is the percentage change in energy consumption to achieve one percent change in national GDP in a specific country over time

Energy Conservation act 2001

- Enacted on 1st October 2001
- Becomes effective from 1st March 2002
- Objective of providing necessary legal Framework for promoting energy conservation measures in the country
- Bureau of Energy Efficiency of operationalised from 1st March 2002

Purpose of the EC act 2001

- The purpose of this act is to provide for efficient use of energy and its conservation
- Provide a policy framework and direction to National energy conservation activities
- Co-ordinate policies and programs on efficient use of energy with stakeholders
- Established systems and procedure to verify measure and monitor improvement
- Leverage multilateral bilateral and private sector support to implement the EC act
- Demonstrate the delivery systems through public-private partnerships
- To promote Energy Efficiency in this country

Important features of energy conservation act 2001

- Energy conservation Building Code (ECBC
- Standards and labelling (S&L)
- Demand side management (DSM)
- Bachat lamp Yojana (BLY)
- Promoting Energy Efficiency in small and medium enterprises (SMEs)
- Designated consumers
- Certification of energy managers and energy auditors

1.2 Important Aspects of Energy Conservation

Conserving usable energy, which is otherwise wasted, has a direct impact on economy, environment and long-term availability of non-renewable energy sources. Energy conservation implies reduction in energy consumption by reducing losses and wastage by employing energy efficient means of generation and utilization of energy. There are three important aspects of energy conservation:

1.2.1. Economic Aspect

(A) Reduction in cost of product Energy conservation ultimately leads to economic benefits as the cost of production is reduced. In some energy intensive industries like steel, aluminium, cement, fertilizer, pulp and paper etc., cost of energy forms a significant part of the total cost of the product. Energy cost (expressed as percent of total cost of the product) in the entire industrial sector in India varies from as low as 0.36 per cent to as high as 65 per cent. We must strive for good energy economy using energy efficient technologies. This will reduce the manufacturing cost and lead to production of cheaper and better quality products. This is essential to stay competent with our commercial rivals.

 (B) *New job opportunities* Energy conservation usually requires new investments in more efficient equipment to replace old inefficient ones, monitoring of energy consumption, training of manpower, etc. Thus, energy conservation can result in new job opportunities.

1.2.2 Environment Aspect

Every type of energy generation / utilization process affects the environment to some extent either directly or indirectly. The extent of degradation of environment depends mainly on the type of primary energy source. Also during any energy conversion stage a part of energy escapes to surroundings and appears in the form of heat. Thus energy is generated and utilized

at the expense of adverse environmental impacts. Adoption of energy conservation means can minimize this damage.

1.2.3 Conservation of Non Renewable Energy Assets

The vast bulk of energy used in the world today comes from fossil fuels, which are non-renewable. These resources were laid down many millions of years ago and are not being made any longer. This finite, non-renewable asset is being used up very fast. The quantity of fossil fuels the world community uses up in one minute what it took the earth a millennium to create. Therefore, its prices are bound to go up relative to everything else. We must abandon wasteful practices in energy utilization and conserve this resource by all means for future generations.

Salient features of energy conservation act 2001

The Act provides a long-range consequence, which is appended below:

- The establishment of Bureau of Energy Efficiency (BEE) in place of existing Energy Management Centre (EMC) to implement the provisions of the act
- Declaration of a user or class of users of energy as a designated consumer
- To lay down minimum energy consumption standards and labeling for identified appliances/equipment and norms for industrial processes for energy intensive industries
- Formation of energy consumption codes
- Dissemination of information and best practices
- Establishment of Energy Conservation Fund both at the central and state levels
- Provision of penalties and adjudication
- The BEE would act as a facilitator for the evolution of a self-regulatory system and organizations would regulate on their own with a view to save energy and thereby bring the commercial concept in the organization

The Central Government has established the BEE with effect from March 1, 2002. Further, the provision of sections 1–29 and sections 46–62 of the Energy Conservation Act 2001 relating to this have come into force from the same date.

Schemes to promote energy conservation and energy efficiency [22]

Ministry of Power, through Bureau of Energy Efficiency (BEE), has initiated a number of energy efficiency initiatives in the areas of household lighting, commercial buildings, standards and labeling of appliances, demand side management in agriculture/municipalities, SMEs (Small and Medium Enterprises) and large industries including the initiation of the process for development of energy consumption norms for industrial sub sectors, capacity building of SDAs (State Designated Agencies), etc. The target of energy savings against these schemes during the XIth Plan period was kept as 10,000 MW of avoided generation capacity. These initiatives have resulted in an avoided capacity generation of 10836 MW during the XIth plan period. The schemes initiated by BEE are discussed below:

1. Standards and Labeling

The Bureau initiated the Standards and Labeling (S and L) programme for equipment and appliances in 2006 to provide the consumer an informed choice about the energy saving and thereby the cost-saving potential of the relevant marketed product. The scheme is invoked for 19 equipment/appliances, i.e. Room Air-Conditioners, Fluorescent Tube Lights, Frost Free Refrigerators, Distribution Transformers, Induction Motors, Direct Cool Refrigerator, electric storage type geyser, Ceiling fans, Color TVs, Agricultural pump sets, LPG stoves, Washing machine, Laptops, ballast, floor standing ACs, office automation products, Diesel Generating sets & Diesel operating pump sets of which the first 4 products have been notified under mandatory labeling from 7th January, 2010. The other appliances are presently under voluntary labeling phase. The energy efficiency labeling programmes under BEE are intended to reduce the energy consumption of appliance without diminishing the services it provides to consumers. Further, the standards and label for refrigerators and air-conditioners have been periodically made more stringent. As a result, the least-efficient products are removed from the market and more efficient products are introduced. The Corporate Average Fuel Consumption Standards (CAFC) for passenger cars has been notified on 30th January, 2014. The most recent additions to the list of labeled products are Diesel Pump Sets & Diesel Generating Set.

During the XIIth plan, Standards and Labelling programme will target at least 3 more new equipment/appliances including upgradation of energy performance standards for equipment/appliances covered during XI Plan.

2. Energy Conservation Building Codes (ECBC)

The Energy Conservation Building Code (ECBC) was developed by Govt. of India for new commercial buildings on 27th May 2007. ECBC sets minimum energy standards for new commercial buildings having a connected load of 100 kW or contract demand of 120 KVA and above. While the Central Government has powers under the EC Act 2001, the state governments have the flexibility to modify the code to suit local or regional needs and notify them. Currently eight States and Union Territories (Rajasthan, Odisha, UT of Puducherry, Uttrakhand, Punjab, Karnataka, Andhra Pradesh & Telangana) notified and adopted the code for their states. In order to promote a market pull for energy efficient buildings, Bureau of Energy Efficiency developed a voluntary Star Rating Programme for buildings which is based on the actual performance of a building, in terms of energy usage in the building over its area expressed in kWh/sq. m/year. Currently, Voluntary Star Labelling programme for 4 categories of buildings (day use office buildings / BPOs / Shopping malls / Hospitals) has been developed and put in public domain.

3. Demand Side Management (DSM) Schemes

(a) Agriculture DSM In order to tap the energy saving potential, Agriculture Demand Side Management (AgDSM) programme was initiated in XIth plan by Bureau of Energy Efficiency with an objective to induce energy efficiency in agriculture sector by creating market based framework for implementation of few pilot projects and create awareness among end users and other stakeholders for adoption of energy efficient pump sets (EEPS).

During the XIIth plan, realizing the vast energy saving potential in the sector, BEE intends to continue the programme with an objective to build up the process of acceleration of sustainable energy efficiency in the plan through following interventions:

- Regulatory mechanism to mandate the use of BEE star labeled pump sets for new connections
- Facilitate implementation of DPRs and setting up monitoring & verification protocol
- Technical assistance and capacity development of all stakeholders

(b) Municipal DSM Identifying the immense energy-saving potential in municipal sector, BEE initiated Municipal Demand Side Management (MuDSM) during XI plan. The basic objective of the project was to improve the overall energy efficiency of the Urban Local Bodies (ULBs), which could lead to substantial savings in the electricity consumption, thereby resulting in cost reduction / savings for the ULBs. Implementation of the project at the ground level is highly necessary which will create a market transformation among technology provider, implementing partners, financial institutions etc. In view of these facts, it is proposed that implementation of demo projects in 15 ULBs will be undertaken on pilot basis during XII plan. In addition, technical support will be provided to the ULBs by appointing technical experts to selected ULBs.

(c) Capacity Building of DISCOMS The objective of the programme is capacity building of DISCOMs (distribution companies) for carrying out load management programme, energy conservation programme, development of DSM action plan and implementation of DSM activities in their respective areas. This programme would help the DISCOMs for reducing peak electricity demand so that they can delay building further capacity.

(d) Energy Efficiency in Small and Medium Enterprises (SMEs) Sector To encourage the energy efficient technologies and operational practices in SME sectors in India, BEE has initiated the energy efficiency interventions in selected 25 SMEs clusters during the XIth plan. A study was conducted to assess energy use and technology gap at unit level, development of the cluster specific energy efficiency manuals, preparation of Detailed Project Reports (DPRs) on energy efficient technologies and capacity building and knowledge enhancement of man-force involved in SMEs. During the XIIth plan, implementations of 100 technology demonstration projects in five SME sectors are envisaged to facilitate large-scale replication.

4. Strengthening Institutional Capacity of States

(a) Strengthening of State Designated Agency (SDAs) As has been mentioned earlier, the implementation and enforcement of the provisions of the Energy Conservation Act in the states is to be carried out by SDAs. As on date, the SDAs have been set up in 32 states by designating one of the existing organizations as required under Section 15 (d) of the Energy Conservation Act 2001. In order to kick start the energy conservation activities at the state level with an emphasis on building institutional capacities of the SDAs, Ministry of Power had approved the scheme of Providing financial assistance to the State Designated Agencies for strengthening their institutional capacities and capabilities during the XI plan. During the XII plan, thrust is given on establishment of the enforcement machinery at the State level.

(b) Contribution to State Energy Conservation Fund (SECF) Scheme The State Energy Conservation Fund (SECF) is an instrument to overcome the major barriers for implementation of energy efficiency projects. The contribution under State Energy Conservation Fund (SECF) was made to those State Govt. / UT Administration who have created their SECF and finalized the rules and regulations to operationalize the same.

5. School Education Programme

Considering the need to make the next generation more aware regarding efficient use of energy resources, it is necessary to introduce children during their school education. In this regard, promotion of energy efficiency in schools is being promoted through the establishment of Energy Clubs. Bureau of Energy Efficiency is implementing the Students Capacity Building Programme under Energy Conservation awareness scheme for XII five year plan and intends to prepare the text / material on Energy Efficiency and Conservation for its proposed incorporation in the existing science syllabi and science textbooks of NCERT for classes 6th to 10th.

Through this project recommendations will also be made to the National Council of Education, Research and Training (NCERT) to update the science textbooks of classes VII to IX to include relevant chapters on Energy Efficiency in the school syllabus.

6. Human Resource Development (HRD)

The potential for improvement of energy efficiency of processes and equipment through awareness creation is vast. A sound policy for creation, retention and up gradation of skills of Human Resources is very crucial for penetration of energy efficient technologies and practices in various sectors. The component under HRD comprises of theory cum practice oriented training programme and providing Energy Audit Instrument Support.

## 7. National Mission for Enhanced Energy Efficiency (NMEEE)

The National Mission for Enhanced Energy Efficiency (NMEEE) is one of the eight missions under the National Action Plan on Climate Change (NAPCC). NMEEE aims to strengthen the market for energy efficiency by creating conducive regulatory and policy regime and has envisaged fostering innovative and sustainable business models to the energy efficiency sector.

The Mission seeks to upscale the efforts to unlock the market for energy efficiency which is estimated to be around Rs. 74,000 crore and help achieve total avoided capacity addition of 19,598 MW, fuel savings of around 23 million tonnes per year and greenhouse gas emissions reductions of 98.55 million tonnes per year at its full implementation stage.

1.3 Area of application of Energy Conservation:

Electrical system is a network in which power is generated using non-renewable sources by conventional method and then transmitted over longer distances at high voltage levels to load centers where it is used for various energy conversion process. End user sector are identified as three major areas -Power Generating station, Transmission & Distribution systems, and Energy consumers. Consumers are further classified as Domestic, commercial and Industrial consumers.

Areas	Consumption (Year-2007)
Domestic	21%
Commercial	18.0%
Industrial	32%
Transportation	29%
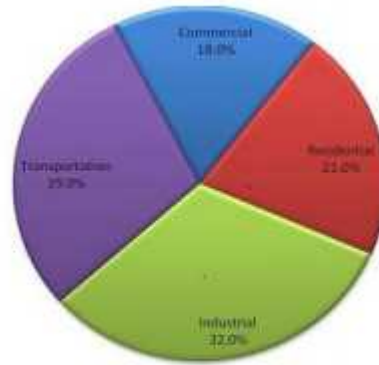
ENERGY CONSERVATION OPPORTUNITIES

Classification of energy conservation opportunities

Based on energy audit and analyses of the plant, a number of potential energy saving projects may be identified. These may be classified into three categories:

1. Category A: Minor ECOs

Minor ECOs are simple, easy to implement, requiring less investment and implementation time. These are related with stopping of leakage points, avoiding careless waste, housekeeping, lapses and carelessness of O & M personnel.

2. Category B: Medium ECOs

Medium ECOs or intermediate ECOs are slightly complex, requiring additional investment and moderate implementation time.

3. Category C: Major ECOs

Major ECOs provide significant energy conservation opportunity. These are high tech., complex and require heavy investment and long implementation period.

General electrical ecos

1. Class A: Simple Electrical ECOs

(a) Switching off the loads (i.e. lights, heaters, ACs, TVs, etc.) when not in use

(b) Changing from electrical heating to solar heating or gas burner heating wherever possible

(c) Proper housekeeping

(d) Reducing peak demand by staggering the use of large loads

(e) Providing automatic thermostatic (or any other) control to water heaters, refrigerators, air-conditioners, etc.

(f) Using recently developed 'tiny switches' which switch off the electronic apparatus during their sleeping mode

(g) Changing operating cycle of electrical equipment to conserve energy.

For example, electrical furnaces may be used continuously in three shifts (instead of two shifts) for better economy.

(h) Replacing inefficient lamps by energy efficient lamps

2. Class B: Intermediate Electrical ECOs

(a) Installation of static VAR sources at substations

(b) Employing automatic controlled load switches

(c) Heat recovery from cooling oil associated with transformer

(d) Automatic voltage control of power consuming devices by means of ON-load tap changer

(e) Installation of shunt capacitors near inductive load for power factor improvement and reducing kVA demand

(f) Improvement in Operation and Maintenance, reducing down time

3. Class C: Comprehensive Electrical ECOs

(a) Modern more efficient and easy to maintain plant equipment may replace old less efficient ones

(b) The simple manual / semi manual controlled equipment in an electrical plant are retrofitted with energy efficient computer controlled equipment. The energy input is matched with optimum energy requirement.

1.4 ENERGY CONSERVATION TECHNIQUES:

1.4.1 EC in Power generating station:

To generate 1MW power generation cost is Rs 4.5 to 5.25 crores and T& D cost is Rs.2 crores. But cost of saved power is Rs.1Crores/Mw. The important note is time period to set a power plant is 5 years; to set up transmission line 1 year and to plan energy conservation is only 1 month. We have less opportunity for EC in generating area but we can improve the performance efficiency of generators by optimization of load, optimal distribution of load among different units, periodical maintenance and also increasing the capacity by adopting advanced technology using renewable energy sources.

1.4.2 EC in Transmission & Distribution:

Areas Consumption (Year-2007) Domestic 21% Commercial 18.0% Industrial 32% Transportation 29% 3 In India the power transmission and distribution (T&D) system is a three tire structure comprising of state grids, regional grids and distribution network. To meet the energy demand power system networks are interconnected through INTRA-REGIONAL LINK.

The inter-regional power transmission capacity of India at end of 2007 was 14000 MW. T&D system in India is characterized by heavy losses of about 34.54% according to statistics of 2005-06, as compared to 10-15% in developed countries

Power losses in T&D system can be classified as Technical losses and Commercial losses.

Power losses in T&D system	
Technical losses	Commercial losses
• Transformer losses • Transmission line losses • Inter-link losses • Distribution losses	• Metering • Inefficient management • Improper maintenance

1.4.2.1- Technical Losses in T&D System:

Power losses occurring in T&D sector due to imperfection in technical aspect which indirectly cause loss of investment in this sector, are technical losses. These technical losses are due to inadequate system planning, improper voltage and also due to poor power factor etc.

Components	Nature of losses	% Losses
Transformer Losses	Electrical Losses= I^2R losses Magnetic Losses = Core losses	Power transformer contributes nearly 40% to 50% of total transmission and distribution losses.
Transmission line losses:	Line losses = $3I^2R$ loss	17%
Inter-link losses:	Line losses = $3I^2R$ loss	
Distribution Losses:	I^2R loss in distribution line High reactive burden. Poor p.f. Harmonic currents. Unbalanced load. Excessive neutral current.	These losses range from 10% to 62%. The average losses are found to be 25%.

1.4.2.2-Commercial Losses:

Commercial losses are those, which are directly responsible for wastage of money invested in transmission and distribution system. These losses are effects of inefficient management, improper maintenance etc. Corruption is also the main reason contributing to the Commercial losses. Metering losses includes loss due to inadequate billings, faulty metering, overuse, because of meters not working properly and outright theft. Many of the domestic energy meters fail because of poor quality of the equipment.

1.4.3 EC Techniques in Transformers:

i) Optimization of loading of transformer:

- By proper Location of Transformer preferably close to the load center, considering other features like centralized control, operational flexibility etc. This will bring down the distribution loss in cables.

- Maintaining maximum efficiency to occur at 38% loading (as recommended by REC), the overall efficiency of transformer can be increased and its losses can be reduced
- Under fluctuating load condition more than one transformer is used in Parallel Operation of Transformers to share the load & can be operated close to the maximum efficiency range

ii) By Improvisation in Design and Material of Transformer:

- To reduce load losses in Transformer, use thicker conductors so that resistance of conductor reduces and load loss also reduces.

- To reduce Core losses use superior quality or improved grades of Cold Rolled Grain Oriented (CRGO) laminations.

iii) Replacing by Energy Efficient Transformers:

- By using energy efficient transformers efficiency improves to 95 % to 97%.
- By using Amorphous transformers efficiency improves to 97 % to 98.5%.
- By using Epoxy Resin cast/ Encapsulated Dry type transformer- efficiency improves to 93% to 97%.

1.4.4 Energy Conservation in Transmission Line:

To reduce line resistance-„R‟ solid conductors are replaced by stranded conductors (ACSR or AAC) and by bundled conductors in HT line.

High Voltage Direct Current (HVDC) is used to transmit large amount of power over long distances or for interconnections between asynchronous grids

By transmitting energy at high voltage level reduces the fraction of energy lost due to Joule heating. (V a1/I so I^{2}R losses reduces).

As load on system increases terminal voltage decreases. Voltage level can be controlled by using voltage controllers and by using voltage stabilizer

If required reactive power transmitted through transmission lines, it causes more voltage drop in the line. To control receiving end voltage, reactive power controllers or reactive power compensating equipments such as Static VAR controllers are used.

1.4.5 Energy Conservation in Distribution Line:

a) Optimization of distribution system: The optimum distribution system is the economical combination of primary line (HT), distribution transformer and secondary line (LT), To reduce this loss and improve voltage HT/LT line length ratio should be optimized.

b) Balancing of phase load- As a result of unequal loads on individual phase sequence, components causes over heating of transformers, cables, conductors, motors. Thus, increasing losses and resulting in the motor malfunctioning under unbalanced voltage conditions.

c) Harmonics: With increase in use of non-linear devices, distortion of the voltage and current waveforms occurs, known as Harmonics. Due to presence of harmonic currents excessive voltage and current in transformers terminals, malfunctioning of control equipments and Energy meter, over effect of power factor correction apparatus, interference with telephone circuits and broad casting occurs. Distribution Static Compensator (DASTACOM) and Harmonic filters can reduce this harmonics.

d) Energy Conservation by using power factor controller: Low power factor will lead to increased current and hence increase losses and will affect the voltage. We can use Power Factor Controller or Automatic Power Factor Controller that can be located near receiving substations, load centres or near loads.

e) Energy Conservation By Demand side management control: Demand-side management is used to describe the actions of a utility, beyond the customer's meter, with the objective of altering the end-use of electricity - whether it be to increase demand, decrease it, shift it between high and low peak periods, or manage it when there are intermittent load demands - in the overall interests of reducing utility costs. Nearly energy of 15,000 MW can be saved through end-use energy efficiency.

By using DSM saving potential in…
                Industry and Agriculture - 30-35%
                Commercial / Government establishments and residential houses. -25-30%

1.4.6 - Energy Conservation in lighting system:

Good lighting is required to improve the quality of work, to reduce human‟s / worker‟s fatigue, to reduce accidents, to protect his eyes and nervous system. In industry it improves production, and quality of products / work. To view economy of lighting system, cost of initial installation cost, running cost, and effect on production / work are to be considered as main parameters. The power consumption by the industrial lighting is nearly 2 to 10 % of total power consumption, depending on type of industries.

a) Optimum use of natural light: Whenever the orientation of a building permits, day lighting has to be used in combination with electric lighting. The maxim use of sunlight can be get by means of transparent roof sheets, north light roof, etc

b) Replacing incandescent lamps by Compact Fluorescent Lamps (CFL's): CFL's are highly suitable for places such as Living rooms, Hotel lounges, Bars, Restaurants, Pathways, Building entrances, Corridors, etc.

Area	Existing lamp		Proposed lamp		Power savings	
Industry	GLS	13w	CFL	9w	4 w	31%
	GLS	200w	Blended	160w	40w	20%
Domestic	GLS	60w	CFL	25w	35w	58%

c) Replacing conventional fluorescent lamp by energy efficient fluorescent lamp: Energy efficient lamps are based on the highly sophisticated technology. They offer excellent colour rendering properties in addition to the very high luminous efficacy.

Area	Lamp Type				Power Saving	
	Existing		Proposed		Watts	Efficiency
Industry	TL	40w	TLD	36w	4w	10%
Street lighting	TL	2*40 w	TL	2*36 w	08w	06
Domestic	TL	40w	T-8	28w	12w	30

d) Replacement of Mercury/Sodium Vapor Lamp by Halides Lamp: MHL provides high colour rendering index and offer efficient white light. Hence for critical applications where higher illumination levels are required, these lamps are used. They are highly suitable for applications such as assembly line, inspection area, painting shops etc.

Area	Existing lamp	Proposed lamp	Power savings	
Industry	HPMV- 400w	MHL- 250w	5 w	17%
Commercial	HPSV- 150w	MHL- 250w	150w	35%
Street lighting	GLS - 200w	ML- 160w	40 w	07%
	GL- 300w	ML- 250w	50 w	17%

e) Replacing HPMV Lamps by High pressure sodium Vapour Lamp (HPSV): Where colour rendering is not critical for such applications e g street lighting, yard lighting because CRI of HPSV is low but offer more efficiency.

Area	Existing lamp	Proposed lamp	Power savings	
Street lighting	HPMV - 125w	HPSV 70w	25 w	44%
	HPMV- 250w	HPSV 150w	100 w	40%
Yard lighting	HPMV- 250w	HPSV 150w	100 w	40 %

f) Replacing filament lamps on panels by LED: LED lamps consumes less power (1 W lamp), withstand high voltage fluctuation in the power supply, longer operating life (>100,000 hrs). Hence nowadays they are also used in street lighting, signaling, advertising boards, even as replacement for tube light or CFL.

g) Replacement of conventional ballast by Electronic ballast: Installation of high frequency (28 – 32Mhz) electronic ballast in place of conventional ballasts helps to reduce power consumption up to 35%.

h) Installation of separate transformer for lighting: In most of the industries, the net lighting load varies between 2 to 10%. If power load and lighting load fed by same transformer, switching operation and load variation causes voltage fluctuations. This also affects the performance of neighboring power load apparatus, lighting load equipments and also reduces lamps. Hence, the lighting equipment has to be isolated from the power feeders. This will reduce the voltage related problems, which in turn provides a better voltage regulation for the lighting This also increases the efficiency of the lighting system.

i) Installation of servo stabilizer for lighting feeder: Wherever, installation of separate transformer for lighting is not economically attractive and then servo stabilizer can be installed for the lighting feeders.

j) Control over energy consumption pattern: Occupancy Sensors, Daylight Linked Control are commonly used in commercial buildings, malls, offices, where more no. Of lights are to be controlled as per operational hours microprocessor based Light control circuits are used. As a single control unit it can be programmed to switch on /off as per the month wise, year wise and even season wise working schedule.

k) Periodic survey and adequate maintenance program: Illumination level reduces due to accumulation of dirt on lamps and luminaries. By carrying periodic maintenance i.e. cleaning, dusting of lamps and luminaries will improve the light output / luminance. As part of maintenance programme, periodic surveys of installation, lightning system with respect lamp positioning and illumination levels, proper operation of control gears should be conducted to take advantage of energy conservation opportunities as user requirements changes.

1.4.7 Energy Conservation in Motors:

Considering all industrial applications 70% of total electrical energy consumed by only electric motors driven equipments.

a. Improving power supply quality: Maintaining the voltage level within the BIS standards i.e. with tolerance of +/-6% and frequency with tolerance of +/-3% motor performance improves and also life.

b. Optimum loading: Proper selection of the rating of the motor will reduce the power consumption. If the motor is operating at less than 50% of loading (<50%) significant power saving can be obtained by replacing with properly sized high efficiency motors. If the motor is operating at loads below 40% of it‟s capacity, an inexpensive and effective measure might be to operate in star mode.

c. Improving transmission efficiency: Proper selection of power transmission means (belts, gears) will reduces transmission losses.

d. Stopping idle or redundant running of motors or lights will save 100% power.

e. By use of Soft Starter: Soft starters are essentially stator voltage controllers; helps to overcome above problem. It helps to **restrict starting current** and also provide **smooth start and stop operation.**

Application	No. Of working hours	No. Of jobs	Energy consumed in kWh	Savings in kWh	Savings in %
Grinding machine					
Without soft starter	7	55	168.0	---	---
With soft starter	7	51	136.8	31.2	18.6
Lathe machine (5.5 kW)					
Without soft starter	7	231	96.4	---	---
With soft starter	7	228	76.4	19.6	20.4

f. By improving power factor: For improving p.f., connect the capacitor bank, which will improve the p.f. of the system from installation to generating station. Maximum improvement in overall system efficiency is achieved, which also reduces max. demand of the system and that will reflect in energy bill.

g. Use of high efficiency or Energy efficient motors: The energy efficient motors have reduced losses through improved design, better materials and improved manufacturing techniques. Generally motor life doubles for each 10^0 C reduction in operating temperature. While selecting EEM, select with 1.15service factor, design for operation at 85% of rated load.

STANDARD vs HIGH EFFICIENCY MOTORS
(Typical 3-Phase Induction Motor)
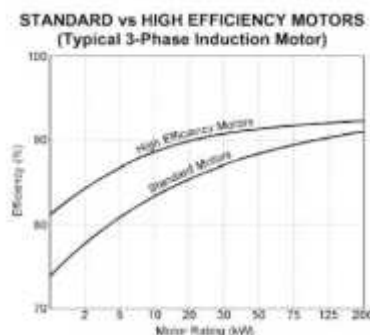
1.5 Energy economics- discount rate, payback period, internal rate of return, net present value, and life cycle cost.

In most respects, investment in energy efficiency is no different from any other area of financial management. So when your organization first decides to invest in increasing its energy efficiency it should apply exactly the same criteria to reducing its energy consumption as it applies to all its other investments. It should not require a faster or slower rate of return on investment in energy efficiency than it demands elsewhere.

Discount rate

The discount rate is the interest rate that firms use to determine how much a future cash flow is worth in the present. The practice of using the discount rate to evaluate cash flows is called discounting

Using the discount rate, the calculation finds the **present value**:

$$\text{Present value} = \frac{\textit{Future Value After t Periods}}{(1+r)^t}$$

- t = Period of time measured in years
- r = The discount rate (interest rate) expressed as a decimal
- The future value after the whole period of time (t)

If the future value after one year is $10,500 and the discount rate is 5% then:

$$\text{Present value} = \frac{10{,}500}{(1.05)^1}$$

Present value = $10,000

If a consumer wants to save their money to earn interest so they can buy a new TV in 2 years, then they can use the price of the TV ($2,500, assuming it does not change) and find out how much money they need to save at 7% interest:

$$\text{Present value} = \frac{2{,}500}{(1.07)^2}$$

Present value = $2,183.59

If they put $2,183.59 away at 7% interest over 2 years then they will have the right amount of money to buy the TV they want.

Simple Payback Period

This is the simplest technique that can be used to appraise a proposal. The simple payback period can be defined as 'the length of time required for the running total of net savings before depreciation to equal the capital cost of the project'. In theory, once the payback period has ended, all the project capital costs will have been recouped and any additional cost savings achieved can be seen as clear 'profit'. Obviously, the shorter the payback period, the more attractive the project becomes. The length of the maximum permissible payback period generally varies with the business culture concerned. In some companies, payback periods in excess of 3 years are considered acceptable.

The payback period can be calculated using the equation

$$\boxed{\text{Simple payback period (years)} \ = \ \frac{\text{Capital cost of the project (in Rs.)}}{\text{Net Annual savings (in Rs.)}}}$$

$$\boxed{\text{PB} \ = \ \frac{\text{CC}}{\text{AS}}}$$

Where PB is the payback period (years), CC is the capital cost of the project (Rs.), and AS is the annual net cost saving achieved (Rs.).

The annual net cost saving (AS) is the least savings achieved after all the operational costs have been met. Simple payback period is illustrated in Example 4.

Example 4

A new small cogeneration plant installation is expected to reduce a company's annual energy bill by Rs.4,86,000. If the capital cost of the new boiler installation is Rs.22,20,000 and the annual maintenance and operating costs are Rs. 42,000, the expected payback period for the project can be worked out as.

Solution

$$\text{PB} = 22,20,000 / (4,86,000 - 42,000) = 5.0 \text{ years}$$

The payback method is a simple technique, which can easily be used to provide a quick evaluation of a proposal. However, it has a number of major weaknesses:

• The payback method does not consider savings that are accrued after the payback period has finished.

 • The payback method does not consider the fact that money, which is invested, should accrue interest as time passes. In simple terms there is a 'time value' component to cash flows. Thus Rs.1000 today is more valuable than Rs.1000 in 10 years' time.

In order to overcome these weaknesses a number of discounted cash flow techniques have been developed, which are based on the fact that money invested in a bank will accrue annual interest. The two most commonly used techniques are the 'net present value' and the 'internal rate of return' methods.

The simple payback period is usually calculated as follows:

$$Simple\ payback\ period = \frac{First\ cost}{Yearly\ benfits - yearly\ costs}$$

Examples

Simple payback period for a continuous Deodorizer that costs Rs.60 lakhs to purchase and install, Rs.1.5 lakhs per year on an average to operate and maintain and is expected to save

Rs. 20 lakhs by reducing steam consumption (as compared to batch deodorizers), may be calculated as follows: According to the payback criterion, the shorter the payback period, the more desirable the project.

$$Simple\ payback\ period = \frac{60}{20 - 1.5} = 3\ years\ 3\ months$$

Internal rate of return method

It can be seen from Example 5 that both projects returned a positive net present value over 10 years, at a discount rate of 8%. However, if the discount rate were reduced there would come a point when the net present value would become zero. It is clear that the discount rate which must be applied, in order to achieve a net present value of zero, will be higher for Project 2 than for Project 1. This means that the average rate of return for Project 2 is higher than for Project 1, with the result that Project 2 is the better proposition.

> The discount rate which achieves a net present value of zero is known as the internal rate of return (IRR). The higher the internal rate of return, the more attractive the project.

Example 6 illustrates how an internal rate of return analysis is performed.

Example 6

A proposed project requires an initial capital investment of Rs.20 000. The cash flows generated by the project are shown in the table below:

Year	Cash flow (Rs.)
0	−20,000.00
1	+6000.00
2	+5500.00
3	+5000.00
4	+4500.00
5	+4000.00
6	+4000.00

Given the above cash flow data, let us find out the internal rate of return for the project.

Solution

	Cash flow (Rs.) (Rs.)	8% discount rate		12% discount rate		16% discount rate	
		Discount factor	Present value (Rs.)	Discount factor	Present value	Discount factor (Rs.)	Present value
0	−20000	1.000	−20000	1.000	−20000	1.000	−20000
1	6000	0.926	5556	0.893	5358	0.862	5172
2	5500	0.857	4713.5	0.797	4383.5	0.743	4086.5
3	5000	0.794	3970	0.712	3560	0.641	3205
4	4500	0.735	3307.5	0.636	3862	0.552	2484
5	4000	0.681	2724	0.567	2268	0.476	1904
6	4000	0.630	2520	0.507	2028	0.410	1640
		NPV = 2791		NPV = 459.5		NPV = −1508.5	

It can clearly be seen that the discount rate which results in the net present value being zero lies somewhere between 12% and 16%. For12% discount rate, NPV is positive; for 16% discount rate, NPV is negative. Thus for some discount rate between 12 and 16 percent, present value benefits are equated to present value costs. To find the value exactly, one can interpolate between the two rates as follows:

$$\text{Internal rate of return} = 0.12 + (0.16 - 0.12) \times \frac{459.5}{(459.5 - (-1508.5))} \times 100$$

$$\text{Internal rate of return} = 0.12 + (0.16 - 0.12) \times \frac{459.5}{(459.5 + 1508.5)} \times 100 = 12.93\%$$

Thus the internal rate of return for the project is 12.93 %. At first sight both the net present value and internal rate of return methods look very similar, and in some respects are. Yet there is an important difference between the two. The net present value method is essentially a comparison tool, which enables a number of projects to be compared, while the internal rate of return method is designed to assess whether or not a single project will achieve a target rate of return.

Net Present Value Method

The net present value method considers the fact that a cash saving (often referred to as a 'cash flow') of Rs.1000 in year 10 of a project will be worth less than a cash flow of Rs.1000 in year 2. The net present value method achieves this by quantifying the impact of time on any particular future cash flow. This is done by equating each future cash flow to its current value today, in other words determining the present value of any future cash flow. The present value (PV) is determined by using an assumed interest rate, usually referred to as a discount rate. Discounting is the opposite process to compounding. Compounding determines the future

value of present cash flows, where" discounting determines the present value of future cash flows.

In order to understand the concept of present vale, consider the case described in Example 3. If instead of installing a new cogeneration system, the company invested Rs.22,20,000 in a bank at an annual interest rate of 8%, then:

The value of the sum at the end of year 1 = 22,20,000 + (0.08 x 22,20,000) = Rs.23,97,600

The value of the sum at the end of year 2 = 23,97,600 + (0.08 x 23,97,600) = Rs.25,89,408

The value of the investment would grow as compound interest is added, until after n years the value of the sum would be:

$$FV = D \times (1 + IR/100)^n$$

Where FV is the future value of investment in Rs., and D is the value of initial deposit (or investment) in Rs., IR is Interest Rate and n is number of years.

Example :

The future value of the investment made at present, after 5 years will be:

$FV = 22,20,000 \times (1 + 8/100)^5 = Rs.32,61,908.4$

So in 5 years the initial investment of 22,20,000 will accrue Rs.10,41,908.4 in interest and will be worth Rs.32,61,908.4. Alternatively, it could equally be said that Rs.32,61908.4 in 5 years time is worth Rs.22,20,000 now (assuming an annual interest rate of 8%). In other words the *present value* of Rs.32,61,908.40 in 5 years time is Rs.22,00,000 now.

The *present value* of an amount of money at any specified time in the future can be determined by the following equation.

$$PV = S \times (1 + IR/100)^{-n}$$

Where PV is the present value of S in n years time (Rs.), and S is the value of cash flow in n years time (Rs.).

The net *present value* method calculates the *present value* of all the yearly cash flows (i.e. capital costs and net savings) incurred or accrued throughout the life of a project, and summates them. Costs are represented as a negative value and savings as a positive value. The sum of all the present values is known as the *net present value* (NPV). The higher the *net present value*, the more attractive the proposed project.

The *present value* of a future cash flow can be determined using the equation above. However, it is common practice to use a *discount factor* (DF) when calculating present value. The discount factor is based on an assumed discount rate (i.e. interest rate) and can be determined by using equation.

$$DF = (1 + IR/100)^{-n}$$

The product of a particular cash flow and the discount factor is the present value.

$$PV = S \times DF$$

The values of various discount factors computed for a range of discount rates (i.e. interest rates) are shown in Table 11.1. The Example 5 illustrates the process involved in a net present value analysis.

TABLE 11.1 COMPUTED DISCOUNT FACTORS

	Discount rate % (or interest rate %)							
Year	2	4	6	8	10	12	14	16
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0.980	0.962	0.943	0.926	0.909	0.893	0.877	0.862
2	0.961	0.825	0.890	0.857	0.826	0.797	0.769	0.743
3	0.942	0.889	0.840	0.794	0.751	0.712	0.675	0.641
4	0.924	0.855	0.792	0.735	0.683	0.636	0.592	0.552
5	0.906	0.822	0.747	0.681	0.621	0.567	0.519	0.476
6	0.888	0.790	0.705	0.630	0.564	0.507	0.456	0.410
7	0.871	0.760	0.665	0.583	0.513	0.452	0.400	0.354
8	0.853	0.731	0.627	0.540	0.467	0.404	0.351	0.305
9	0.837	0.703	0.592	0.500	0.424	0.361	0.308	0.263
10	0.820	0.676	0.558	0.463	0.386	0.322	0.270	0.227
11	0.804	0.650	0.527	0.429	0.350	0.287	0.237	0.195
12	0.788	0.625	0.497	0.397	0.319	0.257	0.208	0.168
13	0.773	0.601	0.469	0.368	0.290	0.229	0.182	0.145
14	0.758	0.577	0.442	0.340	0.263	0.205	0.160	0.125
15	0.743	0.555	0.417	0.315	0.239	0.183	0.140	0.108
16	0.728	0.534	0.394	0.292	0.218	0.163	0.123	0.093
17	0.714	0.513	0.371	0.270	0.198	0.146	0.108	0.080
18	0.700	0.494	0.350	0.250	0.180	0.130	0.095	0.069
19	0.686	0.475	0.331	0.232	0.164	0.116	0.083	0.060
20	0.673	0.456	0.312	0.215	0.149	0.104	0.073	0.051

Life cycle cost

Life cycle costing, or whole-life costing, is the process of estimating how much money you will spend on an asset over the course of its useful life. Whole-life costing covers an asset's costs from the time you purchase it to the time you get rid of it.

Buying an asset is a cost commitment that extends beyond its price tag. For example, think of a car. The car's price tag is only part of the car's overall life cycle cost. You also need to consider expenses for car insurance, interest, gas, oil changes, and any other necessary maintenance to keep the car running. Not planning for these additional costs can set you back.

The cost to buy, use, and maintain a business asset adds up. Whether you're purchasing a car, a copier, a computer, or inventory, you should consider and budget for the asset's future costs.

Life cycle costing process

Conducting a life cycle cost assessment helps you better predict how much your business will pay when you acquire a new asset.

To calculate an asset's life cycle cost, estimate the following expenses:

1. Purchase
2. Installation
3. Operating
4. Maintenance
5. Financing (e.g., interest)
6. Depreciation
7. Disposal

Add up the expenses for each stage of the life cycle to find your total.

You might use past data to help you create a more accurate cost prediction. To simplify the process, start with your fixed costs. Fixed costs for businesses are the expenses that stay the same from month to month. Then, estimate variable costs, which are expenses that change.

Life cycle costing process for intangible assets
You can also use life cycle costing to determine how much your intangible assets will cost. Intangible assets are non-physical property, such as patents, your business's brand, and your reputation.

Although it is more difficult to add up the whole-life cost of an intangible asset than a tangible asset (physical property), it's still possible. Consider the total cost of acquiring and maintaining an intangible asset.

For example, patents cost thousands of dollars. You might also need to hire a lawyer to help you obtain one. And, you will need to pay fees to maintain your patent.

Or, consider your business's brand. You might spend money on all the things that go into creating your brand, such as developing a logo, registering your name, and setting up a small business website. Further, you will spend money on marketing and maintaining your brand.

Life cycle costing assessment example

Let's say you want to buy a new copier for your business.

Purchase: The purchase price is $2,500.

Installation: You spend an additional $75 for setup and delivery.

Operating: You need to buy ink cartridges and paper for it, so you estimate you will spend $1,000 on these supplies over the course of its useful life. And, you expect the total electricity the copier will use to be $300.

Maintenance: If the copier breaks, you estimate repairs will total $450.

Financing: You purchase the copier with your store credit card, which has an interest rate of 3.5% per month. You pay off the printer the next month, meaning you owe $87.50 in interest ($2,500 X 3.5%).

Depreciation: You predict the copier will lose value by $150 each year.

Disposal: You estimate it will cost $100 to hire an independent contractor to remove the copier from your business.

Although the purchase price of the copier is $2,500, the life cycle cost of the copier could end up costing your business over $4,500.

Purpose of the life cycle cost analysis

As mentioned, conducting a life cycle cost analysis helps you estimate how much an asset will cost you over the course of its life.

Take a look at some of the reasons why knowing an asset's total cost can guide your business decisions.

1. Choose between two or more assets

Using life cycle costing helps you make purchasing decisions. If you only factor in the initial cost of an asset, you could end up spending more in the long run. For example, buying a used asset might have a lower price tag, but it could cost you more in repairs and utility bills than a newer model.

Life cycle cost management depends on your ability to make a smart investment. When you are deciding between two or more assets, consider their overall costs, not just the price tag in front of you.

2. Determine the asset's benefits

How do you know if you should buy an asset? Generally, you weigh the pros and cons of your purchase. But if you only consider the initial, short-term cost, you won't know if the asset will benefit your business financially in the long run.

By using life cycle costing, you can more accurately predict if the asset's return on investment (ROI) is worth the expense. If you only look at the asset's current purchase cost and don't factor in future costs, you will overestimate the ROI.

3. Create accurate budgets

When you know how much an asset's total price is, you can create budgets that represent your business's actual expenses. That way, you won't underestimate your business's costs.

A budget is made up of expenses, revenue, and profits. If you underestimate an asset's cost on your budget, you are overestimating your profits. Failing to account for expenses can result in overspending and negative cash flow.

1.6 Energy generation, energy distribution, energy usage by processes, technical and economic evaluation

Identification of Energy Conservation Opportunities

Fuel substitution: Identifying the appropriate fuel for efficient energy conversion

Energy generation: Identifying Efficiency opportunities in energy conversion equipment/utility such as captive power generation, steam generation in boilers, thermic fluid heating, optimal loading of DG sets, minimum excess air combustion with boilers/thermic fluid heating, optimising existing efficiencies, efficient energy conversion equipment, biomass gasifiers, Cogeneration, high efficiency DG sets, etc.

Energy distribution: Identifying Efficiency opportunities network such as transformers, cables, switchgears and power factor improvement in electrical systems and chilled water, cooling water, hot water, compressed air, Etc.

Energy usage by processes: This is where the major opportunity for improvement and many of them are hidden. Process analysis is useful tool for process integration measures.

Technical and Economic feasibility

The technical feasibility should address the following issues

- Technology availability, space, skilled manpower, reliability, service etc

- The impact of energy efficiency measure on safety, quality, production or process.

- The maintenance requirements and spares availability

The Economic viability often becomes the key parameter for the management acceptance. The economic analysis can be conducted by using a variety of methods. Example: Pay back method, Internal Rate of Return method, Net Present Value method etc. For low investment short duration measures, which have attractive economic viability, simplest of the methods, payback is usually sufficient. A sample worksheet for assessing economic feasibility is provided below:

Sample Worksheet for Economic Feasibility
Name of Energy Efficiency Measure

1. Investment	2. Annual operating costs	3. Annual savings
a. Equipments b. Civil works c. Instrumentation d. Auxiliaries	• Cost of capital • Maintenance • Manpower • Energy • Depreciation	• Thermal Energy • Electrical Energy • Raw material • Waste disposal

Net Savings /Year (Rs./year) = (Annual savings-annual operating costs)	Payback period in months = (Investment/net savings/year) x 12

1.7 Understanding Energy Costs:

Understanding energy cost is vital factor for awareness creation and saving calculation. In many industries sufficient meters may not be available to measure all the energy used. In such cases, invoices for fuels and electricity will be useful. The annual company balance sheet is the other sources where fuel cost and power are given with production related information.

Energy invoices can be used for the following purposes:

> • They provide a record of energy purchased in a given year, which gives a base-line for future reference

> • Energy invoices may indicate the potential for savings when related to production requirements or to air conditioning requirements/space heating etc.

> • When electricity is purchased on the basis of maximum demand tariff

> • They can suggest where savings are most likely to be made.

> • In later years invoices can be used to quantify the energy and cost savings made through energy conservation measures

Fuel Costs

A wide variety of fuels are available for thermal energy supply. Few are listed below:

> • Fuel oil

> • Low Sulphur Heavy Stock (LSHS)

> • Light Diesel Oil (LDO)

> • Liquefied Petroleum Gas (LPG)

> • COAL

> • LIGNITE

> • WOOD ETC.

Understanding fuel cost is fairly simple and it is purchased in Tons or Kiloliters. Availability, cost and quality are the main three factors that should be considered while purchasing. The following factors should be taken into account during procurement of fuels for energy efficiency and economics.

> • Price at source, transport charge, type of transport

> • Quality of fuel (contaminations, moisture etc)

> • Energy content (calorific value)

Power Costs

Electricity price in India not only varies from State to State, but also city to city and consumer to consumer though it does the same work everywhere. Many factors are involved in deciding final cost of purchased electricity such as:

• Maximum demand charges, kVA (i.e. How fast the electricity is used?)

• Energy Charges, kWh (i.e., How much electricity is consumed?)

• TOD Charges, Peak/Non-peak period (i.e. When electricity is utilized ?)

• Power factor Charge, P.F (i.e., Real power use versus Apparent power use factor)

• Other incentives and penalties applied from time to time

• High tension tariff and low tension tariff rate changes

• Slab rate cost and its variation

• Type of tariff clause and rate for various categories such as commercial, residential, industrial, Government, agricultural, etc.

• Tariff rate for developed and underdeveloped area/States

• Tax holiday for new projects

Example: Purchased energy Bill

A typical summary of energy purchased in an industry based on the invoices

TABLE 1.4			
Type of energy	Original units	Unit Cost	Monthly Bill Rs.
Electricity	5,00,000 kWh	Rs.4.00/kWh	20,00,000
Fuel oil	200 kL	Rs.10,000/ kL	20,00,000
Coal	1000 tons	Rs.2,000/ton	20,00,000
Total			60,00,000

Unfortunately the different forms of energy are sold in different units e.g. kWh of electricity, liters of fuel oil, tonne of coal. To allow comparison of energy quantities these must be converted to a common unit of energy such as kWh, Giga joules, kCals etc.

Electricity (1 kWh) = 860 kCal/kWh (0.0036 GJ)

Heavy fuel oil (Gross calorific value, GCV) =10000 kCal/litre (0.0411 GJ/litre)

Coal (Gross calorific value, GCV) =4000 kCal/kg (28 GJ/ton)

1.8 Classification of Energy Conservation Measures

Based on energy audit and analyses of the plant, a number of potential energy saving projects may be identified. These may be classified into three categories:

        1. Low cost - high return;

        2. Medium cost - medium return;

        3. High cost - high return

Normally the low cost - high return projects receive priority. Other projects have to be analyzed, engineered and budgeted for implementation in a phased manner. Projects relating to energy cascading and process changes almost always involve high costs coupled with high returns, and may require careful scrutiny before funds can be committed. These projects are generally complex and may require long lead times before they can be implemented. Refer Table 3.1 for project priority guidelines.

TABLE 3.1 PROJECT PRIORITY GUIDELINE			
Priority	Economical Feasibility	Technical Feasibility	Risk / Feasibility
A - Good	Well defined and attractive	Existing technology adequate	No Risk/ Highly feasible
B - May be	Well defined and only marginally acceptable	Existing technology may be updated, lack of confirmation	Minor operating risk/May be feasible
C - Held	Poorly defined and marginally unacceptable	Existing technology is inadequate	Doubtful
D - No	Clearly not attractive	Need major breakthrough	Not feasible

1.9 Benchmarking and Energy Performance

Benchmarking of energy consumption internally (historical / trend analysis) and externally (across similar industries) are two powerful tools for performance assessment and logical evolution of avenues for improvement. Historical data well documented helps to bring out energy consumption and cost trends month-wise / day-wise. Trend analysis of energy consumption, cost, relevant production features, specific energy consumption, help to understand effects of capacity utilization on energy use efficiency and costs on a broader scale.

External benchmarking relates to inter-unit comparison across a group of similar units. However, it would be important to ascertain similarities, as otherwise findings can be grossly misleading. Few comparative factors, which need to be looked into while benchmarking externally are:

        • Scale of operation

        • Vintage of technology

• Raw material specifications and quality

• Product specifications and quality

Benchmarking energy performance permits

• Quantification of fixed and variable energy consumption trends vis-à-vis production levels

• Comparison of the industry energy performance with respect to various production levels (capacity utilization)

• Identification of best practices (based on the external benchmarking data)

• Scope and margin available for energy consumption and cost reduction

• Basis for monitoring and target setting exercises.

The benchmark parameters can be:

• Gross production related

e.g. kWh/MT clinker or cement produced (cement plant)

e.g. kWh/kg yarn produced (Textile unit)

e.g. kWh/MT, kCal/kg, paper produced (Paper plant)

e.g. kCal/kWh Power produced (Heat rate of a power plant)

e.g. Million kilocals/MT Urea or Ammonia (Fertilizer plant)

e.g. kWh/MT of liquid metal output (in a foundry)

• Equipment / utility related

e.g. kW/ton of refrigeration (on Air conditioning plant)

e.g. % thermal efficiency of a boiler plant

e.g. % cooling tower effectiveness in a cooling tower

e.g. kWh/NM3 of compressed air generated

e.g. kWh /litre in a diesel power generation plant.

While such benchmarks are referred to, related crucial process parameters need mentioning for meaningful comparison among peers. For instance, in the above case:

• For a cement plant - type of cement, blaine number (fineness) i.e. Portland and process used (wet/dry) are to be reported alongside kWh/MT figure.

• For a textile unit - average count, type of yarn i.e. polyester/cotton, is to be reported alongside kWh/square meter.

• For a paper plant - paper type, raw material (recycling extent), GSM quality is some important factors to be reported along with kWh/MT, k Cal/Kg figures.

• For a power plant / cogeneration plant - plant % loading, condenser vacuum, inlet cooling water temperature, would be important factors to be mentioned alongside heat rate (kCal/kWh).

• For a fertilizer plant - capacity utilization(%) and on-stream factor are two inputs worth comparing while mentioning specific energy consumption

• For a foundry unit - melt output, furnace type, composition (mild steel, high carbon steel/cast iron etc.) raw material mix, number or power trips could be some useful operating parameters to be reported while mentioning specific energy consumption data.

• For an Air conditioning (A/c) plant - Chilled water temperature level and refrigeration load (TR) are crucial for comparing kW/TR.

• For a boiler plant - fuel quality, type, steam pressure, temperature, flow, are useful com parators alongside thermal efficiency and more importantly, whether thermal efficiency is on gross calorific value basis or net calorific value basis or whether the computation is by direct method or indirect heat loss method, may mean a lot in benchmarking exercise for meaningful comparison.

• Cooling tower effectiveness - ambient air wet/dry bulb temperature, relative humidity, air and circulating water flows are required to be reported to make meaningful sense.

• Compressed air specific power consumption - is to be compared at similar inlet air tem perature and pressure of generation.

• Diesel power plant performance - is to be compared at similar loading %, steady run condition etc.

1.10 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 programme is doing. It compares the change in energy consumption from one year to the other considering production output. Plant energy performance monitoring compares plant energy use at a reference year with the subsequent years to determine the improvement that has been made.

However, a plant production output may vary from year to year and the output has a significant bearing on plant energy use. For a meaningful comparison, it is necessary to determine the energy that would have been required to produce this year production output, if the plant had 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 had operated in the same way as it did in the reference year. It is the ratio of production in the current year to that in the reference year.

$$Production\ factor = \frac{Current\ year's\ production}{Reference\ year's\ production}$$

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 use by the production factor (obtained above)

Reference year equivalent = Reference year energy use x Production factor

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, and is calculated by subtracting the current year's energy use from the reference years equivalent. The result is divided by the reference year equivalent and multiplied by 100 to obtain a percentage

$$Plant\ energy\ performance = \frac{Reference\ year\ equivalent - Current\ year's\ energy}{Reference\ year\ equivalent} \times 100$$

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.

Monthly Energy Performance

Experience however, has shown that once a plant has started measuring yearly energy performance, management wants more frequent performance information in order to monitor and control energy use on an on-going basis. PEP can just as easily be used for monthly reporting as yearly reporting.

1.11 Matching Energy Usage to Requirement

Mismatch between equipment capacity and user requirement often leads to inefficiencies due to part load operations, wastages etc. Worst case design, is a designer's characteristic, while optimization is the energy manager's mandate and many situations present themselves towards an exercise involving graceful matching of energy equipment capacity to end-use needs. Some examples being:

• Eliminate throttling of a pump by impeller trimming, resizing pump, installing variable speed drives

• Eliminate damper operations in fans by impeller trimming, installing variable speed drives, pulley diameter modification for belt drives, fan resizing for better efficiency.

• Moderation of chilled water temperature for process chilling needs

• Recovery of energy lost in control valve pressure drops by back pressure/turbine adoption

• Adoption of task lighting in place of less effective area lighting

1.12 Maximising System Efficiency

Once the energy usage and sources are matched properly, the next step is to operate the equipment efficiently through best practices in operation and maintenance as well as judicious technology adoption. Some illustrations in this context are:

• Eliminate steam leakages by trap improvements

• Maximise condensate recovery

• Adopt combustion controls for maximizing combustion efficiency

• Replace pumps, fans, air compressors, refrigeration compressors, boilers, furnaces, heaters and other energy consuming equipment, wherever significant energy efficiency margins exist.

Optimising the Input Energy Requirements

Consequent upon fine-tuning the energy use practices, attention is accorded to considerations for minimizing energy input requirements. The range of measures could include:

• Shuffling of compressors to match needs.

• Periodic review of insulation thickness

• Identify potential for heat exchanger networking and process integration.

• Optimisation of transformer operation with respect to load.

1.13 Fuel and Energy Substitution

Fuel substitution: Substituting existing fossil fuel with more efficient and less cost/less polluting fuel such as natural gas, biogas and locally available agro-residues.

Energy is an important input in the production. There are two ways to reduce energy dependency; energy conservation and substitution.

Fuel substitution has taken place in all the major sectors of the Indian economy. Kerosene and Liquefied Petroleum Gas (LPG) have substituted soft coke in residential use. Few examples of fuel substitution

• Natural gas is increasingly the fuel of choice as fuel and feedstock in the fertilizer, petro chemicals, power and sponge iron industries.

• Replacement of coal by coconut shells, rice husk etc.

• Replacement of LDO by LSHS

Few examples of energy substitution

  ▪ Replacement of electric heaters by steam heaters
  ▪ Replacement of steam based hotwater by solar systems

Case Study : Example on Fuel Substitution

A textile process industry replaced old fuel oil fired thermic fluid heater with agro fuel fired heater. The economics of the project are given below:

A:	Title of Recommendation :	Use of Agro Fuel (coconut chips) in place of Furnace oil in a Boiler
B:	Description of Existing System and its operation :	A thermic fluid heater with furnace oil currently. In the same plant a coconut chip fired boiler is operating continuously with good performance.
C:	Description of Proposed system and its operation :	It was suggested to replace the oil fired thermic fluid heater with coconut chip fired boiler as the company has the facilities for handling coconut chip fired system
D:	Energy Saving Calculations	
Old System		
	Type of fuel Firing GCV Avg. Thermal Efficiency Heat Duty Operating Hours Annual Fuel Cost	: Furnace Oil fired heater : 10,200 kCal/kg : 82% : 15 lakh kCal / hour : 25 days x 12 month x 24 hours = 7,200 hrs. : Rs.130 lakh (7200 x 1800 Rs./hr.)
Modified System		
	Type of fuel saving GCV Average Thermal Efficiency Heat Duty Annual Operating Cost Annual Savings Additional Auxiliary Power + Manpower Cost Net Annual Saving Investment for New Coconut Fired heater Simple pay back period	= Coconut chips fired Heater = 4200 kCal/kg = 72 % = 15 lakh kCal / hour = 7200 x 700 Rs./hr = 50 lakh = 130 - 50 = Rs.80 lakh . = Rs. 10 lakh = Rs. 70 lakh = Rs. 35 lakh = 6 months

1.14 Energy balancing.

Energy takes many forms, such as heat, kinetic energy, chemical energy, potential energy but because of interconversions it is not always easy to isolate separate constituents of energy balances. However, under some circumstances certain aspects predominate. In many heat balances in which other forms of energy are insignificant; in some chemical situations mechanical energy is insignificant and in some mechanical energy situations, as in the flow of fluids in pipes, the frictional losses appear as heat but the details of the heating need not be considered. We are seldom concerned with internal energies.

Therefore practical applications of energy balances tend to focus on particular dominant aspects and so a heat balance, for example, can be a useful description of important cost and quality aspects of process situation. When unfamiliar with the relative magnitudes of the various forms of energy entering into a particular processing situation, it is wise to put them all down. Then after some preliminary calculations, the important ones emerge and other minor ones can be lumped together or even ignored without introducing substantial errors. With experience, the obviously minor ones can perhaps be left out completely though this always raises the possibility of error.

Energy balances can be calculated on the basis of external energy used per kilogram of product, or raw material processed, or on dry solids or some key component. The energy consumed in food production includes direct energy which is fuel and electricity used on the farm, and in transport and in factories, and in storage, selling, etc.; and indirect energy which is used to actually build the machines, to make the packaging, to produce the electricity and the oil and so on. Food itself is a major energy source, and energy balances can be determined for animal or human feeding; food energy input can be balanced against outputs in heat and mechanical energy and chemical synthesis.

In the SI system there is only one energy unit, the joule. However, kilocalories are still used by some nutritionists and British thermal units (Btu) in some heat-balance work.

The two applications used in this chapter are heat balances, which are the basis for heat transfer, and the energy balances used in analysing fluid flow.

Heat Balances

The most common important energy form is heat energy and the conservation of this can be illustrated by considering operations such as heating and drying. In these, enthalpy (total heat) is conserved and as with the mass balances so enthalpy balances can be written round the various items of equipment. or process stages, or round the whole plant, and it is assumed that no appreciable heat is converted to other forms of energy such as work.

Enthalpy (H) is always referred to some reference level or datum, so that the quantities are relative to this datum. Working out energy balances is then just a matter of considering the various quantities of materials involved, their specific heats, and their changes in temperature or state (as quite frequently latent heats arising from phase changes are encountered). Figure 4.3 illustrates the heat balance.
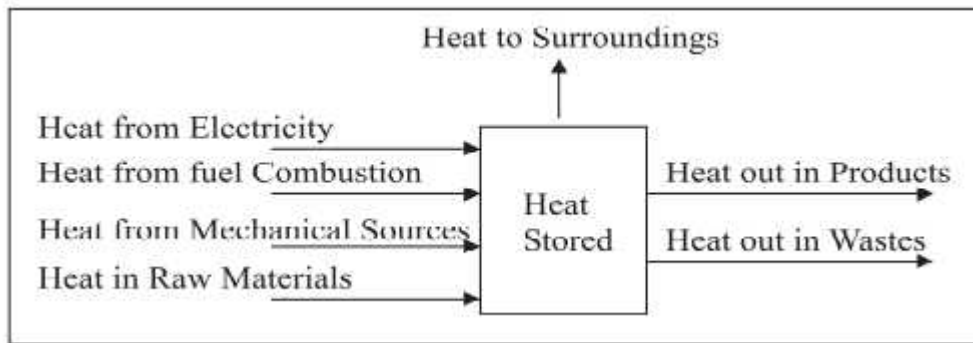
Heat is absorbed or evolved by some reactions in processing but usually the quantities are small when compared with the other forms of energy entering into food processing such as sensible heat and latent heat. Latent heat is the heat required to change, at constant temperature, the physical state of materials from solid to liquid, liquid to gas, or solid to gas. Sensible heat is that heat which when added or subtracted from materials changes their temperature and thus can be sensed. The units of specific heat are J/kg K and sensible heat change is calculated by multiplying the mass by the specific heat by the change in temperature, (m x c x T). The units of latent heat are J/kg and total latent heat change is calculated by multiplying the mass of the material, which changes its phase by the latent heat. Having determined those factors that are significant in the overall energy balance, the simplified heat balance can then be used with confidence in industrial energy studies. Such calculations can be quite simple and straightforward but they give a quantitative feeling for the situation and can be of great use in design of equipment and process.

Example: Dryer heat balance

A textile dryer is found to consume 4 m3 /hr of natural gas with a calorific value of 800 kJ/mole. If the throughput of the dryer is 60 kg of wet cloth per hour, drying it from 55% moisture to 10% moisture, estimate the overall thermal efficiency of the dryer taking into account the latent heat of evaporation only

60 kg of wet cloth contains

60 x 0.55 kg water = 33 kg moisture

and 60 x (1-0.55) = 27 kg bone dry cloth.

As the final product contains 10% moisture, the moisture in the product is 27/9 = 3 kg

And so Moisture removed / hr = 33 - 3 = 30 kg/hr

Latent heat of evaporation = 2257 kJ/K

Heat necessary to supply = 30 x 2257 = 6.8 x 104 kJ/hr

Assuming the natural gas to be at standard temperature and pressure at which 1 mole occupies 22.4 litres

Rate of flow of natural gas = 4 m3 /hr = (4 x 1000)/22.4 = 179 moles/hr

Heat available from combustion = 179 x 800 = 14.3 x 104 kJ/hr

Approximate thermal efficiency of dryer = heat needed / heat used = 6.8 x 104 / 14.3 x 104 = 48%

To evaluate this efficiency more completely it would be necessary to take into account the sensible heat of the dry cloth and the moisture, and the changes in temperature and humidity of the combustion air, which would be combined with the natural gas. However, as the latent heat of evaporation is the dominant term the above calculation gives a quick estimate and shows how a simple energy balance can give useful information.

Similarly energy balances can be carried out over thermal processing operations, and indeed any processing operations in which heat or other forms of energy are used.

Example: Autoclave heat balance in canning

An autoclave contains 1000 cans of pea soup. It is heated to an overall temperature of 100 °C. If the cans are to be cooled to 40 °C before leaving the autoclave, how much cooling water is required if it enters at 15 °C and leaves at 35 °C?

The specific heats of the pea soup and the can metal are respectively 4.1 kJ/ kg °C and 0.50 kJ/ kg °C. The weight of each can is 60g and it contains 0.45 kg of pea soup. Assume that the heat content of the autoclave walls above 40 °C is 1.6 x 104 kJ and that there is no heat loss through the walls.

Let w = the weight of cooling water required; and the datum temperature be 40°C, the temperature of the cans leaving the autoclave.

Heat entering

Heat in cans = weight of cans x specific heat x temperature above datum = 1000 x 0.06 x 0.50 x (100-40) kJ = 1.8 x 10^3 kJ

Heat in can contents = weight pea soup x specific heat x temperature above datum = 1000 x 0.45 x 4.1 x (100 - 40) = 1.1 x 10^5 kJ

Heat in water = weight of water x specific heat x temperature above datum = w x 4.186 x (15-40) = -104.6 w kJ.

Heat leaving

Heat in cans = 1000 x 0.06 x 0.50 x (40-40) (cans leave at datum temperature) = 0

Heat in can contents = 1000 x 0.45 x 4.1 x (40-40) = 0

Heat in water = w x 4.186 x (35-40) = -20.9 w

HEAT-ENERGY BALANCE OF COOLING PROCESS; 40°C AS DATUM LINE

	Heat Entering (kJ)	Heat Leaving (kJ)	
Heat in cans	1800	Heat in cans	0
Heat in can contents	11000	Heat in can contents	0
Heat in autoclave wall	16000	Heat in autoclave wall	0
Heat in water	-104.6 w	Heat in water	-20.9 W
Total heat entering	127.800 – 104.6 w	Total heat leaving	-20.9 W
	Total heat entering =	Total heat leaving	
	127800 – 104.6 w =	-20.9 w	
	w =	1527 kg	

Amount of cooling water required = 1527 kg.

1.15 Electricity Tariff

The electrical energy that is produced in a power station is delivered to a large number of consumers. The consumers can be convinced to use electrical energy if it is sold at a reasonable price. Here comes the idea of tariffs.

Definition: A tariff is the schedule of rates structured by the supplier for supplying electrical energy to various types of consumers. The rate at which electric energy is supplied to a consumer is known as a tariff.

The following elements are engaged into account to determine the tariff:

- Types of load (domestic, commercial, industrial)
- Maximum demand
- Time at which load is required
- The power factor of the load
- Amount of energy used

The way in which consumers pay for electrical energy changes according to their demands. Industrial consumers consume more energy for the relatively longer period than domestic consumers.

Tariffs should be framed in such a way so that it covers the cost of production, cost of supply, and yet yields some reasonable profit.

The price of energy supplied by a generating station depends on the established capacity of the plant and kWh generated. Maximum demand increases the installed capacity of the generating station.

The instant at which maximum demand occurs is too important in plant economics. If the maximum demand of the consumer and the maximum demand on the system take place simultaneously, additional plant capacity is needed.

However, if the maximum demand of the consumer occurs during off-peak hours, then we just need to improve the load factor and no extra plant capacity is needed. Thus, the overall cost per kWh generated is reduced.

Power factor is likewise an important factor from the point of view of plant economics.

At a low-power-factor, the load current is very high. Therefore, the current to be supplied from the generating station is also large. This high current is also responsible for large I2R losses in the system and larger voltage drops. Therefore, the regulation becomes poor; in order to supply the consumer's voltage within permissible limits, power factor correction equipment is to be set up. Therefore, the cost of generation increases.

The cost of electrical energy is reduced by using a large amount of energy for a longer period.

Table 1: Consumers and Their Tariffs

Consumers	Examples	Supply Given	Demand Factor	Tariff
Domestic	Residential load, light, fan, television, radio, electric irons, domestic pumps, coolers, air conditioners	1 : supply up to a load of 5 kW	Small consumers (high unity), big consumers (0.5)	1. Simple
		3 : supply for loads exceeding 5 kW		2. Flat rate
				3. Block rate
Commercial	Shops, business houses, hotels, cinemas, clubs, etc.	1 : supply up to a load of 5 kW	Fairly high	1. Simple
		3 : supply for loads exceeding 5 kW		2. Flat rate
				3. Block rate
Agricultural	Tube wells	3 : power up to 20 kW	Unity	Flat rate
Bulk	Railways, educational institutes, the military establishment, hospitals	3 : power at 415 V or 11 kV depending on their requirement, the load exceeding 10 kW		Flat rate
Industrial (small)	Atta chakkis, small workshop, sawmill, etc.	3 : power supply at 415 V, load not exceeding 20 kW	Usually high (0.8)	Block tariff
Industrial (medium)		3 : power supply at 415 V, the load exceeding 20 kW but not exceeding 100 kW		Two-part tariff
Industrial (large)		Power supplied at 11 kV or 33 kV, the load exceeding 100 kW	0.5	KVA maximum demand factor tariff

Objectives of an Electricity Tariff
1. Recovery of cost of producing electrical energy at the power station.
2. Recovery of cost on the capital investment in transmission and distribution systems.
3. Recovery of cost of operation and maintenance of the supply of electrical energy. For example, metering equipment, billing, etc.
4. A suitable profit on the capital investment.
5.

Electricity Tariff Characteristics
1. *Proper return.* The tariff should be structured in such a way that it guarantees the proper return from each consumer. The total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus the reasonable profit.
2. *Fairness.* The tariff must be fair so that each and every consumer is satisfied with the cost of electrical energy. Thus, a consumer who consumes more electrical energy should be charged at a lower rate than a consumer who consumes little energy. It is because increased energy consumption spreads the fixed charge over a greater number of units. Hence reducing the overall production cost of electrical energy.
3. *Simplicity.* The tariff should be simple and consumer-friendly so that an ordinary consumer can easily understand.
4. *Reasonable profit.* The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of a monopoly.
5. *Attractive.* The tariff should be attractive so that it can attract a large number of consumers to use electricity.

Types of Tariff in Electricity

1 Flat-Demand Tariff

This is one of the primitive forms of tariffs used for charging the consumer for consuming electrical energy. In this case, the total demand and the energy consumption are fixed. If x is the number of loads connected in kW and a is the rate per lamp or per kW of connected load, then

$$\text{Energy Charges} = \text{Rs. } ax$$

2 Simple Tariff

If there is a fixed rate available for per unit of energy consumed, then it is called a simple tariff or uniform rate tariff.

The rate can be delivered as

Cost/kWh=Rs. Annual fixed cost + Annual operating cost/ Total number of units supplied to the consumer per annum

Disadvantages

- We cannot differentiate various types of consumers (domestic, industrial, bulk) having different load factor, diversity, and power factor.
- The cost per kWh delivered is higher.
- It does not encourage the use of electricity.

3 Flat-Rate Tariff

When different types of consumers are charged at different per-unit rates, it is called a flat-rate tariff. In this type of tariff, the consumers are grouped into various categories, and each type of consumers is charged at a different rate. For instance, the flat rate per kWh for lighting load may be 60 paisa, whereas it may slightly less (say 55 paisa) for power load.

Advantages

- More fair to different types of consumers.
- Quite simple in calculations.

Disadvantages

- It varies with the consumption of electrical energy, and separate meters are required for lighting load, power load, etc. This makes the application of such tariff costly and complex.
- A particular category of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, big consumers should be charged at a relatively lower rate, as in this case the fixed charges per unit are reduced.

4 Step-Rate Tariff

A step-rate tariff is a group of flat-rate tariffs of decreasing unit charges for a higher range of consumption. For example,

- Rs. 4.0/unit if the consumption does not exceed 50 kWh.
- Rs. 3.5/unit if the consumption exceeds 50 kW but does not exceed 200 kW.
- Rs. 3.0/unit if the consumption exceeds 200 kW.

Disadvantage

- However, by increasing the energy consumption, the cost is reduced. Thus, there is a tendency with the consumer, just approaching the limit of the step, to anyhow cross the step and enter the next one in order to reduce the total energy cost.

This drawback is removed in block-rate tariff explained below.

5 Block-Rate Tariff

When a specific block of energy is charged at a specified rate and the succeeding blocks of energy are charged at a progressively reduced rate, it is called a block-rate tariff.

For example, the first 40 units may be charged at 70 paisa/unit, next 35 units at 55 paisa/unit, and remaining additional units at 30 paisa/unit.

This is used for the majority of residential and small commercial consumers.

Advantages

- Consumers get an incentive to consume more electrical energy.
- This increases the load factor of the system and hence the cost of generation is reduced.

Disadvantage

- Its principal defect is that it cannot measure the consumer's demand.

6 Two-Part Tariff

When the rate of electrical energy is charged on the basis of maximum demand of the consumers and the units consumed, then it is called two-part tariff or *Hopkinson demand tariff* (Table 1).

In this case, the total cost that is to be charged by the consumer is split into two components:

- *The fixed charges* depend upon the maximum demand of the consumers.
- *The running charges* depend upon the number of units consumed by the consumers.

$$\therefore \text{Total charges} = \text{Rs.} \ (b \times \text{kW} + c \times \text{kWh})$$

Where b is the charge per kW of maximum demand and c is the charge per kWh of energy consumed.

- Applicable to industrial consumers who have appreciable maximum demand.

Advantages

- Easily understood by the consumers.
- It recovers the fixed charges that depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantages

- The consumer has to pay the fixed charges irrespective of whether he or she has consumed or not consumed the electric energy.
- There is always error in determining the maximum demand of the consumer.

7 Maximum-Demand Tariff

It is quite similar to two-part tariff; the only difference is that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer.

Advantage

This eliminates the disadvantage of the two-part tariff, where maximum demand is determined merely on the basis of the chargeable value.

This tariff is mostly applied to big consumers.

8 Three-Part Tariff

In three-part tariff, the total charge to be made from the consumer is split into three parts, that is,

- Fixed charges
- Semi-fixed charges
- Running charges

$$\therefore \text{Total charges} = \text{Rs. } (a + b \times kW + c \times kWh)$$

Where a is the fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labor cost of collecting revenues. b is the charge per kW of maximum demand and c is the charge per kWh of energy consumed.

The principal objection of this tariff is that the charges are split into three compartments. Generally applied to big consumers.

9 Power Factor Tariff

The tariff in which the power factor of the consumer's load is taken into consideration is known as *power factor tariff*.

A low-power-factor increases the rating of the station equipment and line losses. Therefore, a consumer having low-power-factor must be penalized.

The following are the important types of power factor tariff.

9.1 kVA Maximum-Demand Tariff

It is a modified form of the two-part tariff. The fixed charges are formulated on the basis of maximum demand in kVA, and not in kW. As kVA is inversely proportional to the power factor, a consumer having a low-power-factor has to contribute more toward the fixed charges.

Advantage

It encourages the consumers to operate the appliances and machinery at improved power factor.

9.2 Sliding Scale Tariff

This is known as average power factor tariff. In this case, an average power factor (say 0.8 lagging) is taken as the reference. If the power factor of the consumer falls below this factor, suitable additional charges are made. On the other hand, if the power factor is above the reference, a discount is allowed to the consumers.

9.3 kW and kvar Tariff

In this type, both active power (kW) and reactive power (kvar) supplied are charged separately. A consumer having low-power-factor will draw more reactive power and hence shall have to pay more charges.

Electricity Tariff Example 1

The maximum demand of a consumer is 15 A at 230 V and his/her total energy consumption is 9000 kWh. If the energy is charged at the rate of Rs. 5 per unit for 600 h use of the maximum demand per annum plus Rs. 2 per unit for additional units, calculate (1) annual bill and (2) equivalent flat rate.

Solution

Assume the load factor and power factor to be unity.

Maximum Demand=230×15×1/1000=3.45kW

1. Units consumed in 600 h=3.45×600=2070kWh

charges for 2070 kWh=Rs.5×2070=Rs.10,350

Remaining Units=9000−2070=6930kWh

charges for 6930 kWh=Rs.2×6930=Rs.13,860

Total Annual Bill=Rs.(13,860+10,350)=Rs.24,2102.

Equivalent Flat Rate=Rs.24,210/9000=Rs.2.69

Electricity Tariff Example 2

A consumer has a maximum demand of 150 kW at 50% load factor. If the tariff is Rs. 800 per kW of maximum demand plus Rs. 2 per kWh, find the overall cost per kWh.

Solution

$$\text{Units Cosumed/Year=MD×LF×Hours in a year}$$

$$=150×0.5×8760=657,000 \text{ kWh}$$

$$\text{Annual Charges=Annual MD Charges+Annual Energy Charges=Rs.(150×800+2×657,000)}$$

$$=1,434,000$$

$$\therefore \text{Overall Cost / kWh=Rs.1,434,000/657,000=Rs. 2.18}$$

1.16 Calculation of electric bill for a company

Electrical utility or power supplying companies charge industrial customers not only based on the amount of energy used (kWh) but also on the peak demand (kVA) for each month.

Contract Demand

Contract demand is the amount of electric power that a customer demands from utility in a specified interval. Unit used is kVA or kW. It is the amount of electric power that the consumer agreed upon with the utility. This would mean that utility has to plan for the specified capacity.

Maximum demand

Maximum demand is the highest average kVA recorded during any one-demand interval within the month. The demand interval is normally 30 minutes, but may vary from utility to utility from 15 minutes to 60 minutes. The demand is measured using a tri-vector meter / digital energy meter.

Prediction of Load

While considering the methods of load prediction, some of the terms used in connection with power supply must be appreciated.

Connected Load - is the nameplate rating (in kW or kVA) of the apparatus installed on a consumer's premises.

Demand Factor - is the ratio of maximum demand to the connected load.

Load Factor - The ratio of average load to maximum load.

$$Load\ Factor = \frac{Average\ Load}{Maximum\ Load}$$

The load factor can also be defined as the ratio of the energy consumed during a given period to the energy, which would have been used if the maximum load had been maintained throughout that period. For example, load factor for a day (24 hours) will be given by:

$$Load\ Factor = \frac{Energy\ consumed\ during\ 24\ hours}{Maximum\ load\ recorded\ x\ 24\ Hours}$$

PF Measurement

A power analyzer can measure PF directly, or alternately kWh, kVAh or kVArh readings are recorded from the billing meter installed at the incoming point of supply. The relation kWh / kVAh gives the power factor.

Time of Day (TOD) Tariff

Many electrical utilities like to have flat demand curve to achieve high plant efficiency. They encourage user to draw more power during off-peak hours (say during night time) and less power during peak hours. As per their plan, they offer TOD Tariff, which may be incentives or disincentives. Energy meter will record peak and nonpeak consumption separately by timer control. TOD tariff gives opportunity for the user to reduce their billing, as off peak hour tariff charged are quite low in comparison to peak hour tariff.

1.17 EB billing- HT and LT supply

The electricity billing by utilities for medium & large enterprises, in High Tension (HT) category, is often done on two-part tariff structure, i.e. one part for capacity (or demand) drawn and the second part for actual energy drawn during the billing cycle. Capacity or demand is in kVA (apparent power) or kW terms. The reactive energy (i.e.) kVArh drawn by the service is also recorded and billed for in some utilities, because this would affect the load on the utility. Accordingly, utility charges for maximum demand, active energy and reactive power drawn

(as reflected by the power factor) in its billing structure. In addition, other fixed and variable expenses are also levied.

The tariff structure generally includes the following components:

a) Maximum demand Charges

These charges relate to maximum demand registered during month/billing period and corresponding rate of utility.

b) Energy Charges

These charges relate to energy (kilowatt hours) consumed during month / billing period and corresponding rates, often levied in slabs of use rates. Some utilities now charge on the basis of apparent energy (kVAh), which is a vector sum of kWh and kVArh.

c) Power factor penalty or bonus rates, as levied by most utilities, are to contain reactive power drawn from grid.

d) Fuel cost adjustment charges as levied by some utilities are to adjust the increasing fuel expenses over a base reference value.

e) Electricity duty charges levied w.r.t units consumed.

f) Meter rentals

g) Lighting and fan power consumption is often at higher rates, levied sometimes on slab basis or on actual metering basis.

h) Time of Day (TOD) rates like peak and non-peak hours are also prevalent in tariff structure provisions of some utilities.

i) Penalty for exceeding contract demand

j) Surcharge if metering is at LT side in some of the utilities

Analysis of utility bill data and monitoring its trends helps energy manager to identify ways for electricity bill reduction through available provisions in tariff framework, apart from energy budgeting

The utility employs an electromagnetic or electronic trivector meter, for billing purposes. The minimum outputs from the electromagnetic meters are

• Maximum demand registered during the month, which is measured in preset time intervals (say of 30 minute duration) and this is reset at the end of every billing cycle.

• Active energy in kWh during billing cycle

• Reactive energy in kVArh during billing cycle and

• Apparent energy in kVAh during billing cycle

It is important to note that while maximum demand is recorded, it is not the instantaneous demand drawn, as is often misunderstood, but the time integrated demand over the predefined recording cycle.

As example, in an industry, if the drawl over a recording cycle of 30 minutes is :

> *2500 kVA for 4 minutes*
> *3600 kVA for 12 minutes*
> *4100 kVA for 6 minutes*
> *3800 kVA for 8 minutes*

The MD recorder will be computing MD as:

$$\frac{(2500 \times 4) + (3600 \times 12) + (4100 \times 6) + (3800 \times 8)}{30} = 3606.7 \, kVA$$

The month's maximum demand will be the highest among such demand values recorded over the month. The meter registers only if the value exceeds the previous maximum demand value and thus, even if, average maximum demand is low, the industry / facility has to pay for the maximum demand charges for the highest value registered during the month, even if it occurs for just one recording cycle duration i.e., 30 minutes during whole of the month. A typical demand curve is shown in Figure 1.4.
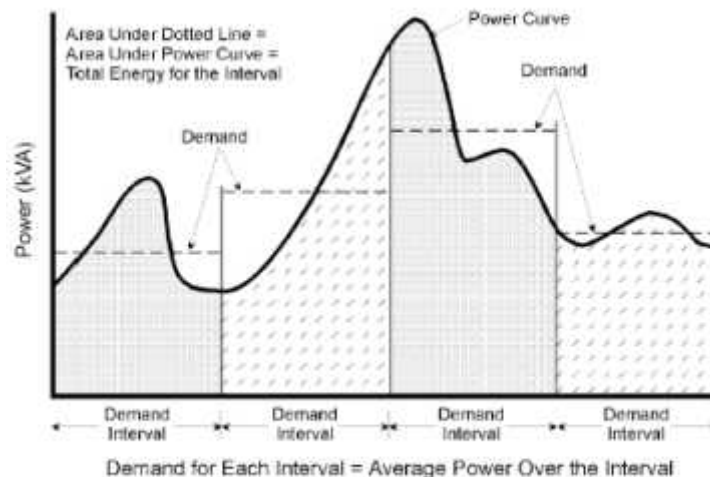
Figure 1.4 Demand Curve

As can be seen from the Figure 1.4 above the demand varies from time to time. The demand is measured over predetermined time interval and averaged out for that interval as shown by the horizontal dotted line.

Of late most electricity boards have changed over from conventional electromechanical trivector meters to electronic meters, which have some excellent provisions that can help the utility as well as the industry. These provisions include:

• Substantial memory for logging and recording all relevant events

• High accuracy up to 0.2 class

• Amenability to time of day tariffs

• Tamper detection /recording

• Measurement of harmonics and Total Harmonic Distortion (THD)

• Long service life due to absence of moving parts

• Amenability for remote data access/downloads

Trend analysis of purchased electricity and cost components can help the industry to identify key result areas for bill reduction within the utility tariff available framework along the following lines.

Month & Year	MD Recorded kVA	Billing Demand* kVA	Total Energy Consumption kWh	Energy Consumption During Peak Hours (kWh)	MD Charge Rs./kVA	Energy Charge Rs./kWh	PF	PF Penalty/ Rebate Rs.	Total Bills Rs.	Average Cost Rs./kWh
TABLE 1.1 PURCHASED ELECTRICAL ENERGY TREND										
Jan.										
Feb.										
....										
....										
....										
Dec.										

*Some utilities charge Maximum Demand on the basis of minimum billing demand, which may be between 75 to 100% of the contract demand or actual recorded demand whichever is higher

1.18 Transformers:

A transformer can accept energy at one voltage and deliver it at another voltage. This permits electrical energy to be generated at relatively low voltages and transmitted at high voltages and low currents, thus reducing line losses and voltage drop (see Figure 1.10). Transformers consist of two or more coils that are electrically insulated, but magnetically linked. The primary coil is connected to the power source and the secondary coil connects to the load. The turn's ratio is the ratio between the number of turns on the secondary to the turns on the primary (See Figure 1.11). The secondary voltage is equal to the primary voltage times the turn's ratio. Ampere-turns are calculated by multiplying the current in the coil times the number of turns. Primary ampere-turns are equal to secondary ampere-turns. Voltage regulation of a transformer is the percent increase in voltage from full load to no load.

Types of Transformers

Transformers are classified as two categories: power transformers and distribution transformers.

Power transformers are used in transmission network of higher voltages, deployed for step-up and step down transformer application (400 kV, 200 kV, 110 kV, 66 kV, 33kV)

Distribution transformers are used for lower voltage distribution networks as a means to end user connectivity. (11kV, 6.6 kV, 3.3 kV, 440V, 230V)

Rating of Transformer

Rating of the transformer is calculated based on the connected load and applying the diversity factor on the connected load, applicable to the particular industry and arrive at the kVA rating

of the Transformer. Diversity factor is defined as the ratio of overall maximum demand of the plant to the sum of individual maximum demand of various equipment. Diversity factor varies from industry to industry and depends on various factors such as individual loads, load factor and future expansion needs of the plant. Diversity factor will always be less than one.

Location of Transformer

Location of the transformer is very important as far as distribution loss is concerned. Transformer receives HT voltage from the grid and steps it down to the required voltage. Transformers should be placed close to the load centre, considering other features like optimisation needs for centralised control, operational flexibility etc. This will bring down the distribution loss in cables.

Transformer Losses and Efficiency

The efficiency varies anywhere between 96 to 99 percent. The efficiency of the transformers not only depends on the design, but also, on the effective operating load.

Transformer losses consist of two parts: No-load loss and Load loss

1. No-load loss (also called core loss) is the power consumed to sustain the magnetic field in the transformer's steel core. Core loss occurs whenever the transformer is energized; core loss does not vary with load. Core losses are caused by two factors: hysteresis and eddy current losses. Hysteresis loss is that energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction. Eddy current loss is a result of induced currents circulating in the core.

2. Load loss (also called copper loss) is associated with full-load current flow in the transformer windings. Copper loss is power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings. Copper loss varies with the square of the load current. ($P = I^2 R$).

Transformer losses as a percentage of load is given in the Figure 1.12.
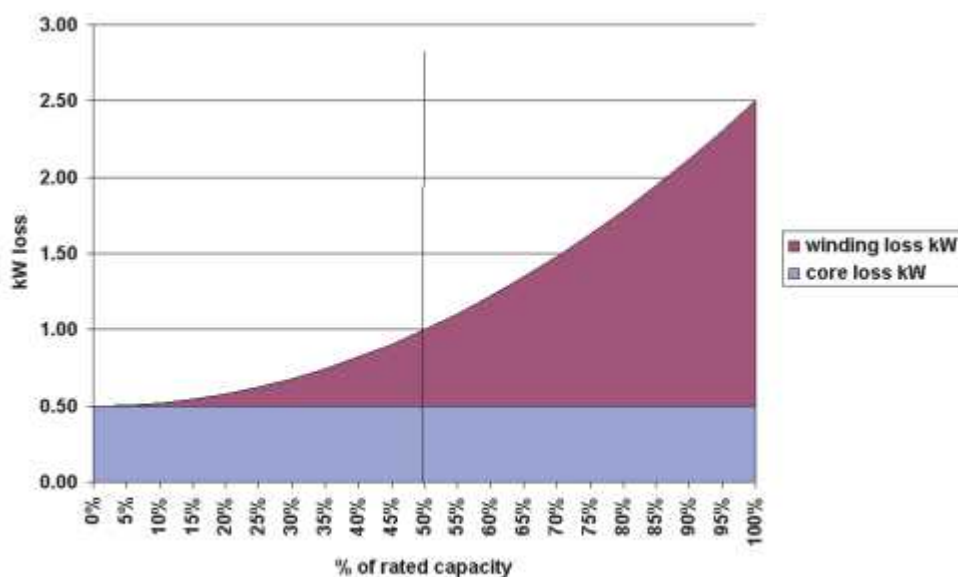
Figure 1.12   Transformer loss vs %Load

For a given transformer, the manufacturer can supply values for no-load loss, $P_{NO-LOAD}$, and load loss, P_{LOAD}. The total transformer loss, P_{TOTAL}, at any load level can then be calculated from:

$$P_{TOTAL} = P_{NO-LOAD} + (\% \ Load/100)^2 \ x \ P_{LOAD}$$

Where transformer loading is known, the actual transformers loss at given load can be computed as:

$$= \ No \ load \ loss \ + \ \left(\frac{kVA \ Load}{Rated \ kVA} \right)^2 \ x \ (full \ load \ loss)$$

Voltage Fluctuation Control

A control of voltage in a transformer is important due to frequent changes in supply voltage level. Whenever the supply voltage is less than the optimal value, there is a chance of nuisance tripping of voltage sensitive devices. The voltage regulation in transformers is done by altering the voltage transformation ratio with the help of tapping. There are two methods of tap changing facility available: **Off-circuit tap changer and On-load tap changer**.

Off-circuit tap changer

It is a device fitted in the transformer, which is used to vary the voltage transformation ratio. Here the voltage levels can be varied only after isolating the primary voltage of the transformer.

On load tap changer (OLTC)

The voltage levels can be varied without isolating the connected load to the transformer. To minimise the magnetisation losses and to reduce the nuisance tripping of the plant, the main transformer (the transformer that receives supply from the grid) should be provided with On Load Tap Changing facility at design stage. The down stream distribution transformers can be provided with off-circuit tap changer. The On-load gear can be put in auto mode or manually depending on the requirement. OLTC can be arranged for transformers of size 250 kVA onwards. However, the necessity of OLTC below 1000 kVA can be considered after calculating the cost economics.

Parallel Operation of Transformers

The design of Power Control Centre (PCC) and Motor Control Centre (MCC) of any new plant should have the provision of operating two or more transformers in parallel. Additional switchgears and bus couplers should be provided at design stage. Whenever two transformers are operating in parallel, both should be technically identical in all aspects and more importantly should have the same impedance level. This will minimise the circulating current between transformers. Where the load is fluctuating in nature, it is preferable to have more than one transformer running in parallel, so that the load can be optimised by sharing the load between transformers. The transformers can be operated close to the maximum efficiency range by this operation.

1.19 Electric motors- motor efficiency computation, energy efficient motors

1.19.0 Introduction

Motors convert electrical energy into mechanical energy by the interaction between the magnetic fields set up in the stator and rotor windings. Industrial electric motors can be broadly classified as induction motors, direct current motors or synchronous motors. All motor types have the same four operating components: stator (stationary windings), rotor (rotating windings), bearings, and frame (enclosure).

1.19.1 Motor Types

Direct-Current Motors

Direct-Current motors, as the name implies, use direct-unidirectional, current. Direct current motors are used in special applications- where high torque starting or where smooth acceleration over a broad speed range is required.

Induction Motors

Induction motors are the most commonly used prime mover for various equipments in industrial applications. In induction motors, the induced magnetic field of the stator winding induces a current in the rotor. This induced rotor current produces a second magnetic field, which tries to oppose the stator magnetic field, and this causes the rotor to rotate.

The 3-phase squirrel cage motor is the workhorse of industry; it is rugged and reliable, and is by far the most common motor type used in industry. These motors drive pumps, blowers and fans, compressors, conveyers and production lines. The 3-phase induction motor has three windings each connected to a separate phase of the power supply.

Synchronous Motors

AC power is fed to the stator of the synchronous motor. The rotor is fed by DC from a separate source. The rotor magnetic field locks onto the stator rotating magnetic field and rotates at the same speed. The speed of the rotor is a function of the supply frequency and the number of magnetic poles in the stator. While induction motors rotate with a slip, i.e., rpm is less than the synchronous speed, the synchronous motor rotate with no slip, i.e., the RPM is same as the synchronous speed governed by supply frequency and number of poles. The slip energy is provided by the D.C. excitation power

1.19.2 Motor Characteristics

Motor Speed

The speed of a motor is the number of revolutions in a given time frame, typically revolutions per minute (RPM). The speed of an AC motor depends on the frequency of the input power and the number of poles for which the motor is wound. The synchronous speed in RPM is given by the following equation, where the frequency is in hertz or cycles per second:

$$\text{Synchronous Speed (RPM)} = \frac{120 \times \text{Frequency}}{\text{No. of Poles}}$$

Indian motors have synchronous speeds like 3000 / 1500 / 1000 / 750 / 600 / 500 / 375 RPM corresponding to no. of poles being 2, 4, 6, 8, 10, 12, 16 (always even) and given the mains frequency of 50 cycles / sec.

Slip

The actual speed, with which the motor operates, will be less than the synchronous speed. The difference between synchronous and full load speed is called slip and is measured in percent. It is calculated using this equation:

$$\text{Slip (\%)} = \frac{\text{Synchronous Speed} - \text{Full Load Rated Speed}}{\text{Synchronous Speed}} \times 100$$

As per relation stated above, the speed of an AC motor is determined by the number of motor poles and by the input frequency. It can also be seen that theoretically speed of an AC motor can be varied infinitely by changing the frequency. Manufacturer's guidelines should be referred for practical limits to speed variation. With the addition of a Variable Frequency Drive (VFD), the speed of the motor can be decreased as well as increased.

Power Factor

The power factor of the motor is given as:

$$\text{Power Factor} = \text{Cos } \phi = \frac{\text{kW}}{\text{kVA}}$$

As the load on the motor comes down, the magnitude of the active current reduces. However, there is no corresponding reduction in the magnetizing current, which is proportional to supply voltage with the result that the motor power factor reduces, with a reduction in applied load. Induction motors, especially those operating below their rated capacity, are the main reason for low power factor in electric systems.

Motor Efficiency

Two important attributes relating to efficiency of electricity use by A.C. Induction motors are efficiency ( ), defined as the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals, and power factor (PF). Motors, like other inductive loads, are characterized by power factors less than one. As a result, the total current draw needed to deliver the same real power is higher than for a load characterized by a higher PF. An important effect of operating with a PF less than one is that resistance losses in wiring upstream of the motor will be higher, since these are proportional to the square of the current. Thus, both a high value for   and a PF close to unity are desired for efficient overall operation in a plant.

Squirrel cage motors are normally more efficient than slip-ring motors, and higher-speed motors are normally more efficient than lower-speed motors. Efficiency is also a function of motor temperature. Totally-enclosed, fan-cooled (TEFC) motors are more efficient than screen protected, drip-proof (SPDP) motors. Also, as with most equipment, motor efficiency increases with the rated capacity.

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design. Intrinsic losses are of two types: fixed losses - independent of motor load, and variable losses - dependent on load.

Fixed losses consist of magnetic core losses and friction and windage losses. Magnetic core losses (sometimes called iron losses) consist of eddy current and hysteresis losses in the stator. They vary with the core material and geometry and with input voltage. Friction and windage losses are caused by friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts.

Variable losses consist of resistance losses in the stator and in the rotor and miscellaneous stray losses. Resistance to current flow in the stator and rotor result in heat generation that is proportional to the resistance of the material and the square of the current (I2 R). Stray losses arise from a variety of sources and are difficult to either measure directly or to calculate, but are generally proportional to the square of the rotor current.

Part-load performance characteristics of a motor also depend on its design. Both   and PF fall to very low levels at low loads. The Figures 2.1 shows the effect of load on power factor and efficiency. It can be seen that power factor drops sharply at part loads. The Figure 2.2 shows the effect of speed on power factor.

1.19.3 Field Tests for Determining Efficiency

No Load Test: The motor is run at rated voltage and frequency without any shaft load. Input power, current, frequency and voltage are noted. The no load P.F. is quite low and hence low PF wattmeters are required. From the input power, stator I2 R losses under no load are subtracted to give the sum of Friction and Windage (F&W) and core losses. To separate core and F & W losses, test is repeated at variable voltages. It is useful to plot no-load input kW versus Voltage; the intercept is Friction & Windage kW loss component.

F&W and core losses = No load power (watts) - (No load current)^2 × Stator resistance

Stator and Rotor I2 R Losses: The stator winding resistance is directly measured by a bridge or volt amp method. The resistance must be corrected to the operating temperature. For modern motors, the operating temperature is likely to be in the range of 100°C to 120°C and necessary correction should be made. Correction to 75°C may be inaccurate. The correction factor is given as follows :

$$\frac{R_2}{R_1} = \frac{235 + t_2}{235 + t_1}, \text{ where, } t_1 = \text{ambient temperature, °C \& } t_2 = \text{operating temperature, °C.}$$

The rotor resistance can be determined from locked rotor test at reduced frequency, but rotor I^2R losses are measured from measurement of rotor slip.

Rotor I^2 R losses = Slip × (Stator Input – Stator I^2 R Losses – Core Loss)

Accurate measurement of slip is possible by stroboscope or non-contact type tachometer. Slip also must be corrected to operating temperature.

Stray Load Losses: These losses are difficult to measure with any accuracy. **IEEE Standard 112** gives a complicated method, which is rarely used on shop floor. IS and IEC standards take

a fixed value as 0.5 % of input. The actual value of stray losses is likely to be more. IEEE – 112 specifies values from 0.9 % to 1.8 % (see Table 2.1.)

TABLE 2.1 MOTOR RATING VS. STRAY LOSSES - IEEE	
Motor Rating	**Stray Losses**
1 – 125 HP	1.8 %
125 – 500 HP	1.5 %
501 – 2499 HP	1.2 %
2500 and above	0.9 %

1.19.4 Pointers for Users:

It must be clear that accurate determination of efficiency is very difficult. The same motor tested by different methods and by same methods by different manufacturers can give a difference of 2 %. In view of this, for selecting high efficiency motors, the following can be done:

a) When purchasing large number of small motors or a large motor, ask for a detailed test certificate. If possible, try to remain present during the tests; this will add cost.

b) See that efficiency values are specified without any tolerance

c) Check the actual input current and kW, if replacement is done

d) For new motors, keep a record of no load input power and current

e) Use values of efficiency for comparison and for confirming; rely on measured inputs for all calculations. R2 235 + t2 = , where, t1 = ambient temperature, °C & t2 = operating temperature, °C. R1 235 +t1

Estimation of efficiency in the field can be done as follows:

a) Measure stator resistance and correct to operating temperature. From rated current value, I ^{2} R losses are calculated.

b) From rated speed and output, rotor I^2 R losses are calculated

c) From no load test, core and F & W losses are determined for stray loss

1.19.5 The method is illustrated by the following example:

Example:

Motor Specifications

Rated power	=	34 kW/45 HP
Voltage	=	415 Volt
Current	=	57 Amps
Speed	=	1475 rpm
Insulation class	=	F
Frame	=	LD 200 L
Connection	=	Delta

No load test Data

Voltage, V	=	415 Volts
Current, I	=	16.1 Amps
Frequency, F	=	50 Hz
Stator phase resistance at 30°C	=	0.264 Ohms
No load power, Pnl	=	1063.74 Watts

a) Calculate iron plus friction and windage losses

b) Calculate stator resistance at 120°C

$$R_2 = R_1 \times \frac{235 + t_2}{235 + t_1}$$

c) Calculate stator copper losses at operating temperature of resistance at 120°C

d) Calculate full load slip(s) and rotor input assuming rotor losses are slip times rotor input.

e) Determine the motor input assuming that stray losses are 0.5 % of the motor rated power

f) Calculate motor full load efficiency and full load power factor

Solution

a) Let Iron plus friction and windage loss, $P_i + fw$
No load power, P_{nl} = 1063.74 Watts

Stator Copper loss, P st-30°C (Pst.cu)
$= 3 \times (16.1 / \sqrt{3})^2 \times 0.264$
$= 68.43$ Watts
$P_i + fw = P_{nl} - Pst.cu$
$= 1063.74 - 68.43$
$= 995.3$ W

b) Stator Resistance at 120°C,

$$R_{120°C} = 0.264 \times \frac{120 + 235}{30 + 235}$$

= 0.354 ohms per phase

c) Stator copper losses at full load, Pst.cu 120°C

$$= 3 \times (57 / \sqrt{3})^2 \times 0.354$$

= 1150.1 Watts

d) Full load slip

S = (1500 − 1475) / 1500

= 0.0167

Rotor input, Pr   = P_{output}/ (1-S)
                                =   34000 / (1-0.0167)
                                =   34577.4 Watts

e) Motor full load input power, P input

$= P_r + Pst.cu\ 120°C + (P_i + fw) + P_{stray}$

$= 34577.4 + 1150.1 + 995.3 + (0.005^* \times 34000)$

= 36892.8 Watts

*where, stray losses = 0.5% of rated output (assumed)

f) Motor efficiency at full load

Efficiency   = $\dfrac{P_{output}}{P_{input}} \times 100$

                            = $\dfrac{34000}{36892.8} \times 100$

                            =   92.2 %

$$\text{Full Load PF} = \frac{P_{input}}{\sqrt{3} \times V \times I_{fl}}$$

$$= \frac{36892.8}{\sqrt{3} \times 415 \times 57}$$

$$= 0.90$$

Comments :

a) The measurement of stray load losses is very difficult and not practical even on test beds.

b) The actual value of stray loss of motors up to 200 HP is likely to be 1 % to 3 % compared to 0.5 % assumed by standards.

c) The value of full load slip taken from the nameplate data is not accurate. Actual measurement under full load conditions will give better results.

d) The friction and windage losses really are part of the shaft output; however, in the above calculation, it is not added to the rated shaft output, before calculating the rotor input power. The error however is minor.

e) When a motor is rewound, there is a fair chance that the resistance per phase would increase due to winding material quality and the losses would be higher. It would be interesting to assess the effect of a nominal 10 % increase in resistance per phase.

1.19.6 Energy-Efficient Motors

Energy-efficient motors (EEM) are the ones in which, design improvements are incorporated specifically to increase operating efficiency over motors of standard design (see Figure 2.3). Design improvements focus on reducing intrinsic motor losses. Improvements include the use of lower-loss silicon steel, a longer core (to increase active material), thicker wires (to reduce resistance), thinner laminations, smaller air gap between stator and rotor, copper instead of aluminium bars in the rotor, superior bearings and a smaller fan, etc.

Energy-efficient motors now available in India operate with efficiencies that are typically 3 to 4 percentage points higher than standard motors. In keeping with the stipulations of the BIS, energy-efficient motors are designed to operate without loss in efficiency at loads between 75 % and 100 % of rated capacity. This may result in major benefits in varying load applications. The power factor is about the same or may be higher than for standard motors. Furthermore, energy
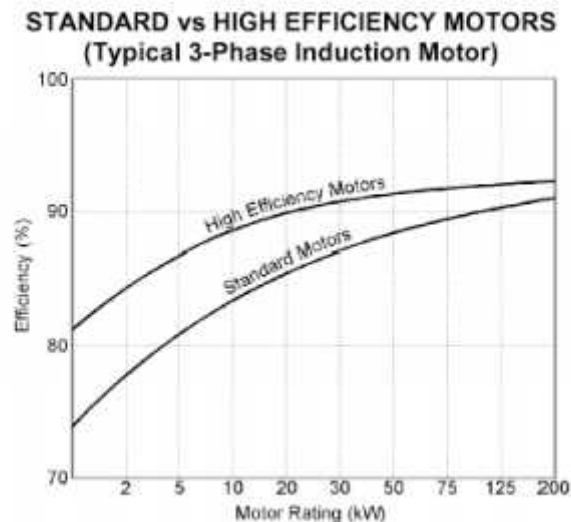
Figure 2.3 Standard vs High Efficiency Motors

efficient motors have lower operating temperatures and noise levels, greater ability to accelerate higher-inertia loads, and are less affected by supply voltage fluctuations.

Measures adopted for energy efficiency address each loss specifically as under:

Stator and Rotor I^2 R Losses

These losses are major losses and typically account for 55% to 60% of the total losses. I2 R losses are heating losses resulting from current passing through stator and rotor conductors. I2 R losses are the function of a conductor resistance, the square of current. Resistance of conductor is a function of conductor material, length and cross sectional area. The suitable selection of copper conductor size will reduce the resistance. Reducing the motor current is most readily accomplished by decreasing the magnetizing component of current. This involves lowering the operating flux density and possible shortening of air gap. Rotor I2 R losses are a function of the rotor conductors (usually aluminium) and the rotor slip. Utilisation of copper conductors will reduce the winding resistance. Motor operation closer to synchronous speed will also reduce rotor I2 R losses.

Core Losses

Core losses are those found in the stator-rotor magnetic steel and are due to hysterisis effect and eddy current effect during 50 Hz magnetization of the core material. These losses are independent of load and account for 20 – 25 % of the total losses. The hysterisis losses which are a function of flux density, are be reduced by utilizing lowloss grade of silicon steel laminations. The reduction of flux density is achieved by suitable increase in the core length of stator and rotor. Eddy current losses are generated by circulating current within the core steel laminations. These are reduced by using thinner laminations.

Friction and Windage Losses

Friction and windage losses results from bearing friction, windage and circulating air through the motor and account for 8 – 12 % of total losses. These losses are independent of load. The reduction in heat generated by stator and rotor losses permit the use of smaller fan. The windage losses also reduce with the diameter of fan leading to reduction in windage losses.

Stray Load-Losses

These losses vary according to square of the load current and are caused by leakage flux induced by load currents in the laminations and account for 4 to 5 % of total losses. These losses are reduced by careful selection of slot numbers, tooth/slot geometry and air gap.

Energy efficient motors cover a wide range of ratings and the full load efficiencies are higher by 3 to 7 %. The mounting dimensions are also maintained as per IS1231 to enable easy replacement

As a result of the modifications to improve performance, the costs of energy-efficient motors are higher than those of standard motors. The higher cost will often be paid back rapidly in saved operating costs, particularly in new applications or end-of-life motor replacements. In cases where existing motors have not reached the end of their useful life, the economics will be less clearly positive.

Because the favourable economics of energy-efficient motors are based on savings in operating costs, there may be certain cases which are generally economically ill-suited to energyefficient motors. These include highly intermittent duty or special torque applications such as hoists and cranes, traction drives, punch presses, machine tools, and centrifuges. In addition, energy, efficient designs of multi-speed motors are generally not available. Furthermore, energy-efficient motors are not yet available for many special applications, e.g. for flame-proof operation in oil-field or fire pumps or for very low speed applications (below 750 rpm). Also, most energy-efficient motors produced today are designed only for continuous duty cycle operation.

Given the tendency of over sizing on the one hand and ground realities like ; voltage, frequency variations, efficacy of rewinding in case of a burnout, on the other hand, benefits of EEM's can be achieved only by careful selection, implementation, operation and maintenance efforts of energy managers.

A summary of energy efficiency improvements in EEMs is given in the Table 2.2:

TABLE 2.2 ENERGY EFFICIENT MOTORS	
Power Loss Area	**Efficiency Improvement**
1. Iron	Use of thinner gauge, lower loss core steel reduces eddy current losses. Longer core adds more steel to the design, which reduces losses due to lower operating flux densities.
2. Stator I^2R	Use of more copper and larger conductors increases cross sectional area of stator windings. This lowers resistance (R) of the windings and reduces losses due to current flow (I).
3. Rotor I^2R	Use of larger rotor conductor bars increases size of cross section, lowering conductor resistance (R) and losses due to current flow (I).
4. Friction & Windage	Use of low loss fan design reduces losses due to air movement.
5. Stray Load Loss	Use of optimized design and strict quality control procedures minimizes stray load losses.

1.20 Pumps:

1.20.0 Pumps

- A pump is a machine for raising a liquid - a relatively **incompressible** fluid - to a higher level of pressure or head

1.20.1 Pump Types

Pumps come in a variety of sizes for a wide range of applications. They can be classified according to their basic operating principle as dynamic or displacement pumps. Dynamic pumps can be sub-classified as centrifugal and special effect pumps. Displacement pumps can be sub-classified as rotary or reciprocating pumps.

In principle, any liquid can be handled by any of the pump designs. Where different pump designs could be used, the centrifugal pump is generally the most economical followed by rotary and reciprocating pumps. Although, positive displacement pumps are generally more efficient than centrifugal pumps, the benefit of higher efficiency tends to be offset by increased maintenance costs.

Since, worldwide, centrifugal pumps account for the majority of electricity used by pumps, the focus of this chapter is on centrifugal pump.

Pumps are in general classified as Centrifugal Pumps (or Roto-dynamic pumps) and Positive Displacement Pumps.

Centrifugal Pumps (Roto-dynamic pumps)

The centrifugal or roto-dynamic pump produce a head and a flow by increasing the velocity of the liquid through the machine with the help of the rotating vane impeller. Centrifugal pumps include radial, axial and mixed flow units.

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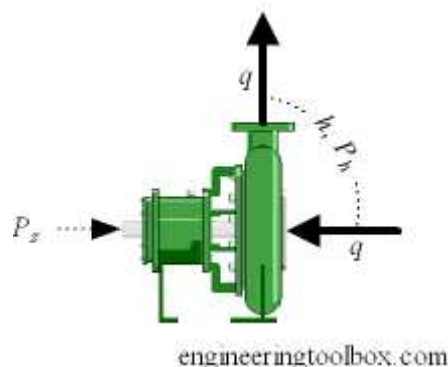
Centrifugal pumps can be classified further as

- end suction pumps
- in-line pumps

- double suction pumps
- vertical multistage pumps
- horizontal multistage pumps
- submersible pumps
- self-priming pumps
- axial-flow pumps
- regenerative pumps

Positive Displacement Pumps

A positive displacement pump operates by alternating filling a cavity and then displacing a given volume of liquid. A positive displacement pump delivers a constant volume of liquid for each cycle independent of discharge pressure or head.

The positive displacement pump can be classified as:

- Reciprocating pumps - piston, plunger and diaphragm
- Power pumps
- Steam pumps
- Rotary pumps - gear, lobe, screw, vane, regenerative (peripheral) and progressive cavity

Selecting between Centrifugal or Positive Displacement Pumps

Selecting between a Centrifugal Pump or a Positive Displacement Pump is not always straight forward.

Flow Rate and Pressure Head

The two types of pumps behave very differently regarding pressure head and flow rate:

- The Centrifugal Pump has varying flow depending on the system pressure or head
- The Positive Displacement Pump has more or less a constant flow regardless of the system pressure or head. Positive Displacement pumps generally makes more pressure than Centrifugal Pump's.

Capacity and Viscosity

Another major difference between the pump types is the effect of viscosity on capacity:

- In a Centrifugal Pump the flow is reduced when the viscosity is increased
- In a Positive Displacement Pump the flow is increased when viscosity is increased

Liquids with high viscosity fills the clearances of Positive Displacement Pumps causing higher volumetric efficiencies and Positive Displacement Pumps are better suited for higher viscosity applications. A Centrifugal Pump becomes very inefficient at even modest viscosity.

Mechanical Efficiency

The pumps behaves different considering mechanical efficiency as well.

- Changing the system pressure or head has little or no effect on the flow rate in a Positive Displacement Pump
- Changing the system pressure or head may have a dramatic effect on the flow rate in a Centrifugal Pump

Net Positive Suction Head - NPSH

Another consideration is the Net Positive Suction Head - NPSH.

- In a Centrifugal Pump, NPSH varies as a function of flow determined by pressure
- In a Positive Displacement Pump, NPSH varies as a function of flow determined by speed. Reducing the speed of the Positive Displacement Pump pump, reduces the NPSH

Hydraulic power, pump shaft power and electrical input power

Hydraulic power P_h = Q (m³/s) x Total head, h_d - h_s (m) x ρ (kg/m³) x g (m/s²) / 1000

Where h_d – discharge head, h_s – suction head, ρ – density of the fluid, g – acceleration due to gravity

Pump shaft power P_s = Hydraulic power, P_h / pump efficiency, η_{Pump}

Electrical input power = $\dfrac{\text{Pump shaft power } P_s}{\eta_{Motor}}$

1.20.2 Centrifugal Pumps

A centrifugal pump converts input power to kinetic energy by accelerating liquid in a revolving device - an impeller.

The most common is the volute pump - where fluid enters the pump through the eye of the impeller which rotates at high speed. The fluid accelerates radially outward from the pump chasing and a vacuum is created at the impellers eye that continuously draws more fluid into the pump.

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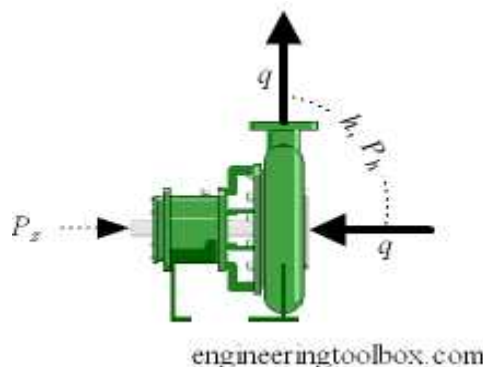
The energy from the pumps prime mover is transfered to kinetic energy according the Bernoulli Equation. The energy transferred to the liquid corresponds to the velocity at the edge or vane tip of the impeller. The faster the impeller revolves or the bigger the impeller is, the higher will the velocity of the liquid energy transferred to the liquid be. This is described by the Affinity Laws.

Pressure and Head

If the discharge of a centrifugal pump is pointed straight up into the air the fluid will pumped to a certain height - or head - called the **shut off head**. This maximum head is mainly determined by the outside diameter of the pump's impeller and the speed of the rotating shaft. The head will change as the capacity of the pump is altered.

The kinetic energy of a liquid coming out of an impeller is obstructed by creating a **resistance** in the flow. The first resistance is created by the pump casing which catches the liquid and slows it down. When the liquid slows down the kinetic energy is converted to pressure energy.

- it is the resistance to the pump's flow that is read on a pressure gauge attached to the discharge line

A pump does not create pressure, it only creates flow. The gauge pressure is a measurement of the resistance to flow.

In fluids the term **head** is used to measure the kinetic energy which a pump creates. Head is a measurement of the height of the liquid column the pump could create from the kinetic energy the pump gives to the liquid.

- the main reason for using head instead of pressure to measure a centrifugal pump's energy is that the pressure from a pump will change if the specific gravity (weight) of the liquid changes, but the head will not

The pump's performance on any Newtonian fluid can always be described by using the term head.

Different Types of Pump Head

- Total Static Head - Total head when the pump is not running
- Total Dynamic Head (Total System Head) - Total head when the pump is running
- Static Suction Head - Head on the suction side, with pump off, if the head is higher than the pump impeller
- Static Suction Lift - Head on the suction side, with pump off, if the head is lower than the pump impeller
- Static Discharge Head - Head on discharge side of pump with the pump off
- Dynamic Suction Head/Lift - Head on suction side of pump with pump on
- Dynamic Discharge Head - Head on discharge side of pump with pump on

The head is measured in either feet or meters and can be converted to common units for pressure - like psi, Pa or bar.

- it is important to understand that the pump will pump all fluids to the same height if the shaft is turning at the same rpm

The only difference between the fluids is the amount of power it takes to get the shaft to the proper rpm. The higher the specific gravity of the fluid the more power is required.

- Centrifugal Pumps are "**constant head machines**"

Note that the latter is not a constant pressure machine, since pressure is a function of head and density. The head is constant, even if the density (and therefore pressure) changes.

The head of a pump can be expressed in metric units as:

$$h = (p_2 - p_1) / (\rho\, g) + v_2^2 / (2\, g) \qquad\qquad (1)$$

where

h = total head developed (m)

p_2 = pressure at outlet (N/m²)

p_1 = pressure at inlet (N/m²)

ρ = density (kg/m³)

g = acceleration of gravity (9.81) m/s²

v_2 = velocity at the outlet (m/s)

Head described in simple terms

- a pump's vertical discharge "pressure-head" is the vertical lift in height - usually measured in feet or m of water - at which a pump can no longer exert enough pressure to move water. At this point, the pump may be said to have reached its "shut-off" head pressure. In the flow curve chart for a pump the "shut-off head" is the point on the graph where the flow rate is zero

Pump Efficiency

Pump efficiency, η (%) is a measure of the efficiency with which the pump transfers useful work to the fluid.

$$\eta = P_{out} / P_{in} \quad (2)$$

where

η = efficiency (%)

P_{in} = power input

P_{out} = power output

Centrifugal Pumps - Speed Torque Curve

Centrifugal pumps and the characteristic speed torque curve

The speed torque curve characterize a centrifugal pump. The theoretical characteristic is a parabola starting from the origin and proportional to the square of the speed.

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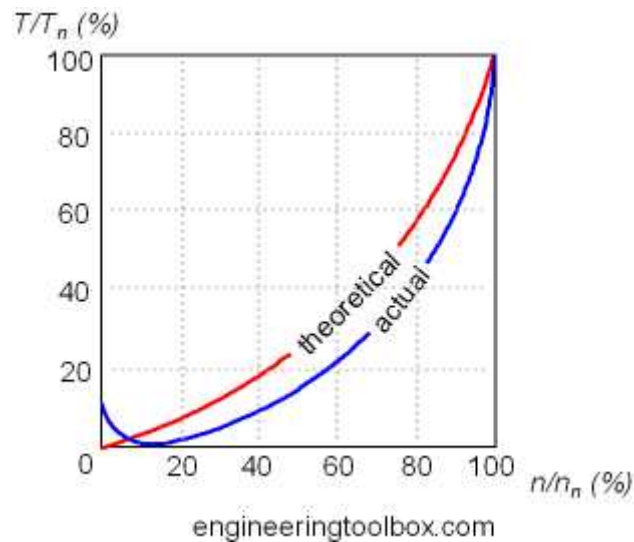
The torque can be expressed as

$$T = k\,n^2 \qquad\qquad (1)$$

where

T = torque (Nm, lb$_f$ ft)

k = constant

n = pump speed or velocity (rpm)

With the discharge valve closed the torque amounts to *30 - 50 %* of the nominal torque at full speed.

Full Load Torque

The torque at full load can be calculated as

$$T = 30\,P\,/\,(\ n) \qquad\qquad (2)$$

where

T = torque (kN m)

P = power (kW)

1.20.3 Positive Displacement Pumps

A Positive Displacement Pump has an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pumps as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is a constant given each cycle of operation.

The positive displacement pumps can be divided in two main classes

- reciprocating
- rotary

The positive displacement principle applies whether the pump is a

- rotary lobe pump
- progressing cavity pump
- rotary gear pump
- piston pump
- diaphragm pump
- screw pump
- gear pump
- vane pump
- regenerative (peripheral) pump
- peristaltic

A Positive Displacement Pump, unlike a Centrifugal or Roto-dynamic Pump, will produce the same flow at a given speed (RPM) no matter the discharge pressure.

- A Positive Displacement Pumps is a "**constant flow machine**"

A Positive Displacement Pump must never operate against closed valves on the discharge side of the pump - it has no shut-off head like Centrifugal Pumps. A Positive Displacement Pump operating against closed discharge valves continues to produce flow until the pressure in the discharge line is increased until the line bursts or the pump is severely damaged - or both.

A **relief or safety valve** on the discharge side of the Positive Displacement Pump is **absolute necessary**. The relief valve can be internal or external the pump. An internal valve should in general only be used as a safety precaution. An external relief valve installed in the discharge line with a return line back to the suction line or supply tank is highly recommended.

Reciprocating Pumps

Typical reciprocating pumps are

- plunger pumps
- diaphragm pumps

Plunger pumps consists of a cylinder with a reciprocating plunger in it. In the head of the cylinder the suction and discharge valves are mounted. In the suction stroke the plunger retracts and the suction valves opens causing suction of fluid into the cylinder. In the forward stroke the plunger push the liquid out the discharge valve.

With only one cylinder the fluid flow varies between maximum flow when the plunger moves through the middle positions, and zero flow when the plunger is in the end positions. A lot of energy is wasted when the fluid is accelerated in the piping system. Vibration and "water hammers" may be a serious problem. In general the problems are compensated by using two or more cylinders not working in phase with each other.

In a diaphragm pump the plunger pressurizes hydraulic oil which is used to flex a diaphragm in the pumping cylinder. Diaphragm pumps are used to pump hazardous and toxic fluids.

Rotary Pumps

Typical rotary pumps are

- gear pumps
- lobe pumps
- vane pumps
- progressive cavity pumps
- peripheral pumps
- screw pumps

In a gear pump the liquid is trapped by the opening between the gear teeth of two identical gears and the chasing of the pump on the suction side. On the pressure side the fluid is squeezed out when the teeth of the two gears are rotated against each other.

A lobe pump operates similar to a gear pump, but with two lobes driven by external timing gears. The lobes do not make contact.

A progressive cavity pump consist of a metal rotor rotating within an elastomer-lined or elastic stator. When the rotor turns progressive chambers from suction end to discharge end are formed between the rotor and stator, moving the fluid.

1.21 Fans, blowers, compressed air systems:

1.21.0 Introduction

Fans

- A Fan is a machine used to move fluid or air. It is operated through a motor via electricity which rotates the blades that are attached to a shaft.

Blowers

- A blower is a machine for moving volumes of a gas with **moderate increase of pressure**

Compressors

- A compressor is a machine for raising a gas - a **compressible** fluid - to a higher level of pressure

Fans and blowers provide air for ventilation and industrial process requirements. Fans generate a pressure to move air (or gases) against a resistance caused by ducts, dampers, or other components in a fan system. The fan rotor receives energy from a rotating shaft and transmits it to the air.

Difference between Fans, Blowers and Compressors Fans, blowers and compressors are differentiated by the method used to move the air, and by the system pressure they must operate against. 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, blowers and compressors (see Table 5.1).

TABLE 5.1 DIFFERENCES BETWEEN FANS, BLOWER AND COMPRESSOR		
Equipment	Specific Ratio	Pressure rise (mmWg)
Fans	Up to 1.11	1136
Blowers	1.11 to 1.20	1136 – 2066
Compressors	more than 1.20	–

1.21.1 Fan Types

Fan and blower selection depends on the volume flow rate, pressure, type of material handled, space limitations, and efficiency. Fan efficiencies differ from design to design and also by types. Typical ranges of fan efficiencies are given in Table 5.2.

Fans fall into two general categories: centrifugal flow and axial flow.

In centrifugal flow, airflow changes direction twice - once when entering and second when leaving (forward curved, backward curved or inclined, radial) (see Figure 5.1).

In axial flow, air enters and leaves the fan with no change in direction (propeller, tubeaxial, vaneaxial) (see Figure 5.2).

Depending on their designs, the following are main types of fans:

- Centrifugal fans: In this type of fan, airflow changes direction. They can be inclined, radial, forward curved, backward curved etc. These kinds of fans are suitable for high temperatures and low and medium blade tip speeds at high pressures. These can be effectively used for highly contaminated airstreams.
- *Axial Fans*: In this type of fan, there is no change in direction of air flow. They can be Vanaxial, Tubeaxial, and Propeller. They produce lower pressure than the Centrifugal fans. Propeller-type fans are capable of high-flow rates at low pressures. Tube-axial fans have low/medium pressure and high flow capability. Vane-axial fans have an inlet or outlet guide vanes, exhibit high pressure and medium flow-rate capabilities.

The air flow required in the process along with required outlet pressure are key factors determining the selection of type and size of a fan. Fan enclosure and duct design also determine how efficiently they can work.
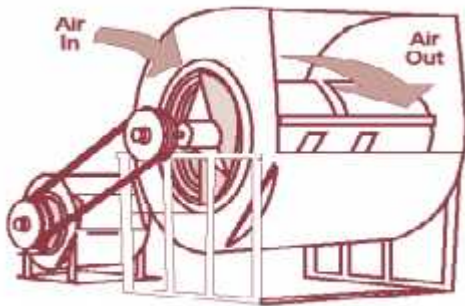
Figure 5.1 Centrifugal Fan
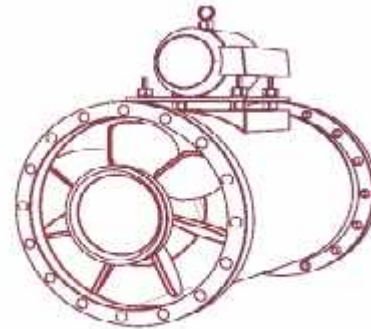
Figure 5.2 Axial Fan

TABLE 5.2 FAN EFFICIENCIES	
Type of fan	**Peak Efficiency Range**
Centrifugal Fans	
Airfoil, backward curved/inclined	79–83
Modified radial	72–79
Radial	69–75
Pressure blower	58–68
Forward curved	60–65
Axial fan	
Vane axial	78–85
Tube axial	67–72
Propeller	45–50

Centrifugal Fan: Types

The major types of centrifugal fan are: radial, forward curved and backward curved (see Figure 5.3). Radial fans are industrial workhorses because of their high static pressures (upto 1400 mm WC) and ability to handle heavily contaminated airstreams. Because of their simple design, radial fans are well suited for high temperatures and medium blade tip speeds.

Forward-curved fans are used in clean environments and operate at lower temperatures. They are well suited for low tip speed and high-airflow work - they are best suited for moving large volumes of air against relatively low pressures. Backward-inclined fans are more efficient than forward-curved fans.

Backward-inclined fans reach their peak power consumption and then power demand drops off well within their useable airflow range. Backward-inclined fans are known as "non-overloading" because changes in static pressure do not overload the motor.

Figure 5.3 Types of Centrifugal Fans
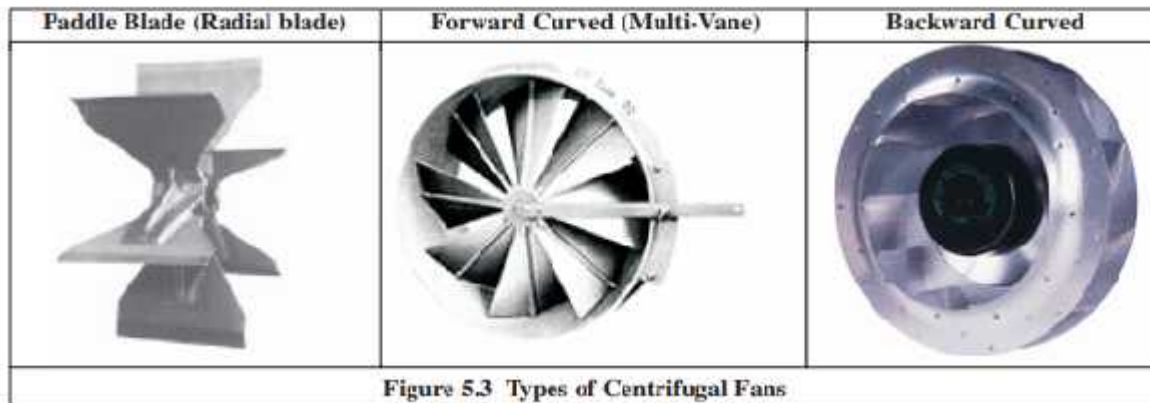
Axial Flow Fan: Types

The major types of axial flow fans are: tube axial, vane axial and propeller (see Figure 5.4.)

Tubeaxial fans have a wheel inside a cylindrical housing, with close clearance between blade and housing to improve airflow efficiency. The wheel turn faster than propeller fans, enabling operation under high-pressures 250 – 400 mm WC. The efficiency is up to 65%.

Vaneaxial fans are similar to tubeaxials, but with addition of guide vanes that improve efficiency by directing and straightening the flow. As a result, they have a higher static pressure with less dependence on the duct static pressure. Such fans are used generally for pressures upto 500 mmWC. Vaneaxials are typically the most energy-efficient fans available and should be used whenever possible.

Propeller fans usually run at low speeds and moderate temperatures. They experience a large change in airflow with small changes in static pressure. They handle large volumes of air at low pressure or free delivery. Propeller fans are often used indoors as exhaust fans. Outdoor applications include air-cooled condensers and cooling towers. Efficiency is low – approximately 50% or less.

Figure 5.4 Types of Axial Fans
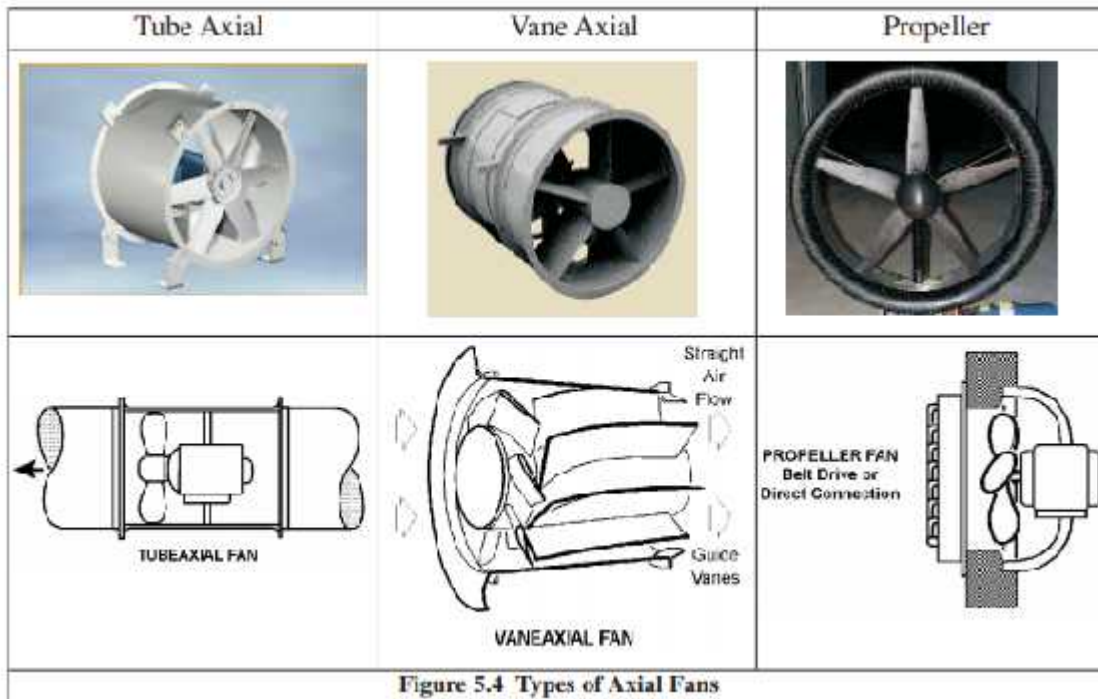
The different types of fans, their characteristics and typical applications are given in Table 5.3.

TABLE 5.3 TYPES OF FANS, CHARACTERISTICS, AND TYPICAL APPLICATIONS

Centrifugal Fans			Axial-flow Fans		
Type	**Characteristics**	**Typical Applications**	**Type**	**Characteristics**	**Typical Applications**
Radial	High pressure, medium flow, efficiency close to tube-axial fans, power increases continuously	Various industrial applications, suitable for dust laden, moist air/gases	Propeller	Low pressure, high flow, low efficiency, peak efficiency close to point of free air delivery (zero static pressure)	Air-circulation, ventilation, exhaust
Forward-curved blades	Medium pressure, high flow, dip in pressure curve, efficiency higher than radial fans, power rises continuously	Low pressure HVAC, packaged units, suitable for clean and dust laden air / gases	Tube-axial	Medium pressure, high flow, higher efficiency than propeller type, dip in pressure-flow curve before peak pressure point.	HVAC, drying ovens, exhaust systems
Backward curved blades	High pressure, high flow, high efficiency, power reduces as flow increases beyond point of highest efficiency	HVAC, various industrial applications forced draft fans, etc.	Vane-axial	High pressure, medium flow, dip in pressure-flow curve, use of guide vanes improves efficiencyexhausts	High pressure applications including HVAC systems,
Airfoil type	Same as backward curved type, highest efficiency	Same as backward curved, but for clean air applications			

Fan efficiency

Fan manufacturers generally use two ways to mention fan efficiency: mechanical efficiency (sometimes called the total efficiency) and static efficiency. Both measure how well the fan converts horsepower into flow and pressure.

The equation for determining mechanical efficiency is:

$$\text{Fan Mechanical Efficiency } \eta_{mechanical} \% = \frac{\text{Volume in } m^3/Sec \times \Delta p \text{ (total pressure) in mmwc}}{102 \times \text{Power input to the fan shaft in (kW)}} \times 100$$

The static efficiency equation is the same except that the outlet velocity pressure is not added to the fan static pressure

$$\text{Fan Static Efficiency } \eta_{static} \% = \frac{\text{Volume in } m^3/Sec \times \Delta p \text{ (static pressure) in mmwc}}{102 \times \text{Power input to the fan shaft in (kW)}} \times 100$$

Drive motor kW can be measured by a load analyzer. This kW multiplied by motor efficiency gives the shaft power to the fan.

1.21.2 Blowers

Blower is equipment or a device which increases the velocity of air or gas when it is passed through equipped impellers. They are mainly used for flow of air/gas required for exhausting, aspirating, cooling, ventilating, conveying etc. Blower is also commonly known as Centrifugal Fans in industry. In a blower, the inlet pressure is low and is higher at the outlet. The kinetic energy of the blades increases the pressure of the air at the outlet. Blowers are mainly used in industries for moderate pressure requirements where the pressure is more than the fan and less than the compressor.

Blower Types

Blowers can achieve much higher pressures than fans, as high as 1.20 kg/cm2 . They are also used to produce negative pressures for industrial vacuum systems. Major types are: centrifugal blower and positive-displacement blower.

Centrifugal blowers look more like centrifugal pumps than fans. The impeller is typically gear-driven and rotates as fast as 15,000 rpm. In multi-stage blowers, air is accelerated as it passes through each impeller. In single-stage blower, air does not take many turns, and hence it is more efficient.

Centrifugal blowers typically operate against pressures of 0.35 to 0.70 kg/cm2 , but can achieve higher pressures. One characteristic is that airflow tends to drop drastically as system pressure increases, which can be a disadvantage in material conveying systems that depend on a steady air volume. Because of this, they are most often used in applications that are not prone to clogging.

Positive-displacement blowers have rotors, which "trap" air and push it through housing. Positive-displacement blowers provide a constant volume of air even if the system pressure varies. They are especially suitable for applications prone to clogging, since they can produce enough pressure - typically up to 1.25 kg/cm2 - to blow clogged materials free. They turn much slower than centrifugal blowers (e.g. 3,600 rpm), and are often belt driven to facilitate speed changes.

1.21.3 Compressed air systems

Air compressors are used in a variety of industries to supply process requirements, to operate pneumatic tools and equipment, and to meet instrumentation needs.

Types of Compressors

Compressors are broadly classified as: Positive displacement compressor and Dynamic compressor.

Positive displacement compressors increase the pressure of the gas by reducing the volume. Positive displacement compressors are further classified as reciprocating and rotary compressors.

Dynamic compressors increase the air velocity, which is then converted to increased pressure at the outlet. Dynamic compressors are basically centrifugal compressors and are further classified as radial and axial flow types.

The flow and pressure requirements of a given application determine the suitability of a particulars type of compressor.
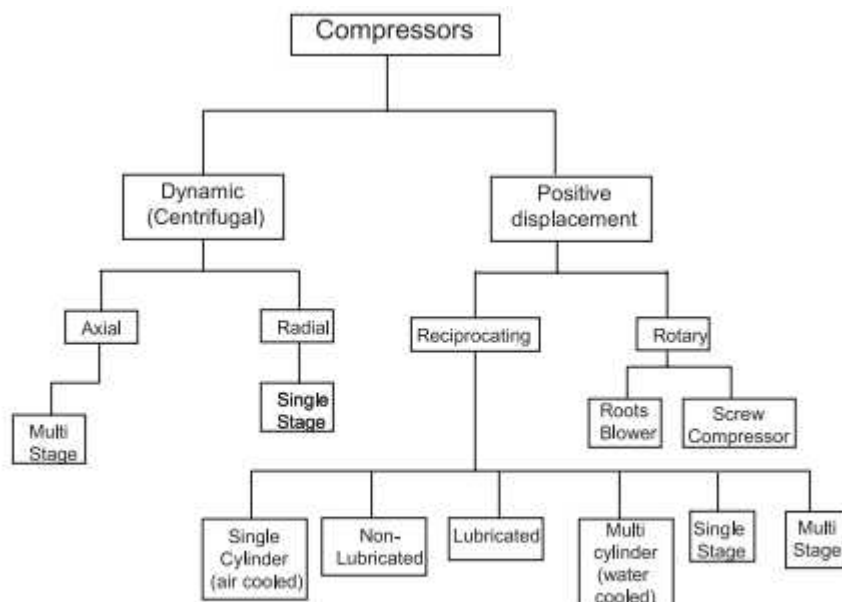
Figure 3.2 Compressor Chart

Positive displacement compressors use a system which induces in a volume of air in a chamber, and then reduce the volume of the chamber to compress the air. As the name suggests, there is a displacement of the component that reduces the volume of the chamber thereby compressing air/gas. On the other hand, in a **dynamic compressor**, there is a change in velocity of the fluid resulting in kinetic energy which creates pressure.

Reciprocating compressors use pistons where discharge pressure of air is high, the quantity of air handled is low and which has a low speed of the compressor. They are suitable for medium and high-pressure ratio and gas volumes. On the other hand, rotary compressors are suitable for low and medium pressures and for large volumes. These compressors do not have any

pistons and crankshaft. Instead, these compressors have screws, vanes, scrolls etc. So they can be further categorized on the basis of the component they are equipped with.

Types of Rotary compressors

- Scroll: In this equipment, air is compressed using two spirals or scrolls. One scroll is fixed and does not move and the other one movese in circular motion. Air gets trapped inside the spiral way of that element and gets compressed at the middle of the spiral. These are often with oil-free designs and require low maintenance.
- Vane: This consists of vanes that move in and out inside an impeller and compression occurs because of this sweeping motion. This forces the vapor into small volume sections, changing it into high pressure and high temperature vapor.
- Lobe: This consists of two lobes which rotate inside a closed casing. These lobes are displaced with 90 degrees to one another. As the rotor rotates, air is drawn into the inlet side of the cylinder casing and is pushed with a force out from the outlet side against the system pressure. The compressed air is then delivered to delivery line.
- Screw: This is equipped with two inter-meshing screws which traps air between the screw and the compressor casing, which results in squeezing and delivering it at a higher pressure from the delivery valve. The screw compressors are suitable and efficient in low air pressure requirements. In comparison to a reciprocating compressor, the compressed air delivery is continuous in this type of compressor and it is quiet in operation.
- Scroll: The scroll type compressors have scrolls driven by the prime mover. The scrolls outer edges trap air and then as they rotate, the air travel from outwards to inwards thus getting compressed due to a reduction in the area. The compressed air is delivered through central space of the scroll to the delivery airline.
- Liquid ring: In this type of compressor vanes are built inside a cylindrical casing. When the motor rotates, gas gets compressed. Then liquid mostly water is fed into the device and by centrifugal acceleration, it forms a liquid ring through the vanes, which in turn forms a compressing chamber. It is capable of compressing all gases and vapors, even with dust and liquids.

Reciprocating Compressor

- Single-Acting Compressors: It has piston working on air only in one direction. The air is compressed only on the top part of the piston.
- Double-Acting Compressors: It has two sets of suction/intake and delivery valves on both sides of the piston. Both sides of the piston are utilized in compressing the air.

Dynamic Compressors

The main difference between displacement and dynamic compressors is that a displacement compressor works at a constant flow, whereas a dynamic compressor such as Centrifugal and Axial works at a constant pressure and their performance is affected by external conditions such as changes in inlet temperatures etc. In an axial compressor, the gas or fluid flows parallel to the axis of rotations or axially. It is a rotating compressor that can continuously pressurize gases. The blades of an axial compressor are relatively closer to each other. In a centrifugal compressor, fluid enters from the center of the impeller, and moves outward through the

periphery by guide blades thereby reducing the velocity and increasing pressure. It is also known as a turbo compressor. They are efficient and reliable compressors. However, its compression ratio is lesser than axial compressors. Also, centrifugal compressors are more reliable if API (American petroleum Institute) 617 standards are followed.

TABLE 3.1 GENERAL SELECTION CRITERIA FOR COMPRESSORS

Type of Compressor	Capacity (m³/h)		Pressure (bar)	
	From	To	From	To
Roots blower compressor single stage	100	30000	0.1	1
Reciprocating				
– Single / Two stage	100	12000	0.8	12
– Multi stage	100	12000	12.0	700
Screw				
– Single stage	100	2400	0.8	13
– Two stage	100	2200	0.8	24
Centrifugal	600	300000	0.1	450

Compressor Performance

A. Capacity of a Compressor

Capacity of a compressor is the full rated volume of flow of gas compressed and delivered at conditions of total temperature, total pressure, and composition prevailing at the compressor inlet. It sometimes means actual flow rate, rather than rated volume of flow. This also termed as Free Air Delivery (FAD) i.e. air at atmospheric conditions at any specific location. Because the altitude, barometer, and temperature may vary at different localities and at different times, it follows that this term does not mean air under identical or standard conditions.

B. Compressor Efficiency Definitions

Several different measures of compressor efficiency are commonly used: volumetric efficiency, adiabatic efficiency, isothermal efficiency and mechanical efficiency. Adiabatic and isothermal efficiencies are computed as the isothermal or adiabatic power divided by the actual power consumption. The figure obtained indicates the overall efficiency of compressor and drive motor.

Isothermal Efficiency

$$\text{Isothermal Efficiency} = \frac{Isothermal Power}{\text{Actual measured input power}}$$

Isothermal power(kW)	=	$P_1 \times Q_1 \times \log_e r / 36.7$
P_1	=	Absolute intake pressure kg/ cm²
P_2	=	Absolute delivery pressure kg/ cm²
Q_1	=	Free air delivered m³/hr.
r	=	Pressure ratio P_2/P_1

The calculation of isothermal power does not include power needed to overcome friction and generally gives an efficiency that is lower than adiabatic efficiency. The reported value of efficiency is normally the isothermal efficiency. This is an important consideration when selecting compressors based on reported values of efficiency.

$$\text{Volumetric efficiency} = \frac{\text{Free air delivered (m}^3\text{/min)}}{\text{Compressor displacement (m}^3\text{/min)}} \times 100$$

Volumetric Efficiency

$$\text{Compressor Displacement} = \frac{\Pi}{4} \times D^2 \times L \times S \times \chi \times n$$

D	=	Cylinder bore, metre
L	=	Cylinder stroke, metre
S	=	Compressor speed rpm
χ	=	1 for single acting and
		2 for double acting cylinders
n	=	No. of cylinders

For practical purposes, the most effective guide in comparing compressor efficiencies is the specific power consumption ie kW/volume flow rate , for different compressors that would provide identical duty.

Compressed Air System Components

Compressed air systems consist of following major components: Intake air filters, inter-stage coolers, after coolers, air dryers, moisture drain traps, receivers, piping network, filters, regulators and lubricators (see Figure 3.6).

• Intake Air Filters: Prevent dust from entering compressor; Dust causes sticking valves, scoured cylinders, excessive wear etc.

• Inter-stage Coolers: Reduce the temperature of the air before it enters the next stage to reduce the work of compression and increase efficiency. They are normally watercooled.

• After Coolers: The objective is to remove the moisture in the air by reducing the temperature in a water-cooled heat exchanger.

• Air-dryers: The remaining traces of moisture after after-cooler are removed using air dryers, as air for instrument and pneumatic equipment has to be relatively free of any moisture. The moisture is removed by using adsorbents like silica gel /activated carbon, or refrigerant dryers, or heat of compression dryers.

• Moisture Drain Traps: Moisture drain traps are used for removal of moisture in the compressed air. These traps resemble steam traps. Various types of traps used are manual drain cocks, timer based / automatic drain valves etc.

• Receivers: Air receivers are provided as storage and smoothening pulsating air output - reducing pressure variations from the compressor

1.22 Refrigeration and air conditioning systems

1.22.0 Introduction

The Heating, Ventilation and Air Conditioning (HVAC) and refrigeration system transfers the heat energy from or to the products, or building environment. Energy in form of electricity or heat is used to power mechanical equipment designed to transfer heat from a colder, low-energy level to a warmer, high-energy level

Refrigeration deals with the transfer of heat from a low temperature level at the heat source to a high temperature level at the heat sink by using a low boiling refrigerant.

There are several heat transfer loops in refrigeration system as described below:
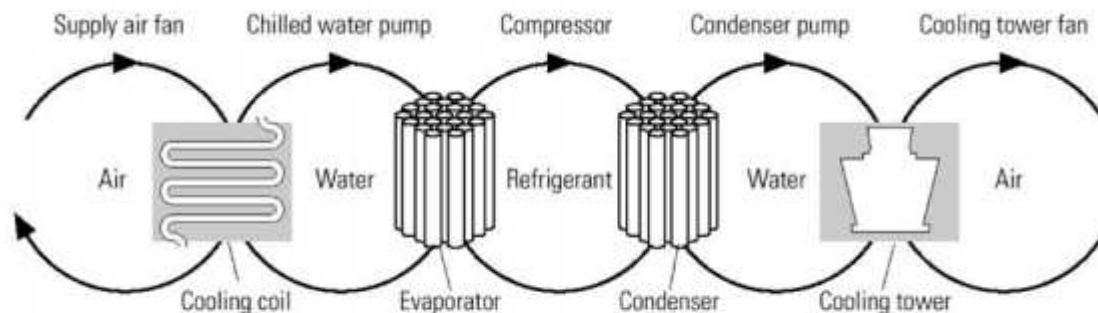
Figure 4.1   Heat Transfer Loops In Refrigeration System

In the Figure 4.1, thermal energy moves from left to right as it is extracted from the space and expelled into the outdoors through five loops of heat transfer:

– Indoor air loop. In the leftmost loop, indoor air is driven by the supply air fan through a cooling coil, where it transfers its heat to chilled water. The cool air then cools the building space.

– Chilled water loop. Driven by the chilled water pump, water returns from the cooling coil to the chiller's evaporator to be re-cooled.

– Refrigerant loop. Using a phase-change refrigerant, the chiller's compressor pumps heat from the chilled water to the condenser water.

– Condenser water loop. Water absorbs heat from the chiller's condenser, and the condenser water pump sends it to the cooling tower.

– Cooling tower loop. The cooling tower's fan drives air across an open flow of the hot condenser water, transferring the heat to the outdoors.

Air-Conditioning Systems Depending on applications, there are several options / combinations, which are available for use as given below:

- Air Conditioning (for comfort / machine)
- Split air conditioners
- Fan coil units in a larger system
- Air handling units in a larger system

Refrigeration Systems (for processes)

- Small capacity modular units of direct expansion type similar to domestic refrigerators, small capacity refrigeration units.
- Centralized chilled water plants with chilled water as a secondary coolant for temperature range over 5°C typically. They can also be used for ice bank formation.
- Brine plants, which use brines as lower temperature, secondary coolant, for typically sub zero temperature applications, which come as modular unit capacities as well as large centralized plant capacities.
- The plant capacities upto 50 TR are usually considered as small capacity, 50 – 250 TR as medium capacity and over 250 TR as large capacity units.

A large industry may have a bank of such units, often with common chilled water pumps, condenser water pumps, cooling towers, as an off site utility. The same industry may also have two or three levels of refrigeration & air conditioning such as:

- Comfort air conditioning (20° – 25° C)
- Chilled water system (8° – 10° C)
- Brine system (sub-zero applications)

Two principle types of refrigeration plants found in industrial use are: Vapour Compression Refrigeration (VCR) and Vapour Absorption Refrigeration (VAR). VCR uses mechanical energy as the driving force for refrigeration, while VAR uses thermal energy as the driving force for refrigeration.

1.22.1 Types of Refrigeration System

Vapour Compression Refrigeration

Heat flows naturally from a hot to a colder body. In refrigeration system the opposite must occur i.e. heat flows from a cold to a hotter body. This is achieved by using a substance called a refrigerant, which absorbs heat and hence boils or evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained to ambient air or water and turns back (condenses) into a liquid. In this way heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source. The refrigeration cycle can be broken down into the following stages (see Figure 4.2):

1 – 2 Low pressure liquid refrigerant in the evaporator absorbs heat from its surroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

2 – 3 The superheated vapour enters the compressor where its pressure is raised. There will also be a big increase in temperature, because a proportion of the energy input into the compression process is transferred to the refrigerant.

3 – 4 The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process (3 - 3a) desuperheats the gas before it is then turned back into liquid (3a - 3b). The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b - 4), so that the refrigerant liquid is sub-cooled as it enters the expansion device.

4 – 1 The high-pressure sub-cooled liquid passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.
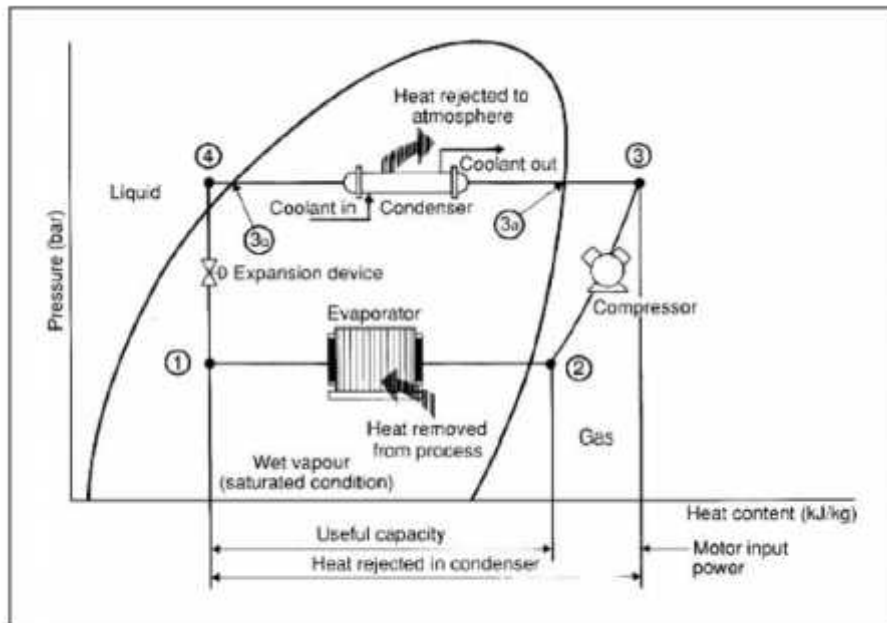

Figure 4.2: Schematic of a Basic Vapor Compression Refrigeration System

It can be seen that the condenser has to be capable of rejecting the combined heat inputs of the evaporator and the compressor; i.e. (1 – 2) + (2 – 3) has to be the same as (3 – 4). There is no heat loss or gain through the expansion device.

1.23 DG SET SYSTEM

1.23.0 Introduction

Diesel engine is the prime mover, which drives an alternator to produce electrical energy. In the diesel engine, air is drawn into the cylinder and is compressed to a high ratio (14:1 to 25:1). During this compression, the air is heated to a temperature of 700–900°C. A metered quantity of diesel fuel is then injected into the cylinder, which ignites spontaneously because of the high temperature. Hence, the diesel engine is also known as compression ignition (CI) engine.

DG set can be classified according to cycle type as: two stroke and four stroke. However, the bulk of IC engines use the four stroke cycle. Let us look at the principle of operation of the four-stroke diesel engine.

1.23.1 Four Stroke - Diesel Engine

The 4 stroke operations in a diesel engine are: induction stroke, compression stroke, ignition and power stroke and exhaust stroke.

1st: Induction stroke - while the inlet valve is open, the descending piston draws in fresh air.

2nd: Compression stroke - while the valves are closed, the air is compressed to a pressure of up to 25 bar.

3rd: Ignition and power stroke - fuel is injected, while the valves are closed (fuel injection actually starts at the end of the previous stroke), the fuel ignites spontaneously and the piston is forced downwards by the combustion gases.

4th: Exhaust stroke - the exhaust valve is open and the rising piston discharges the spent gases from the cylinder.
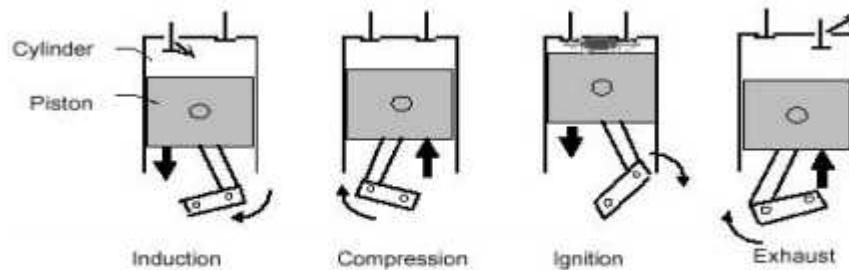
Figure 9.1 Schematic Diagram of Four-Stroke Diesel Engine

Since power is developed during only one stroke, the single cylinder four-stroke engine has a low degree of uniformity. Smoother running is obtained with multi cylinder engines because the cranks are staggered in relation to one another on the crankshaft. There are many variations of engine configuration, for example. 4 or 6 cylinder, in-line, horizontally opposed, vee or radial configurations.

1.23.2 DG Set as a System

A diesel generating set should be considered as a system since its successful operation depends on the well-matched performance of the components, namely:

a) The diesel engine and its accessories.

b) The AC Generator.

c) The control systems and switchgear.

d) The foundation and power house civil works.

e) The connected load with its own components like heating, motor drives, lighting etc.

It is necessary to select the components with highest efficiency and operate them at their optimum efficiency levels to conserve energy in this system.
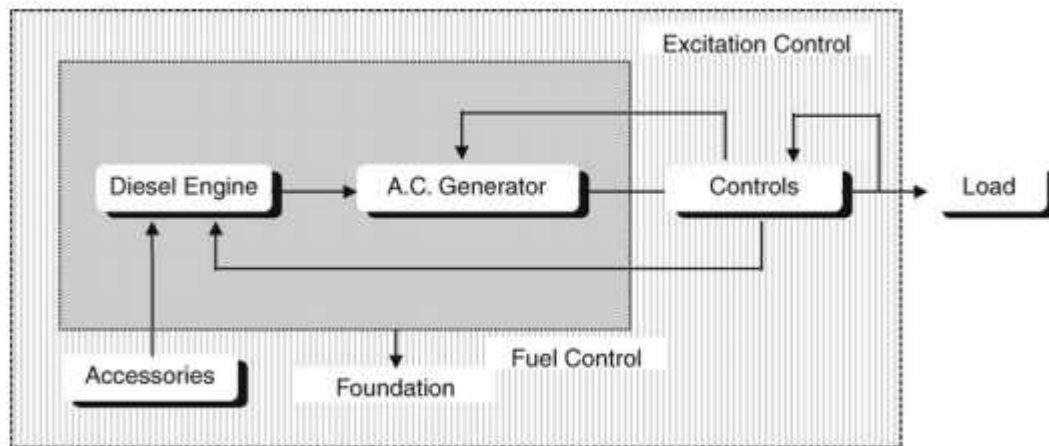
Fig 9.2   DG Set System

1.24 Power Factor Improvement and Benefits

1.24.0 Power factor Basics

In all industrial electrical distribution systems, the major loads are resistive and inductive. Resistive loads are incandescent lighting and resistance heating. In case of pure resistive loads, the voltage (V), current (I), resistance (R) relations are linearly related, i.e.

$$V = I \times R \text{ and Power (kW)} = V \times I$$

Typical inductive loads are A.C. Motors, induction furnaces, transformers and ballast-type lighting. Inductive loads require two kinds of power: a) active (or working) power to perform the work and b) reactive power to create and maintain electro-magnetic fields.

Active power is measured in kW (Kilo Watts). Reactive power is measured in kVAr (Kilo Volt-Amperes Reactive).

The vector sum of the active power and reactive power make up the total (or apparent) power used. This is the power generated by the SEBs for the user to perform a given amount of work. Total Power is measured in kVA (Kilo Volts-Amperes) (See Figure 1.6).
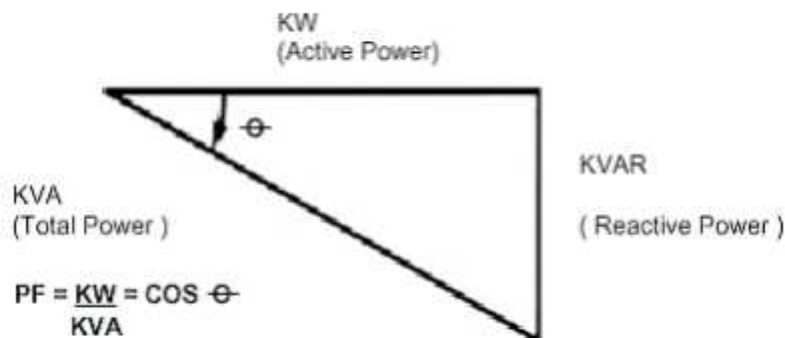
Figure 1.6   kW, kVAr and kVA Vector

The active power (shaft power required or true power required) in kW and the reactive power required (kVAr) are 90° apart vectorically in a pure inductive circuit i.e., reactive power kVAr lagging the active kW. The vector sum of the two is called the apparent power or kVA, as illustrated above and the kVA reflects the actual electrical load on distribution system.

The ratio of kW to kVA is called the power factor, which is always less than or equal to unity. Theoretically, when electric utilities supply power, if all loads have unity power factor, maximum power can be transferred for the same distribution system capacity. However, as the loads are inductive in nature, with the power factor ranging from 0.2 to 0.9, the electrical distribution network is stressed for capacity at low power factors.

1.4.1 Improving Power Factor

The solution to improve the power factor is to add power factor correction capacitors (see Figure 1.7) to the plant power distribution system. They act as reactive power generators, and provide the needed reactive power to accomplish kW of work. This reduces the amount of reactive power, and thus total power, generated by the utilities.

Example:

A chemical industry had installed a 1500 kVA transformer. The initial demand of the plant was 1160 kVA with power factor of 0.70. The % loading of transformer was about 78% (116~ 0/1500 = 77.3%). To improve the power factor and to avoid the penalty, the unit had added about 410 kVAr in motor load end. This improved the power factor to 0.89, and reduced the required kVA to 913, which is the vector sum of kW and kVAr (see Figure 1.8).
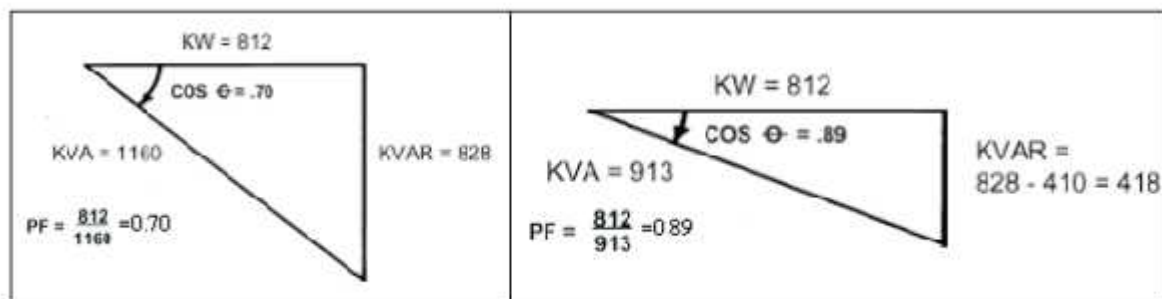
Figure 1.8   Power factor before and after Improvement

After improvement the plant had avoided penalty and the 1500 kVA transformer now loaded only to 60% of capacity. This will allow the addition of more load in the future to be supplied by the transformer.

1.24.2 The advantages of PF improvement by capacitor addition

a) Reactive component of the network is reduced and so also the total current in the system from the source end.

b) I^2R power losses are reduced in the system because of reduction in current.

c) Voltage level at the load end is increased.

d) kVA loading on the source generators as also on the transformers and lines upto the capacitors reduces giving capacity relief. A high power factor can help in utilising the full capacity of your electrical system.

1.24.3 Cost benefits of PF improvement

While costs of PF improvement are in terms of investment needs for capacitor addition the benefits to be quantified for feasibility analysis are:

a) Reduced kVA (Maximum demand) charges in utility bill

b) Reduced distribution losses (KWH) within the plant network

c) Better voltage at motor terminals and improved performance of motors

d) A high power factor eliminates penalty charges imposed when operating with a low power factor e) Investment on system facilities such as transformers, cables, switchgears etc for delivering load is reduced.

1.24.5 Selection and location of capacitors

Direct relation for capacitor sizing.

kVAr Rating = kW [tan ϕ_1 – tan ϕ_2]

where kVAr rating is the size of the capacitor needed, kW is the average power drawn, tan ϕ_1 is the trigonometric ratio for the present power factor, and tan ϕ_2 is the trigonometric ratio for the desired PF.

ϕ_1 = Existing (Cos-1 PF1) and ϕ_2 = Improved (Cos-1 PF2)

Alternatively the Table 1.2 can be used for capacitor sizing.

The figures given in table are the multiplication factors which are to be multiplied with the input power (kW) to give the kVAr of capacitance required to improve present power factor to a new desired power factor.

TABLE 1.2 MULTIPLIERS TO DETERMINE CAPACITOR kVAr REQUIREMENTS FOR POWER FACTOR CORRECTION

Orig. Power Factor	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.0
0.50	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	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	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	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.090	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	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	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.068	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	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	0.965	1.108
0.68	0.329	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	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	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	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
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	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
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	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
0.75	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
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.685	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	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	0.633	0.776
0.80	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	0.609	0.750
0.81		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
0.82			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	0.555	0.698
0.83				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	0.529	0.672
0.84					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
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90											0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.079	0.126	0.186	0.329
0.96																	0.000	0.041	0.089	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.060	0.203
0.99																				0.000	0.143
																					0.000

Example:

The utility bill shows an average power factor of 0.72 with an average KW of 627. How much kVAr is required to improve the power factor to .95 ?

Using formula

Cos ϕ_1 = 0.72 , tan ϕ_1 = 0.963 Cos ϕ_2 = 0.95 , tan ϕ_2 = 0.329 kVAr required = P (tan ϕ_1 - tan ϕ_2) = 627 (0.964 – 0.329) = 398 kVAr

Using table (see Table 1.2)

1) Locate 0.72 (original power factor) in column (1).

2) Read across desired power factor to 0.95 column. We find 0.635 multiplier

3) Multiply 627 (average kW) by 0.635 = 398 kVAr.

4) Install 400 kVAr to improve power factor to 95%.

1.24.6 Location of Capacitors

The primary purpose of capacitors is to reduce the maximum demand. Additional benefits are derived by capacitor location. The Figure 1.9 indicates typical capacitor locations. Maximum benefit of capacitors is derived by locating them as close as possible to the load. At this location, its kVAr are confined to the smallest possible segment, decreasing the load current. This, in turn, will reduce power losses of the system substantially. Power losses are proportional to the square of the current. When power losses are reduced, voltage at the motor increases; thus, motor performance also increases. Locations C1A, C1B and C1C of Figure 1.9 indicate three different arrangements at the load. Note that in all three locations extra switches are not required, since the capacitor is either switched with the motor starter or the breaker before the starter. Case C1A is recommended for new installation, since the maximum benefit is derived and the size of the motor thermal protector is reduced. In Case C1B, as in Case C1A, the capacitor is energized only when the motor is in operation. Case C1B is recommended in cases where the installation already exists and the thermal protector does not need to be re-sized. In position C1C, the capacitor is permanently connected to the circuit but does not require a separate switch, since capacitor can be disconnected by the breaker before the starter.
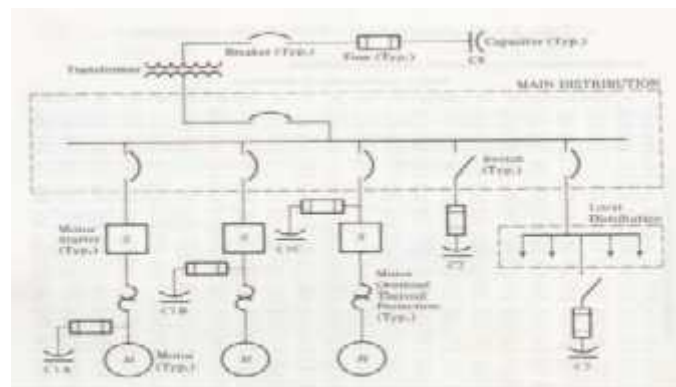
Figure 1.9:   Power Distribution Diagram Illustrating Capacitor Locations

It should be noted that the rating of the capacitor should not be greater than the no-load magnetizing kVAr of the motor. If this condition exists, damaging over voltage or transient torques can occur. This is why most motor manufacturers specify maximum capacitor ratings to be applied to specific motors.

The next preference for capacitor locations as illustrated by Figure 1.9 is at locations C2 and C3. In these locations, a breaker or switch will be required. Location C4 requires a high voltage breaker. The advantage of locating capacitors at power centres or feeders is that they can be grouped together. When several motors are running intermittently, the capacitors are permitted to be on line all the time, reducing the total power regardless of load.

From energy efficiency point of view, capacitor location at receiving substation only helps the utility in loss reduction. Locating capacitors at tail end will help to reduce loss reduction within the plants distribution network as well and directly benefit the user by reduced consumption. Reduction in the distribution loss % in kWh when tail end power factor is raised from PF1 to a new power factor PF2, will be proportional to

$$\left[1 - \left(PF_1 \,/\, PF_2\right)^2\right] \times 100$$

1.24.7 Capacitors for Other Loads

The other types of load requiring capacitor application include induction furnaces, induction heaters and arc welding transformers etc. The capacitors are normally supplied with control gear for the application of induction furnaces and induction heating furnaces. The PF of arc furnaces experiences a wide variation over melting cycle as it changes from 0.7 at starting to 0.9 at the end of the cycle. Power factor for welding transformers is corrected by connecting capacitors across the primary winding of the transformers, as the normal PF would be in the range of 0.35.

1.24.8 Performance Assessment of Power Factor Capacitors

Voltage effects:

Ideally capacitor voltage rating is to match the supply voltage. If the supply voltage is lower, the reactive kVAr produced will be the ratio V1 2 /V2 2 where V1 is the actual supply voltage, V2 is the rated voltage. On the other hand, if the supply voltage exceeds rated voltage, the life of the capacitor is adversely affected.

Material of capacitors:

Power factor capacitors are available in various types by dielectric material used as; paper/ polypropylene etc. The watt loss per kVAr as well as life vary with respect to the choice of the dielectric material and hence is a factor to be considered while selection.

Connections:

Shunt capacitor connections are adopted for almost all industry/ end user applications, while series capacitors are adopted for voltage boosting in distribution networks.

Operational performance of capacitors:

This can be made by monitoring capacitor charging current vis- a- vis the rated charging current. Capacity of fused elements can be replenished as per requirements. Portable analyzers can be used for measuring kVAr delivered as well as charging current. Capacitors consume 0.2 to 6.0 Watt per kVAr, which is negligible in comparison to benefits.

Some checks that need to be adopted in use of capacitors are :

i) Nameplates can be misleading with respect to ratings. It is good to check by charging currents.

ii) Capacitor boxes may contain only insulated compound and insulated terminals with no capacitor elements inside.

iii) Capacitors for single phase motor starting and those used for lighting circuits for voltage boost, are not power factor capacitor units and these cannot withstand power system conditions.

1.25 Harmonics

In any alternating current network, flow of current depends upon the voltage applied and the impedance (resistance to AC) provided by elements like resistances, reactances of inductive and capacitive nature. As the value of impedance in above devices is constant, they are called linear whereby the voltage and current relation is of linear nature. However in real life situation, various devices like diodes, silicon controlled rectifiers, PWM systems, thyristors, voltage & current chopping saturated core reactors, induction & arc furnaces are also deployed for various requirements and due to their varying impedance characteristic, these NON LINEAR devices cause distortion in voltage and current waveforms which is of increasing concern in recent times. Harmonics occurs as spikes at intervals which are multiples of the mains (supply) frequency and these distort the pure sine wave form of the supply voltage & current. Harmonics are multiples of the fundamental frequency of an electrical power system. If, for example, the fundamental frequency is 50 Hz, then the 5th harmonic is five times that frequency, or 250 Hz. Likewise, the 7th harmonic is seven times the fundamental or 350 Hz, and so on for higher order harmonics. Harmonics can be discussed in terms of current or voltage. A 5th harmonic current is simply a current flowing at 250 Hz on a 50 Hz system. The 5th harmonic current flowing through the system impedance creates a 5th harmonic voltage. Total Harmonic Distortion (THD) expresses the amount of harmonics. The following is the formula for calculating the THD for current:

$$THD_{current} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{I_n}{I_1}\right)^2} \times 100$$

Then...

$$I_{THD} = \sqrt{\left[\left(\frac{50}{250}\right)^2 + \left(\frac{35}{250}\right)^2\right]} \times 100 = 24\%$$

When harmonic currents flow in a power system, they are known as "poor power quality" or "dirty power". Other causes of poor power quality include transients such as voltage spikes, surges, sags, and ringing. Because they repeat every cycle, harmonics are regarded as a steadystate cause of poor power quality.

When expressed as a percentage of fundamental voltage THD is given by,

where V1 is the fundamental frequency voltage and Vn is nth harmonic voltage component.

Major Causes of Harmonics

Devices that draw non-sinusoidal currents when a sinusoidal voltage is applied create harmonics. Frequently these are devices that convert AC to DC. Some of these devices are listed below:

Electronic Switching Power Converters

• Computers, Uninterruptible power supplies (UPS), Solid-state rectifiers

• Electronic process control equipment, PLC's, etc

• Electronic lighting ballasts, including light dimmer

• Reduced voltage motor controllers

Arcing Devices

• Discharge lighting, e.g. Fluorescent, Sodium and Mercury vapor

• Arc furnaces, Welding equipment, Electrical traction system

Ferromagnetic Devices

• Transformers operating near saturation level

• Magnetic ballasts (Saturated Iron core)

• Induction heating equipment, Chokes, Motors

Appliances

• TV sets, air conditioners, washing machines, microwave ovens

• Fax machines, photocopiers, printers

These devices use power electronics like SCRs, diodes, and thyristors, which are a growing percentage of the load in industrial power systems. The majority use a 6-pulse converter. Most loads which produce harmonics, do so as a steady-state phenomenon. A snapshot reading of an operating load that is suspected to be non-linear can determine if it is producing harmonics. Normally each load would manifest a specific harmonic spectrum.

Many problems can arise from harmonic currents in a power system. Some problems are easy to detect; others exist and persist because harmonics are not suspected. Higher RMS current and voltage in the system are caused by harmonic currents, which can result in any of the problems listed below:

1. Blinking of Incandescent Lights - Transformer Saturation

2. Capacitor Failure - Harmonic Resonance

3. Circuit Breakers Tripping - Inductive Heating and Overload

4. Conductor Failure - Inductive Heating

5. Electronic Equipment Shutting down - Voltage Distortion

6. Flickering of Fluorescent Lights - Transformer Saturation

7. Fuses Blowing for No Apparent Reason - Inductive Heating and Overload

8. Motor Failures (overheating) - Voltage Drop

9. Neutral Conductor and Terminal Failures - Additive Triplen Currents

10. Electromagnetic Load Failures - Inductive Heating

11. Overheating of Metal Enclosures - Inductive Heating

12. Power Interference on Voice Communication - Harmonic Noise

13. Transformer Failures - Inductive Heating

Overcoming Harmonics

Tuned Harmonic filters consisting of a capacitor bank and reactor in series are designed and adopted for suppressing harmonics, by providing low impedance path for harmonic component.

Module II: (12 Hours)

Electrical energy audit: **Energy consumption pattern and scenario of any region; Energy auditing: Need, types, methodology and approaches; Preliminary energy audit methodology (initial site visit and preparation required for detailed auditing, detailed energy audit activities, information and data collection, process flow diagram and process steps); Procedure and techniques: Data gathering, evaluation of saving opportunities, and energy audit reporting; and Energy audit instruments**.

2.0 Introduction

- Energy is one of the major input for the development of any country

- Energy can be classified into several types based on the following criteria

    - Primary and Secondary Energy

    - Commercial and Non Commercial Energy

    - Renewable and Non Renewable Energy

Primary and Secondary Energy

- Primary Energy refers to all type of energy extracted or captured directly from natural resource

- Primary Energy further divided into two groups

    - Renewable (Solar, Wind, Geothermal, Tidal, Biomas, etc)

    - Non Renewable (Fossile Fules, Cruide Oil, Coal, NaturalGas, etc)

- All Fuels generally expressed in terms of toe (tonne of oil equivalent) and is based the following conversion factor

toe= 10x106 Kcal=11630kwh=41870MJ
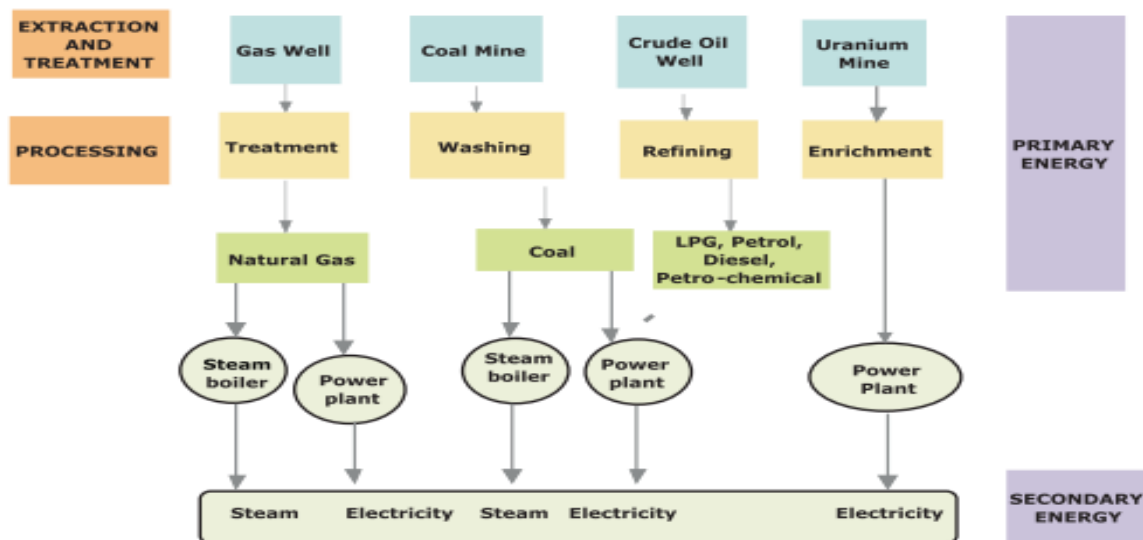
Figure 1.1 Major Primary and Secondary Energy Sources

Commercial and Non Commercial Energy

Commercial Energy

- The energy sources that are available in the market for a definite price are known as commercial energy.

- Examples: Electricity, lignite, coal, oil, natural gas etc.

Non-Commercial Energy

- The energy sources that are not available in the commercial market for a price are classified as non-commercial energy.

- Example: Firewood, agro waste in rural areas

Renewable and Non-Renewable Energy

- Renewable energy is energy obtained from sources that are essentially inexhaustible.

- Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power (See Figure 1.2).

- The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.

- Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

Figure 1.2 Renewable and Non-Renewable Energy
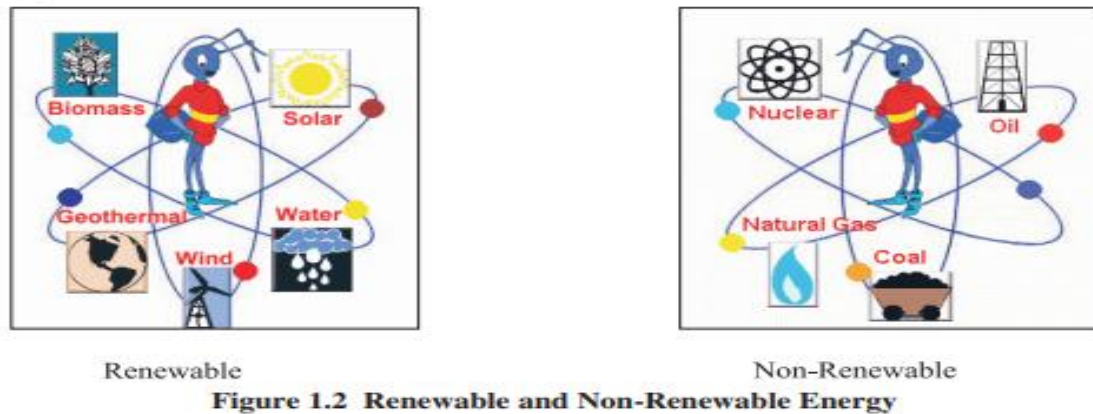
2.1 Energy consumption pattern and scenario of any region;

2.1.0 Global Primary Energy Reserves*

Coal

The proven global coal reserve was estimated to be 9,84,453 million tonnes by end of 2003. The USA had the largest share of the global reserve (25.4%) followed by Russia (15.9%), China (11.6%). India was 4th in the list with 8.6%.

Oil

The global proven oil reserve was estimated to be 1147 billion barrels by the end of 2003. Saudi Arabia had the largest share of the reserve with almost 23%. (One barrel of oil is approximately 160 litres)

Gas

The global proven gas reserve was estimated to be 176 trillion cubic metres by the end of 2003. The Russian Federation had the largest share of the reserve with almost 27%. (*Source: BP Statistical Review of World Energy, June 2004)

2.1.1 Global Primary Energy Consumption:

The global primary energy consumption at the end of 2003 was equivalent to 9741 million tonnes of oil equivalent (Mtoe).

The primary energy consumption for few of the developed and developing countries are shown in Table 1.1. It may be seen that India's absolute primary energy consumption is only 1/29th of the world, 1/7th of USA, 1/1.6th time of Japan but 1.1, 1.3, 1.5 times that of Canada, France and U.K respectively.

TABLE 1.1 PRIMARY ENERGY CONSUMPTION BY FUEL, 2003						
In Million tonnes oil equivalent						
Country	Oil	Natural Gas	Coal	Nuclear Energy	Hydro electric	Total
USA	914.3	566.8	573.9	181.9	60.9	2297.8
Canada	96.4	78.7	31.0	16.8	68.6	291.4
France	94.2	39.4	12.4	99.8	14.8	260.6
Russian Federation	124.7	365.2	111.3	34.0	35.6	670.8
United Kingdom	76.8	85.7	39.1	20.1	1.3	223.2
China	275.2	29.5	799.7	9.8	64.0	1178.3
India	113.3	27.1	185.3	4.1	15.6	345.3
Japan	248.7	68.9	112.2	52.2	22.8	504.8
Malaysia	23.9	25.6	3.2	-	1.7	54.4
Pakistan	17.0	19.0	2.7	0.4	5.6	44.8
Singapore	34.1	4.8	-	-	-	38.9
TOTAL WORLD	3636.6	2331.9	2578.4	598.8	595.4	9741.1

2.1.2 Indian Energy Scenario

Coal dominates the energy mix in India, contributing to 55% of the total primary energy production. Over the years, there has been a marked increase in the share of natural gas in primary energy production from 10% in 1994 to 13% in 1999. There has been a decline in the share of oil in primary energy production from 20% to 17% during the same period.

Energy Supply

Coal Supply

India has huge coal reserves, at least 84,396 million tonnes of proven recoverable reserves (at the end of 2003). This amounts to almost 8.6% of the world reserves and it may last for about 230 years at the current Reserve to Production (R/P) ratio. In contrast, the world's proven coal reserves are expected to last only for 192 years at the current R/P ratio.

Reserves/Production (R/P) ratio- If the reserves remaining at the end of the year are divided by the production in that year, the result is the length of time that the remaining reserves would last if production were to continue at that level. India is the fourth largest producer of coal and lignite in the world. Coal production is concentrated in these states (Andhra Pradesh, Uttar Pradesh, Bihar, Madhya Pradesh, Maharashtra, Orissa, Jharkhand, West Bengal).

Oil Supply

Oil accounts for about 36 % of India's total energy consumption. India today is one of the top ten oil-guzzling nations in the world and will soon overtake Korea as the third largest consumer of oil in Asia after China and Japan. The country's annual crude oil production is peaked at about 32 million tonne as against the current peak demand of about 110 million tonne. In the current scenario, India's oil consumption by end of 2007 is expected to reach 136 million tonne(MT), of which domestic production will be only 34 MT. India will have to pay an oil bill of roughly $50 billion, assuming a weighted average price of $50 per barrel of crude. In 2003- 04, against total export of $64 billion, oil imports accounted for $21 billion. India imports 70% of its crude needs mainly from gulf nations. The majority of India's roughly 5.4 billion barrels in oil reserves are located in the Bombay High, upper Assam, Cambay, Krishna-Godavari. In terms of sector wise petroleum product consumption, transport accounts for 42% followed by domestic and industry with 24% and 24% respectively. India spent more than Rs.1,10,000 crore on oil imports at the end of 2004.

The ever rising import bill		
Year	Quantity (MMT)	Value (Rs Crore)
1996-97	33.90	18,337
1997-98	34.49	15,872
1998-99	39.81	19,907
1999-00	57.80	40,028
2000-01	74.10	65,932
2001-02	84.90	80116
2002-03	90	85,042
2003-04	95	93,159
*2004-05	100	1,30,000
* Estimated		
Source: Ministry of Petroleum and Natural Gas		

Natural Gas

Supply Natural gas accounts for about 8.9 per cent of energy consumption in the country. The current demand for natural gas is about 96 million cubic metres per day (mcmd) as against availability of 67 mcmd. By 2007, the demand is expected to be around 200 mcmd. Natural gas reserves are estimated at 660 billion cubic meters.

Electrical Energy Supply

The all India installed capacity of electric power generating stations under utilities was 1,12,581 MW as on 31st May 2004, consisting of 28,860 MW- hydro, 77,931 MW - thermal and 2,720 MW- nuclear and 1,869 MW- wind (Ministry of Power). The gross generation of power in the year 2002-2003 stood at 531 billion units (kWh).

Nuclear Power Supply

Nuclear Power contributes to about 2.4 per cent of electricity generated in India. India has ten nuclear power reactors at five nuclear power stations producing electricity. More nuclear reactors have also been approved for construction.

Hydro Power Supply

India is endowed with a vast and viable hydro potential for power generation of which only 15% has been harnessed so far. The share of hydropower in the country's total generated units has steadily decreased and it presently stands at 25% as on 31st May 2004. It is assessed that exploitable potential at 60% load factor is 84,000 MW.

Final Energy Consumption

Final energy consumption is the actual energy demand at the user end. This is the difference between primary energy consumption and the losses that takes place in transport, transmission & distribution and refinement. The actual final energy consumption (past and projected) is given in Table 1.2.

TABLE 1.2 DEMAND FOR COMMERCIAL ENERGY FOR FINAL CONSUMPTION (BAU SCENARIO)					
Source	Units	1994-95	2001-02	2006-07	2011-12
Electricity	Billion Units	289.36	480.08	712.67	1067.88
Coal	Million Tonnes	76.67	109.01	134.99	173.47
Lignite	Million Tonnes	4.85	11.69	16.02	19.70
Natural Gas	Million Cubic Meters	9880	15730	18291	20853
Oil Products	Million Tonnes	63.55	99.89	139.95	196.47
Source: Planning Commission BAU:_Business As Usual					

Sector Wise Energy Consumption in India

The major commercial energy consuming sectors in the country are classified as shown in the Figure 1.5. As seen from the figure, industry remains the biggest consumer of commercial energy and its share in the overall consumption is 49%. (Reference year: 1999/2000)
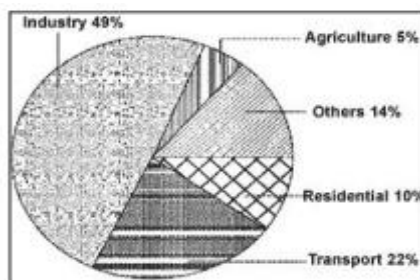
2.2 Energy Audit: Nee, Types and Methodology:

Energy Audit is the key to a systematic approach for decision-making in the area of energy management. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. Industrial energy audit is an effective tool in defining and pursuing comprehensive energy management programme. As per the Energy Conservation Act, 2001, Energy Audit is defined as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption".

2.2.0 Need for Energy Audit:

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction. Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists. The Energy Audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Such an audit programme will help to keep focus on variations which occur in the energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc. In general, Energy Audit is the translation of conservation ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame. The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a "bench-mark" (Reference point) for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization.

2.2.1Type of Energy Audit:

The type of Energy Audit to be performed depends on:

- Function and type of industry

- Depth to which final audit is needed, and

 - Potential and magnitude of cost reduction desired

Thus Energy Audit can be classified into the following two types.

      i)   **Preliminary Audit**

     ii)   **Targeted Audit**

   iii)   **Detailed Audit**

2.2.2 Preliminary Energy Audit Methodology:

Preliminary energy audit is a relatively quick exercise to:

- Establish energy consumption in the organization

- Estimate the scope for saving

- Identify the most likely (and the easiest areas for attention

- Identify immediate (especially no-/low-cost) improvements/ savings

- Set a 'reference point' • Identify areas for more detailed study/measurement

- Preliminary energy audit uses existing, or easily obtained data

2.2.3 Targeted Energy Audit Methodology:

- Targeted energy audits often results from preliminary audits.

- They provide data and detailed analysis on specified target project.

- For example an Organization may target its light system or boiler system or steam system or compressed air system with a view of effecting energy savings.

- Targeted audits therefore involved detailed survey of the target subjects and analysis of the energy flows and cost associated with the targets.

- Final outcome is the recommendations regarding action to be taken.

2.2.4 Detailed Energy Audit Methodology:

A comprehensive audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems.

This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all projects, accounts for the energy use of all major equipment, and includes detailed energy cost saving calculations and project cost.

In a comprehensive audit, one of the key elements is the energy balance. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated use is then compared to utility bill charges.

Detailed energy auditing is carried out in three phases: Phase I, II and III.

Phase I - Pre Audit Phase

Phase II - Audit Phase

Phase III - Post Audit Phase

A Guide for Conducting Energy Audit at a Glance

Industry-to-industry, the methodology of Energy Audits needs to be flexible.

A comprehensive ten-step methodology for conduct of Energy Audit at field level is pre- sented below. Energy Manager and Energy Auditor may follow these steps to start with and add/change as per their needs and industry types.

Ten Steps Methodology for Detailed Energy Audit

Step No	PLAN OF ACTION	PURPOSE / RESULTS
	Phase I –Pre Audit Phase	
Step 1	• Plan and organise • Walk through Audit • Informal Interview with Energy Manager, Production / Plant Manager	• Resource planning, Establish/organize a Energy audit team • Organize Instruments & time frame • Macro Data collection (suitable to type of industry.) • Familiarization of process/plant activities • First hand observation & Assessment of current level operation and practices
Step 2	• Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.)	• Building up cooperation • Issue questionnaire for each department • Orientation, awareness creation

	Phase II –Audit Phase	
Step 3	• Primary data gathering, Process Flow Diagram, & Energy Utility Diagram	• Historic data analysis, Baseline data collection • Prepare process flow charts • All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution. • Design, operating data and schedule of operation • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview)
Step 4	• Conduct survey and monitoring	• Measurements : Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data.

Step 5	• Conduct of detailed trials /experiments for selected energy guzzlers	• Trials/Experiments:
		  - 24 hours power monitoring (MD, PF, kWh etc.).
		  - Load variations trends in pumps, fan compressors etc.

		- Boiler/Efficiency trials for (4 – 8 hours) - Furnace Efficiency trials Equipments Performance experiments etc
Step6	• Analysis of energy use	• Energy and Material balance & energy loss/waste analysis
Step 7	• Identification and development of Energy Conservation (ENCON) opportunities	• Identification & Consolidation ENCON measures • Conceive, develop, and refine ideas • Review the previous ideas suggested by unit personal • Review the previous ideas suggested by energy audit if any • Use brainstorming and value analysis techniques • Contact vendors for new/efficient technology
Step 8	• Cost benefit analysis	• Assess technical feasibility, economic viability and prioritization of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step9	• Reporting Identification and the Top Management	• Documentation, Report Presentation to the top Management.
Step10	Phase III –Post Audit phase • Implementation and Follow-up	Assist and Implement ENCON recommendation measures and Monitor the performance • Action plan, Schedule for implementation • Follow-up and periodic review

Phase I -Pre Audit Phase Activities

A structured methodology to carry out an energy audit is necessary for efficient working. An initial study of the site should always be carried out, as the planning of the procedures necessary for an audit is most important.

Initial Site Visit and Preparation Required for Detailed Auditing

An initial site visit may take one day and gives the Energy Auditor/Engineer an opportunity to meet the personnel concerned, to familiarize him with the site and to assess the procedures necessary to carry out the energy audit.

During the initial site visit the Energy Auditor/Engineer should carry out the following actions: -

• Discuss with the site's senior management the aims of the energy audit.

• Discuss economic guidelines associated with the recommendations of the audit.

• Analyse the major energy consumption data with the relevant personnel.

• Obtain site drawings where available - building layout, steam distribution, compressed air distribution, electricity distribution etc.

• Tour the site accompanied by engineering/production

The main aims of this visit are: -
• To finalise Energy Audit team
• To identify the main energy consuming areas/plant items to be surveyed during the audit.
• To identify any existing instrumentation/ additional metering required.
• To decide whether any meters will have to be installed prior to the audit eg. kWh, steam, oil or gas meters.
• To identify the instrumentation required for carrying out the audit.
• To plan with time frame
• To collect macro data on plant energy resources, major energy consuming centers
• To create awareness through meetings/ programme

Phase II- Detailed Energy Audit Activities

Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. Whenever possible, checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.

The audit report will include a description of energy inputs and product outputs by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process. Means of improving these efficiencies will be listed, and at least a preliminary assessment of the cost of the improvements will be made to indicate the expected payback on any capital investment needed. The audit report should conclude with specific recommendations for detailed engineering studies and feasibility analyses,

which must then be performed to justify the implementation of those conservation measures that require investments.

The information to be collected during the detailed audit includes: -

1. Energy consumption by type of energy, by department, by major items of process equipment, by end-use
2. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)
3. Energy cost and tariff data
4. Process and material flow diagrams
5. Generation and distribution of site services (eg.compressed air, steam).
6. Sources of energy supply (e.g. electricity from the grid or self-generation)
7. Potential for fuel substitution, process modifications, and the use of co-generation systems (combined heat and power generation).
8. Energy Management procedures and energy awareness training programs within the establishment.
Existing baseline information and reports are useful to get consumption pattern, production cost and productivity levels in terms of product per raw material inputs. The audit team should collect the following baseline data:
- Technology, processes used and equipment details
- Capacity utilisation - Amount & type of input materials used
- Water consumption
- Fuel Consumption
- Electrical energy consumption
- Steam consumption
- Other inputs such as compressed air, cooling water etc
- Quantity & type of wastes generated
- Percentage rejection / reprocessing
- Efficiencies / yield

DATA COLLECTION HINTS

It is important to plan additional data gathering carefully. Here are some basic tips to avoid wasting time and effort:
• Measurement systems should be easy to use and provide the information to the accuracy that is needed, not the accuracy that is technically possible
• Measurement equipment can be inexpensive (flow rates using a bucket and stopwatch)
• The quality of the data must be such that the correct conclusions are drawn (what grade of prod uct is on, is the production normal etc)
• define how frequent data collection should be to account for process variations.
• Measurement exercises over abnormal workload periods (such as startup and shutdowns)
• Design values can be taken where measurements are difficult (cooling water through heat exchang er)

<div align="center">

DO NOT ESTIMATE WHEN YOU CAN CALCULATE
DO NOT CALCULATE WHEN YOU CAN MEASURE

</div>

Draw process flow diagram and list process steps; identify waste streams and obvious energy wastage

An overview of unit operations, important process steps, areas of material and energy use and sources of waste generation should be gathered and should be represented in a flowchart as shown in the figure below. Existing drawings, records and shop floor walk through will help in making this flow chart. Simultaneously the team should identify the various inputs & output streams at each process step.

Example: A flowchart of Penicillin-G manufacturing is given in the figure3.1 below. Note that waste stream (Mycelium) and obvious energy wastes such as condensate drained and steam leakages have been identified in this flow chart

The audit focus area depends on several issues like consumption of input resources, energy efficiency potential, impact of process step on entire process or intensity of waste generation / energy consumption. In the above process, the unit operations such as germinator, pre-fermen- tor, fermentor, and extraction are the major conservation potential areas identified.
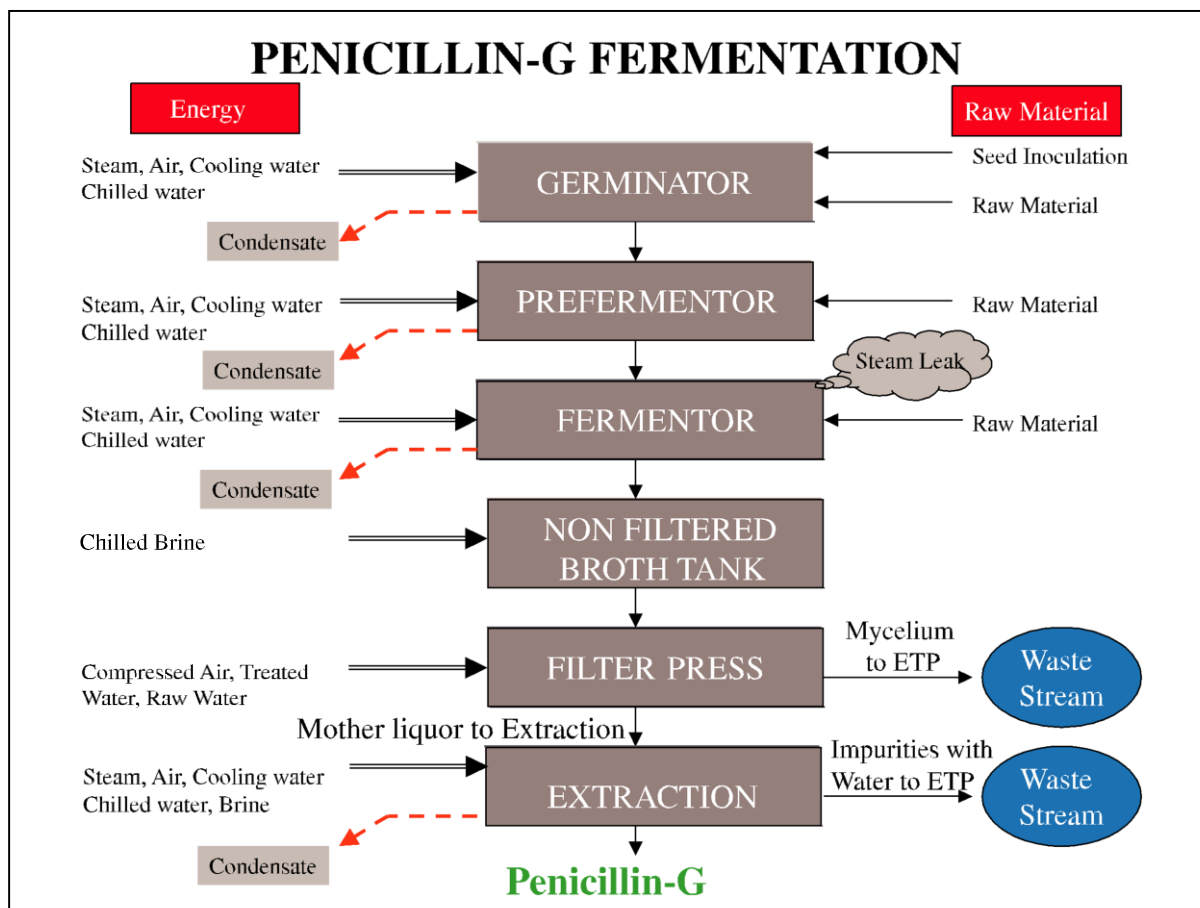
Figure 2.1

2.3 Energy Audit Reporting Format

After successfully carried out energy audit energy manager/energy auditor should report to the top management for effective communication and implementation. A typical energy audit reporting contents and format are given below. The following format is applicable for most of the industries. However the format can be suitably modified for specific requirement applicable for a particular type of industry.

Report on

DETAILED ENERGY AUDIT

TABLE OF CONTENTS

4.0 Detailed Process flow diagram and Energy& Material balance

  4.1 Flow chart showing flow rate, temperature, pressures of all input-output streams

  4.2 Water balance for entire industry

5.0 Energy efficiency in utility and process systems

  5.1 Specific Energy consumption

  5.2 Boiler efficiency assessment

  5.3 Thermic Fluid Heater performance assessment

  5.4 Furnace efficiency Analysis

  5.5 Cooling water system performance assessment

  5.6 DG set performance assessment

  5.7 Refrigeration system performance

  5.8 Compressed air system performance

  5.9 Electric motor load analysis

  5.10 Lighting system

6.0 Energy Conservation Options & Recommendations

  6.1 List of options in terms of No cost/ Low Cost, Medium cost and high investment Cost, Annual Energy & Cost savings, and payback

  6.2 Implementation plan for energy saving measures/Projects

ANNEXURE

  A1. List of Energy Audit Worksheets

  A2. List of instruments

  A3. List of Vendors and Other Technical details

The following Worksheets (refer Table 3.2 & Table 3.3) can be used as guidance for energy audit assessment and reporting.

TABLE 3.2 SUMMARY OF ENERGY SAVING RECOMMENDATIONS					
S.No.	Energy Saving Recommendations	Annual Energy (Fuel & Electricity) Savings (kWh/MT or kl/MT)	Annual Savings Rs.Lakhs	Capital Investment (Rs.Lakhs)	Simple Payback period
1					
2					
3					
4					
Total					

TABLE 3.3 TYPES AND PRIORITY OF ENERGY SAVING MEASURES				
	Type of Energy Saving Options	Annual Electricity /Fuel savings	Annual Savings	Priority
		KWh/MT or kl/MT	(Rs Lakhs)	
A	No Investment (Immediate) - Operational Improvement - Housekeeping			
B	Low Investment (Short to Medium Term) - Controls - Equipment Modification - Process change			
C	High Investment (Long Term) - Energy efficient Devices - Product modification - Technology Change			

Table 4.4 Reporting Format for Energy Conservation Recommendations		
A: Title of Recommendation	:	Combine DG set cooling tower with main cooling tower
B: Description of Existing System and its Operation	:	Main cooling tower is operating with 30% of its capacity. The rated cooling water flow is 5000 m³/hr. Two cooling water pumps are in operation continuously with 50% of its rated capacity. A separate cooling tower is also operating for DG set operation continuously.
C: Description of Proposed System and its Operation	:	The DG Set cooling water flow is only 240 m³/h. By adding this flow into the main cooling tower will eliminate the need for a separate cooling tower operation for DG set, besides improving the %loading of main cooling tower. It is suggested to stop the DG set cooling tower operation.
D: Energy Saving Calculations		
Capacity of main cooling tower	=	5000 m³/ hr
Temp across cooling tower (design)	=	8 °C
Present capacity	=	3000 m³/hr
Temperature across cooling tower (operating)	=	4 °C
% loading of main cooling tower	=	(3000 x 4)/(5000 x 8) = 30%
Capacity of DG Set cooling tower	=	240 m³/hr
Temp across the tower	=	5°C
Heat Load (240x1000 x 1x 5)	=	1200,000 kCal/hr
Power drawn by the DG set cooling tower		
No of pumps and its rating	=	2 Nos x 7.5 kW
No of fans and its rating	=	2 Nos x 22 kW
Power consumption@ 80% load	=	(22 x2 +7.5 x2) x.80 = 47 kW
Additional power required for main cooling tower for additional water flow of 240m³/h (66.67 l/s) with 6 kg/cm²	=	(66.67 x 6) / (102 x 0.55) = 7 kW
Net Energy Savings	=	47 – 7 = 40 kW
E: Cost Benefits		
Annual Energy Saving Potential	=	40 kW x 8400 hr = 3,36,000 Units/Year
Annual Cost Savings	=	3,36,000 xRs.4.00 = Rs.13.4 Lakh per year
Investment (Only cost of piping)	=	Rs 1.5 Lakhs
Simple Payback Period	=	Less than 2 months

Phase III - Post Audit Phase

On completion of energy audit, energy action plan should be prepared. The energy action plan list the ENCONs which should be implemented first, and suggest an overall implementations schedule. Energy audit is incomplete without monitoring and its associated feedback. Monitoring consists of collecting and interpreting data. The data to be collected depends upon goals chosen in the energy action plan. Electrical power consumption and fuel consumption must be evaluated and monitored.

The monitoring data should provide direct feedback to those most able to implement the changes. Often additional instruments should be installed in various departments in addition to main meeting.

Monitoring should result in more action. Good practices should be replicated. If the gap between planned objectives and actual achievement in large, reasons should be analysed and new objectives, new action should be installed and result should be monitored. In this way, analysis, action and monitoring are a cycle process.

3.4 Energy Audit Instruments

The requirement for an energy audit such as identification and quantification of energy necessitates measurements; these measurements require the use of instruments. These instruments must be portable, durable, easy to operate and relatively inexpensive. The parameters generally monitored during energy audit may include the following:

Basic Electrical Parameters in AC &DC systems - Voltage (V), Current (I), Power factor, Active power (kW), apparent power (demand) (kVA), Reactive power (kVAr), Energy consumption (kWh), Frequency (Hz), Harmonics, etc.

Parameters of importance other than electrical such as temperature & heat flow, radiation, air and gas flow, liquid flow, revolutions per minute (RPM), air velocity, noise and vibration, dust concentration, Total Dissolved Solids (TDS), pH, moisture content, relative humidity, flue gas analysis - CO_2, O_2, CO, SOx, NOx, combustion efficiency etc.

Key instruments for energy audit are listed below.

The operating instructions for all instruments must be understood and staff should familiarize themselves with the instruments and their operation prior to actual audit use.

	Electrical Measuring Instruments: These are instruments for measuring major electrical parameters such as kVA, kW, PF, Hertz, kVAr, Amps and Volts. In addition some of these instruments also measure harmonics. These instruments are applied on-line i.e on running motors without any need to stop the motor. Instant measurements can be taken with hand-held meters, while more advanced ones facilitates cumulative readings with print outs at specified intervals.
	Combustion analyzer: This instrument has in-built chemical cells which measure various gases such as O_2, CO, NO_X and SO_X.
	Fuel Efficiency Monitor: This measures oxygen and temperature of the flue gas. Calorific values of common fuels are fed into the microprocessor which calculates the combustion efficiency.
	Fyrite: A hand bellow pump draws the flue gas sample into the solution inside the fyrite. A chemical reaction changes the liquid volume revealing the amount of gas. A separate fyrite can be used for O_2 and CO_2 measurement.

	Contact thermometer: These are thermocouples which measures for example flue gas, hot air, hot water temperatures by insertion of probe into the stream. For surface temperature, a leaf type probe is used with the same instrument.
	Infrared Thermometer: This is a non-contact type measurement which when directed at a heat source directly gives the temperature read out. This instrument is useful for measuring hot spots in furnaces, surface temperatures etc.
	Pitot Tube and manometer: Air velocity in ducts can be measured using a pitot tube and inclined manometer for further calculation of flows.
	Water flow meter: This non-contact flow measuring device using Doppler effect / Ultra sonic principle. There is a transmitter and receiver which are positioned on opposite sides of the pipe. The meter directly gives the flow. Water and other fluid flows can be easily measured with this meter.
 Tachometer Stroboscope	**Speed Measurements:** In any audit exercise speed measurements are critical as thay may change with frequency, belt slip and loading. A simple tachometer is a contact type instrument which can be used where direct access is possible. More sophisticated and safer ones are non contact instruments such as stroboscopes.
	Leak Detectors: Ultrasonic instruments are available which can be used to detect leaks of compressed air and other gases which are normally not possible to detect with human abilities.
	Lux meters: Illumination levels are measured with a lux meter. It consists of a photo cell which senses the light output, converts to electrical impulses which are calibrated as lux.

Illumination: Illumination, luminous flux, lumen, luminous intensity, candela power, brightness, glare, types of lighting (incandescent, CFL, and LED), requirements of lux for various purposes, determine the method of lighting, select the lighting equipment's, and calculate the lighting parameters.

Illumination, an observable property and effect of light, may also refer to

- **Lighting,** the use of light sources
- Illumination (image), the use of light and shadow in art
- Illuminated manuscript, the artistic decoration of hand-written texts
- Global illumination, algorithms used in 3D computer graphics

3.1 Introduction

Lighting is an essential service in all the industries. The power consumption by the industrial lighting varies between 2 to 10% of the total power depending on the type of industry. Innovation and continuous improvement in the field of lighting, has given rise to tremendous energy saving opportunities in this area.

Lighting is an area, which provides a major scope to achieve energy efficiency at the design stage, by incorporation of modern energy efficient lamps, luminaires and gears, apart from good operational practices.

Light: It is defined as the radiation energy from a hot body which produces the visual sensation upon the human eye. It is usually denoted by Q, expressed in lumen-hours and is analogous to watt-hour.

Luminous flux: it is defined as the total quantity of light energy emitted per second form a luminous body. It is represented by symbol F and is measured in lumens. The concept of luminous flux helps us to specify the output and efficiency of a given light source.

Luminous intensity: luminous intensity in any given direction is the luminous flux emitted by the source per unit solid angle, measured in the direction in which the intensity is required. It is denoted by symbol I and is measured in candela(cd) or lumens/steradian.

If **F** is the luminous flux radiated out by source within a solid angle of ω steradian in any particular direction then I $= F/\omega$ lumens/steradian or candela (cd).

Lumen: The lumen is the unit of luminous flux and is defined as the amount of luminous flux given out in a space represented by one unit of solid angle by a source having an intensity of one candle power in all directions.

Lumens = candle power X solid angle = cp X ω

Total lumens given out by source of one candela are 4π lumens.

Candle power: Candle power is the light radiating capacity of a source in a given direction and is defined as the number of lumens given out by the source in a unit solid angle in a given direction. It is denoted by a symbol **C.P.**

$$C.P. = lumens/\omega$$

Illumination: When the light falls upon any surface, the phenomenon is called the illumination. It is defined as the number of lumens, falling on the surface, per unit area. It is denoted by symbol E and is measured in lumens per square meter or meter-candle or lux.

If a flux of **F** lumens falls on a surface of area **A**, then the illumination of that surface is
E =F/A   lumens/m² or lux

Lux or meter candle: It is the unit of illumination and is defined as the luminous flux falling per square meter on the surface which is everywhere perpendicular to the rays of light from a source of one candle power and one meter away from it.

Foot candle: It is also the unit of illumination and is defined as the luminous flux falling per square foot on the surface which is everywhere perpendicular to the rays of light from a source of one candle power and one foot away from it.
1 foot-candle = 1 lumen/ft2 =10.76 meter candle or lux

Candle: It is the unit of luminous intensity. It is defined as 1/60 th of the luminous intensity per cm^2 of a black body radiator at the temperature of solidification of platinum (2,043 ^{0}K).

Mean horizontal candle power: (M.H.C.P) It is defined as the mean of candle powers in all directions in the horizontal plane containing the source of light.

Mean spherical candle power: (M.S.C.P) It is defined as the mean of the candle powers in all directions and in all planes from the source of light.

Mean hemi-spherical candle power: (M.H.S.C.P) It is defined as the mean of candle powers in all directions above or below the horizontal plane passing through the source of light.

Reduction factor: Reduction factor of a source of light is the ratio of its mean spherical candle power to its mean horizontal candle power.

reduction factor = M.S.C.P./M.H.C.P.

Lamp efficiency: It is defined as the ratio of the luminous flux to the power input. It is expressed in lumens per watt.

Specific consumption: It is defined as the ratio of the power input to the average candle power. It is expressed in watt per candela.

Brightness: When the eye receives a great deal of light from an object we say it is bright, and brightness is an important quantity in illumination. It is all the same whether the light is produced by the object or reflected from it.
Brightness is defined as the luminous intensity per unit projected area of either a surface source of light or a reflecting surface and is denoted by L.

If a surface area A has an effective luminous intensity of I candelas in a direction θ to the normal, than the brightness (luminance) of that surface is

$$L = I/a \; cos\theta$$

The unit of brightness is candela/m^2 (nits), candela/cm^2 (stilb) or candela/ft

Glare:- The size of the opening of the pupil in the human eye is controlled by its iris. If the eye is exposed to a very bright source of light the iris automatically contacts in order to produce the amount of light admitted and prevent damaged to retina this reduces the sensitivity, so that other objects within the field of vision can be only imperfectly seen.

In other words glare maybe defined as brightness with in the field of vision of such a character as the cause annoyance discomfort interference with vision.

Space height ratio:- it is defined as the ratio of distance between adjacent lamps and height of their mountains.

$$Space \; toheight \; ratio = \frac{horizontal \; distance \; between \; two \; adjacent \; lamps}{mounting \; height \; of lamps \; above \; working \; plane}$$

Utilization factor or co-efficient of utilization:- It is defined as the ratio of total lumens reaching the working plane to total lumens given out by the lamp.

$$Utilization \; Factor = \frac{total \; lumens \; reaching \; the \; working \; plane}{total \; lumens \; given \; out \; by \; the \; lamp}$$

Maintenance factor: Due to accumulation of dust, dirt and smoke on the lamps, they emit less light than that they emit when they are new ones and similarly the walls and ceilings e.t.c. after being covered with dust, dirt and smoke do not reflect the same output of light, which is reflected when they are new. Lumens

The ratio of illumination under normal working conditions to the illumination when the things are perfectly clean is known as maintenance factor.

$$Mintenance \; Factor = \frac{illumination \; under \; normal \; working \; conditions}{illumination \; when \; every \; thing \; is \; clean}$$

Depreciation factor: this is merely reverse of the maintenance factor and is defined as the ratio of the initial meter-candles to the ultimate maintained metre-candles on the working plane. Its value is more than unity.

Waste light factor: Whenever a surface is illuminated by a number of sources of light, there is always a certain amount of waste of light on account of over-lapping and falling of light outside at the edges of the surface. The effect is taken into account by multiplying the theoretical value of lumens required by 1.2 for rectangular areas and 1.5 for irregular areas and objects such as statues, monuments etc.

Absorption factor: In the places where atmosphere is full of smoke fumes, such as in foundries, there is a possibility of absorption of light. The ratio of total lumens available after absorption to the total lumens emitted by the source of light is called the absorption factor. Its value varies from unity for clean atmosphere to 0.5 for foundries.

Beam factor: the ratio of lumens in the beam of a projector to the lumens given out by lamps is called the beam factor. This factor takes into the account the absorption of light by reflector and front glass of the projector lamp. Its value varies from 0.3 to 0.6.

Reflection factor: When a ray of light impinges on a surface it is reflected from the surface at an angle of incidence, as shown in the fallowing figure. A certain portion of incident light is absorbed by the surface. The ratio of reflected light to the incident light is called the **reflection factor.** It's value always less than unity.

Plane angle: A plane angle is the angle subtended at a point in a plane by two converging lines. It is denoted by the Greek letter 'θ' (theta) and is usually measured in degrees or radians.
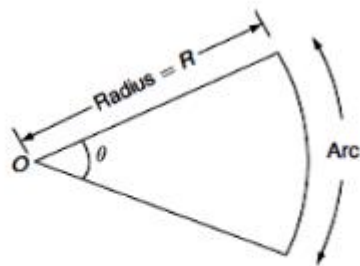
$$\theta = \frac{arc}{radious} \; radians$$

One radian is defined as the angle subtended by an arc of a circle whose length by an arc of a circle whose length is equals to the radius of the circle.

Solid angle: Solid angle is the angle subtended at a point in space by an area, i.e., theangle enclosed in the volume formed by numerous lines lying on the surface and meeting at the point. It is usually denoted by symbol 'ω' and is measured in steradian.
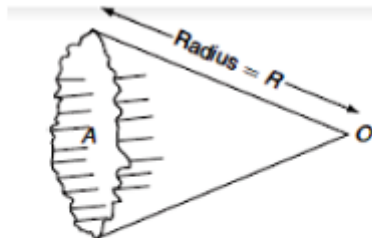
$$\omega = \frac{area}{(radious)^2} = \frac{A}{r^2}$$

The largest solid angle subtended at a point is that due to a sphere at its centre. If **r** is the radius of any sphere, its surface area is $4\pi^2$ and the distance of its surface area from the centre is r, therefore, solid angle subtended at its centre by its surface,

$$\omega = \frac{4\pi r^2}{(r)^2} = 4\pi \text{ } steradians$$

Example 1: A 200-V lamp takes a current of 1.2 A, it produces a total flux of 2,860 lumens. Calculate:
1. the MSCP of the lamp and
2. the efficiency of the lamp.
Solution:
Given V = 200 V, I = 1.2 A, flux = 2,860 lumens.

$$\text{MSCP} = \frac{\text{total flux}}{4\pi} = \frac{2860}{4\pi} = 227.59.$$

Lamp efficiency = lumens flux/power input = 2860/(200*1.2) lumens/watt

Example 2: A room with an area of 6 × 9 m is illustrated by ten 80-W lamps. The luminous efficiency of the lamp is 80 lumens/W and the coefficient of utilization is 0.65.
Find the average illumination.

Solution:
Room area = 6 × 9 = 54 m .
Total wattage = 80 × 10 = 800 W.
Total flux emitted by ten lamps = 80 × 800 = 64,000 lumens.
Flux reaching the working plane = 64,000 × 0.65 = 41,600 lumens.

$$\therefore \text{Illumination, } E = \frac{\phi}{A} = \frac{41,600}{54} = 770.37 \text{ lux.}$$

Laws of Illumination
Mainly there are two laws of illumination.
1. Inverse square law.
2. Lambert's cosine law.

1. Inverse square law: This law states that 'the illumination of a surface is inversely proportional to the square of distance of the surface from the source of light.
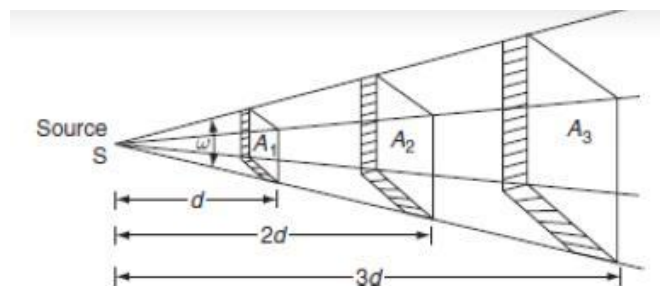
Let, 'S' be a point source of luminous intensity 'I' candela, the luminous flux emitting from source crossing the three parallel plates having areas A A , and A square meters, which are separated by a distances of d, $2d$, and $3d$ from the point source respectively as shown in Fig.

For are A_1, solid angle $\omega = A_1/d^2$

Luminous flux reaching the area A_1 = luminous intensity × solid angle

$$= I * \omega = I * A_1/d^2$$

Illumination 'E_1' on the surface area 'A_1' is:

$E_1 = flux/area = I * A_1/d^2 * 1/A_1$

$E_1 = I/d^2$ *lux*

Similarly, illumination 'E_2' on the surface *area A_2* is:

$E_2 = I/(2d)^2$ *lux*

Similarly, illumination 'E_3' on the surface *area A_3* is:

$E_3 = I/(3d)^2$ *lux*

From above equations

$E_1 : E_2 : E_3 = I/d^2 : I/(2d)^2 : I/(3d)^2$

Hence, from Equation, illumination on any surface is inversely proportional to the square of distance between the surface and the source.

2. Lambert's cosine law: This law states that illumination, E at any point on a surface is directly proportional to the cosine of the angle between the line of flux AND the normal at that point.

(a)   (b)
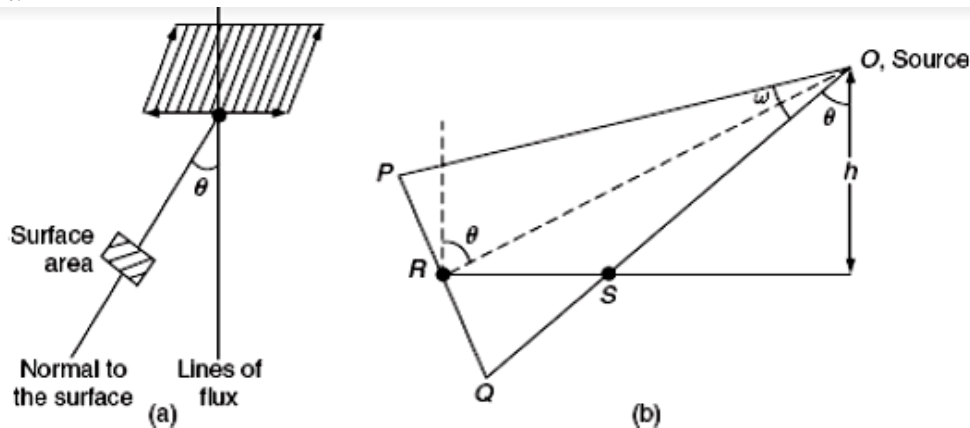
Let us assume that the surface is inclined at an angle 'θ' to the lines of flux as shown in Fig. (a)

PQ = The surface area normal to the source and inclined at 'θ' to the vertical axis.

RS = The surface area normal to the vertical axis and inclined at an angle θ to the source 'O'.

$PQ = RS \cos\theta$.

∴ The illumination of the surface PQ, $E_{PQ} = \dfrac{\text{flux}}{\text{area of } PQ}$

$$= \frac{I \times \omega}{\text{area of } PQ} = \frac{I}{\text{area of } PQ} \times \frac{\text{area of } PQ}{d^2} \quad \left[\because \omega = \text{area}/(\text{radius})^2 \right]$$

$$= \frac{I}{d^2}.$$

∴ The illumination of the surface RS, $E_{RS} = \dfrac{\text{flux}}{\text{area of } RS} = \dfrac{\text{flux}}{\text{area of } PQ/\cos\theta}$

$$[\because PQ = RS \cos\theta]$$

$$= \frac{I}{d^2}\cos\theta.$$

From Fig (b)

$cos\theta = h/d$
or $d = h/cos\theta$

Substitute value of d in above equation

$$\therefore E_{RS} = \frac{I}{(h/\cos\theta)^2} \times \cos\theta = \frac{I}{h^2}\cos^3\theta$$

$$\therefore E_{RS} = \frac{I}{d^2}\cos\theta = \frac{I}{h^2}\cos^3\theta$$

where d is the distance between the source and the surface in m, h is the height of source from the surface in m, and I is the luminous intensity in candela.

Hence, above Equation is also known as 'cosine cube' law. This law states that the illumination at any point on a surface is dependent on the cube of cosine of the angle between line of flux and normal at that point.

Note - From the above laws of illumination, it is to be noted that inverse square law is only applicable for the surfaces if the surface is normal to the line of flux. And Lambert's cosine law is applicable for the surfaces if the surface is inclined an angle 'θ' to the line of flux.

Color Rendering Index (CRI): is a measure of the effect of light on the perceived color of objects. To determine the CRI of a lamp, the color appearances of a set of standard color chips are measured with special equipment under a reference light source with the same correlated color temperature as the lamp being evaluated. If the lamp renders the color of the chips identical to the reference light source, its CRI is 100. If the color rendering differs from the reference light source, the CRI is less than 100. A low CRI indicates that some colors may appear unnatural when illuminated by the lamp.

3.2 Types of lighting (incandescent, CFL, and LED):

Lamps

Lamp is equipment, which produces light. The most commonly used lamps are described briefly as follows:

• Incandescent lamps:

Incandescent lamps produce light by means of a filament heated to incandescence by the flow of electric current through it. The principal parts of an incandescent lamp, also known as GLS (General Lighting Service) lamp include the filament, the bulb, the fill gas and the cap.

• Reflector lamps:

Reflector lamps are basically incandescent, provided with a high quality internal mirror, which follows exactly the parabolic shape of the lamp. The reflector is resistant to corrosion, thus making the lamp maintenance free and output efficient.

• Gas discharge lamps:

The light from a gas discharge lamp is produced by the excitation of gas contained in either a tubular or elliptical outer bulb. The most commonly used discharge lamps are as follows:

- Fluorescent tube lamps (FTL)
- Compact Fluorescent Lamps (CFL)
- Mercury Vapour Lamps
- Sodium Vapour Lamps
- Metal Halide Lamps

• Light Emitting Diode LED Lamp:

A **light**-emitting diode (**LED**) is a semiconductor **light** source that emits **light** when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. ... The first visible-**light** LEDs were of low intensity and limited to red.

3.2.1 Incandescent lamps:

The electrical light source which works on the principle of **incandescent phenomenon** is called **Incandescent Lamp**. In other words, the lamp working due to glowing of the filament caused by electric current through it, is called **incandescent lamp**.

History of Incandescent Lamp

It is normally considered that **Thomas Edison** was the inventor of the incandescent lamp, but the actual history was not like that. There were numbers of scientists who worked and designed prototype for the incandescent lamp before Edison did. One of them was British physicist **Joseph Wilson Swan**. From the record, it is found that he got the first patent for the incandescent lamp in 1878. Later Edison and Swan merged to produce incandescent lamps in commercial scale in 1880.

How do Incandescent Lamps Work?

When an object is made hot, the atoms inside the object become thermally excited. If the object does not melt, the outer orbit electrons of the atoms jump to higher energy level due to the supplied energy. The electrons on these higher energy levels are not stable, they again fall back to lower energy levels. While falling from higher to lower energy levels, the electrons release their extra energy in a form of photons. These photons are then emitted from the surface of the object in the form of electromagnetic radiation.

This radiation will have different wavelengths. A portion of the wavelengths is in the visible range of wavelengths, and a significant portion of wavelengths are in infrared range. The electromagnetic wave with wavelengths within the range of infrared is heat energy and the electromagnetic wave with wavelengths within visible range is light energy.

Incandescent means producing visible light by heating an object. An **incandescent lamp** works in the same principle. The simplest form of the artificial source of light using electricity is an incandescent lamp. Here we use electric current to flow through a thin and fine filament to produce visible light. The current rises the temperature of the filament to such extent that it becomes luminous.

Construction of Incandescent Lamp

The filament is attached across two lead wires. One lead wire is connected to the foot contact and other is terminated on the metallic base of the bulb. Both of the lead wires pass through glass support mounted at the lower middle of the bulb. Two support wires also attached to glass support, are used to support filament at its middle portion. The foot contact is isolated from metallic base by insulating materials. The entire system is encapsulated by a colored or phasphare coated or transparent glass bulb. The glass bulb may be filled with inert gases or it is kept vacuum depending upon rating of the incandescent lamp.

The filament of **incandescent lamps** is air-tightly evacuated with a glass bulb of suitable shape and size. This glass bulb is used to isolate the filament from surrounding air to prevent oxidation of filament and to minimize convention current surrounding the filament hence to keep the temperature of the filament high.

The glass bulb is either kept vacuum or filled with inert gases like argon with a small percentage of nitrogen at low pressure. Inert gases are used to minimize the evaporation of filament during service of the lamps. But due to convection flow of inert gas inside the bulb, there will be greater chances of losing the heat of filament during operation.

Again vacuum is a great insulation of heat, but it accelerates the evaporation of filament during operation. In the case of gas-filled incandescent lamps, 85% of argon mixed with 15% of nitrogen is used. Occasionally krypton can be used to reduce filament evaporation because the molecular weight of krypton gas is quite higher.

But it costs greater. At about 80% of atmospheric pressure, the gasses are filled into the bulb. Gas is filled in the bulb with the rating more than 40 W. But for less than 40 W bulb; there is no gas used.

The various parts of an incandescent lamp are shown below.
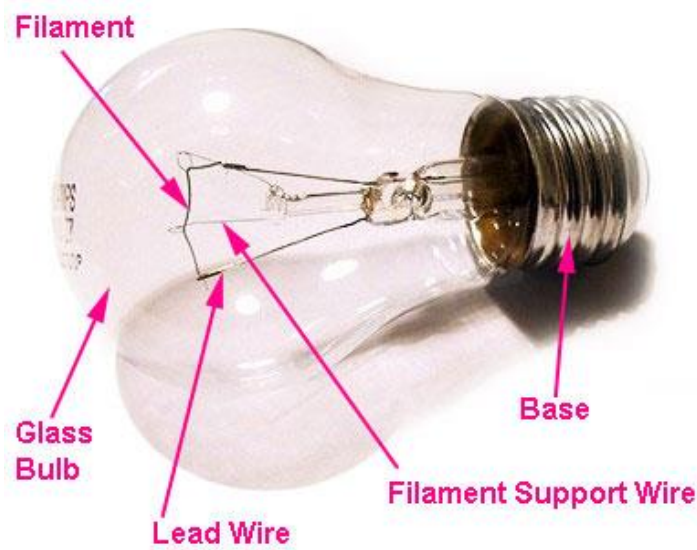
Filament of Incandescent Lamp

In present days, **incandescent lamps** are available in different wattage ratings such as 25, 40, 60, 75, 100 and 200 watts etc. There are different shapes of bulbs, but basically, all are rounded in shape. There are mainly three materials used for producing the filament of incandescent lamps, and these are carbon, tantalum, and tungsten. Carbon was previously used for filament material, but presently tungsten is used most for the purpose.

The melting point of carbon filament is about 3500°C, and the operating temperature of this filament is about 1800°C hence the chance of evaporation is quite less. Because of that carbon filament, incandescent lamps are free from darkening due to filament evaporation. Darkening of filament lamp occurs when molecules of filament material are deposited on the inner wall of the glass bulb due to evaporation of filament during operations.

This darkening becomes prominent after the long life span of the lamp. The efficiency of carbon filament lamp is not good it is about 4.5 lumens per watt. Tantalum was used as the filament, but its efficiency is much poor, it is about 2 lumens per watt. This is because tantalum is very rarely used as filament element.

The most widely used filament material now a day is tungsten because of its high luminous efficacy. It can give 18 lumens per watt when it operates at 2000°C. This efficacy can be up to 30 lumens per watt when it operates at 2500°C. The high melting point is a major criterion for filament material as it has to work at very high temperature without being evaporated.

Although tungsten has the little bit poorer melting point than that of carbon but still tungsten is more preferable as filament material. This is because of high operating temperatures which makes tungsten much luminous efficient. The mechanical strength of tungsten filament is quite high to withstand mechanical vibrations.

Life Span of Incandescent Lamps

Whatever may be the technology of manufacturing, each type of incandescent lamps has some approximate life span. This is because of filament evaporation phenomenon which can be minimized but cannot be avoided completely.

Due to filament evaporation, the glass bulb darkens over a period. Due to filament evaporation the filament becomes thinner which makes the filament less luminous efficient and at last, the filament is broken. As the filament lamps are directly connected to the power supply line, the voltage fluctuations in the line, affect the performance of the bulb.

It is found that luminous efficacy of an incandescent lamp is directly proportional to the square of supply voltage but at the same time, the life span of the lamp is inversely proportional to 13th to 14th power of supply voltage. The main advantages of incandescent lamps are that these are cheap enough and very suitable for lighting at small areas. But these lamps are not energy efficient and about 90% of input electrical energy is lost as heat.

Availability of the Incandescent Bulbs in the Market

There are various attractive shapes and sizes of the bulbs available in the market. PS30 lamps have a pear shape, T12 bulb is tubular with diameter 1.5 inch, R40 bulb is with reflector bulb envelope with a diameter of 5 inches. Based on availability of wattage the bulbs are common in the market with 25, 40, 60, 75, 100, 150 and 200W etc. We can follow the table below to get important data about the **incandescent lamp**.

Watts	Filament Temperature (K)	Initial Lumens	Initial Lumen/Watt	Life (H)	Uncoiled filament length (cm)	Filament Diameter (µm)	% lumen Depreciation
25	2560	235	9.4	2500	56.4	30.5	79
40	2740	455	11.4	1500	38.1	33	88
60	2770	870	14.5	1000	53.3	45.7	93
75	2840	1.190	15.9	750	54.9	53.3	92
100	2860	1.750	17.5	750	57.9	63.5	91
200	2890	3.710	18.5	750	63.5	96.5	85
300	2920	5.820	19.4	1000	76.2	129.5	86
500	3000	10.850	21.7	1000	87.4	180.3	89

The principal parts of an incandescent lamp also known as GLS lamp (General Lighting Service lamp) include the filament, the bulb, the fill gas or vacuum and the cap. Incandescent lamps (Figure 8.3 A&B) produce light by means of a wire or filament heated to incandescence by the flow of electric current through it. The filament is enclosed in an evacuated glass bulb filled with gas such as argon, krypton, or nitrogen that helps to increase the brilliance of lamp and to prevent the filament from burning out.
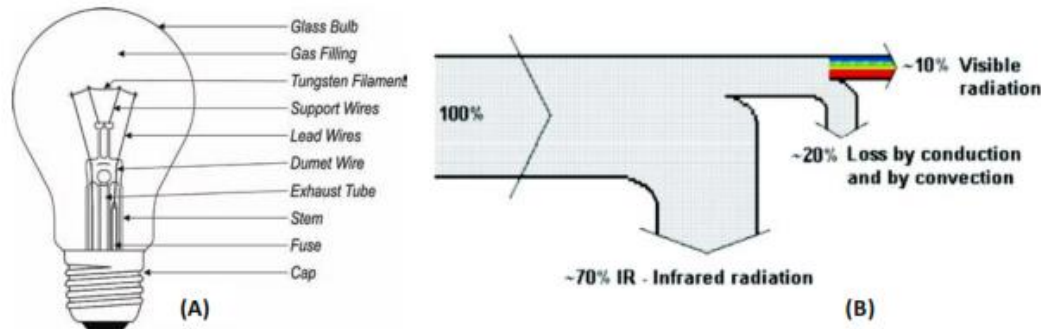
Figure 8.3 Incandescent Lamp and Energy Flow Diagram

3.2.2 Fluorescent tube lamps (FTL)

What is Fluorescent Lamp?

A **fluorescent lamp** is a low weight mercury vapour lamp that uses fluorescence to deliver visible light. An electric current in the gas energizes mercury vapor which delivers ultraviolet radiation through discharge process and the ultraviolet radiation causes the phosphor coating of the lamp inner wall to radiate visible light.
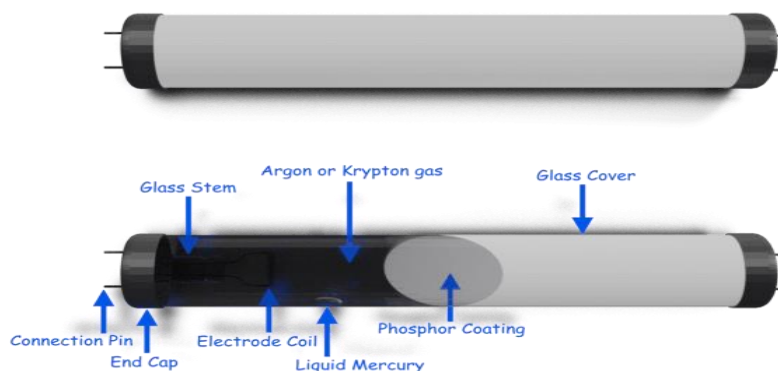
A fluorescent lamp has changed over electrical energy into useful light energy to a great deal more proficiently than incandescent lamps. The normal luminous viability of fluorescent lighting frameworks is 50 to100 lumens per watt, which is a few times the adequacy of incandescent lamps with equivalent light yield.

How does a Fluorescent Lamp work?

Before going through the working principle of a fluorescent lamp, we will first show the circuit of a fluorescent lamp in other words circuit of tube light.

Fluorescent lamp starter
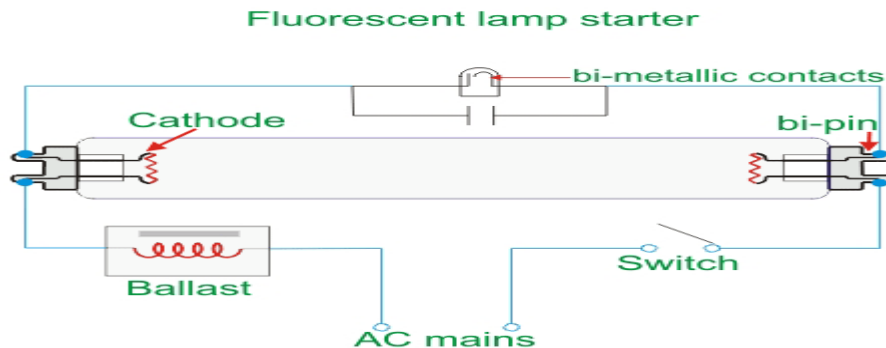
Here we connect one ballast, and one switch and the supply is series as shown. Then we connect the fluorescent tube and a starter across it.

- When we switch ON the supply, full voltage comes across the lamp and as well as across the starter through the ballast. But at that instant, no discharge happens, i.e., no lumen output from the lamp.
- At that full voltage first the glow discharge is established in the starter. This is because the electrodes gap in the neon bulb of starter is much lesser than that of the fluorescent lamp.
- Then gas inside the starter gets ionized due to this full voltage and heats the bimetallic strip. That causes to bend the bimetallic strip to connect to the fixed contact. Now, current starts flowing through the starter. Although the ionization potential of the neon is more than that of the argon but still due to small electrode gap, a high voltage gradient appears in the neon bulb and hence glow discharge gets started first in the starter.
- As soon as the current starts flowing through the touched contacts of the neon bulb of the starter, the voltage across the neon bulb gets reduced since the current, causes a voltage drop across the inductor (ballast). At reduced or no voltage across the neon bulb of the starter, there will be no more gas discharge taking place and hence the bimetallic strip gets cool and breaks away from the fixed contact. At the time of breaking of the contacts in the neon bulb of the starter, the current gets interrupted, and hence at that moment, a large voltage surge comes across the inductor (ballast).

$$V = L\frac{di}{dt}$$

$Where,\ L\ is\ inductance\ of\ inductor$

$and\ \dfrac{di}{dt}\ is\ rate\ of\ change\ of\ current.$

- This high valued surge voltage comes across the fluorescent lamp (tube light) electrodes and strikes penning mixture (mixture argon gas and mercury vapor).
- Gas discharge process gets started and continues and hence current again gets a path to flow through the fluorescent lamp tube (tube light) itself. During discharging of penning gas mixture the resistance offered by the gas is lower than the resistance of starter.

- The discharge of mercury atoms produces ultraviolet radiation which in turn excites the phosphor powder coating to radiate visible light.
- Starter gets inactive during glowing of fluorescent lamp (tube light) because no current passes through the starter in that condition.

Construction of Fluorescent Lamp

A **fluorescent tube light** consists of

1. a lime glass tube
2. drop of mercury
3. argon gas
4. phosphor coating
5. electrode coils
6. mounting assemblies
7. aluminum cap

Total set up of a lamp requires two bases and electromagnetic ballast or choke coil with a starter.

- The electrode mount assemblies are at both the ends of lamp tube.
- This electrode mounting assembly is almost similar to the stem press unit in the incandescent lamps.
- The electrode is similar to the incandescent lamp filament.
- The filaments of electrodes play both roles as anode and cathode.
- Small plates are attached to the filament to protect the electron bombardment and reduce the wattage loss at both ends.
- The filament is dipped in a mixture of barium, strontium and calcium carbonate. It is baked during manufacturing to become oxides and thus it becomes capable of providing abundance of free electrons easily.
- Liquid mercury is provided inside the lamp bulb.
- Phosphor coating is used on inner wall of the bulb tube.
- At a certain pressure argon gas is filled up inside the tube.
- Two pins at each end are taken out of the lamp body through the cap.

The figure of an electrode is shown below.
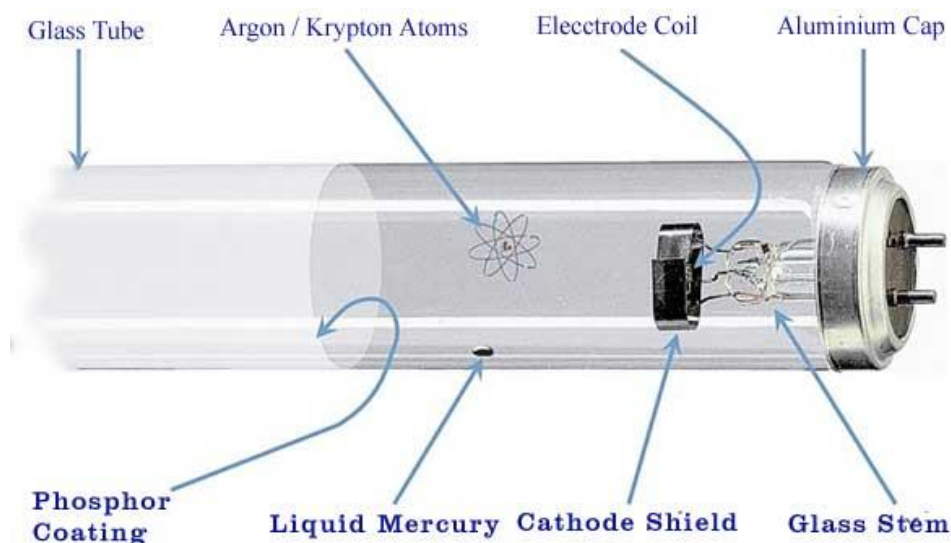
A **fluorescent lamp** tube is loaded with a gas containing low-pressure mercury vapor and argon. The pressure inside the lamp is around 0.3% of environmental pressure. The inward surface of the lamp is coated with a fluorescent (and frequently marginally luminous). This coating is made of shifting mixes of metallic and uncommon earth phosphor salts. The lamp's anodes are normally made of snaked tungsten and typically alluded to as cathodes due to their prime capacity of discharging electrons. For this, they are coated with a blend of barium, strontium, and calcium oxides to have a low thermionic emission temperature. Fluorescent lamp tubes are normally straight and long. The length of the commonly used lamp is around 100 millimeters (3.9 in). A few lamps have the tube twisted into a circle, utilized for table lamps or different spots where a more conservative light source is required. Bigger U-shaped lamps are utilized to give the same measure of light in a smaller region. Minimal fluorescent lamps have a few little width tubes joined in a heap of two, four, or six or a little breadth tube curled into a helix, to give a high measure of light yield in little volume.

To **construct a fluorescent tube light** a lime glass tube, drop of mercury, argon gas, phosphor coating and the electrodes with their mount assemblies are required. Total set up of a lamp requires two bases and choke coil with a starter. The electrode mount assembly is almost similar to the stem press unit in the incandescent lamps. The filaments play both roles as anode and cathode. Generally, small plates are attached to the filament to protect it from electron bombardment   and   to   reduce   the   wattage   loss   at   both   ends. The electrode is similar to the incandescent lamp filament. But an exception is that this filament is dipped in a mixture of barium, strontium, and calcium carbonate. It is baked during manufacturing to become oxides and thus it becomes capable of providing the abundance of free electrons easily.

Linear tubes

- T12 - 38 mm (1.5"diameter)
- T8 - 25 mm (1"diameter)
- T5 - 16mm (5/8"diameter)
- T2 - 6 mm (1/4''diameter)

U-bent tubes

- T12- 38 mm (1.5"diameter)
- T8 - 25 mm (1" diameter)

Circular tubes

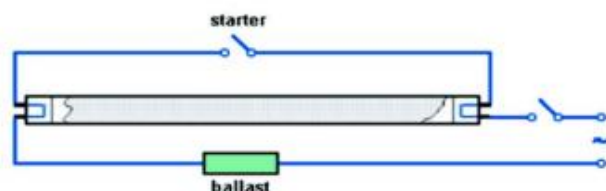- T9 - 38 mm (1.5"diameter)
- T5 - 16 mm (5/8"diameter)

Figure 8.5 (A) Fluorescent Tube Lamp

These four lamps vary in diameter (ranging from 1.5 inches that is 12/8 of an inch for T12 to 0.625 or 5/8 of an inch in diameter for T5 lamps). Efficacy is another area that distinguishes one from another. T5 & T8 lamps offer a 5-percent increase in efficacy over 40-watt T12 lamps, and have become the most popular choice for new installations.

3.2.3 Compact Fluorescent Lamps (CFL)

Compact Fluorescent lamps (Figure 8.6) are compact / miniature versions of the linear or circular fluorescent lamps and operate in a very similar way. The luminous flux depends on temperature. CFL's use less power and have a longer rated life compared to an incandescent lamp.

They are designed to replace an incandescent lamp and can fit into most existing light fixtures formerly used for incandescent. CFL's are available in screw type/ pin type which fit into standard sockets, and gives off light that is similar to common fluorescent lamps.

Figure 8.6 Compact Fluorescent Lamp

3.2.4 Mercury Vapour Lamps

In case of fluorescent lamp the **mercury vapour** pressure is maintained at lower level such that 60% of the total input energy gets converted into 253.7 nm single line. Again transition of the electrons requires least amount of input energy from a colliding electron. As pressure increases the chance of multiple collisions gets increased.

John Thomas Way developed **Mercury Vapour Lamp** in the year 1860. He tested them in Hammersmith Bridge in London. The modern High Pressure mercury Vapour Lamp is developed in the year1936 by Philips (no individual Names are Available).

The mercury Vapour lamp is a high intensity discharge lamp and it is also called as hot chatode discharge lamp. The recent development in the High Pressure mercury Vapour Lamp is an altra pressure lamp operating at about 40atm and its efficiency is more than Sodium Vapour lamp.

Construction of High Pressure mercury Vapour Lamp:

A schematic diagram of mercury lamp is shown below. This lamp is containing an inner quartz arc tube and outer borosilicate glass envelope. The quartz tube is able to withstand arc temperature 1300K, whereas the outer tube withstands only 700K.
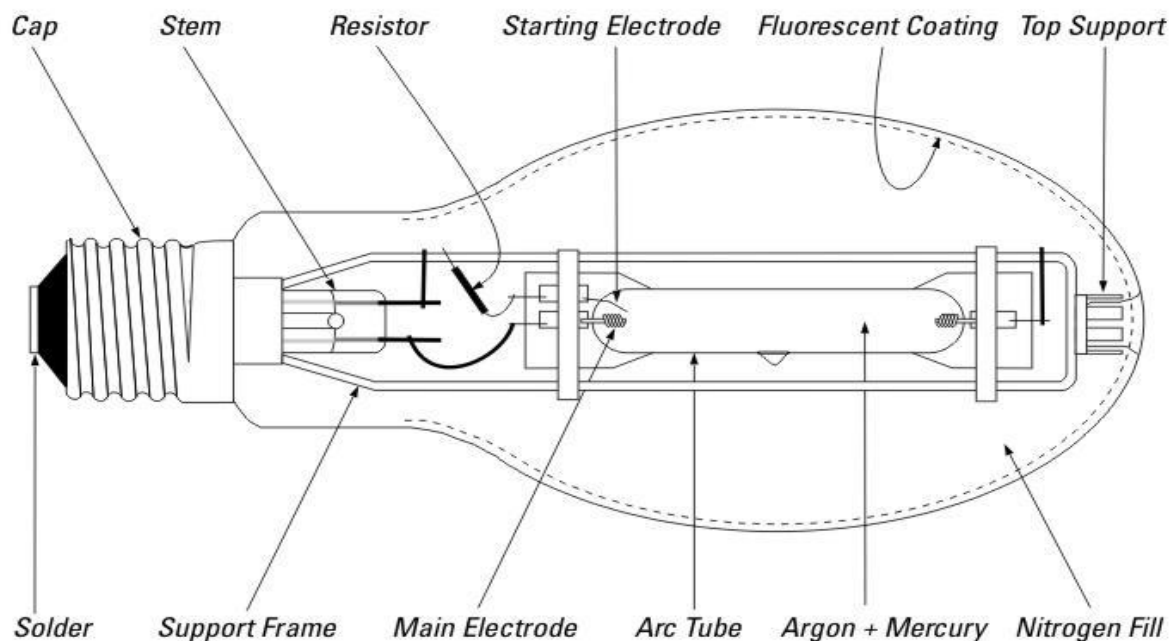
Between two tubes nitrogen gas is filled to provide thermal insulation. This insulation is for to protect the metal parts from oxidation due to higher arc temperature. The arc tube contains the mercury and argon gas. Its operational function is same as the fluorescent lamp. Two main electrodes and a starting electrode (Auxiliary) are inside the arc tube. Each main electrode holds a tungsten rod upon which a double layer of coiled tungsten wire is wound. Basically the electrodes are dipped into a mixture of thorium, calcium and barium carbonates.

They are heated to convert these compounds into oxides after dipping. Thus they get thermally and chemically stable to produce electrons. The electrodes are connected through a quartz tube by molybdenum foil leads.

Generally **mercury Vapour Lamp** operating power factor is 0.65, to improve the power factor, we connected a capacitor across the supply. And choke is used to develop a high voltage at the time of starting.

Working of Mercury Vapour Lamp

Just when the main supply voltage is applied to the mercury lamp, this voltage comes across the starting electrode and the adjacent main electrode (bottom electrode) as well as across two main electrodes (bottom and top electrodes). As the gap between starting electrode and bottom main electrode is small the voltage gradient is high in this gap.

Because of this high voltage gradient across the stating electrode and the adjacent main electrode (bottom), a local argon arc is created, but the current gets limited by using a starting resistor.

This initial arc heats up the mercury and vaporizes it and this mercury vapour helps to strike the main arc soon. But the resistance for the main arc current control resistor is somewhat less than the resistance of the resistor used in the initial arc current control purpose. For this reason initial arc stops and main arc continues to operate. It takes 5 to 7 minutes to make all of the mercury to be vaporized completely. The lamp gets its state of its operational stability. The mercury vapor arc gives visible spectra of green, yellow and violet. But there may be still some invisible ultraviolet radiation during discharging process of **mercury vapour** so phosphor coating may be provided on outer glass cover to improve efficiency of the mercury lamp.

As the wattage increases the initial lumen ratings for the phosphor coated lamps get available with 4200, 8600, 12100, 22500 and 63000 ratings. The average life of mercury lamp is 24000 hours i.e. 2 years 8 months.

Mercury Lamp **data is given below.**

Watts	Bulb	Clear Lamp Initial Lumens	Initial Lamp Lumens/watt	Life in hour	Mean Lumen
100	E23$\frac{1}{2}$	3850	38	24000	3120
175	E28	7950	43	24000	7470
250	E28	11200	45	24000	10300
400	E37	21000	52	24000	19100
1000	BT56	57000	57	24000	48400

Advantages

The **advantages of the mercury vapor lamp** include the following.
- They are energy efficient (35 to 65 lumens/watts)
- Rated life of 24,000 hrs
- The output is clear white light
- It provides with high intensity
- It can be available in different colors, shapes, sizes, and ratings.

Disadvantages

The disadvantages of the mercury vapor lamp include the following.

- Maintenance of lumen is poor

- It takes 5 to 7 minutes warmup before fully glowing the bulb

- The cooling time is 5 to 6 minutes

- They are voltage sensitive

Applications of Mercury Vapor Lamp

The applications are
- Industrial areas
- Street lights
- [Security](#)
- Stairwells
- Home appliances like garages.

3.2.5 Sodium Vapour Lamps

3.2.5a Low Pressure Sodium Vapour Lamp:

A Low-Pressure Sodium Vapour lamp (or LPSV lamp) is termed as a "miscellaneous discharge lamp" as it possesses some characteristics of High-Intensity Discharge (HID) lamps as well as it resembles fluorescent lamps in other areas.

Low-Pressure Sodium Vapor lamp is invented first in **1920by Arther H Compton at Washington house, USA.**

Basically, an LPSV lamp is a gas discharge lamp that uses sodium in an excited state to produce light. A typical LPSV lamp is shown in the figure below.
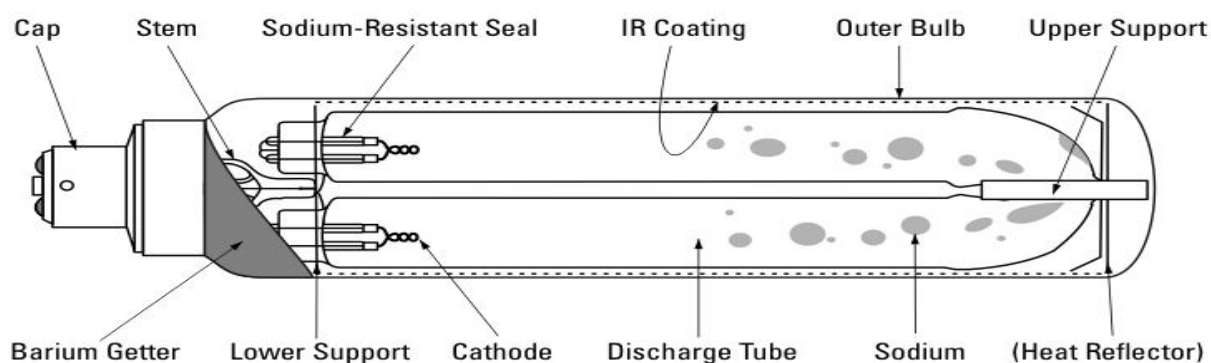
The constructional features of the LPSV lamp are given below:

1. The LPSV lamp contains two glass tubes one is outer glass tube (outer envelope) made up of borosilicate glass. The inner surface of the outer glass case is coated with indium oxide. This heat-reflective coating of indium oxide allows visible light to pass but reflects infra-red radiation back inside the tube as a result of which both light output and temperature inside the tube increases.
2. The arc tube of the LPSV lamp is made of glass and bent in the form of a U-shape in order to increase the length of the arc. The arc tube is supported at both ends. The arc tube contains a mixture of metallic sodium and inert gases argon and neon.
3. Neon gas serves to start discharge and to develop enough heat to vaporize sodium. Organ has lower growth, low voltage, organ helps the smaller start at a lower voltage.
4. Its operating power factor is 0.3, hence suitable capacitor must be used to improve the power factor.

Operation of Low pressure Sodium vapour Lamp:

Now we will discuss how an LPSV lamp actually operates. The basic operation of the LPSV lamp is similar to other gas discharge lamps in a sense that an arc is passed through a tube containing a metallic vapour. A starting gas is also required which is generally a mixture of inert gases argon and neon. The operation is explained step by step in details below:

1. When the lamp is not in operation the sodium is usually in the form of solid (metallic), deposited on the side walls of the tube
2. Electric power is given to the lamp and it is energized.
3. The electrodes produce an arc and this arc strikes through the conductive gas and the lamp produces a reddish-pink light, characteristic of neon.
4. Current flowing through the inert gas mixture of argon and neon generates heat.
5. This heat vaporises the metallic sodium.
6. With the passage of time, the quantity of sodium in the arc stream increases and this produces the characteristic monochromatic orange color at a wavelength of 489.6 nm.

For proper operation of LPSV lamp, typical pressure is about .005 torr and a temperature range between 250° to 270°

LPS Lamp
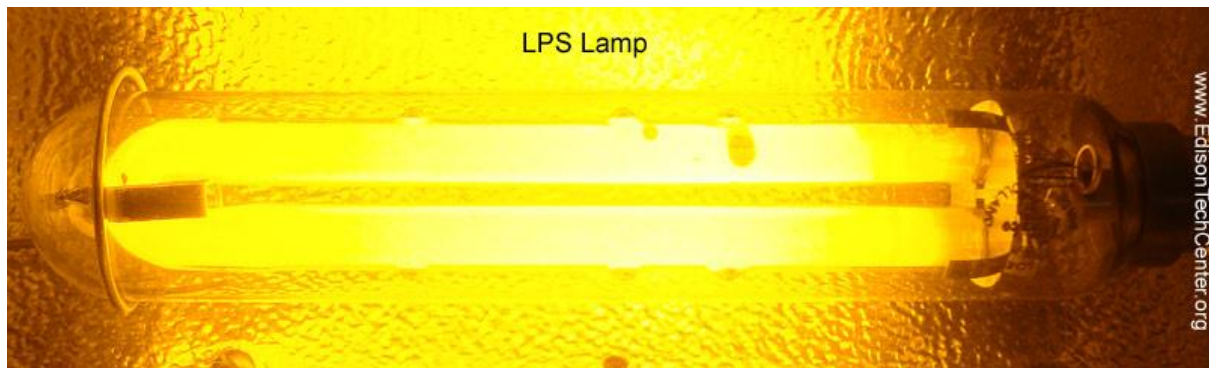
Photometric Parameters

The luminous efficacy of the LPSV lamp is around 150-200 Lumens/Watt. Its **CRI** is very poor as it is monochromatic in nature. Its **CCT** is less than 2000K and the average life is around 18000 burning hours. LPSV lamps are not instant starting and take almost 5-10 minutes to come to full glow.

Applications of LPSV Lamps

LPSV lamps are economical to use in road lighting and security lighting where the color of the object is not important. They are most suitable to use during foggy weathers

3.2.5b High Pressure Sodium Lamps or HPS Lamps

High-pressure sodium lamps (also known as HPS Lamps or HPS lights) are a type of sodium lamp that is widely used in industrial lighting and many public outdoor areas. They are commonly used in public parking lots, roadways, and other security areas.

A big driver behind their use is their high efficiency – around 100 lumens per Watt (when measured for photopic lighting conditions) Some higher-power lamps (>600 Watt) can achieve efficacies of around 150 lumens per watt.

It is very difficult to get any material which is free from corrosion in presence of sodium vapour in high temperature and pressure. This is the main difficulty of producing **high-pressure sodium lamp**.

In 1959, the development of polycrystalline alumina (PCA) or Lucalox (aluminium oxide ceramic) opened a new path to introduce the high-pressure sodium vapour Lamp, as this material is very rarely affected by high pressure and temperature sodium vapour. The first lamp with 400 W, 42000 initial lumens and 6000-hour life first came in the market in 1965. But afterward, some improvements made this lamp with 50000 initial lumens with 24000 hours at 10 hours per start. We can get a lamp that has 2.4 times the lumens output of its mercury counterpart with same rated life span.

Construction High Pressure Sodium Lamp

Diagram of High Pressure Sodium Lamp
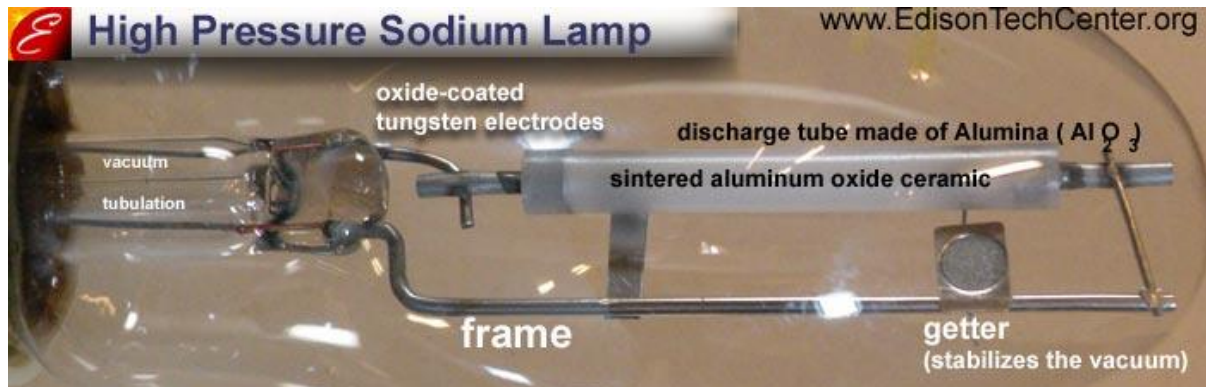
The HPS lamp consists of a narrow arc tube supported by a frame in a bulb. The arc tube has a high pressure inside for higher efficiency. It has an inner PCA arc tube that is filled with Sodium, mercury and xenon gas. This xenon gas is used for starting purpose of the lamp as ionization potential of xenon gas is lowest among all other inert gases used for this purpose. In each end, back wound and coated tungsten electrodes are mounted. To seal the tube monolithic seal is used instead of niobium end cap.

The arc tube is inserted into a heat resistant outer bulb. It is supported by an end clamp that is floating. This end clamp permits the entire structure to expand and contract without distorting.

The space between the tube and the bulb is a vacuum space. This vacuum space is needed to insulate heat from the arc tube because it is necessary to keep the arc tube at required temperature to sustain arc during normal operation. **High pressure sodium lamp** has very small diameter (3/8 inch). So there is no enough space to provide any starting electrode in the arc tube. So a higher voltage is required to initiate the arc. A ballast with igniter is used for this purpose. High voltage is fed to the lamp from the ballast by using the phenomenon of superimposing a low energy high voltage pulse.

Operation of High pressure sodium lamp
Generally a typical pulse has a peak voltage of 2500V and it has durability for only 1 microsecond only. This high voltage pulse makes the xenon gas ionized sufficiently. Then it initiates and maintains the xenon arc. The initial arc has sky blue color. Amalgam used in the reservoir formed inside the arc tube. It is in the back of one of the electrodes. It is normally vaporized during lamp operation. As the xenon arc has started temperature of arc tube is increased which first vaporizes mercury and the lamp start glowing with bluish white color. This color represents the effect of the xenon and mercury mixture at excitation. Gradually the temperature again rises, and sodium becomes vaporized lastly and becomes excited, a low pressure monochromatic yellow sodium spectrum results. During the period of sodium spectral line becomes at 589 nm. With temperature the sodium pressure increases from 0.02 atm in the monochromatic discharge to over 1 atm in the final steady state, broad spectrum condition. Also presence of excited mercury and xenon gives bluish effect to the lamp radiation and finally pleasant golden bright light comes out.

Watts	Bulb	Clear Lamp initial Lumens	Initial Lamp lm/W	Life in hour	Mean Lumens
100	E23$\frac{1}{2}$	9500	95	24000	8500
150	E23$\frac{1}{2}$	16000	106	24000	14400
150	E28	12000	80	12000	10800
215	E28	19000	88	12000	17100
250	E18	27500	110	24000	24750
360	E18	37000	103	16000	33300
400	E18	50000	125	24000	45000
1000	T18	140000	140	24000	126000

These lamps have high luminous efficacy and life span is about 24000 hours. It has excellent lumen maintenance capability. Data of several common **high pressure sodium lamps** are given below.

3.2.6 Metal Halide Lamps

What is Metal Halide Lamp?

Metal halide lamp is special type of arc discharge lamp that works on the arc stream via some iodide salts along with argon gas and mercury vapor pressure at several millimeters with the arc tube temperature of 1000 K.
Who Invented Metal Halide Lamp?

Dr. Reiling had discovered Metal Halide Lamp in 1960.

What is the Constructional Feature of a Metal Halide Lamp?

Metal halide lamp consists of
1. Glass bulb
2. Arc tube
3. Electrodes
4. Auxiliary electrode with high resistance
5. Glass stem
6. Molybdenum wire
7. Argon gas
8. Mercury vapor
9. Indium, thallium and sodium iodides

Schematic Diagram of Metal Halide Lamp

Getter ring for maintaining high vacuum

Hard-glass outer bulb

Quartz discharge tube

Sleeve protecting the support

Lead-in wire/support

Screw base
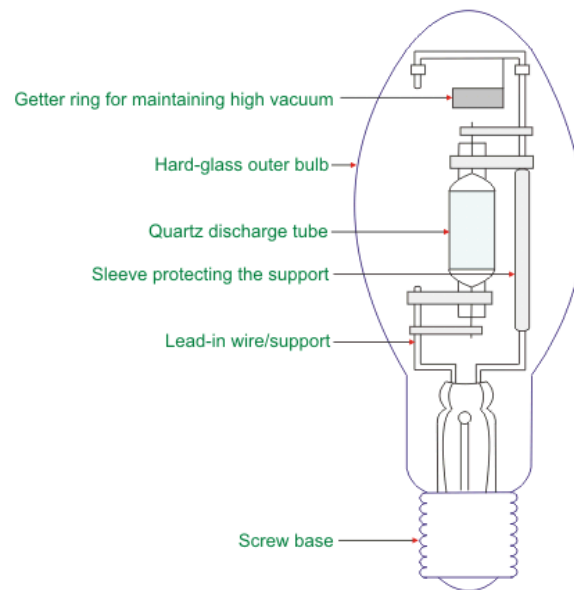
How does a Metal Halide Lamp Work?

- When full voltage is applied across the main electrodes, no arc is produced at the time of switching.
- The auxiliary electrode or starter electrode near the main electrodes attached to the glass stem creates initial discharge between them.
- A bimetal switch is there to short the starter electrode to the main electrode just at the time of starting.
- Starter electrode is used to create initial arc between main and auxiliary electrode that heats up the metal halide salts.
- Starter electrode or auxiliary electrode is of high resistance to limit the current at initial arc.
- Again discharge is first in argon and then in mercury.
- Small amount of mercury vapor helps to establish main arc formation between main electrodes through metal halides vapor one by one.
- To reach up to full light output this lamp takes 5 minutes.

How arc Inside the Metal Halide Arc Tube is Established?

In the OFF condition of the lamp, metal iodides i.e. indium, thallium and sodium iodides used inside the lamp are present on the bulb wall.

Due to rising of arc temperature, the metal iodides vaporize and diffuse from wall into the arc stream. Then they dissociate and yield free metal and iodine atoms. Almost like this fashion, the mercury atoms inside the bulb are excited and ionized. Generally all iodide salts do not get vaporized at same time in **metal halide lamp**. So step wise, the process of vaporization is

- First argon gas and then mercury get vaporized to form arc.
- Only indium gets vaporized first to form a blue sheath around the mercury arc.

- Then thallium gets vaporized and it forms yellow sheath around the thallium.
- Finally sodium iodides get vaporized and it makes the lamp very sensitive to changes in the lamp wattage.

Lamp will be deficient in yellow and red if the lamp watts are lower than rated value. It is because of very small amount of sodium gets vaporized. Again in case of sodium-scandium **metal halide lamps**, scandium vaporizes first and then sodium.

What are the Basic Requirements of Metal Halides Inside the Arc Tube?

The basic requirements of the metal additive are mentioned below:

1. The iodide vapor pressure must be relatively high enough.
2. The energy level configuration of the metal must be robust to encourage a high percentage of the visible radiation.
3. At the bulb wall operating temperature of the iodide of the metal must be stable.
4. The excitation level of the metal atoms must be lower than the average of the excitation level of mercury (about 7.8 eV).

Thallium has a strong spectral line at 535 nm and it requires only 3.3 eV for its arc generation. Its iodide salt creates vapor pressure at about 10 mm at 800 K on the arc tube.

Why Metal Halide Lamp is with Frameless Construction?

This lamp has frameless construction. Molybdenum is used as outer electric wire and it is non magnetic. The reason is ac current would flow through the frame and create pulsating magnetic field. So this would cause the electron to leave the frame and would attract to combine with the sodium ions which would migrate through the arc tube wall. It would cause serious depletion of the sodium from the arc stream.

Why is there Reflective Coating at both ends of Metal Halide Arc Tube?

The **metal halide lamp** has an arc tube whose ends are taken to be treated with a reflective white coating that is used to redirect the energy back into the tube. A uniform temperature can be maintained over entire arc tube length due to short length.

What are the Ratings of Metal Halide Lamp Available in the Market?

Watts	Bulb	Clear Lamp Initial Lumen	Initial Lamp lm/W	Life in hours	Mean Lumen
175	BT28	14000	80	7500	10800
250	BT28	20500	82	7500	17000
400	B37	34000	85	15000	20400
1000	BT56	115000	115	10000	92000
1500	BT56	155000	103	1500	14000

## 3.2.7 Light Emitting Diode LED Lamp

What is a Light Emitting Diode (LED)?

A **light-emitting diode** (**LED**) is a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. The color of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor.

A Light Enitting Diode (LED) is a special type of PN junction diode. The light emitting diode is specially doped and made of a special type of semiconductor. This diode can emit light when it is in the forward biased state. Aluminum indium gallium phosphide (AlInGaP) and indium gallium nitride (InGaN) are two of the most commonly used semiconductors for LED technologies.

Older LED technologies used gallium arsenide phosphide (GaAsP), gallium phosphide (GaP), and aluminum gallium arsenide (AlGaAs). LEDs generate visible radiation by electroluminescence phenomenon when a low-voltage direct current is applied to a suitably doped crystal containing a p-n junction, as shown in the diagram below.

The doping is typically carried out with elements from column III and V of the periodic table. When a forward biased current, I_F, energizes the p-n junction, it emits light at a wavelength defined by the active region energy gap, E_g.
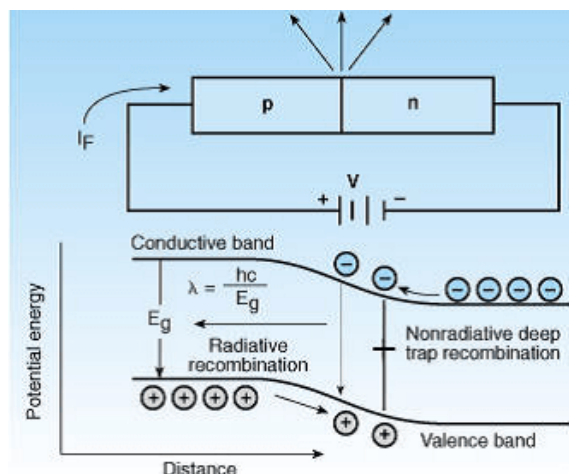
Construction of LED

The recombination of the charge carrier occurs in the P-type material, and hence P-material is the surface of the LED. For the maximum emission of light, the anode is deposited at the edge of the P-type material. The cathode is made of gold film, and it is usually placed at the bottom of the N-region. This gold layer of cathode helps in reflecting the light to the surface.

The gallium arsenide phosphide is used for the manufacturing of LED which emits red or yellow light for emission. The LED are also available in green, yellow amber and red in colour.
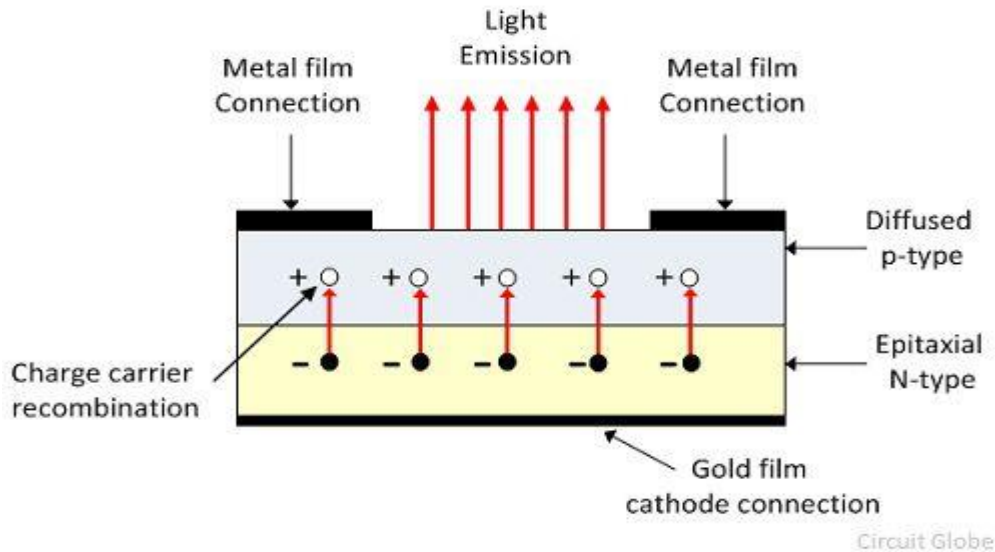
How Does a Light Emitting Diode (LED) Work?

- Light Emitting Diode (LED) works only in forward bias condition. When Light Emitting Diode (LED) is forward biased, the free electrons from n-side and the holes from p-side are pushed towards the junction.
- When free electrons reach the junction or depletion region, some of the free electrons recombine with the holes in the positive ions. We know that positive ions have less number of electrons than protons. Therefore, they are ready to accept electrons. Thus, free electrons recombine with holes in the depletion region. In the similar way, holes from p-side recombine with electrons in the depletion region.
- Because of the recombination of free electrons and holes in the depletion region, the width of depletion region decreases. As a result, more charge carriers will cross the p-n junction.

Light Emitting Diode (LED)

Physics and Radio-Electronics
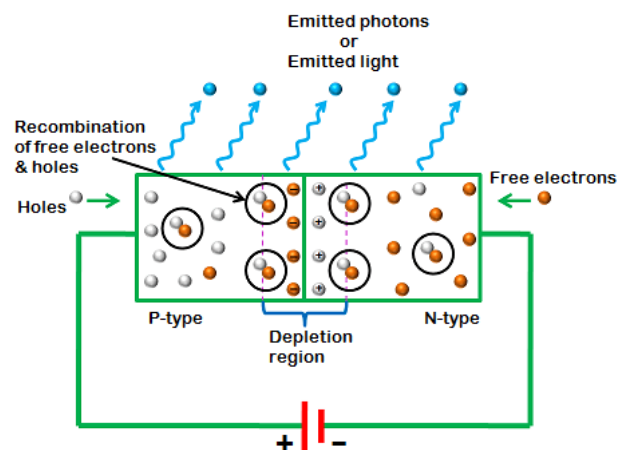
- Some of the charge carriers from p-side and n-side will cross the p-n junction before they recombine in the depletion region. For example, some free electrons from n-type semiconductor cross the p-n junction and recombines with holes in p-type semiconductor. In the similar way, holes from p-type semiconductor cross the p-n junction and recombines with free electrons in the n-type semiconductor.
- Thus, recombination takes place in depletion region as well as in p-type and n-type semiconductor.
  The free electrons in the conduction band releases energy in the form of light before they recombine with holes in the valence band.
  In silicon and germanium diodes, most of the energy is released in the form of heat and emitted light is too small.
- However, in materials like gallium arsenide and gallium phosphide the emitted photons have sufficient energy to produce intense visible light.

	AlInGaP	InGaN
Energy gap (E_g)	1.8–2.31 eV	3.4 eV (blue)
Peak wavelength (λ)	585 nm (amber)	460 nm (blue) 520 nm (green)
Luminous efficacy (external)	20–25 lm/W (amber)	6 lm/W (blue) 30 lm/W (green)

The efficacy depends on the light energy generated at the junction and losses due to re-absorption when light tries to escape through the crystal. The high index of refraction of most semiconductors causes the light to reflect back from the surface into the crystal and highly attenuated before finally exiting. The efficacy expressed in terms of this ultimate measurable visible energy is called the external efficacy.

The phenomenon of electroluminescence was observed in the year 1923 in naturally occurring junctions, but it was impractical at that time due to its low luminous efficacy in converting electric energy to light. But, today efficacy has increased considerably and LEDs are used not only in signals, indicators, signs, and displays but also in indoor lighting applications and road lighting applications.

VI Characteristics and Symbol of LED
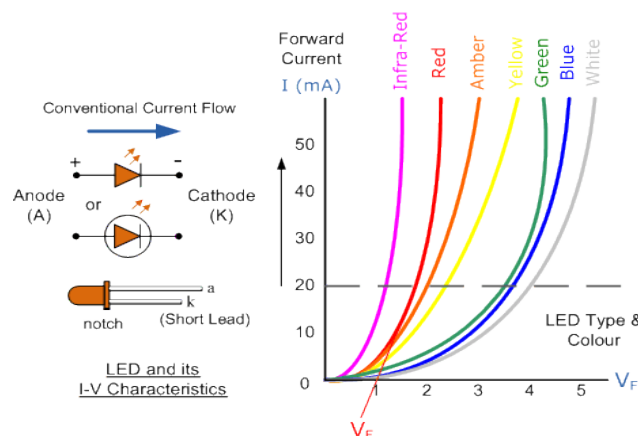
Types of Light Emitting Diode

- **Gallium Arsenide (GaAs) – infra-red**

- **Gallium Arsenide Phosphide (GaAsP) – red to infra-red, orange**

- **Aluminium Gallium Arsenide Phosphide (AlGaAsP) – high-brightness red, orange-red, orange, and yellow**

- **Gallium Phosphide (GaP) – red, yellow and green**

- **Aluminium Gallium Phosphide (AlGaP) – green**

- **Gallium Nitride (GaN) – green, emerald green**

- **Gallium Indium Nitride (GaInN) – near ultraviolet, bluish-green and blue**

- **Silicon Carbide (SiC) – blue as a substrate**

- **Zinc Selenide (ZnSe) – blue**

- **Aluminium Gallium Nitride (AlGaN) – ultraviolet**
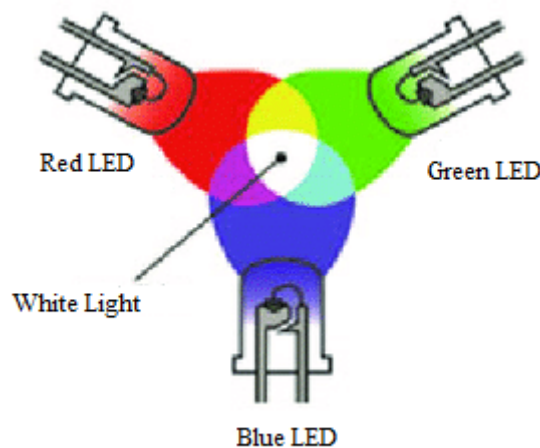
Color of an LED

The color of an LED device is expressed in terms of the dominant wavelength emitted, λd (in nm). AlInGaP LEDs produce the colors red (626 to 630 nm), red-orange (615 to 621 nm), orange (605 nm), and amber (590 to 592 nm). InGaN LEDs produce the colors green (525 nm), blue green (498 to 505 nm), and blue (470 nm). The color and forward voltage of AlInGaP LEDs depend on the temperature of the LED p-n junction.

As the temperature of the LED p-n junction increases, the luminous intensity decreases, the dominant wavelength shifts towards longer wavelengths, and the forward voltage drops. The variation in luminous intensity of InGaN LEDs with operating ambient temperature is small (about 10%) from − 20°C to 80°C. However, the dominant wavelength of InGaN LEDs does vary with LED drive current; as the LED drive current increases, dominant wavelength moves toward shorter wavelengths.
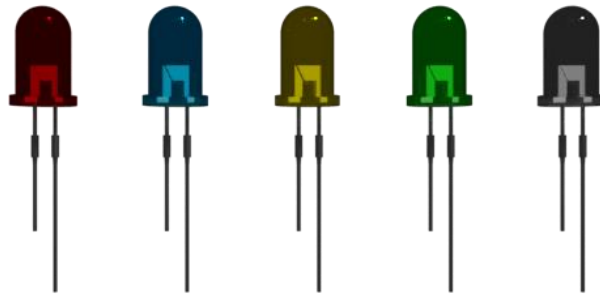
If you're looking to use colored LEDs for an electronics project, the best Arduino starter kits include a variety of colored LEDs.
Dimming

LEDs may be dimmed to give 10% of their rated light output by reducing the drive current. LEDs are generally dimmed using Pulse Width Modulation techniques.

Reliability

The rated maximum junction temperature (TJMAX) is the most critical parameter for an LED. Temperatures exceeding this value usually result in damage of the plastic encapsulated LED device. Mean Time Between Failures (MTBF) is used to find out the average life for LED. MTBF is determined by operating a quantity of LED devices at rated current in an ambient temperature of 55°C and recording when half the devices fail.

White LEDs

White LEDs are being manufactured now using two methods: In the first method red, green, and blue LED chips are combined in the same package to produce white light; In the second method phosphorescence is used. Fluorescence in the phosphor that is encapsulated in the epoxy surrounding the LED chip is activated by the short-wavelength energy from the InGaN LED device.

Luminous Efficacy

Luminous efficacy of LED is defined as the emitted luminous flux (in lm) per unit electrical power consumed (in W). Blue LEDs have a rated internal efficacy in the order of 75 lm/W; red LEDs, approximately 155 lm/W; and amber LEDs, 500 lm/W. Taking into consideration losses due to internal re-absorption, the luminous efficacy is on the order of 20 to 25 lm/W for amber and green LEDs. This definition of efficacy is called external efficacy and is analogous to the definition of efficacy typically used for other light source types.

Applications of LEDs

- Electronic displays such as OLEDs, micro-LEDs, quantum dots etc.
- As an LED indicator.
- In remote controls.

- Lightings.
- Opto-isolators.

Advantages of LED in electronic displays

The followings are the major advantages of the LED in an electronics displays.

1. The LED are smaller in sizes, and they can be stacked together to form numeric and alphanumeric display in the high-density matrix.
2. The intensity of the light output of the LED depends on the current flows through it. The intensity of their light can be controlled smoothly.
3. The LED are available which emits light in the different colours like red, yellow, green and amber.
4. The on and off time or switching time of the LED is less than of 1 nanoseconds. Because of this, the LED are used for the dynamic operation.
5. The LEDs are very economical and giving the high degree of reliability because they are manufactured with the same technology as that of the transistor.
6. The LED are operated over a wide range of temperature say $0° - 70°$. Also, it is very durable and can withstand shock and variation.
7. The LED have a high efficiency, but they require moderate power for operation. Typically, the voltage of 1.2V and the current of 20mA is required for full brightness. Therefore, it is used in a place where less power are available.

Disadvantages of LED

The LED consume more power as compared to LCD, and their cost is high. Also, it is not used for making the large display.

3.3 Luminous Performance Characteristics of commonly used Luminaries

Table	Luminous Performance Characteristics of Commonly Used Luminaries				
Type of Lamp	Lumens / Watt		Colour Rendering Index	Typical Application	Typical Life (hours)
	Range	Avg.			
Incandescent	8-18	14	Excellent (100)	Homes, restaurants, general lighting, emergency lighting	1000
Fluorescent lamps	46-60	50	Good w.r.t. coating (67-77)	Offices, shops, hospitals, homes	5000
Compact fluorescent lamps (CFL)	40-70	60	Very good (85)	Hotels, shops, homes, offices	8000-10000
High pressure mercury (HPMV)	44-57	50	Fair (45)	General lighting in factories, garages, car parking, flood lighting	5000

Halogen lamps	18-24	20	Excellent (100)	Display, flood lighting, stadium exhibition grounds, construction areas	2000-4000
High pressure sodium (HPSV) SON	67-121	90	Fair (22)	General lighting in factories, ware houses, street lighting	6000-12000
Low pressure sodium (LPSV) SOX	101-175	150	Poor (10)	Roadways, tunnels, canals, street lighting	6000-12000
Metal halide lamps	75-125	100	Good (70)	Industrial bays, spot lighting, flood lighting, retail stores	8000
LED lamps	30-50	40	Good (70)	Reading lights, desk lamps, night lights, spotlights, security lights, signage lighting, etc.	40,000-1,00,000

3.4 Recommended Illuminance Levels for Various Tasks / Activities / Locations:

Recommendations on Illuminance

Scale of Illuminance: The minimum illuminance for all non-working interiors, has been mentioned as 20 Lux (as per IS 3646). A factor of approximately 1.5 represents the smallest significant difference in subjective effect of illuminance. Therefore, the following scale of illuminances is recommended.

20–30–50–75–100–150–200–300–500–750–1000–1500–2000, … Lux

Illuminance ranges: Because circumstances may be significantly different for different interiors used for the same application or for different conditions for the same kind of activity, a range of illuminances is recommended for each type of interior or activity intended of a single value of illuminance. Each range consists of three successive steps of the recommended scale of illuminances. For working interiors the middle value (R) of each range represents the recommended service illuminance that would be used unless one or more of the factors mentioned below apply.

The higher value (H) of the range should be used at exceptional cases where low reflectances or contrasts are present in the task, errors are costly to rectify, visual work is critical, accuracy or higher productivity is of great importance and the visual capacity of the worker makes it necessary.

Similarly, lower value (L) of the range may be used when reflectances or contrasts are unusually high, speed and accuracy is not important and the task is executed only occasionally.

Recommended Illumination

The following Table gives the recommended illuminance range for different tasks and activities for chemical sector. The values are related to the visual requirements of the task, to user's

satisfaction, to practical experience and to the need for cost effective use of energy.(Source IS 3646 (Part I) : 1992).

For recommended illumination in other sectors, reader may refer Illuminating Engineers Society Recommendations Handbook/

Petroleum, Chemical and Petrochemical works	
Exterior walkways, platforms, stairs and ladders	30-50-100
Exterior pump and valve areas	50-100-150
Pump and compressor houses	100-150-200
Process plant with remote control	30-50-100
Process plant requiring occasional manual intervention	50-100-150
Permanently occupied work stations in process plant	150-200-300
Control rooms for process plant	200-300-500
Pharmaceuticals Manufacturer and Fine chemicals manufacturer **Pharmaceutical manufacturer**	
Grinding, granulating, mixing, drying, tableting, sterilising, washing, preparation of solutions, filling, capping, wrapping, hardening	300-500-750
Fine chemical manufacturers	
Exterior walkways, platforms, stairs and ladders	30-50-100
Process plant	50-100-150
Fine chemical finishing	300-500-750
Inspection	300-500-750
Soap manufacture	
General area	200-300-500
Automatic processes	100-200-300
Control panels	200-300-500
Machines	200-300-500
Paint works	
General	200-300-500
Automatic processes	150-200-300
Control panels	200-300-500
Special batch mixing	500-750-1000
Colour matching	750-100-1500

3.5 lighting equipment's:

3.5.1 Control gear
A wide range of lamps require control gear of some kind to ensure correct running and, in some cases, starting of the lamp. With discharge lamps it is the job of the control gear to limit the current through the lamp whereas with some incandescent lamps the gear is there to reduce the voltage. Some low voltage tungsten lamps need units to supply them with the correct voltage and LEDs need electronics to limit the current going through them.

3.5.1.1 Ballasts for discharge light sources
General principles
Control gear for discharge lamps has to perform a number of functions:

- limit and stabilises lamp current: due to the negative resistance characteristic of gas discharge lamps (see Section 3.1.2) it is necessary to control the current in the lamp circuit
- ensure that the lamp continues to operate despite the mains voltage falling to zero at the end of each half cycle
- provide the correct condition for the ignition of the lamp: this generally requires the gear to provide a high voltage and in the case of fluorescent lamps requires a heating current to be passed through the electrodes.

As well as these basic functions control gear may also have the following requirements placed on it:

- ensure a high power factor
- limit the harmonic distortion in the mains current
- limit any electromagnetic interference (EMI) produced by the lamp and ballast
- limit the short-circuit and run up currents to protect the lamp electrodes and to help the supply wiring system
- keep the lamp current and voltage within the specified limits for the lamp during mains voltage fluctuations.

With electromagnetic control gear several separate control components may be needed — these may include ballasts, starters, igniters, capacitors and filter-coils.

When electronic control gear is used it is common to integrate all the components into one package. The details of the various circuits used are discussed in the following sections.

Electromagnetic control gear for fluorescent light sources
Choke coils used to be the most common type of current limiting device used with linear and compact fluorescent lamps. The most common circuit is the switch start, see Figure 5.1.
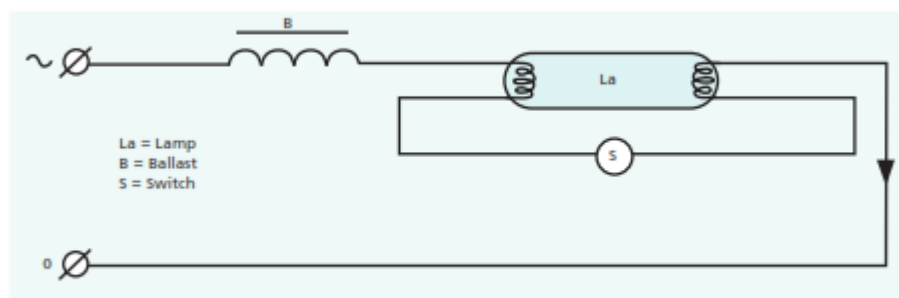
Figure 5.1 Schematic diagram of a fluorescent lamp operated using a choke ballast and a switch start

The choke ballast is made from a large number of windings of copper on a laminated iron core. It works on the self-inductance principle and is designed so that impedance of the choke limits the current through the circuit to the correct value for a given lamp and supply voltages. A range of ballasts is available for different lamps and different voltages. Also the ballast design has to be changed if it is to operate at a different mains supply frequency.
To start the lamp it is common to use a glow starter. The glow starter switch consists of one or two bi-metallic strips enclosed in a glass tube containing a noble gas. The glow starter is connected across the lamp so it is possible for a current to pass through the ballast, through the electrode at one end of the lamp, through the electrode at the other end of the lamp and back to neutral.

When the mains voltage is first applied to the lamp circuit, the total mains voltage appears across the electrodes of the starter and this initiates a glow discharge. This discharge heats the bi-metallic elements within the starter and as the electrodes heat up they bend towards each other until eventually they touch. While the electrodes are touching the current passing through the lamp electrodes pre-heats them. While the electrodes in the starter are touching there is no glow discharge and so the electrodes cool and separate. A t the moment that the electrodes come apart the current through the ballast is interrupted causing a voltage peak across the lamp. *Note:* the glow starter does not always create the conditions for the lamp to start and sometimes the starting cycle has to be repeated a number of times. Figures 5.2 to 5.4 illustrate the starting process.

Figure 5.2 The heat from the discharge in the starter causes the bi-metallic electrodes to bend together
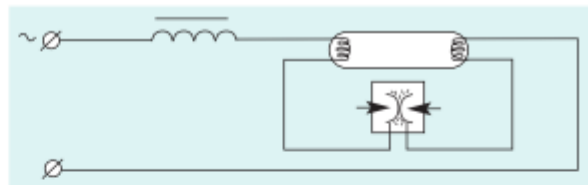
Figure 5.3 The bi-metallic electrodes touch and a current flows through the circuit preheating the electrodes of the lamp
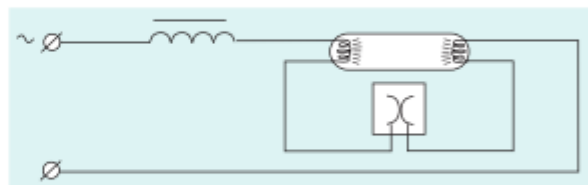
Figure 5.4 The electrodes cool and separate, causing a voltage peak which ignites the lamp
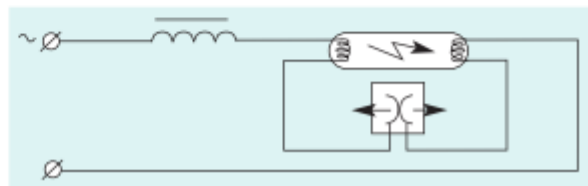
In addition to the ballast and the starter most fluorescent lamps circuits have a capacitor connected across the supply terminals to ensure a high power factor for the circuit.

Electromagnetic control gear for HID light sources
There are a number of different types of circuits used for high intensity discharge (HID) lamps; they vary according to the type of lamp and its requirements for starting.
The most common type of ballast used is a choke or inductive ballast in series with the lamp. The choke, which is a coil of copper wire wound on a laminated iron core, limits the current through the lamp. Figure 5.5 shows a typical circuit using a choke.
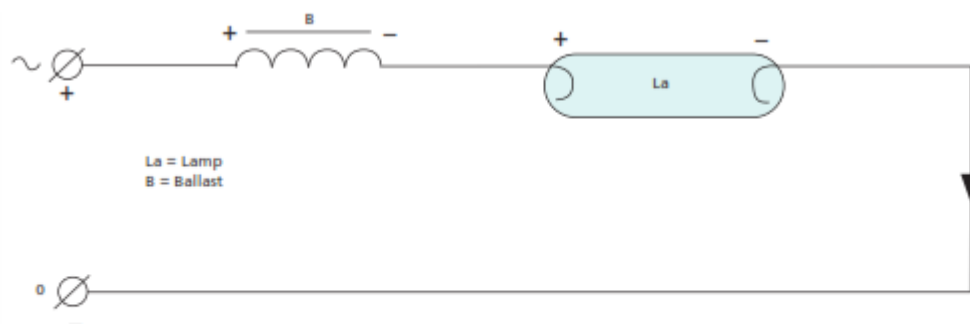

La = Lamp
B = Ballast

Figure 5.5 Schematic diagram of a HID lamp circuit using a choke

This type of circuit is used for all high intensity discharge lamps apart from the low pressure sodium lamp. The low pressure sodium lamp has a long run-up during which time the voltage across the lamp needs to be greater than normal mains voltage; this has given rise to a number of circuits for running the lamp that provide the necessary voltage. The most common of these circuits is the autoleak transformer (Figure 5.6).
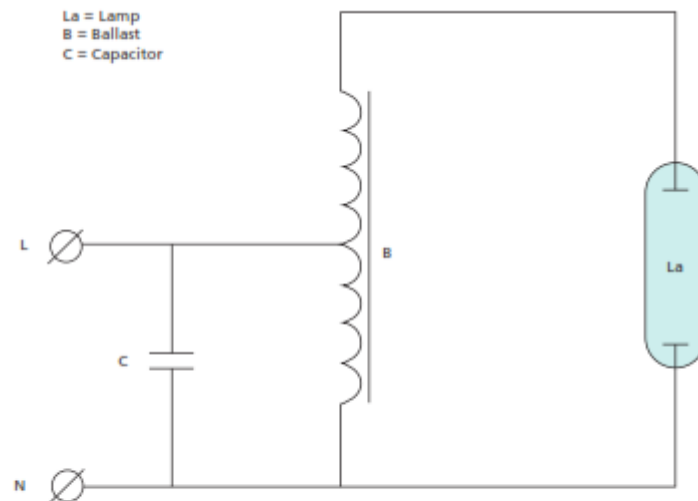

Figure 5.6 Schematic diagram of a low pressure sodium lamp circuit using an autoleak transformer

The autoleak transformer works like an autotransformer increasing the supply voltage, but bycareful design of the secondary winding it can also act as a choke to control the current through the lamp.

Most high pressure sodium lamps and metal halide lamps require a high voltage pulse to start the arc in the lamp. This is usually provided by an electronic ignitor. There are several types of ignitor circuits, the two most common are the semi-parallel and the superimposed pulse type (Figures 5.7 and 5.8).
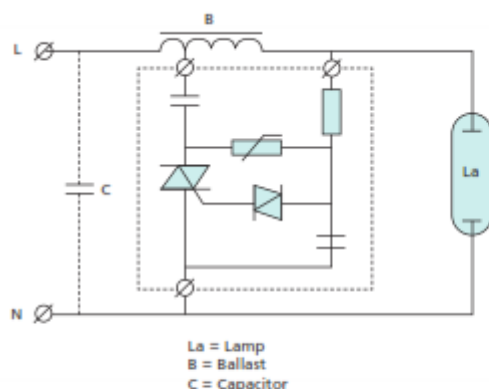

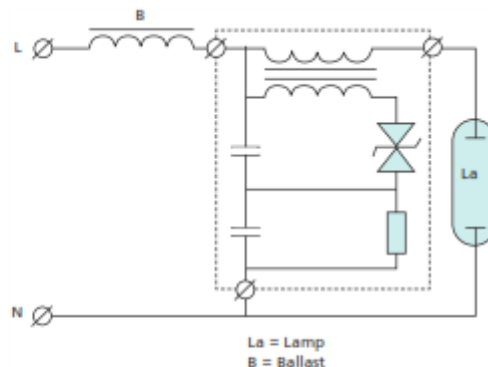
Figure 5.7
A semi-parallel ignition system

Figure 5.8
A superimposed ignition system

The semi-parallel ignitor relies on the tapped ballast coil to generate the ignition pulse whereas the superimposed type ignitor has its own coil to generate the pulse. The semi-parallel has many advantages in that it consumes no power when the lamp is running, it is cheaper and

lighter but, as it relies on the ballast, it may only be used with the ballast for which it has been specifically designed.

Ignitors sometimes have other features built in such as self-stopping ignitors that will not continually try to restrike a lamp that has come to the end of its life. There are also some that are designed to produce extra high voltages that can restrike hot lamps.

Electronic control gear for fluorescent light sources

Operating fluorescent lamps at high frequency has a number of advantages and most modern control gear is now of this type. Most electronic ballasts for fluorescent lamps are integrated into a single package that performs a number of functions.

These functions are:
- a low pass filter: this limits the amount of harmonic distortion caused by the ballast, controls the amount of radio frequency interference, protects the ballast against high voltage mains peaks and limits the inrush current
- the rectifier: this converts the AC power from the mains supply into DC
- a buffer capacitor: this stores the charge from each mains cycle thus providing a steady voltage to the circuits that provide the power to the lamps
- the HF power oscillator takes the steady DC voltage from the buffer capacitor and using semiconductor switches controlled by the ballast controller creates a high frequency square wave
- the output of the power oscillator is fed through a small HF coil that acts as a stabilisation coil to the lamp.

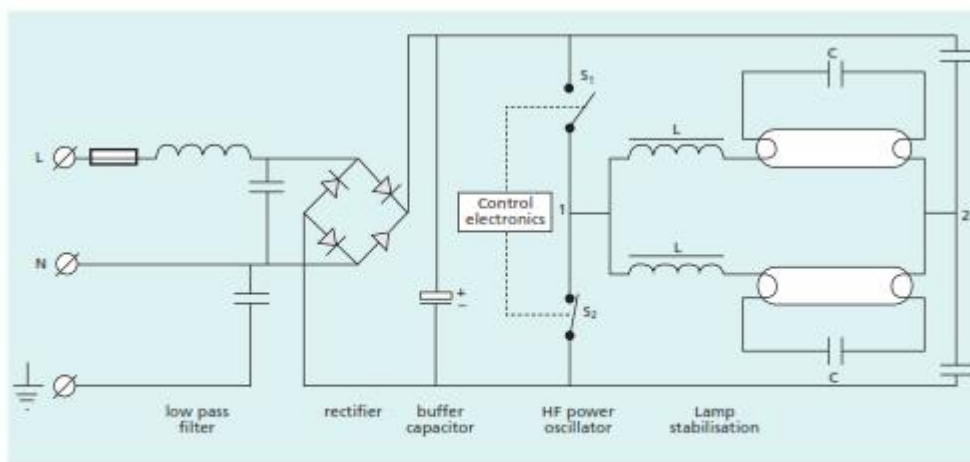Figure 5.9 shows the main components in typical HF fluorescent lamp ballast

Figure 5.9 A circuit diagram of an electronic ballast for two fluorescent lamps

In some ballasts the electronics that control the power oscillator can vary the frequency at which the power oscillator runs; as the frequency increases the current passing through the coils decreases and thus it is possible to dim the lamps. Some types of ballast have a 0 to 10 volt input that is used to regulate the output while some have digital interfaces. See Section 5.2 for further information on controls.

Electronic gear for HID light sources

Making electronic control gear for HID light sources is a complex process. There are many different lamp types each with different electrical requirements and a limited range of

frequencies in which they can be operated. Also many lamp types do not show a significant gain in efficiency when operated on high frequencies. For these reasons electronic control gear has been developed more slowly for HID lamps than for fluorescent lamps.

However, it is possible to gain a number of benefits from electronic gear for HID lamps. These include:

- increased lamp life
- elimination of visible flicker
- better system efficacy
- less sensitivity to mains voltage or temperature fluctuations
- the possibility of dimming with some lamp types.

Not all these benefits are possible for all lamp types and all control gear combinations. However, the availability and quality of electronic gear available for HID lamps is rapidly increasing.

3.5.1.2 Transformers for low voltage light sources

Many tungsten halogen lamps are designed to run on low voltages the most common of which is 12 volts. Thus they need a device to reduce the supply voltage. The traditional way to do this was by using a transformer. Figure 5.10 shows the various currents and voltages in a transformer and gives the approximate relationship between the voltages, currents and the number of turns in the primary and secondary coils.
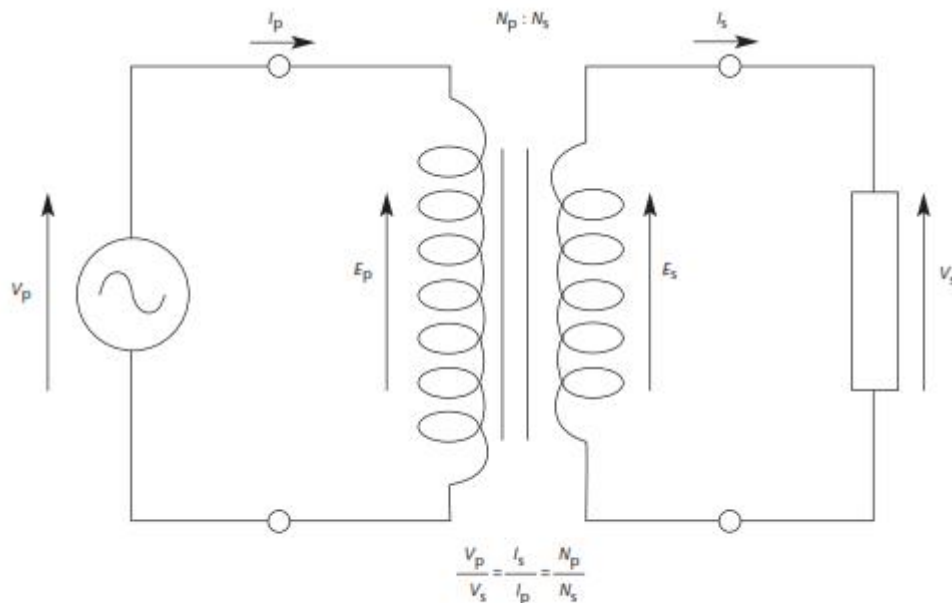

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

Figure 5.10 A circuit diagram for a transformer

As well as reducing the voltage the transformer also isolates the lamp supply from the mains. This means that even under a fault condition the voltage in the secondary circuit will not rise significantly above the nominal output voltage and so it will always be safe to touch the conductors on the low voltage side.

Most modern transformers for halogen lamps involve electronics. They usually contain high frequency oscillators to permit the use of smaller transformers that have smaller power losses. With the introduction of electronics it is possible to introduce additional features such as constant voltage output and soft starting of the lamps.

3.5.1.3 Drivers for LEDs

LEDs need to be run at a controlled current to ensure proper operation. To provide this drivers re used. Most drivers take mains power and provide a constant current output. However, it is possible to control some drivers so that output current is varied so that the LED may be dimmed. In more complex systems it is possible to dim three separate channels separately, so that when red, green and blue LEDs are used together it is possible to make colour changes. Most LED drivers can maintain their constant current output over a range of voltages so it is often possible to connect a number of LEDs in series on one driver.

3.5.2 Lighting controls

3.5.2.1 Options for control

There are a number of factors that need to be considered in any control system; these are the inputs to system, how the system controls the lighting equipment and what is the control process that decides how a particular set of inputs will impact on the lighting. Thus for a control system to work it must have:

- **input devices**: such as switches, presence detectors, timers and photocells
- **control processes:** these may consist of a simple wiring network through to a computer based control system
- **Controlled luminaires:** the system may control luminaires in a number of ways, from simply switching them on and off to dimming the lamp and in more complex systems causing movement and colour changes.

3.5.2.2 Input devices

Manual inputs

These vary from simple switches used to turn the lights on though dimmer switches and remote control units that interface to a control system to lighting control desks that are used in theatres. The point of these units is to allow people to control the lighting and care is always needed in the application of such devices to ensure that users of the system can readily understand the function of any such control.

Presence detectors

Most presence detectors are based on passive infrared (PIR) detectors, however some devices are based on microwave or ultrasonic technology. PIR devices monitor changes in the amount of infrared radiation that they are receiving. The movement of people in a space will be detected by them and this can be signalled to a control system. Thus, if a device detects the presence of a person this can be used to signal the control system to switch the lights on, but if the device has not detected anybody for some time this can be used to signal that there is nobody there and that the lights can be turned off.

Timers

Most computerised control systems have timers built in so that they can turn the lighting on or off at particular times. However, there are also a large number of time switches available that can turn lamps on an off at given times. There are also timers used in street lighting that change the time that they switch at throughout the year so that the lamps are switched at dawn and dusk.

Photocells

There are many different types of photocell used to control lighting. The simplest to use are those which switch on at one illuminance value and switch off at another; these are commonly used to turn exterior lights on at dusk and off at dawn. Some photocells communicate the illuminance value to the central control system, which uses the information to adjust the lighting in some way. Some photocells are mounted on ceilings with shields around them so that they only receive light reflected from the working plane, this makes them act like luminance meters and provided the reflectance of the working plane remains constant they can be set up to follow the illuminance of that plane.

3.5.2.3 Control processes and systems

In the case of simple control systems these are generally configured as some form of automated switching in the power supply to a luminaire or group of luminaires. However, more complex systems are generally configured as a network of devices including luminaires, sensors and control inputs. In most systems the devices are physically connected using some form of cabled network but, in principle, devices can be controlled using wireless or infrared communication.

There are several systems in common use for lighting systems and care needs to be taken to specify the correct type for each component in the system. Two of the most common systems available are DALI and DMX 512.

The basic specification for DALI systems is contained in BS EN 60929: 2006: *AC-supplied electronic ballasts for tubular fluorescent lamps — Performance requirements.* The DALI system is largely used for lighting systems in buildings but has been extended so that it can be used more widely.

It controls luminaires via the ballast used to control the lamps. The system is designed to run up to 64 luminaires on one circuit but there are devices that can control a series of different DALI clusters thus making it possible to control all the lights in a large building.

DMX 512 was designed to control lights and other equipment in the entertainment industry. The system provides 512 channels of control to a series of devices. In a typical spotlight that has its aiming controlled, three channels may be used, one to dim the luminaire and one for each axis of rotation. The system has traditionally been used in theatres but is increasingly being used in architectural feature lighting where the lighting equipment is more complex. The basic operating properties of the system are described in ANSI E1.11: USITT DMX512-A: *Asynchronous serial digital data transmission standard for controlling lighting equipment and accessories.*

3.6 Determine the method of lighting, and calculate the lighting parameters.

• Design Considerations
• Typical Calculations
      • Watts/sq.m method
      • Lumen Method
      • Point-by-point Method

• Other Calculations
• Outdoor Lighting

3.6.1 Design Considerations

• **Basic lighting calculations that are required to carry out a lighting design**
   • Luminous flux, luminous intensity, illuminance, luminance, colour rendering, colour temperature
   • Glare, working plane, surface reflectances
   • Indoor lighting: calculations are done for both the direct and inter-reflected light; room geometry; maintenance
   • Outdoor lighting: light falls directly on the working plane

• **Lighting design checklist**
   • Safety (e.g. emergency escape lighting)
   • Task requirements
   • Lighting scheme to provide suitable quantity and direction for the task; colour rendering; glare problems
   • Lighting appearance
   • Architecture/Interior design
   • Energy efficiency
   • Lighting equipment, controls, daylighting

• **Lighting equipment checklist**
   • Lamps
   • Operating characteristics, lamp size/shape, colour
   • Luminaires
   • Size and shape, light distribution, glare control, ballast
   • Operating environment (e.g. corrosive, dusty)
   • Lighting controls
   • Manual switches, time switches, dimming, daylightlinked controls, occupant sensing

• **Collect information for lighting design**
   • **Room details:**
   • Room size (length, width, height)
   • Horizontal working plane height above floor level
   • Room surface reflectance (ceiling, walls, and floor)
   • Window size/s and position
   • Room index
      $$K = (L \times W)/(L + W) H$$
   • Cleanliness of the room/environment
   • The regularity of the cleaning
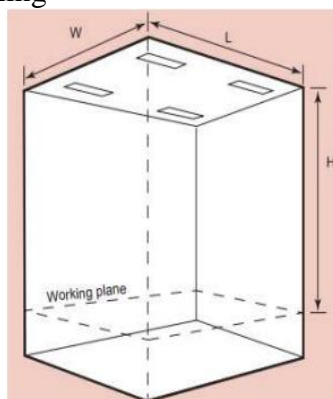
• **Task details:**
   • Type of task/application (e.g. office, industrial, retail)

- Task position (e.g. horizontal/vertical, general/local)
- Special task lighting requirement (e.g. critical inspection, computer use, disabled persons)
- Special hazards (e.g. wet or dusty environment, rotating machines) --- luminaire thermal and mechanical protection

- **Task lighting requirements:**
    - Task illuminance (lux)
    - Task illuminance uniformity (e.g. uniform (0.8), nonuniform (as appropriate))
    - Light colour rendering quality and index (Ra)
    - Average installed power density target (W/m 2), to meet building energy code
    - Light pollution, sustainable lighting design
- **Task lighting requirements:**
    - Task illuminance (lux)
    - Task illuminance uniformity (e.g. uniform (0.8), nonuniform (as appropriate))
    - Light colour rendering quality and index (Ra)
    - Average installed power density target (W/m 2), to meet building energy code
    - Light pollution, sustainable lighting design
- **Room lighting requirements**:
    - Accent lighting (e.g. display lighting, decorative lighting)
    - Wall lighting (e.g. display lighting, lighting to create room lightness)
    - Ceiling lighting (e.g. lighting to create room lightness)
    - Light colour appearance (e.g. warm, intermediate, cool)
    - Emergency and/or escape lighting requirement

3.6.2 Typical Calculations
- To calculate the amount of light that will result from a design
    - Critical for commercial & institutional buildings
    - Seldom required for residential design
- Basic considerations
    - Light sources (lamp lumens)
    - Luminaires & light distribution
    - Initial vs. maintained light levels (as lamps age and luminaires get dirty, light level drops)
- Design calculations for simple situations
    - The number and layout of luminaires needed for general lighting
    - What additional luminaires are needed to provide local emphasis or accents
    - Energy efficiency of the installation and financial benefits
- **Calculation methods:**
    - Manual, data sheets/tables, graphical, spreadsheet, computer software
- Determine illuminance level
    - Horizontal (most common)
    - Average illumination on the work plane (lux)
    - Sitting 0.75 to 0.9 m; Standing 0.85 to 1.2m
    - Vertical (e.g. on wall surface)
    - Inclined
- Analyse light distribution
    - Using light distribution curves, illumination and isolux diagrams
        - Illuminance (lux) or luminance (cd/m 2)
- Predict general & ambient light levels

- Rough estimation based on a **Watts/sq.m method**
  - Not very accurate, but good for prelim. planning
- **Lumen method calculations (light flux method)**
  - Determines average illuminance in large open areas
  - Good for general lighting
- **Point-by-point computer calculations**
  - Determines light levels at a specific point on an object or surface; complicated, start from fundamental laws
  - Can be used for outdoor lighting

## Rough estimation based on a Watts/sq.m method

Average light level desired & typical application	Watts/sq.m of fluorescent, CFL or HID lights	Watts/sq.m of incandescent or halogen lamps
25-50 lux Hotel corridors, stair towers	1-2	3-7
50-100 lux Office corridors, parking garages, theatres (house lights)	2-4	7-10
100-200 lux Building lobbies, waiting areas, malls, hotel function spaces	4-8	10-20
200-500 lux Office areas, classrooms, lecture halls, conference rooms, ambient retail lighting, workshops	15-25	Not recommended
500-1000 lux Grocery stores, laboratories, work areas, big box retail stores	12-20	Not recommended

- Predict task lighting & focal lighting levels
  - Difficult to predict accurately
    - Methods commonly used
      - Use data/guide of the luminaire's manufacturer
      - Use the inverse-square law to estimate
      - Use a display lighting software program
- **Lumen Method:**
  - Lumen Method: average illuminance (E) is

$$E = \frac{F \times n \times N \times UF \times MF}{A}$$

  - F = initial bare lamp luminous flux (lumens)
  - n = number of lamps per luminaire

- N = number of luminaires
- UF = utilisation factor
- MF = maintenance factor
- A = area of the surface (m^2)
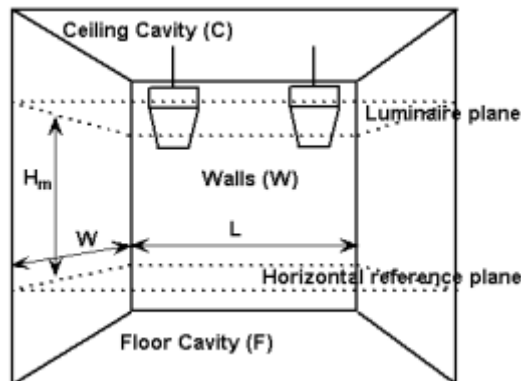
- Room index (K): a measure of the proportions of the room, for rectangular room
    - K = (L x W)/(L + W) h_m
        - L = length of the room
        - W = width of the room
        - h m = height of luminaire above horiz. reference plane
- Effective reflectances of ceiling, walls & floor
    - Cavity index (CI) = (L x W)/(L + W) h = K x h m/h
        - h = depth of the cavity (ceiling or floor)
    - Determine effective reflectance from tables or formulae

- Utilisation factor (UF)
    - Ratio of total flux received by the surface to the total lamp flux of the installation
        - Indicates the effectiveness of the lighting scheme
    - UF depends upon: the efficiency of luminaire, luminaire distribution, geometry of the space, room reflectance, polar curve
    - Usually, UF tables are prepared for general lighting with regular arrays of luminaires, for 3 main room surfaces: ceiling cavity, walls, and floor cavity or horizontal reference plane
- Maintenance factor (MF)
    - Ratio of maintained illuminance to initial illuminance (losses for lamp lumen maintenance) • MF = LLMF x LSF x LMF x RSMF
    - Lamp lumen maintenance factor (LLMF)
    - Lamp survival factor (LSF)
    - Luminaire maintenance factor (LMF)
    - Room surface maintenance factor (RSMF)
    - See CIBSE/SLL Code of Lighting for description

## Maintenance factor and light depreciation

Environmental condition	Maintenance factor
Clean	0.9
Average	0.8
Dirty	0.7

• The number of luminaires required for a required illuminance level E (lux) is:

$$N = \frac{E \times A}{F \times n \times UF \times MF}$$

• Planning the luminaire layout
    • Work out a regular layout of luminaires with an acceptable uniformity
    • Rounding the number found to a whole number that will divide into a regular grid
    • Check on the spacing to height ratio

Luminaire layout and spacing
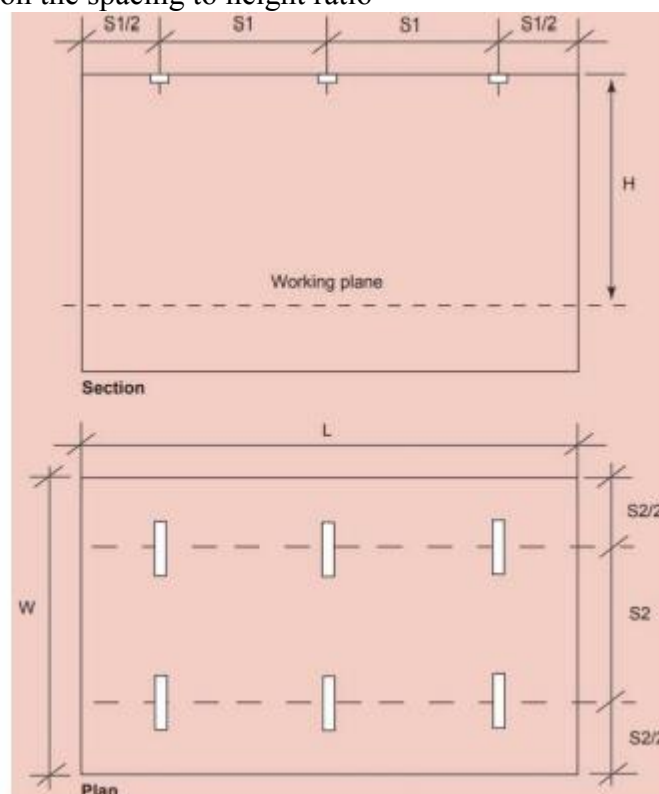
• Spacing to height ratio (SHR)
    • Ratio of distance between adjacent luminaires (centre to centre) to their height above the working plane
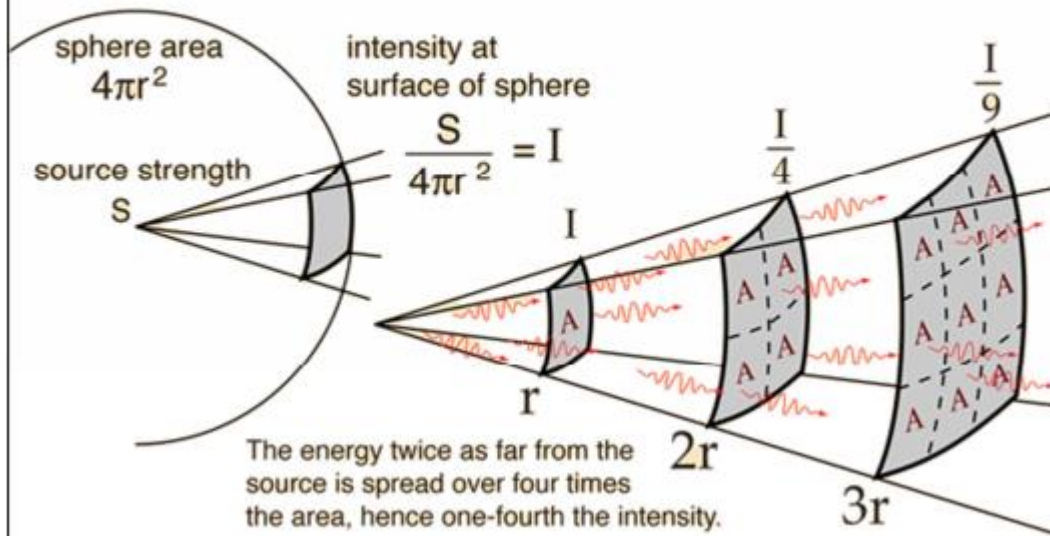
$$SHR = \frac{1}{H_m} \sqrt{\frac{A}{N}}$$

• where H m = mounting height; A = total floor area; N = number of luminaires
• Maximum spacing to height ratio (SHRmax)
    • Luminaire spacing shall not exceed the max. (provided by manufacturer) to ensure uniformity
• **Lumen method: calculation procedure --- a summary**
    • Calculate room index K, floor/ceiling cavity index
    • Calculate effective reflectances of ceiling cavity, walls & floor cavity
    • Determine utilisation factor (UF) from manufacturer's data, using the room index and effective reflectances
    • Determine maintenance factor (MF)
    • Obtain nos. of luminaires required
    • Determine a suitable layout
    • Check that the geometric mean spacing-to-height ratio
    • Check the layout does not exceed SHRmax
    • Calculate illuminance achieved by the final layout
• Basic assumptions underlying the lumen method
    • Rectangular room
    • Ratio of length to width = 1.6 : 1, with a max. of 4 : 1
    • Completely empty room
    • Uniform reflectance and completely diffuse reflection properties of the perimeter surfaces
    • Uniform distribution of luminous flux over all areas
    • Regular luminaire configuration throughout the room
    • In the case of fluorescent lamps, luminaire axis = room axis

• Examples of lumen method calculations:
    • Lighting Design Calculation in a Building – Step by Step
    http://www.electricaltechnology.org/2017/03/lighting-design-calculation-in-building.html

    • Lumen method calculations
    http://www.arca53.dsl.pipex.com/index_files/lummethd.htm

    • The installer's guide to lighting design, Good Practice Guide 300 (page 22-26)
    http://www.cibse.org/getmedia/0276ac78-dc41-4694-9378-8f984ef924f2/GPG300-The-Installers-Guide-to-Lighting-Design.pdf.aspx
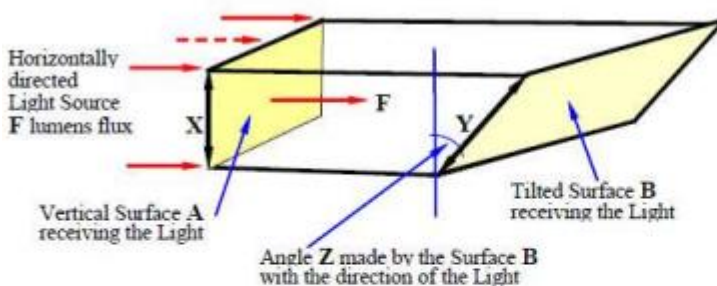
Point-by-point Method
    • Predict direct illuminance at each point on a plane, using measured data of luminous intensity distribution of a source or a luminaire
        • Based on the inverse square law and cosine law
    • Three factors must be considered:
        • Luminous intensity
        • Distance
        • Orientation of the surface

Inverse Square Law for lighting calculations

sphere area
$4\pi r^2$

source strength
S

intensity at surface of sphere
$\dfrac{S}{4\pi r^2} = I$

I

$\dfrac{I}{4}$

$\dfrac{I}{9}$

r

2r

3r

The energy twice as far from the source is spread over four times the area, hence one-fourth the intensity.

Cosine Law for lighting calculations

COSINE LAW (Illuminance on Tilted Surface)

Horizontally directed Light Source F lumens flux

F

X

Y

Vertical Surface A receiving the Light

Tilted Surface B receiving the Light

Angle Z made by the Surface B with the direction of the Light

Light Source Intensity = I Candelas
$E = I / D^2$

D

DESK

Light Source Intensity = I Candelas
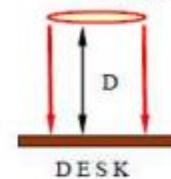$E = I / D^2 * \cos(Z)$

Angle Z

D

DESK

The Areas A and B are proportional to the lengths of their sides X and Y

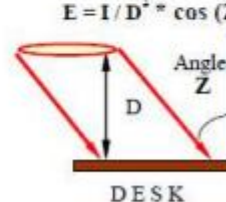$A / B = \cos(Z)$ $\qquad B = A / \cos(Z)$ $\qquad$ Illuminace $E_A = F / A$

Illuminace $E_B = F / B = F / (A / \cos(Z)) = F / A * \cos(Z) = E_A * \cos(Z)$

$E = I / D^2$ when the incident angle is 0 degrees. The general equation becomes $E = I / D^2 * \cos(Z)$

Cosine Values of Angles

| 0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90
1.000	0.995	0.978	0.951	0.914	0.866	0.809	0.743	0.669	0.588	0.500	0.407	0.309	0.208	0.105	0.000

- Limits for using point by point method:
  - Maximum physical dimension of the surface under design is not larger than 1/5th the mounting height above the evaluation point
  - Does not apply to a surface of infinite length
- Computer software can be used to perform numerical point-by-point calculations of direct or reflected light incident on any real surface or imaginary plane
  - The results can be used to predict or quantify the distribution of artificial or natural light in any environment (lighting simulation)
  - Brightness of room surfaces and patterns of light on the ceiling, walls, and floor
  - Also lighting quality & visual performance

- Two calculation techniques when simulating a lighting application
- Direct Calculation Method
    - A simplified technique when reflected light need not be considered in the results; often used in exterior lighting applications e.g. road and sports lighting
    - It cannot be rendered
- Full Radiosity Method
    - Accurate computation of interreflected light; for interior lighting applications or when rendering is desired
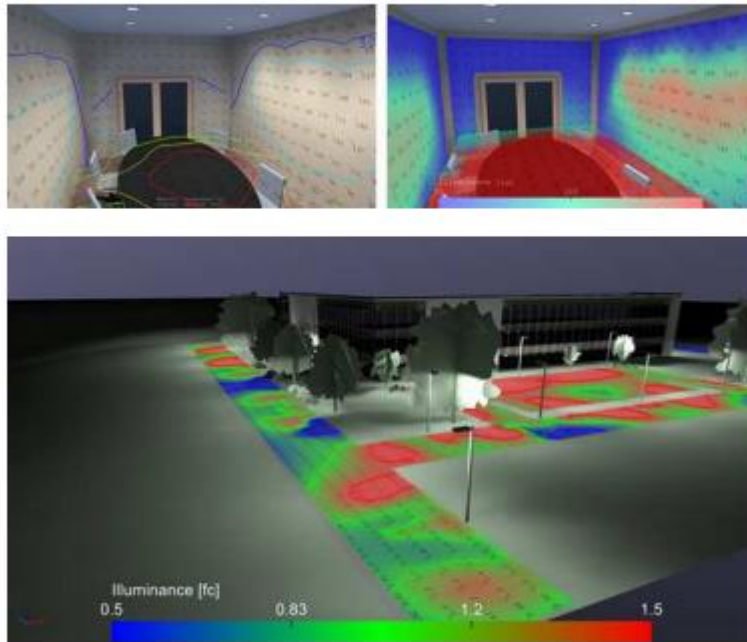

Two calculation techniques for simulating a lighting application

Direct calculation Full Radiosity calculation
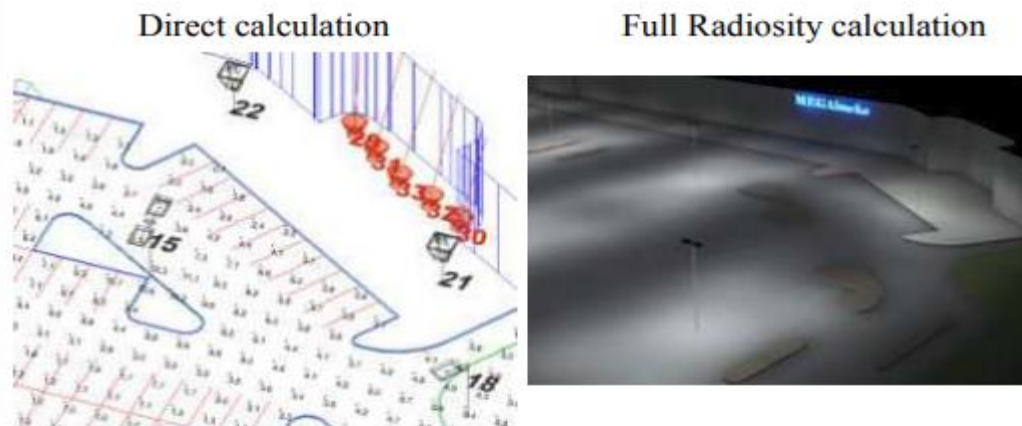
Lighting calculations and simulation in Revit BIM using ElumTools
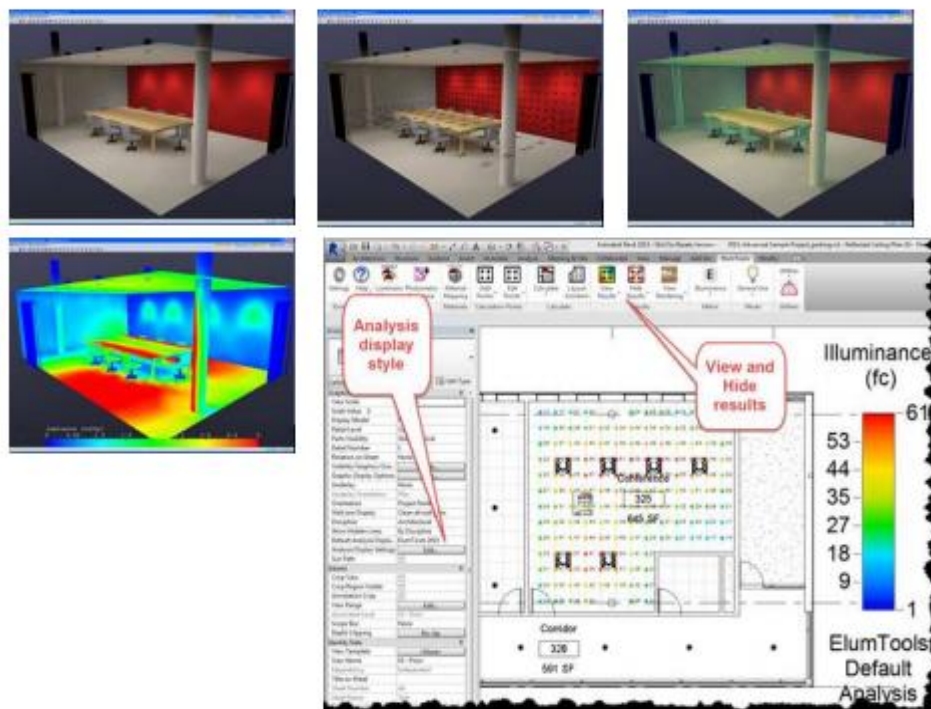
Using isolines and spatial maps to evaluate the gradient of light across a workplane or surface

3.5.3 Other Calculations

- Lighting to provide local emphasis
    - Emphasis or accent lighting is used to draw attention to an area or an object, e.g. a reception desk in an entrance area or a display in a shop
    - The amount of light needed to emphasise or draw attention to an object depends on the level of general lighting
    - Ratio of display light to general lighting:
        - 'Subtle' effect --- 5 : 1
        - 'Moderate' emphasis --- 15 : 1
        - 'Strong' emphasis --- 30 : 1
- Example: Use spotlight for local emphasis
    - Manufacturers usually provide information in a diagrammatic form showing the effect of a particular spotlamp at various distances
        - Width of the beam and either the illuminance at the beam centre or the average illuminance across the beam
        - Calculate the illuminance from a spotlight or any other small source using the 'point source formula'
    - Wall washing: This uses luminaires that usually have an asymmetric beam shape. The manufacturers usually provide details of the luminaire layout and illuminance performance

Typical performance data for spotlight and wall-washing luminaire
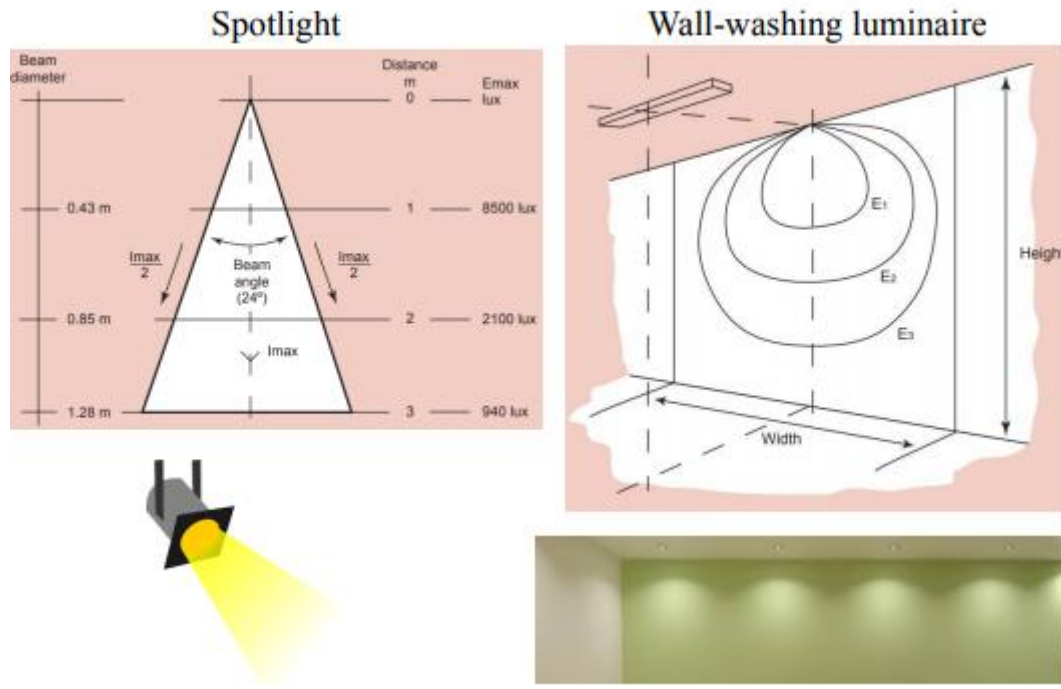
- Outdoor area lighting design, such as floodlighting, sports and road lighting
  - Area lighting Design Calculations - Part One
  http://www.electrical-knowhow.com/2013/01/area-lighting-design-calculations-part.html

- Daylighting and daylight factor
- http://personal.cityu.edu.hk/~bsapplec/methods.htm

- Other lighting system related calculations:
  - Checking for energy efficiency
    - Local building/lighting energy efficiency code
    - Average installed power density (W/m^2)
  - Energy-saving payback calculations
    - Demonstrate to a client that the additional cost of installing efficient equipment is worthwhile is by calculating payback period – the length of time before the savings match the extra initial cost
    - Payback = (the extra initial cost) / (annual cost savings)
  - After this period, the user has saved more than he has spent and continues to save money

3.5.4 Outdoor Lighting

- Outdoor (or exterior) lighting
  - Floodlighting: flooding a surface with light
    - Achieve illumination on vertical or horizontal surfaces
  - Design issues
    - Appearance during daytime
    - Glare from the installation
    - Decorative lighting

- • Lighting for specific outdoor activities e.g. sports
- • Applications:
  - • Building façade, sports, road lighting
- • Floodlighting a building
  - • Requires a sense of drama and colour
  - • Select locations for putting floodlights & aiming points
  - • Peak intensity & beam angle
  - • Usually all the beams from each floodlight shall overlap
  - • Uniformity ratio (max : average) about 5:1
- • Floodlighting a horizontal open area
  - • Use isolux diagram (horizontal illumination plots)
  - • Or isocandela and zonal flux diagram
  - • Calculate using inverse square law and cosine law