General Saving Tips

sources are just one part of saving energy and reducing costs while saving the planet. Renewable or sustainable energy sources are very important in the future of the world's energy generation. However, until such time that all the renewable sources can be successfully harnessed for each household, you can do a few other things to save energy.

Plan your energy use. Use the heating system only when necessary. Use the water heater in a way that it does not run the whole day. Plan ahead so you can shower and do the dishes while it is one and the switch it off to save power. Cook meals ahead of time on one day and saves energy by only using the stove and oven once or twice a week. Use timers to manage when your lights are needed. Automated home systems are making the management and planning of energy use very easy.

Unplug unused appliances. This really does make a difference in energy use and costs. When you are not using the microwave or your hair dryer or your laptop or your printer, unplug it. There are some appliances that have to stay on like the refrigerator, but non-essential appliances that are not used should be unplugged. This has been proven to save energy.

Make your own energy-saving devices. There are so many ideas from solar panels made from CDs to green roofs and mini wind turbines. Make use of some of these gadgets or activities to help reduce your energy use and impact on the planet. It can be a family activity and it will stimulate your creative side. Once you see these small and affordable devices make a change to your daily life you will wonder why you didn't try it sooner.

Avoid using electrical appliances if you can. Some appliances like the oven and refrigerator are necessary. However, a clothes dryer uses a lot of energy and the sun can dry your clothes just as well and actually help avoid mould development. So, instead of shoving your washing into the dryer, rather let them dry in the sun. The same can work for dishwashers. If you don't have a lot of dishes dirty at the same time, wait to use the dishwasher. Alternatively, you can wash small amounts of dirty dishes by hand instead of using the dishwasher. If you have a look at your daily electricity use, you will find other devices you can use less and swop for non-electrical options.

Dress warmer before you turn the heat on. Instead of just automatically going for the heat switch, try and put on another jersey or jacket and get a blanket. Saving energy is a good reason to cuddle with loved ones and keep each other warm. The same goes for cooling systems. Before you switch on the fan or air conditioning system, try other methods of cooling down. You can insulate your home and plant trees strategically to block the sun.

Incorporate renewable energy sources. If you can afford it and your property allows for it, install solar panels or wind turbines. These alternative energy sources will save you a lot of money and it will also reduce your use of fossil fuel energy. These sources can be expensive to install, but if you are able to do it, it is an investment. You will be very grateful in the coming years. For those who cannot yet afford it, don't worry. The technology is improving constantly and soon everyone will be able to afford alternative energy sources and benefit from them. You can have a look at the options offered by 3D printing to start with small things.

Use eco-friendly products. Buy eco-friendly light bulbs for your home and office. They use much less energy than normal bulbs. Also, look at buying energy-efficient appliances when you need to buy new ones or upgrade. Most kitchen appliances and things like washing machines have eco-friendly counterparts.

Have your house inspected. You can do this yourself if you don't want to hire someone. Inspect things like door and window frames. If you can see light or feel air coming through the cracks, you may be losing heat that is causing an increase in energy use to heat up the home. Also, have a look at your home's insulation and roofing and see if it may need upgrading or repairs. Heaters and other appliances can also be inspected for condition. If any appliances become hot while in use, it may be a sign of bad wiring or a potential energy problem. You can check out any devices and appliances and ensure that they are functioning correctly and not using more energy than they should.

Automate your house. This is not an option for everyone, but if you can afford it, you will save a lot of money. Automation systems use monitors that sense the levels of heat and cold and adjust heating and cooling accordingly. You can also control these systems through your cell phone or mobile device. For example, if you forgot to switch off a light or the oven, you can send a message to the system and will switch the appliance off. These systems are also easy to connect to alternative energy sources like solar systems or wind turbines. Automated home systems also warn you when it picks up problems with appliances and energy use.

These are simple ways in which you can save energy and save yourself some money. Many of the options to go completely green are still costly, but soon they will be more affordable. Technology is improving daily and if you can make small changes, you will soon be able to integrate all your efforts. Try and work in some creativity to make the transition fun. You won't regret making the change to go green.a

Energy Audit

1. Definition of Energy Audit • As per Indian 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. . Why the Need for Energy Audit • The three top operating expenses are energy (both electrical and thermal), labour and materials. • Energy would emerge as a top ranker for cost reduction • 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
3. Types of Energy Audits 1. Preliminary Energy Audit 2. Targeted Energy Audit 3. Detailed Energy Audit
4. . Preliminary Energy Audit • Preliminary energy audit uses existing or easily obtained data • Find out the energy consumption area in the organization • Estimates the scope for saving • Identifies the most likely areas for attention • Identifies immediate(no cost or low cost) improvements • Sets a 'reference point' • Identifies areas for more detailed study/measurement
5. • Targeted energy audits are mostly based upon the outcome of the preliminary audit results. • They provide data and detailed analysis on specified target projects. • As an example, an organization may target its lighting system or boiler system or compressed air

system with a view to bring about energy savings. • Targeted audits therefore involve detailed surveys of the target subjects/areas with analysis of the energy flows and costs associated with those targets. Targeted Energy Audits

6. . Detailed Energy Audit Detailed Energy Audit evaluates all systems and equipment which consume energy and the audit comprises a detailed study on energy savings and costs. Detailed Energy Audit is carried out in 3 phases – The Pre-audit Phase – The Audit Phase – The Post-Audit Phase
7. . Organize Instruments • Resource planning, Establish/organize a Energy audit team • Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.) • Informal Interview with Energy Manager, Production / Plant Manager • Walk through Audit • Plan and organise •The Ten Steps for Detailed Audit Step No PLAN OF ACTION PURPOSE / RESULTS Step 1 Step 2 Phase I –Pre Audit Phase & First hand observation • Familiarization of process/plant activities • Macro Data collection (suitable to type of industry.) •time frame & Orientation, awareness creation • Issue questionnaire for each department • Building up cooperation •Assessment of current level operation and practices
8. . Primary data gathering, Process Flow Diagram, •Step 3 Step 4 Phase II –Audit Phase & All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air • Prepare process flow charts • Historic data analysis, Baseline data collection • Conduct survey and monitoring •Energy Utility Diagram & 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. • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview) • Design, operating data and schedule of operation •steam distribution.
9. . Reporting • Cost benefit analysis • Identification and development of Energy Conservation (ENCON) opportunities • Analysis of energy use • Conduct of detailed trials /experiments for selected energy guzzlers •Step 5 Step6 Step 7 Step 8 Step9 & Energy and Material balance • 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 •Presentation to the Top Management & Identification •energy loss/waste analysis & Review the ♣Conceive, develop, and refine ideas ♣Consolidation ENCON measures Prioritise by low, medium, long term measures Documentation, Report Presentation to the top Management. • Select the most promising projects • Assess technical feasibility, economic viability and prioritization of ENCON options for implementation •Contact vendors for new/efficient technology ♣Use brainstorming and value analysis techniques ♣Review the previous ideas suggested by energy audit if any ♣previous ideas suggested by unit personal
10. . Follow-up and periodic review ♣Action plan, Schedule for implementation ♣ Implementation and Follow- up Assist and Implement ENCON recommendation measures and Monitor the performance •Step10 Phase III –Post Audit phase
11. . Questions which an Energy Auditor should ask • What function does this system serve? • How does this system serve its function? • What is the energy consumption of this system? • What are the indications that this system is working properly ? • If this system is not working, how can it be restored to good working conditions/ • How can the energy cost of this system be reduced?
12. . DETAILED ENERGY AUDIT A TYPICAL INDUSTRIAL FORMAT OF REPORT Energy Audit Team Executive Summary –Scope & Purpose Energy Audit Options & Recommendations 1.0 Introduction about the plant 1.1 General Plant details and descriptions 1.2 Component of production cost (Raw materials, energy, chemicals, manpower, overhead, others) 1.3 Major Energy use and Areas 2.0 Production Process Description 2.1 Brief description of manufacturing process 2.2 Process flow diagram and

Major Unit operations 2.3 Major Raw material Inputs, Quantity and Costs 3.0 Energy and Utility System Description 3.1 List of Utilities 3.2 Brief Description of each utility 3.2.1 Electricity 3.2.2 Steam 3.2.3 Water 3.2.4 Compressed air 3.2.5 Chilled water 3.2.6 Cooling water

13. . 4.0 Detailed Process flow diagram and Energy& Material balance 4.1 Flow chart showing flow rate, temperature, pressures of all input- Output streams 4Water 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 assessments 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 cost, annual energy savings and payback 6.2 Implementation plan for energy saving measures/Projects ANNEXURE Al. List of instruments A2. List of Vendors and Other Technical details
14. . Energy Audit Instruments 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. POWER ANALYSERS
15. . Combustion analyzer: This instrument has in-built chemical cells which measure various gases such as CO2, CO, NOX, SOX etc 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. Percentage Oxygen or CO2 can be read from the scale. FLUE GAS ANALYSERS
16. . 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 Pyrometer: This is a non-contact type measurement which when directed at a heat source directly gives the temperature read out. Can be useful for measuring hot jobs in furnaces, surface temperatures etc. TEMPERATURE MEASURMENTS
17. . Pitot Tube and manometer: Air velocity in ducts can be measured using a pitot tube and inclined manometer for further calculation of flows. Ultrasonic flow meter: This a non contact flow measuring device using Doppler effect 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. FLOW MEASURMENTS – AIR ,WATER
18. . 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. 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.
19. . Identification of Energy Conservation Factors & Areas Steps for conserving energy can be taken if we know the correct factors and areas to be studied and also details of fuels used. These can be: • Energy generation • Energy distribution • Energy usage by processes • Fuel substitution
20. . Waste disposal Net Savings /Year (Rs./year) = (Annual savings-annual operating costs) Payback period in months = (Investment/net savings/year) x 12 Technology availability,

space, skilled manpower, reliability, service,Impact of measure on safety, quality, production or process.Maintenance requirements and spares availability • Raw material • Electrical Energy • Thermal Energy • Depreciation 3. Annual savings • Energy • Manpower • Maintenance • Cost of capital •Technical and Economic feasibility- Factors Sample Worksheet for Economic Feasibility Name of Energy Efficiency Measure i. Investment a. Equipments b. Civil works c. Instrumentati on d. Auxiliaries 2. Annual operating costs

21. . Energy Costs in Indian Scenario ? Common Fuels • Fuel oil,• Low Sulphur Heavy Stock (LSHS),• Light Diesel Oil (LDO),• Liquefied Petroleum Gas (LPG) • Coal,• Lignite,• Wood Fuels Cost Inputs & Factors • Price at source, transport charge, type of transport, • Quality of fuel • Contaminations, Moisture, Energy content (GCV) Power Costs In India Electricity costs vary substantially not only from State to State, but also from city to city and also within consumer to consumer – though power does the same work everywhere. Reason: •Tariff Structure
22. Energy conservation measures
23. Understanding energy costs Electricity (1 kWh) = 860 kcal/kWh (0.0036 GJ) Heavy fuel oil (calorific value, GCV) =10.000 kcal/litre (0.0411 GJ/litre) Coal (calorific value, GCV) =4000 kcal/kg (28 GJ/ton) An industrial energy bill summary Conversion to common unit of energy ENERGY BILL EXAMPLE 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.11,000 KL 22,00,000 Coal 1000 tons Rs.2,200/ton 22,00,000 Total 64,00,000
24. Benchmarking • Benchmarking can be a useful tool for understanding energy consumption patterns in the industrial sector and also to take requisite measures for improving energy efficiency. • FACTORS INVOLVED: – Scale of operation – use of technology – Raw material specifications and quality – Product specifications and quality
25. . Across similar industries Scale of operation, use of technology, raw material specification and quality and product specification and quality– Historical and trend analysis • External Benchmarking –Benchmarking for Energy Performance • Internal Benchmarking
26. . Bench Marking Energy Performance • Quantification of fixed and variable energy consumption trends vis-à-vis production levels • Comparison of the industry energy performance w.r.t. 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
27. . Benchmarking parameters Production or Equipment Related •Gross production related e.g. kWh/MT clinker or cement produced (Cement plant) e.g. kWh/MT, kCal/kg, paper produced (Paper plant) •Equipment / utility related e.g. kWh/ton of refrigeration (on Air conditioning plant) e.g. kWh /litre in a diesel power generation plant.
28. . Measuring Energy Performance Production Factor = Current year's production Reference year's production • Reference Year Equivalent Energy Use • The reference year's equivalent energy use (or reference year equivalent) is the energy that would have been used to produce the current year's production output. • 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 • Plant Energy Performance is the improvement or deterioration from the reference year. It is a measure of plant's energy progress. • Plant energy performance = Reference year equivalent – Current year's energy x 100 Reference year equivalent
29. . Maximizing System Efficiencies - Some Measures • Replace pumps, fans, air compressors, refrigeration compressors, boilers, furnaces, heaters and other energy conservation equipment, wherever significant energy efficiency margins exist • Eliminate steam leakages by trap improvements • Maximize condensate recovery • Adopt combustion controls for maximizing combustion efficiency
30. . Matching Energy Usage to Requirement • The mismatch between equipment capacity and user requirement often leads to inefficiencies due to part load operations, wastages etc. It is thus essential that proper energy matching studies are carried out & actions implemented.

Examples : Eliminate throttling Eliminate damper operations Fan resizing for better efficiency. Moderation of chilled water temperature for process chilling needs

31. . Identify potential for heat exchanger networking and process integration.} Periodic review of insulation thickness } Shuffling of compressors to match needs. } EXAMPLES: } In order to ensure that the energy given to the system is being put to optimal use, site specific measures and checks should be carried out regularly. }Optimising Energy Input Requirement
32. . Identification of energy conservation opportunities Fuel substitution • Replacement of coal by coconut shells, rice husk etc • Replacement of LDO by LSHS Energy substitution • Replacement of electric heaters by steam heaters • Replacement of steam based hot water by solar systems Energy Generation • Captive power plant • Steam generation Energy usage by processes • Analyze which process gets high energy consumption
33. . Energy monitoring & targeting Importance An effective monitoring & implementing system with adequate technical ability for analyzing energy saving options is key to ENERGY MANAGEMENT Energy monitoring and targeting is primarily a management technique that uses energy information as a basis to eliminate waste, reduce and control current level of energy use and improve the existing operating procedures. These techniques covers all plant and building utilities such as fuel, steam, refrigeration, compressed air, water, effluent, and electricity are managed as controllable resources in the same way that raw materials, finished product inventory, building occupancy, personnel and capital are managed.----It Becomes the “Energy Cost Centers.”
34. . Elements of Monitoring & Targeting System • Recording - Measuring and recording energy consumption • • Analyzing - Correlating energy consumption to a measured output, such as production quantity • • Comparing -Comparing energy consumption to an appropriate standard benchmark • • Setting Targets -Setting targets to reduce or control energy consumption • • Monitoring - Comparing energy consumption to the set target on a regular basis • • Reporting -Reporting the results including any variances from the targets which have been set • • Controlling - Implementing management measures to correct any variances, which may have been occurred. • Particularly M&T system will involve the following: • Checking the accuracy of energy invoices • Allocating energy costs to specific departments (Energy Accounting Centres) • Determining energy performance/efficiency • Recording energy use, so that projects intended to improve energy efficiency can bechecked * Highlighting performance problems in equipment or systems
35. . Data and Information Analysis • Plant level information can be derived from financial accounting systems-utilities cost centre • Plant department level information can be found in comparative energy consumption data for a group of similar facilities, service entrance meter readings etc. • System level (for example, boiler plant) performance data can be determined from sub metering data • Equipment level information can be obtained from nameplate data, run-time and schedule information, sub-metered data on specific energy consuming equipment
36. . Relating Energy Consumption and Production • After collection of energy consumption, energy cost and production data, the next stage of the monitoring process is to study and analyze the data and represent it for day to day controls—so represent it graphically
37. . Specific Energy Consumption(SEC) is energy consumption per unit of production
38. . CUSUM -Cumulative Sum • Cumulative Sum (CUSUM) represents the difference between the base line and the actual consumption points over the base line period of time. • This useful technique not only provides a trend line, it also calculates savings/losses to date and shows when the performance changes.
39. . CUSUM Technique CUSUM analysis 1 Plot the Energy - Production graph for the first 9 months 2. Draw the best fit straight line 3. Derive the equation of the line, y=mx+c 4. Calculate the expected energy consumption based on the equation 5. Calculate the difference between actual and calculated energy use 6. Compute CUSUM 7. Plot the

CUSUM graph 8. Estimate the savings accumulated from use of the heat recovery system 1-Given 4-Analysis-TABLE 2-plot graph 3-fit equation

40. . Case Study The CUSUM Technique Energy consumption and production data were collected for a plant over a period of 18 months. During month 9, a heat recovery system was installed. Using the plant monthly data, estimate the savings made with the heat recovery system. The plant data is given in Table 8.3: * toe = tonnes of oil equivalent.
41. . Based on the graph 8.10 (see Table 8.4), savings of 44 toe (50-6) have been accumulated in the last 7 months. This represents savings of almost 2% of energy consumption.
42. . 5-CUSUM -Analysis
43. . The Sankey Diagram and its Use The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment or system such as boiler, fired heaters, furnaces after carrying out energy balance calculation. This diagram represents visually various outputs and losses so that energy managers can focus on finding improvements in a prioritized manner. Example: The Figure 4.2 shows a Sankey diagram for a reheating furnace. From the Figure 4.2, it is clear that exhaust flue gas losses are a key area for priority attention.
44. . • We know, equation of slope, Y=mx+c Where, "y" is dependent variable(i.e energy consumption) "x" is independent variable(i.e production) "c" is the value at which the straight line curve intersect the "y" axis. "m" is the gradient of straight line curve. Least Square Method Therefore, Energy consumed for the period=C+m*production for the same period.
45. . • Consider the sample points, (X1,y1).(x2,y2)……(xn,yn) Therefore, Equation of straight lines are, 1. cn+m∑x=∑y 2. c∑x+m∑X2 = ∑xy….(on the basis of production i.e independent variable) n= no. of data points These equations are known as normal equations of the problems and they can be used to establish the value of "c" and "m".

1.1 Introduction (Lighting System)

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.

1.2 Basic Terms in Lighting System and Features 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

Luminaire Luminaire is a device that distributes, filters or transforms the light emitted from one or more lamps. The luminaire includes, all the parts necessary for fixing and protecting the lamps, except the lamps themselves. In some cases, luminaires also include the necessary circuit auxiliaries, together with the means for connecting them to the electric supply. The basic physical principles used in optical luminaire are reflection, absorption, transmission and refraction.

Control Gear The gears used in the lighting equipment are as follows:

• **Ballast:** Acurrent limiting device, to counter negative resistance characteristics of any discharge lamps. In case of fluorescent lamps, it aids the initial voltage build-up, required for starting.

• **Ignitors:** These are used for starting high intensity Metal Halide and Sodium vapour lamps.

Illuminance This is the quotient of the illuminous flux incident on an element of the surface at a point of surface containing the point, by the area of that element. The lighting level produced by a lighting installation is usually qualified by the illuminance produced on a specified plane. In most cases, this plane is the major plane of the tasks in the interior and is commonly called the working plane. The illuminance provided by an installation affects both the performance of the tasks and the appearance of the space.

Lux (lx) : This is the illuminance produced by a luminous flux of one lumen, uniformly distributed over a surface area of one square metre. One lux is equal to one lumen per square meter.

Luminous Efficacy (lm/W) : This is the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. It is a reflection of efficiency of energy conversion from electricity to light form.

Colour Rendering Index (RI) Is a measure of the degree to which the colours of surfaces illuminated by a given light source confirm to those of the same surfaces under a reference illuminent; suitable allowance having been made for the state of Chromatic adaptation.

1.4 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). Afactor 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 theLumens / Watt Color Typical Type of Lamp Range Avg. Rendering Typical Application Life Index (hours) Incandescent 8–18 14 Excellent Homes, restaurants, 1000 general lighting, emergency lighting Fluorescent Lamps 46–60 50 Good w.r.t. Offices, shops, 5000 coating hospitals, homes Compact fluorescent 40–70 60 Very good Hotels, shops, 8000–10000 lamps (CFL) homes, offices High pressure 44–57 50 Fair General lighting in 5000 mercury (HPMV) factories, garages, car parking, flood lighting Halogen lamps 18–24 20 Excellent Display, flood 2000–4000 lighting, stadium exhibition grounds, construction areas High pressure sodium 67–121 90 Fair General lighting 6000–12000 (HPSV) SON in factories, ware houses, street lighting Low pressure sodium 101–175 150 Poor Roadways, tunnels, 6000–12000 (LPSV) SOX canals, street lighting 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 & 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/ Chemicals 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, s 300–500–750 terilising, washing, preparation of solutions, filling, capping, wrapping, hardening 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 200–300–500Paint 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

1.5 Methodology of Lighting System Energy Efficiency Study:

Astep-by-step approach for assessing energy efficiency of lighting system is given below:

Step–1: Inventorise the Lighting System elements, & transformers in the facility .

2.. No. Plant Lighting Rating in Watts Population No. of hours Location Device & Lamp & Ballast Numbers / Day Ballast Type

3. No. Plant Lighting Numbers Meter Provisions Available Location Transformer Installed Volts / Amps / kW / Energy Rating (kVA)

1. In case of distribution boards (instead of transformers) being available, fuse ratings may be inventorised along the above pattern in place of transformer kVA.

Step–2: With the aid of a lux meter, measure and document the lux levels at various plant locations at working level, as daytime lux and night time lux values alongside the number of lamps "ON" during measurement.

Step–3: With the aid of portable load analyzer, measure and document the voltage, current, power factor and power consumption at various input points, namely the distribution boards or the lighting voltage transformers at the same as that of the lighting level audit.

Step–4: Compare the measured lux values with standard values as reference and identify locations as under lit and over lit areas.

Step–5: Collect and Analyse the failure rates of lamps, ballasts and the actual life expectancy levels from the past data.

Step–6:Based on careful assessment and evaluation, bring out improvement options, which could include :

i) Maximise sunlight use through use of transparent roof sheets, north light roof, etc.

ii) Examine scope for replacements of lamps by more energy efficient lamps, with due consideration to luminiare, color rendering index, lux level as well as expected life comparison.

iii) Replace conventional magnetic ballasts by more energy efficient ballasts, with due consideration to life and power factor apart from watt loss.

iv) Select interior colours for light reflection.

v) Modify layout for optimum lighting.

vi) Providing individual / group controls for lighting for energy efficiency such as: a. On / off type voltage regulation type (for illuminance control) b. Group control switches / units c. Occupancy sensors d.

Photocell controls e. Timer operated controls f. Pager operated controls g. Computerized lighting control programs

vii) Install input voltage regulators / controllers for energy efficiency as well as longer life expectancy for lamps where higher voltages, fluctuations are expected.

viii) Replace energy efficient displays like LED's in place of lamp type displays in control panels / instrumentation areas, etc.

1.6 Case Examples Energy Efficient Replacement Options :

The lamp efficacy is the ratio of light output in lumens to power input to lamps in watts. Over the years development in lamp technology has led to improvements in efficacy of lamps. However, the low efficacy lamps, such as incandescent bulbs, still constitute a major share of the lighting load. High efficacy gas discharge lamps suitable for different types of applications offer appreciable scope for energy conservation. Typical energy efficient replacement options, along with the per cent energy saving.

Energy Saving Potential in Street Lighting The energy saving potential, in typical cases of replacement of inefficient lamps with efficient lamps in street lighting.

Lamp type Power savingSector

Existing Proposed Watts % Domestic/Commercial GLS 100 W *CFL 25 W 75 75 Industry GLS 13 W *CFL 9 W 4 31 GLS 200 W Blended 160 W 40 20 TL 40 W TLD 36 W 4 10 Industry/Commercial HPMV 250 W HPSV 150 W 100 37 HPMV 400 W HPSV 250 W 150 35

* Wattages of CFL includes energy consumption in ballasts.

Existing lamp Replaced units Saving

Type W Life Type W Life W % GLS 200 1000 ML 160 5000 40 7 GLS 300 1000 ML 250 5000 50 17 TL 2 X 40 5000 TL 2 X 36 5000 8 6 HPMV 125 5000 HPSV 70 12000 25 44 HPMV 250 5000 HPSV 150 12000 100 40 HPMV 400 5000 HPSV 250 12000 150 38

1.7 Some Good Practices in Lighting Installation of energy efficient fluorescent lamps in place of "Conventional" fluorescent lamps. Energy efficient lamps are based on the highly sophisticated tri-phosphor fluorescent powder technology. They offer excellent colour rendering properties in addition to the very high luminous efficacy.

Installation of Compact Fluorescent Lamps (CFL's) in place of incandescent lamps. Compact fluorescent lamps are generally considered best for replacement of lower wattage incandescent lamps. These lamps have efficacy ranging from 55 to 65 lumens/Watt. The average rated lamp life is 10,000 hours, which is 10 times longer than that of a normal incandescent

lamps. CFL's are highly suitable for places such as Living rooms, Hotel lounges, Bars, Restaurants, Pathways, Building entrances, Corridors, etc.

Installation of metal halide lamps in place of mercury / sodium vapour lamps. Metal halide lamps provide high color rendering index when compared with mercury & sodium vapour lamps. These lamps offer efficient white light. Hence, metal halide is the choice for colour critical applications where, higher illumination levels are required. These lamps are highly suitable for applications such as assembly line, inspection areas, painting shops, etc. It is recommended to install metal halide lamps where colour rendering is more critical.

Installation of High Pressure Sodium Vapour(HPSV) lamps forapplications where colour rendering is not critical. High pressure sodium vapour (HPSV) lamps offer more efficacy. But the colour rendering property of HPSV is very low. Hence, it is recommended to install HPSV lamps for applications such street lighting, yard lighting, etc.

Installation of LED panel indicator lamps in place of filament lamps. Panel indicator lamps are used widely in industries for monitoring, fault indication, signaling, etc. Conventionally filament lamps are used for the purpose, which has got the following disadvantages:

• High energy consumption (15 W/lamp)

• Failure of lamps is high (Operating life less than 1,000 hours)

• Very sensitive to the voltage fluctuations Recently, the conventional filament lamps are being replaced with Light Emitting Diodes (LEDs). The LEDs have the following merits over the filament lamps.

• Lesser power consumption (Less than 1 W/lamp)

• Withstand high voltage fluctuation in the power supply.

• Longer operating life (more than 1,00,000 hours) It is recommended to install LEDs for panel indicator lamps at the design stage.

Light distribution Energy efficiency cannot be obtained by mere selection of more efficient lamps alone. Efficient luminaires along with the lamp of high efficacy achieve the optimum efficiency. Mirror-optic luminaires with a high output ratio and bat-wing light distribution can save energy. For achieving better efficiency, luminaires that are having light distribution characteristics appropriate for the task interior should be selected. The luminaires fitted with a lamp should ensure that discomfort glare and veiling reflections are minimised. Installation of suitable luminaires, depends upon the height - Low, Medium & High Bay. Luminaires for high intensity discharge lamp are classified as follows:

• Low bay, for heights less than 5 metres.

• Medium bay, for heights between 5 – 7 metres.

• High bay, for heights greater than 7 metres.

System layout and fixing of the luminaires play a major role in achieving energy efficiency. This also varies from application to application. Hence, fixing the luminaires at optimum height and usage of mirror optic luminaries leads to energy efficiency.

Light Control The simplest and the most widely used form of controlling a lighting installation is "On-Off" switch. The initial investment for this set up is extremely low, but the resulting operational costs may be high. This does not provide the flexibility to control the lighting, where it is not required. Hence, a flexible lighting system has to be provided, which will offer switch-off or reduction in lighting level, when not needed. The following light control systems can be adopted at design stage:

• Grouping of lighting system, to provide greater flexibility in lighting control Grouping of lighting system, which can be controlled manually or by timer control.

• Installation of microprocessor based controllers Another modern method is usage of microprocessor / infrared controlled dimming or switching circuits. The lighting control can be obtained by using logic units located in the ceiling, which can take pre-programme commands and activate specified lighting circuits. Advanced lighting control system uses movement detectors or lighting sensors, to feed signals to the controllers.

• Optimum usage of daylighting Whenever the orientation of a building permits, day lighting can be used in combination with electric lighting. This should not introduce glare or a severe imbalance of brightness in visual environment. Usage of day lighting (in offices/air conditioned halls) will have to be very limited, because the air conditioning load will increase on account of the increased solar heat dissipation into the area. In many cases, a switching method, to enable reduction of electric light in the window zones during certain hours, has to be designed.

• Installation of "exclusive" transformer for lighting In most of the industries, lighting load varies between 2 to 10%. Most of the problems faced by the lighting equipment and the "gears" is due to the "voltage" fluctuations. Hence, the lighting equipment has to be isolated from the power feeders. This provides a better voltage regulation for the lighting. This will reduce the voltage related problems, which in turn increases the efficiency of the lighting system.

• Installation of servo stabilizer for lighting feeder Wherever, installation of exclusive transformer for lighting is not economically attractive, servo stabilizer can be installed for the lighting feeders. This will provide stabilized voltage for the lighting equipment. The performance of "gears" such as chokes, ballasts, will also improved due to the stabilized voltage. This set up also provides, the option to optimise the voltage level fed to the lighting feeder. In many plants, during the non-peaking hours, the voltage levels are on the higher side. During this period, voltage can be optimised, without any significant drop in the illumination level.

• Installation of high frequency (HF) electronic ballasts in place of conventional ballasts New high frequency (28–32 kHz) electronic ballasts have the following advantages over the traditional magnetic ballasts: Energy savings up to 35% Less heat dissipation, which reduces the air conditioning load

• Lights instantly

• Improved power factor

• Operates in low voltage load

• Less in weight

• Increases the life of lamp

The advantage of HF electronic ballasts, out weigh the initial investment (higher costs when compared with conventional ballast). In the past the failure rate of electronic ballast in Indian Industries was high. Recently, many manufacturers have improved the design of the ballast leading to drastic improvement in their reliability. The life of the electronic ballast is high especially when, used in a lighting circuit fitted with a automatic voltage stabiliser.

Location Source Luminaire Gear Controls Plant HID/FTL Industrial rail reflector: Conventional/low Manual/electronic High bay loss electronic Medium bay ballast Low bay Office FTL/CFL FTL/CFL Electronic/low Manual/auto loss Yard HID Flood light Suitable Manual Road HID/PL Street light luminaire Suitable Manual peripheral

QUESTIONS 1. What are the types of commonly used lamps?

2. What do the following terms mean? – Illuminance – Luminous efficacy – Luminaire – Control gear – Colour rendering index

3. What is the function of ballast in a lighting system?

4. Rate the following with respect to their luminous efficacy – GLS lamp – FTL – CFL – HPSV – LPSV

5. Rate the following with respect to colour rendering index – GLS lamp – HPSV lamp – Metal halide lamps – LPSV lamp

6. Briefly describe the methodology of lighting energy audit in an industrial facility?

7. List the energy savings opportunities in industrial lighting systems.

8. Explain how electronic ballast saves energy?

9. ACFL can replace a) FTL b) GLS c) HPMV d) HPSV

10. Explain briefly about various lighting controls available?

Salient features of the Energy Conservation Act 2001

The Act empowers the Central Government and, in some instances, State Governments to:

- specify energy consumption standards for notified equipment and appliances;
- direct mandatory display of label on notified equipment and appliances;
- prohibit manufacture, sale, purchase and import of notified equipment and appliances not conforming to energy consumption standards;
- notify energy intensive industries, other establishments, and commercial buildings as designated consumers;
- establish and prescribe energy consumption norms and standards for designated consumers;
- prescribe energy conservation building codes for efficient use of energy and its conservation in new commercial buildings having a connected load of 500 kW or a contract demand of 600 kVA and above;
- direct designated consumers to:-

1. designate or appoint certified energy manager in charge of activities for efficient use of energy and its conservation;
2. get an energy audit conducted by an accredited energy auditor in the specified manner and interval of time;
3. furnish information with regard to energy consumed and action taken on the recommendation of the accredited energy auditor to the designed agency;
4. comply with energy consumption norms and standards;
5. prepare and implement schemes for efficient use of energy and its conservation if the prescribed energy consumption norms and standards are not fulfilled;

- get energy audit of the building conducted by an accredited energy auditor in this specified manner and intervals of time;

State Governments may –

1. amend the energy conservation building codes prepared by the Central Government to suit regional and local climatic conditions;
2. direct every owners or occupier of a new commercial building or building complex being a designated consumer to comply with the provisions of energy conservation building codes;
3. direct, if considered necessary for efficient use of energy and its conservation, any designated consumer to get energy audit conducted by an accredited energy auditor in such manner and at such intervals of time as may be specified;

General Saving Tips

sources are just one part of saving energy and reducing costs while saving the planet. Renewable or sustainable energy sources are very important in the future of the world's energy generation. However, until such time that all the renewable sources can be successfully harnessed for each household, you can do a few other things to save energy.

Plan your energy use. Use the heating system only when necessary. Use the water heater in a way that it does not run the whole day. Plan ahead so you can shower and do the dishes while it is one and the switch it off to save power. Cook meals ahead of time on one day and saves energy by only using the stove and oven once or twice a week. Use timers to manage when your lights are needed. Automated home systems are making the management and planning of energy use very easy.

Unplug unused appliances. This really does make a difference in energy use and costs. When you are not using the microwave or your hair dryer or your laptop or your printer, unplug it. There are some appliances that have to stay on like the refrigerator, but non-essential appliances that are not used should be unplugged. This has been proven to save energy.

Make your own energy-saving devices. There are so many ideas from solar panels made from CDs to green roofs and mini wind turbines. Make use of some of these gadgets or activities to help reduce your energy use and impact on the planet. It can be a family activity and it will stimulate your creative side. Once you see these small and affordable devices make a change to your daily life you will wonder why you didn't try it sooner.

Avoid using electrical appliances if you can. Some appliances like the oven and refrigerator are necessary. However, a clothes dryer uses a lot of energy and the sun can dry your clothes just as well and actually help avoid mould development. So, instead of shoving your washing into the dryer, rather let them dry in the sun. The same can work for dishwashers. If you don't have a lot of dishes dirty at the same time, wait to use the dishwasher. Alternatively, you can wash small amounts of dirty dishes by hand instead of using the dishwasher. If you have a look at your daily electricity use, you will find other devices you can use less and swop for non-electrical options.

Dress warmer before you turn the heat on. Instead of just automatically going for the heat switch, try and put on another jersey or jacket and get a blanket. Saving energy is a good reason to cuddle with loved ones and keep each other warm. The same goes for cooling systems. Before you switch on the fan or air conditioning system, try other methods of cooling down. You can insulate your home and plant trees strategically to block the sun.

Incorporate renewable energy sources. If you can afford it and your property allows for it, install solar panels or wind turbines. These alternative energy sources will save you a lot of money and it will also reduce your use of fossil fuel energy. These sources can be expensive to install, but if you are able to do it, it is an investment. You will be very grateful in the coming years. For those who cannot yet afford it, don't worry. The technology is improving constantly and soon everyone will be able to afford alternative energy sources and benefit from them. You can have a look at the options offered by 3D printing to start with small things.

Use eco-friendly products. Buy eco-friendly light bulbs for your home and office. They use much less energy than normal bulbs. Also, look at buying energy-efficient appliances when you need to buy new ones or upgrade. Most kitchen appliances and things like washing machines have eco-friendly counterparts.

Have your house inspected. You can do this yourself if you don't want to hire someone. Inspect things like door and window frames. If you can see light or feel air coming through the cracks, you may be losing heat that is causing an increase in energy use to heat up the home. Also, have a look at your home's insulation and roofing and see if it may need upgrading or repairs. Heaters and other appliances can also be inspected for condition. If any appliances become hot while in use, it may be a sign of bad wiring or a potential energy problem. You can check out any devices and appliances and ensure that they are functioning correctly and not using more energy than they should.

Automate your house. This is not an option for everyone, but if you can afford it, you will save a lot of money. Automation systems use monitors that sense the levels of heat and cold and adjust heating and cooling accordingly. You can also control these systems through your cell phone or mobile device. For example, if you forgot to switch off a light or the oven, you can send a message to the system and will switch the appliance off. These systems are also easy to connect to alternative energy sources like solar systems or wind turbines. Automated home systems also warn you when it picks up problems with appliances and energy use.

These are simple ways in which you can save energy and save yourself some money. Many of the options to go completely green are still costly, but soon they will be more affordable. Technology is improving daily and if you can make small changes, you will soon be able to integrate all your efforts. Try and work in some creativity to make the transition fun. You won't regret making the change to go green.a

Energy Audit

1. Definition of Energy Audit • As per Indian 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. . Why the Need for Energy Audit • The three top operating expenses are energy (both electrical and thermal), labour and materials. • Energy would emerge as a top ranker for cost reduction • 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
3. Types of Energy Audits 1. Preliminary Energy Audit 2. Targeted Energy Audit 3. Detailed Energy Audit
4. . Preliminary Energy Audit • Preliminary energy audit uses existing or easily obtained data • Find out the energy consumption area in the organization • Estimates the scope for saving • Identifies the most likely areas for attention • Identifies immediate(no cost or low cost) improvements • Sets a 'reference point' • Identifies areas for more detailed study/measurement
5. • Targeted energy audits are mostly based upon the outcome of the preliminary audit results. • They provide data and detailed analysis on specified target projects. • As an example, an organization may target its lighting system or boiler system or compressed air

system with a view to bring about energy savings. • Targeted audits therefore involve detailed surveys of the target subjects/areas with analysis of the energy flows and costs associated with those targets. Targeted Energy Audits

6. . Detailed Energy Audit Detailed Energy Audit evaluates all systems and equipment which consume energy and the audit comprises a detailed study on energy savings and costs. Detailed Energy Audit is carried out in 3 phases – The Pre-audit Phase – The Audit Phase – The Post-Audit Phase
7. . Organize Instruments • Resource planning, Establish/organize a Energy audit team • Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.) • Informal Interview with Energy Manager, Production / Plant Manager • Walk through Audit • Plan and organise •The Ten Steps for Detailed Audit Step No PLAN OF ACTION PURPOSE / RESULTS Step 1 Step 2 Phase I –Pre Audit Phase & First hand observation • Familiarization of process/plant activities • Macro Data collection (suitable to type of industry.) •time frame & Orientation, awareness creation • Issue questionnaire for each department • Building up cooperation •Assessment of current level operation and practices
8. . Primary data gathering, Process Flow Diagram, •Step 3 Step 4 Phase II –Audit Phase & All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air • Prepare process flow charts • Historic data analysis, Baseline data collection • Conduct survey and monitoring •Energy Utility Diagram & 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. • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview) • Design, operating data and schedule of operation •steam distribution.
9. . Reporting • Cost benefit analysis • Identification and development of Energy Conservation (ENCON) opportunities • Analysis of energy use • Conduct of detailed trials /experiments for selected energy guzzlers •Step 5 Step6 Step 7 Step 8 Step9 & Energy and Material balance • 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 •Presentation to the Top Management & Identification •energy loss/waste analysis & Review the ♣Conceive, develop, and refine ideas ♣Consolidation ENCON measures Prioritise by low, medium, long term measures Documentation, Report Presentation to the top Management. • Select the most promising projects • Assess technical feasibility, economic viability and prioritization of ENCON options for implementation •Contact vendors for new/efficient technology ♣Use brainstorming and value analysis techniques ♣Review the previous ideas suggested by energy audit if any ♣previous ideas suggested by unit personal
10. . Follow-up and periodic review ♣Action plan, Schedule for implementation ♣ Implementation and Follow- up Assist and Implement ENCON recommendation measures and Monitor the performance •Step10 Phase III –Post Audit phase
11. . Questions which an Energy Auditor should ask • What function does this system serve? • How does this system serve its function? • What is the energy consumption of this system? • What are the indications that this system is working properly ? • If this system is not working, how can it be restored to good working conditions/ • How can the energy cost of this system be reduced?
12. . DETAILED ENERGY AUDIT A TYPICAL INDUSTRIAL FORMAT OF REPORT Energy Audit Team Executive Summary –Scope & Purpose Energy Audit Options & Recommendations 1.0 Introduction about the plant 1.1 General Plant details and descriptions 1.2 Component of production cost (Raw materials, energy, chemicals, manpower, overhead, others) 1.3 Major Energy use and Areas 2.0 Production Process Description 2.1 Brief description of manufacturing process 2.2 Process flow diagram and

Major Unit operations 2.3 Major Raw material Inputs, Quantity and Costs 3.0 Energy and Utility System Description 3.1 List of Utilities 3.2 Brief Description of each utility 3.2.1 Electricity 3.2.2 Steam 3.2.3 Water 3.2.4 Compressed air 3.2.5 Chilled water 3.2.6 Cooling water

13. . 4.0 Detailed Process flow diagram and Energy& Material balance 4.1 Flow chart showing flow rate, temperature, pressures of all input- Output streams 4Water 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 assessments 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 cost, annual energy savings and payback 6.2 Implementation plan for energy saving measures/Projects ANNEXURE Al. List of instruments A2. List of Vendors and Other Technical details
14. . Energy Audit Instruments 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. POWER ANALYSERS
15. . Combustion analyzer: This instrument has in-built chemical cells which measure various gases such as CO_2, CO, NOX, SOX etc 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. Percentage Oxygen or CO_2 can be read from the scale. FLUE GAS ANALYSERS
16. . 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 Pyrometer: This is a non-contact type measurement which when directed at a heat source directly gives the temperature read out. Can be useful for measuring hot jobs in furnaces, surface temperatures etc. TEMPERATURE MEASURMENTS
17. . Pitot Tube and manometer: Air velocity in ducts can be measured using a pitot tube and inclined manometer for further calculation of flows. Ultrasonic flow meter: This a non contact flow measuring device using Doppler effect 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. FLOW MEASURMENTS – AIR ,WATER
18. . 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. 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.
19. . Identification of Energy Conservation Factors & Areas Steps for conserving energy can be taken if we know the correct factors and areas to be studied and also details of fuels used. These can be: • Energy generation • Energy distribution • Energy usage by processes • Fuel substitution
20. . Waste disposal Net Savings /Year (Rs./year) = (Annual savings-annual operating costs) Payback period in months = (Investment/net savings/year) x 12 Technology availability,

space, skilled manpower, reliability, service,Impact of measure on safety, quality, production or process.Maintenance requirements and spares availability • Raw material • Electrical Energy • Thermal Energy • Depreciation 3. Annual savings • Energy • Manpower • Maintenance • Cost of capital •Technical and Economic feasibility- Factors Sample Worksheet for Economic Feasibility Name of Energy Efficiency Measure i. Investment a. Equipments b. Civil works c. Instrumentati on d. Auxiliaries 2. Annual operating costs

21. . Energy Costs in Indian Scenario ? Common Fuels • Fuel oil,• Low Sulphur Heavy Stock (LSHS),• Light Diesel Oil (LDO),• Liquefied Petroleum Gas (LPG) • Coal,• Lignite,• Wood Fuels Cost Inputs & Factors • Price at source, transport charge, type of transport, • Quality of fuel • Contaminations, Moisture, Energy content (GCV) Power Costs In India Electricity costs vary substantially not only from State to State, but also from city to city and also within consumer to consumer – though power does the same work everywhere. Reason: •Tariff Structure
22. Energy conservation measures
23. Understanding energy costs Electricity (1 kWh) = 860 kcal/kWh (0.0036 GJ) Heavy fuel oil (calorific value, GCV) =10.000 kcal/litre (0.0411 GJ/litre) Coal (calorific value, GCV) =4000 kcal/kg (28 GJ/ton) An industrial energy bill summary Conversion to common unit of energy ENERGY BILL EXAMPLE 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.11,000 KL 22,00,000 Coal 1000 tons Rs.2,200/ton 22,00,000 Total 64,00,000
24. Benchmarking • Benchmarking can be a useful tool for understanding energy consumption patterns in the industrial sector and also to take requisite measures for improving energy efficiency. • FACTORS INVOLVED: – Scale of operation – use of technology – Raw material specifications and quality – Product specifications and quality
25. . Across similar industries Scale of operation, use of technology, raw material specification and quality and product specification and quality– Historical and trend analysis • External Benchmarking –Benchmarking for Energy Performance • Internal Benchmarking
26. . Bench Marking Energy Performance • Quantification of fixed and variable energy consumption trends vis-à-vis production levels • Comparison of the industry energy performance w.r.t. 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
27. . Benchmarking parameters Production or Equipment Related •Gross production related e.g. kWh/MT clinker or cement produced (Cement plant) e.g. kWh/MT, kCal/kg, paper produced (Paper plant) •Equipment / utility related e.g. kWh/ton of refrigeration (on Air conditioning plant) e.g. kWh /litre in a diesel power generation plant.
28. . Measuring Energy Performance Production Factor = Current year's production Reference year's production • Reference Year Equivalent Energy Use • The reference year's equivalent energy use (or reference year equivalent) is the energy that would have been used to produce the current year's production output. • 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 • Plant Energy Performance is the improvement or deterioration from the reference year. It is a measure of plant's energy progress. • Plant energy performance = Reference year equivalent – Current year's energy x 100 Reference year equivalent
29. . Maximizing System Efficiencies - Some Measures • Replace pumps, fans, air compressors, refrigeration compressors, boilers, furnaces, heaters and other energy conservation equipment, wherever significant energy efficiency margins exist • Eliminate steam leakages by trap improvements • Maximize condensate recovery • Adopt combustion controls for maximizing combustion efficiency
30. . Matching Energy Usage to Requirement • The mismatch between equipment capacity and user requirement often leads to inefficiencies due to part load operations, wastages etc. It is thus essential that proper energy matching studies are carried out & actions implemented.

Examples : Eliminate throttling Eliminate damper operations Fan resizing for better efficiency. Moderation of chilled water temperature for process chilling needs

31. . Identify potential for heat exchanger networking and process integration.} Periodic review of insulation thickness } Shuffling of compressors to match needs. } EXAMPLES: } In order to ensure that the energy given to the system is being put to optimal use, site specific measures and checks should be carried out regularly. }Optimising Energy Input Requirement
32. . Identification of energy conservation opportunities Fuel substitution • Replacement of coal by coconut shells, rice husk etc • Replacement of LDO by LSHS Energy substitution • Replacement of electric heaters by steam heaters • Replacement of steam based hot water by solar systems Energy Generation • Captive power plant • Steam generation Energy usage by processes • Analyze which process gets high energy consumption
33. . Energy monitoring & targeting Importance An effective monitoring & implementing system with adequate technical ability for analyzing energy saving options is key to ENERGY MANAGEMENT Energy monitoring and targeting is primarily a management technique that uses energy information as a basis to eliminate waste, reduce and control current level of energy use and improve the existing operating procedures. These techniques covers all plant and building utilities such as fuel, steam, refrigeration, compressed air, water, effluent, and electricity are managed as controllable resources in the same way that raw materials, finished product inventory, building occupancy, personnel and capital are managed.----It Becomes the “Energy Cost Centers.”
34. . Elements of Monitoring & Targeting System • Recording - Measuring and recording energy consumption • • Analyzing - Correlating energy consumption to a measured output, such as production quantity • • Comparing -Comparing energy consumption to an appropriate standard benchmark • • Setting Targets -Setting targets to reduce or control energy consumption • • Monitoring - Comparing energy consumption to the set target on a regular basis • • Reporting -Reporting the results including any variances from the targets which have been set • • Controlling - Implementing management measures to correct any variances, which may have been occurred. • Particularly M&T system will involve the following: • Checking the accuracy of energy invoices • Allocating energy costs to specific departments (Energy Accounting Centres) • Determining energy performance/efficiency • Recording energy use, so that projects intended to improve energy efficiency can bechecked * Highlighting performance problems in equipment or systems
35. . Data and Information Analysis • Plant level information can be derived from financial accounting systems-utilities cost centre • Plant department level information can be found in comparative energy consumption data for a group of similar facilities, service entrance meter readings etc. • System level (for example, boiler plant) performance data can be determined from sub metering data • Equipment level information can be obtained from nameplate data, run-time and schedule information, sub-metered data on specific energy consuming equipment
36. . Relating Energy Consumption and Production • After collection of energy consumption, energy cost and production data, the next stage of the monitoring process is to study and analyze the data and represent it for day to day controls—so represent it graphically
37. . Specific Energy Consumption(SEC) is energy consumption per unit of production
38. . CUSUM -Cumulative Sum • Cumulative Sum (CUSUM) represents the difference between the base line and the actual consumption points over the base line period of time. • This useful technique not only provides a trend line, it also calculates savings/losses to date and shows when the performance changes.
39. . CUSUM Technique CUSUM analysis 1 Plot the Energy - Production graph for the first 9 months 2. Draw the best fit straight line 3. Derive the equation of the line, y=mx+c 4. Calculate the expected energy consumption based on the equation 5. Calculate the difference between actual and calculated energy use 6. Compute CUSUM 7. Plot the

CUSUM graph 8. Estimate the savings accumulated from use of the heat recovery system 1-Given 4-Analysis-TABLE 2-plot graph 3-fit equation

40. . Case Study The CUSUM Technique Energy consumption and production data were collected for a plant over a period of 18 months. During month 9, a heat recovery system was installed. Using the plant monthly data, estimate the savings made with the heat recovery system. The plant data is given in Table 8.3: * toe = tonnes of oil equivalent.
41. . Based on the graph 8.10 (see Table 8.4), savings of 44 toe (50-6) have been accumulated in the last 7 months. This represents savings of almost 2% of energy consumption.
42. . 5-CUSUM -Analysis
43. . The Sankey Diagram and its Use The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment or system such as boiler, fired heaters, furnaces after carrying out energy balance calculation. This diagram represents visually various outputs and losses so that energy managers can focus on finding improvements in a prioritized manner. Example: The Figure 4.2 shows a Sankey diagram for a reheating furnace. From the Figure 4.2, it is clear that exhaust flue gas losses are a key area for priority attention.
44. . • We know, equation of slope, Y=mx+c Where, “y” is dependent variable(i.e energy consumption) “x” is independent variable(i.e production) “c” is the value at which the straight line curve intersect the “y” axis. “m” is the gradient of straight line curve. Least Square Method Therefore, Energy consumed for the period=C+m*production for the same period.
45. . • Consider the sample points, (X1,y1).(x2,y2)……(xn,yn) Therefore, Equation of straight lines are, 1. cn+m∑x=∑y 2. c∑x+m∑X2 = ∑xy….(on the basis of production i.e independent variable) n= no. of data points These equations are known as normal equations of the problems and they can be used to establish the value of “c” and “m”.

1.1 Introduction (Lighting System)

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.

1.2 Basic Terms in Lighting System and Features 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

Luminaire Luminaire is a device that distributes, filters or transforms the light emitted from one or more lamps. The luminaire includes, all the parts necessary for fixing and protecting the lamps, except the lamps themselves. In some cases, luminaires also include the necessary circuit auxiliaries, together with the means for connecting them to the electric supply. The basic physical principles used in optical luminaire are reflection, absorption, transmission and refraction.

Control Gear The gears used in the lighting equipment are as follows:

• **Ballast:** Acurrent limiting device, to counter negative resistance characteristics of any discharge lamps. In case of fluorescent lamps, it aids the initial voltage build-up, required for starting.

• **Ignitors:** These are used for starting high intensity Metal Halide and Sodium vapour lamps.

Illuminance This is the quotient of the illuminous flux incident on an element of the surface at a point of surface containing the point, by the area of that element. The lighting level produced by a lighting installation is usually qualified by the illuminance produced on a specified plane. In most cases, this plane is the major plane of the tasks in the interior and is commonly called the working plane. The illuminance provided by an installation affects both the performance of the tasks and the appearance of the space.

Lux (lx) : This is the illuminance produced by a luminous flux of one lumen, uniformly distributed over a surface area of one square metre. One lux is equal to one lumen per square meter.

Luminous Efficacy (lm/W) : This is the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. It is a reflection of efficiency of energy conversion from electricity to light form.

Colour Rendering Index (RI) Is a measure of the degree to which the colours of surfaces illuminated by a given light source confirm to those of the same surfaces under a reference illuminent; suitable allowance having been made for the state of Chromatic adaptation.

1.4 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). Afactor 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 theLumens / Watt Color Typical Type of Lamp Range Avg. Rendering Typical Application Life Index (hours) Incandescent 8–18 14 Excellent Homes, restaurants, 1000 general lighting, emergency lighting Fluorescent Lamps 46–60 50 Good w.r.t. Offices, shops, 5000 coating hospitals, homes Compact fluorescent 40–70 60 Very good Hotels, shops, 8000–10000 lamps (CFL) homes, offices High pressure 44–57 50 Fair General lighting in 5000 mercury (HPMV) factories, garages, car parking, flood lighting Halogen lamps 18–24 20 Excellent Display, flood 2000–4000 lighting, stadium exhibition grounds, construction areas High pressure sodium 67–121 90 Fair General lighting 6000–12000 (HPSV) SON in factories, ware houses, street lighting Low pressure sodium 101–175 150 Poor Roadways, tunnels, 6000–12000 (LPSV) SOX canals, street lighting 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 & 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/ Chemicals 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, s 300–500–750 terilising, washing, preparation of solutions, filling, capping, wrapping, hardening 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 200–300–500Paint 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

1.5 Methodology of Lighting System Energy Efficiency Study:

Astep-by-step approach for assessing energy efficiency of lighting system is given below:

Step–1: Inventorise the Lighting System elements, & transformers in the facility .

2.. No. Plant Lighting Rating in Watts Population No. of hours Location Device & Lamp & Ballast Numbers / Day Ballast Type

3. No. Plant Lighting Numbers Meter Provisions Available Location Transformer Installed Volts / Amps / kW / Energy Rating (kVA)

1. In case of distribution boards (instead of transformers) being available, fuse ratings may be inventorised along the above pattern in place of transformer kVA.

Step–2: With the aid of a lux meter, measure and document the lux levels at various plant locations at working level, as daytime lux and night time lux values alongside the number of lamps "ON" during measurement.

Step–3: With the aid of portable load analyzer, measure and document the voltage, current, power factor and power consumption at various input points, namely the distribution boards or the lighting voltage transformers at the same as that of the lighting level audit.

Step–4: Compare the measured lux values with standard values as reference and identify locations as under lit and over lit areas.

Step–5: Collect and Analyse the failure rates of lamps, ballasts and the actual life expectancy levels from the past data.

Step–6:Based on careful assessment and evaluation, bring out improvement options, which could include :

i) Maximise sunlight use through use of transparent roof sheets, north light roof, etc.

ii) Examine scope for replacements of lamps by more energy efficient lamps, with due consideration to luminiare, color rendering index, lux level as well as expected life comparison.

iii) Replace conventional magnetic ballasts by more energy efficient ballasts, with due consideration to life and power factor apart from watt loss.

iv) Select interior colours for light reflection.

v) Modify layout for optimum lighting.

vi) Providing individual / group controls for lighting for energy efficiency such as: a. On / off type voltage regulation type (for illuminance control) b. Group control switches / units c. Occupancy sensors d.

Photocell controls e. Timer operated controls f. Pager operated controls g. Computerized lighting control programs

vii) Install input voltage regulators / controllers for energy efficiency as well as longer life expectancy for lamps where higher voltages, fluctuations are expected.

viii) Replace energy efficient displays like LED's in place of lamp type displays in control panels / instrumentation areas, etc.

1.6 Case Examples Energy Efficient Replacement Options :

The lamp efficacy is the ratio of light output in lumens to power input to lamps in watts. Over the years development in lamp technology has led to improvements in efficacy of lamps. However, the low efficacy lamps, such as incandescent bulbs, still constitute a major share of the lighting load. High efficacy gas discharge lamps suitable for different types of applications offer appreciable scope for energy conservation. Typical energy efficient replacement options, along with the per cent energy saving.

Energy Saving Potential in Street Lighting The energy saving potential, in typical cases of replacement of inefficient lamps with efficient lamps in street lighting.

Lamp type Power savingSector

Existing Proposed Watts % Domestic/Commercial GLS 100 W *CFL 25 W 75 75 Industry GLS 13 W *CFL 9 W 4 31 GLS 200 W Blended 160 W 40 20 TL 40 W TLD 36 W 4 10 Industry/Commercial HPMV 250 W HPSV 150 W 100 37 HPMV 400 W HPSV 250 W 150 35

* Wattages of CFL includes energy consumption in ballasts.

Existing lamp Replaced units Saving

Type W Life Type W Life W % GLS 200 1000 ML 160 5000 40 7 GLS 300 1000 ML 250 5000 50 17 TL 2 X 40 5000 TL 2 X 36 5000 8 6 HPMV 125 5000 HPSV 70 12000 25 44 HPMV 250 5000 HPSV 150 12000 100 40 HPMV 400 5000 HPSV 250 12000 150 38

1.7 Some Good Practices in Lighting Installation of energy efficient fluorescent lamps in place of "Conventional" fluorescent lamps. Energy efficient lamps are based on the highly sophisticated tri-phosphor fluorescent powder technology. They offer excellent colour rendering properties in addition to the very high luminous efficacy.

Installation of Compact Fluorescent Lamps (CFL's) in place of incandescent lamps. Compact fluorescent lamps are generally considered best for replacement of lower wattage incandescent lamps. These lamps have efficacy ranging from 55 to 65 lumens/Watt. The average rated lamp life is 10,000 hours, which is 10 times longer than that of a normal incandescent

lamps. CFL's are highly suitable for places such as Living rooms, Hotel lounges, Bars, Restaurants, Pathways, Building entrances, Corridors, etc.

Installation of metal halide lamps in place of mercury / sodium vapour lamps. Metal halide lamps provide high color rendering index when compared with mercury & sodium vapour lamps. These lamps offer efficient white light. Hence, metal halide is the choice for colour critical applications where, higher illumination levels are required. These lamps are highly suitable for applications such as assembly line, inspection areas, painting shops, etc. It is recommended to install metal halide lamps where colour rendering is more critical.

Installation of High Pressure Sodium Vapour(HPSV) lamps forapplications where colour rendering is not critical. High pressure sodium vapour (HPSV) lamps offer more efficacy. But the colour rendering property of HPSV is very low. Hence, it is recommended to install HPSV lamps for applications such street lighting, yard lighting, etc.

Installation of LED panel indicator lamps in place of filament lamps. Panel indicator lamps are used widely in industries for monitoring, fault indication, signaling, etc. Conventionally filament lamps are used for the purpose, which has got the following disadvantages:

• High energy consumption (15 W/lamp)

• Failure of lamps is high (Operating life less than 1,000 hours)

• Very sensitive to the voltage fluctuations Recently, the conventional filament lamps are being replaced with Light Emitting Diodes (LEDs). The LEDs have the following merits over the filament lamps.
• Lesser power consumption (Less than 1 W/lamp)

• Withstand high voltage fluctuation in the power supply.

• Longer operating life (more than 1,00,000 hours) It is recommended to install LEDs for panel indicator lamps at the design stage.

Light distribution Energy efficiency cannot be obtained by mere selection of more efficient lamps alone. Efficient luminaires along with the lamp of high efficacy achieve the optimum efficiency. Mirror-optic luminaires with a high output ratio and bat-wing light distribution can save energy. For achieving better efficiency, luminaires that are having light distribution characteristics appropriate for the task interior should be selected. The luminaires fitted with a lamp should ensure that discomfort glare and veiling reflections are minimised. Installation of suitable luminaires, depends upon the height - Low, Medium & High Bay. Luminaires for high intensity discharge lamp are classified as follows:

• Low bay, for heights less than 5 metres.

• Medium bay, for heights between 5 – 7 metres.

• High bay, for heights greater than 7 metres.

1. Lighting System

160Bureau of Energy Efficiency

System layout and fixing of the luminaires play a major role in achieving energy efficiency. This also varies from application to application. Hence, fixing the luminaires at optimum height and usage of mirror optic luminaries leads to energy efficiency.

Light Control The simplest and the most widely used form of controlling a lighting installation is "On-Off" switch. The initial investment for this set up is extremely low, but the resulting operational costs may be high. This does not provide the flexibility to control the lighting, where it is not required. Hence, a flexible lighting system has to be provided, which will offer switch-off or reduction in lighting level, when not needed. The following light control systems can be adopted at design stage:

• Grouping of lighting system, to provide greater flexibility in lighting control Grouping of lighting system, which can be controlled manually or by timer control.

• Installation of microprocessor based controllers Another modern method is usage of microprocessor / infrared controlled dimming or switching circuits. The lighting control can be obtained by using logic units located in the ceiling, which can take pre-programme commands and activate specified lighting circuits. Advanced lighting control system uses movement detectors or lighting sensors, to feed signals to the controllers.

• Optimum usage of daylighting Whenever the orientation of a building permits, day lighting can be used in combination with electric lighting. This should not introduce glare or a severe imbalance of brightness in visual environment. Usage of day lighting (in offices/air conditioned halls) will have to be very limited, because the air conditioning load will increase on account of the increased solar heat dissipation into the area. In many cases, a switching method, to enable reduction of electric light in the window zones during certain hours, has to be designed.

• Installation of "exclusive" transformer for lighting In most of the industries, lighting load varies between 2 to 10%. Most of the problems faced by the lighting equipment and the "gears" is due to the "voltage" fluctuations. Hence, the lighting equipment has to be isolated from the power feeders. This provides a better voltage regulation for the lighting. This will reduce the voltage related problems, which in turn increases the efficiency of the lighting system.

• Installation of servo stabilizer for lighting feeder Wherever, installation of exclusive transformer for lighting is not economically attractive, servo stabilizer can be installed for the lighting feeders. This will provide stabilized voltage for the lighting equipment. The performance of "gears" such as chokes, ballasts, will also improved due to the stabilized voltage. This set up also provides, the option to optimise the voltage level fed to the lighting feeder. In many plants, during the non-peaking hours, the voltage levels are on the higher side. During this period, voltage can be optimised, without any significant drop in the illumination level.

• Installation of high frequency (HF) electronic ballasts in place of conventional ballasts New high frequency (28–32 kHz) electronic ballasts have the following advantages over the traditional magnetic ballasts: Energy savings up to 35% Less heat dissipation, which reduces the air conditioning load

• Lights instantly

• Improved power factor

• Operates in low voltage load

• Less in weight

• Increases the life of lamp

The advantage of HF electronic ballasts, out weigh the initial investment (higher costs when compared with conventional ballast). In the past the failure rate of electronic ballast in Indian Industries was high. Recently, many manufacturers have improved the design of the ballast leading to drastic improvement in their reliability. The life of the electronic ballast is high especially when, used in a lighting circuit fitted with a automatic voltage stabiliser.

Location Source Luminaire Gear Controls Plant HID/FTL Industrial rail reflector: Conventional/low Manual/electronic High bay loss electronic Medium bay ballast Low bay Office FTL/CFL FTL/CFL Electronic/low Manual/auto loss Yard HID Flood light Suitable Manual Road HID/PL Street light luminaire Suitable Manual peripheral

QUESTIONS 1. What are the types of commonly used lamps?

2. What do the following terms mean? – Illuminance – Luminous efficacy – Luminaire – Control gear – Colour rendering index

3. What is the function of ballast in a lighting system?

4. Rate the following with respect to their luminous efficacy – GLS lamp – FTL – CFL – HPSV – LPSV

5. Rate the following with respect to colour rendering index – GLS lamp – HPSV lamp – Metal halide lamps – LPSV lamp

6. Briefly describe the methodology of lighting energy audit in an industrial facility?

7. List the energy savings opportunities in industrial lighting systems.

8. Explain how electronic ballast saves energy?

9. ACFL can replace a) FTL b) GLS c) HPMV d) HPSV

10. Explain briefly about various lighting controls available?

Salient features of the Energy Conservation Act 2001

The Act empowers the Central Government and, in some instances, State Governments to:

- specify energy consumption standards for notified equipment and appliances;
- direct mandatory display of label on notified equipment and appliances;
- prohibit manufacture, sale, purchase and import of notified equipment and appliances not conforming to energy consumption standards;
- notify energy intensive industries, other establishments, and commercial buildings as designated consumers;
- establish and prescribe energy consumption norms and standards for designated consumers;
- prescribe energy conservation building codes for efficient use of energy and its conservation in new commercial buildings having a connected load of 500 kW or a contract demand of 600 kVA and above;
- direct designated consumers to:-

1. designate or appoint certified energy manager in charge of activities for efficient use of energy and its conservation;
2. get an energy audit conducted by an accredited energy auditor in the specified manner and interval of time;
3. furnish information with regard to energy consumed and action taken on the recommendation of the accredited energy auditor to the designed agency;
4. comply with energy consumption norms and standards;
5. prepare and implement schemes for efficient use of energy and its conservation if the prescribed energy consumption norms and standards are not fulfilled;

- get energy audit of the building conducted by an accredited energy auditor in this specified manner and intervals of time;

State Governments may –

1. amend the energy conservation building codes prepared by the Central Government to suit regional and local climatic conditions;
2. direct every owners or occupier of a new commercial building or building complex being a designated consumer to comply with the provisions of energy conservation building codes;
3. direct, if considered necessary for efficient use of energy and its conservation, any designated consumer to get energy audit conducted by an accredited energy auditor in such manner and at such intervals of time as may be specified;

8. LIGHTING SYSTEM

Syllabus
Lighting System: Light source, Choice of lighting, Luminance requirements, and Energy conservation avenues

8.1 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.

8.2 Basic Terms in Lighting System and Features

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

Luminaire

Luminaire is a device that distributes, filters or transforms the light emitted from one or more lamps. The luminaire includes, all the parts necessary for fixing and protecting the lamps, except the lamps themselves. In some cases, luminaires also include the necessary circuit auxiliaries, together with the means for connecting them to the electric supply. The basic physical principles used in optical luminaire are reflection, absorption, transmission and refraction.

Control Gear

The gears used in the lighting equipment are as follows:

- **Ballast:**

A current limiting device, to counter negative resistance characteristics of any discharge lamps. In case of fluorescent lamps, it aids the initial voltage build-up, required for starting.

- **Ignitors:**

These are used for starting high intensity Metal Halide and Sodium vapour lamps.

Illuminance

This is the quotient of the illuminous flux incident on an element of the surface at a point of surface containing the point, by the area of that element.

The lighting level produced by a lighting installation is usually qualified by the illuminance produced on a specified plane. In most cases, this plane is the major plane of the tasks in the interior and is commonly called the working plane. The illuminance provided by an installation affects both the performance of the tasks and the appearance of the space.

Lux (lx)

This is the illuminance produced by a luminous flux of one lumen, uniformly distributed over a surface area of one square metre. One lux is equal to one lumen per square meter.

Luminous Efficacy (lm/W)

This is the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. It is a reflection of efficiency of energy conversion from electricity to light form.

Colour Rendering Index (RI)

Is a measure of the degree to which the colours of surfaces illuminated by a given light source confirm to those of the same surfaces under a reference illuminent; suitable allowance having been made for the state of Chromatic adaptation.

8.3 Lamp Types and their Features

The Table 8.1 shows the various types of lamp available along with their features.

TABLE 8.1 LUMINOUS PERFORMANCE CHARACTERISTICS OF COMMONLY USED LUMINARIES

Type of Lamp	Lumens / Watt		Color Rendering Index	Typical Application	Typical Life (hours)
	Range	Avg.			
Incandescent	8–18	14	Excellent	Homes, restaurants, general lighting, emergency lighting	1000
Fluorescent Lamps	46–60	50	Good w.r.t. coating	Offices, shops, hospitals, homes	5000
Compact fluorescent lamps (CFL)	40–70	60	Very good	Hotels, shops, homes, offices	8000–10000
High pressure mercury (HPMV)	44–57	50	Fair	General lighting in factories, garages, car parking, flood lighting	5000
Halogen lamps	18–24	20	Excellent	Display, flood lighting, stadium exhibition grounds, construction areas	2000–4000
High pressure sodium (HPSV) SON	67–121	90	Fair	General lighting in factories, ware houses, street lighting	6000–12000
Low pressure sodium (LPSV) SOX	101–175	150	Poor	Roadways, tunnels, canals, street lighting	6000–12000

8.4 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 & 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/*

Chemicals

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, s terilising, 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

8.5 Methodology of Lighting System Energy Efficiency Study

A step-by-step approach for assessing energy efficiency of lighting system is given below:

Step–1: Inventorise the Lighting System elements, & transformers in the facility as per following typical format (Table – 8.2 and 8.3).

TABLE 8.2 DEVICE RATING, POPULATION AND USE PROFILE

S. No.	Plant Location	Lighting Device & Ballast Type	Rating in Watts Lamp & Ballast	Population Numbers	No. of hours / Day

TABLE 8.3 LIGHTING TRANSFORMER / RATING AND POPULATION PROFILE:

S. No.	Plant Location	Lighting Transformer Rating (kVA)	Numbers Installed	Meter Provisions Available Volts / Amps / kW / Energy

In case of distribution boards (instead of transformers) being available, fuse ratings may be inventorised along the above pattern in place of transformer kVA.

Step–2: With the aid of a lux meter, measure and document the lux levels at various plant locations at working level, as daytime lux and night time lux values alongside the number of lamps "ON" during measurement.

Step–3: With the aid of portable load analyzer, measure and document the voltage, current, power factor and power consumption at various input points, namely the distribution boards or the lighting voltage transformers at the same as that of the lighting level audit.

Step–4: Compare the measured lux values with standard values as reference and identify locations as under lit and over lit areas.

Step–5: Collect and Analyse the failure rates of lamps, ballasts and the actual life expectancy levels from the past data.

Step–6: Based on careful assessment and evaluation, bring out improvement options, which could include :

i) Maximise sunlight use through use of transparent roof sheets, north light roof, etc.

ii) Examine scope for replacements of lamps by more energy efficient lamps, with due consideration to luminiare, color rendering index, lux level as well as expected life comparison.

iii) Replace conventional magnetic ballasts by more energy efficient ballasts, with due consideration to life and power factor apart from watt loss.

iv) Select interior colours for light reflection.

v) Modify layout for optimum lighting.

vi) Providing individual / group controls for lighting for energy efficiency such as:
   a. On / off type voltage regulation type (for illuminance control)
   b. Group control switches / units
   c. Occupancy sensors
   d. Photocell controls
   e. Timer operated controls
   f. Pager operated controls
   g. Computerized lighting control programs

vii) Install input voltage regulators / controllers for energy efficiency as well as longer life expectancy for lamps where higher voltages, fluctuations are expected.

viii) Replace energy efficient displays like LED's in place of lamp type displays in control panels / instrumentation areas, etc.

8.6 Case Examples

Energy Efficient Replacement Options

The lamp efficacy is the ratio of light output in lumens to power input to lamps in watts. Over the years development in lamp technology has led to improvements in efficacy of lamps. However, the low efficacy lamps, such as incandescent bulbs, still constitute a major share of the lighting load. High efficacy gas discharge lamps suitable for different types of applications offer appreciable scope for energy conservation. Typical energy efficient replacement options, along with the per cent energy saving, are given in Table-8.4.

TABLE 8.4 SAVINGS BY USE OF HIGH EFFICACY LAMPS						
Sector	Lamp type				Power saving	
	Existing		Proposed		Watts	%
Domestic/Commercial	GLS	100 W	*CFL	25 W	75	75
Industry	GLS	13 W	*CFL	9 W	4	31
	GLS	200 W	Blended	160 W	40	20
	TL	40 W	TLD	36 W	4	10
Industry/Commercial	HPMV	250 W	HPSV	150 W	100	37
	HPMV	400 W	HPSV	250 W	150	35

* Wattages of CFL includes energy consumption in ballasts.

Energy Saving Potential in Street Lighting

The energy saving potential, in typical cases of replacement of inefficient lamps with efficient lamps in street lighting is given in the Table 8.5

TABLE 8.5 SAVING POTENTIAL BY USE OF HIGH EFFICACY LAMPS FOR STREET LIGHTING							
Existing lamp			Replaced units			Saving	
Type	W	Life	Type	W	Life	W	%
GLS	200	1000	ML	160	5000	40	7
GLS	300	1000	ML	250	5000	50	17
TL	2 X 40	5000	TL	2 X 36	5000	8	6
HPMV	125	5000	HPSV	70	12000	25	44
HPMV	250	5000	HPSV	150	12000	100	40
HPMV	400	5000	HPSV	250	12000	150	38

8.7 Some Good Practices in Lighting

Installation of energy efficient fluorescent lamps in place of "Conventional" fluorescent lamps.

Energy efficient lamps are based on the highly sophisticated tri-phosphor fluorescent powder technology. They offer excellent colour rendering properties in addition to the very high luminous efficacy.

Installation of Compact Fluorescent Lamps (CFL's) in place of incandescent lamps.

Compact fluorescent lamps are generally considered best for replacement of lower wattage incandescent lamps. These lamps have efficacy ranging from 55 to 65 lumens/Watt. The average rated lamp life is 10,000 hours, which is 10 times longer than that of a normal incandescent lamps. CFL's are highly suitable for places such as Living rooms, Hotel lounges, Bars, Restaurants, Pathways, Building entrances, Corridors, etc.

Installation of metal halide lamps in place of mercury / sodium vapour lamps.

Metal halide lamps provide high color rendering index when compared with mercury & sodium vapour lamps. These lamps offer efficient white light. Hence, metal halide is the choice for colour critical applications where, higher illumination levels are required. These lamps are highly suitable for applications such as assembly line, inspection areas, painting shops, etc. It is recommended to install metal halide lamps where colour rendering is more critical.

Installation of High Pressure Sodium Vapour (HPSV) lamps for applications where colour rendering is not critical.

High pressure sodium vapour (HPSV) lamps offer more efficacy. But the colour rendering property of HPSV is very low. Hence, it is recommended to install HPSV lamps for applications such street lighting, yard lighting, etc.

Installation of LED panel indicator lamps in place of filament lamps.

Panel indicator lamps are used widely in industries for monitoring, fault indication, signaling, etc. Conventionally filament lamps are used for the purpose, which has got the following disadvantages:

- High energy consumption (15 W/lamp)
- Failure of lamps is high (Operating life less than 1,000 hours)
- Very sensitive to the voltage fluctuations Recently, the conventional filament lamps are being replaced with Light Emitting Diodes (LEDs).

The LEDs have the following merits over the filament lamps.

- Lesser power consumption (Less than 1 W/lamp)
- Withstand high voltage fluctuation in the power supply.
- Longer operating life (more than 1,00,000 hours)

It is recommended to install LEDs for panel indicator lamps at the design stage.

Light distribution

Energy efficiency cannot be obtained by mere selection of more efficient lamps alone. Efficient luminaires along with the lamp of high efficacy achieve the optimum efficiency. Mirror-optic luminaires with a high output ratio and bat-wing light distribution can save energy.

For achieving better efficiency, luminaires that are having light distribution characteristics appropriate for the task interior should be selected. The luminaires fitted with a lamp should ensure that discomfort glare and veiling reflections are minimised. Installation of suitable luminaires, depends upon the height - Low, Medium & High Bay. Luminaires for high intensity discharge lamp are classified as follows:

- Low bay, for heights less than 5 metres.
- Medium bay, for heights between 5 – 7 metres.
- High bay, for heights greater than 7 metres.

System layout and fixing of the luminaires play a major role in achieving energy efficiency. This also varies from application to application. Hence, fixing the luminaires at optimum height and usage of mirror optic luminaries leads to energy efficiency.

Light Control

The simplest and the most widely used form of controlling a lighting installation is "On-Off" switch. The initial investment for this set up is extremely low, but the resulting operational costs may be high. This does not provide the flexibility to control the lighting, where it is not required.

Hence, a flexible lighting system has to be provided, which will offer switch-off or reduction in lighting level, when not needed. The following light control systems can be adopted at design stage:

- **Grouping of lighting system, to provide greater flexibility in lighting control**

Grouping of lighting system, which can be controlled manually or by timer control.

- **Installation of microprocessor based controllers**

Another modern method is usage of microprocessor / infrared controlled dimming or switching circuits. The lighting control can be obtained by using logic units located in the ceiling, which can take pre-programme commands and activate specified lighting circuits. Advanced lighting control system uses movement detectors or lighting sensors, to feed signals to the controllers.

- **Optimum usage of daylighting**

Whenever the orientation of a building permits, day lighting can be used in combination with electric lighting. This should not introduce glare or a severe imbalance of brightness in visual environment. Usage of day lighting (in offices/air conditioned halls) will have to be very limited, because the air conditioning load will increase on account of the increased solar heat dissipation into the area. In many cases, a switching method, to enable reduction of electric light in the window zones during certain hours, has to be designed.

- **Installation of "exclusive" transformer for lighting**

In most of the industries, lighting load varies between 2 to 10%. Most of the problems faced by the lighting equipment and the "gears" is due to the "voltage" fluctuations. Hence, the lighting equipment has to be isolated from the power feeders. This provides a better voltage regulation for the lighting. This will reduce the voltage related problems, which in turn increases the efficiency of the lighting system.

- **Installation of servo stabilizer for lighting feeder**

Wherever, installation of exclusive transformer for lighting is not economically attractive, servo stabilizer can be installed for the lighting feeders. This will provide stabilized voltage for the lighting equipment. The performance of "gears" such as chokes, ballasts, will also improved due to the stabilized voltage.

This set up also provides, the option to optimise the voltage level fed to the lighting feeder. In many plants, during the non-peaking hours, the voltage levels are on the higher side. During this period, voltage can be optimised, without any significant drop in the illumination level.

- **Installation of high frequency (HF) electronic ballasts in place of conventional ballasts**

New high frequency (28–32 kHz) electronic ballasts have the following advantages over the traditional magnetic ballasts:

Energy savings up to 35%

Less heat dissipation, which reduces the air conditioning load

- Lights instantly
- Improved power factor
- Operates in low voltage load
- Less in weight
- Increases the life of lamp

The advantage of HF electronic ballasts, out weigh the initial investment (higher costs when compared with conventional ballast). In the past the failure rate of electronic ballast in Indian Industries was high. Recently, many manufacturers have improved the design of the ballast leading to drastic improvement in their reliability. The life of the electronic ballast is high especially when, used in a lighting circuit fitted with a automatic voltage stabiliser.

The Table 8.6 gives the type of luminaire, gear and controls used in different areas of industry.

TABLE 8.6 TYPES OF LUMINAIRE WITH THEIR GEAR AND CONTROLS USED IN DIFFERENT INDUSTRIAL LOCATIONS

Location	Source	Luminaire	Gear	Controls
Plant	HID/FTL	Industrial rail reflector: High bay Medium bay Low bay	Conventional/low loss electronic ballast	Manual/electronic
Office	FTL/CFL	FTL/CFL	Electronic/low loss	Manual/auto
Yard	HID	Flood light	Suitable	Manual
Road peripheral	HID/PL	Street light luminaire	Suitable	Manual

QUESTIONS	
1.	What are the types of commonly used lamps?
2.	What do the following terms mean? – Illuminance – Luminous efficacy – Luminaire – Control gear – Colour rendering index
3.	What is the function of ballast in a lighting system?
4.	Rate the following with respect to their luminous efficacy – GLS lamp – FTL – CFL – HPSV – LPSV
5.	Rate the following with respect to colour rendering index – GLS lamp – HPSV lamp – Metal halide lamps – LPSV lamp
6.	Briefly describe the methodology of lighting energy audit in an industrial facility?
7.	List the energy savings opportunities in industrial lighting systems.
8.	Explain how electronic ballast saves energy?
9.	A CFL can replace a) FTL b) GLS c) HPMV d) HPSV
10.	Explain briefly about various lighting controls available?

REFERENCES

1. NPC Experiences

CHAPTER 1
INTRODUCTION

1.1 CONSERVATION OF ENERGY

Conservation of electrical energy is a vital area, which is being regarded as one of the global objectives. Along with economic scheduling in generation of electricity and use of modern equipments in transmission and distribution network, it is also important to optimize the energy requirement of electric loads.

It is said that energy saved is energy generated. Improving the efficiency of electrical equipment is now recognized in many countries as a less costly means than construction of new power plants for meeting some of the increased demand for electricity services [1]. In today's energy scenario, industries are the major consumers of electric energy produced in any country. Electrical motors, being the most widely used energy converters in any industry, even a small percentage of energy saving in it is considered to be a big deal in existing industrial drive applications.

1.2 METHODS OF ENERGY CONSERVATION

In India, about 60 % of the generated electricity is consumed by 3 – phase squirrel–cage Induction motors installed in industrial, agricultural and other applications. It is estimated that, every one percent reduction in energy consumption by this electric drive would save around Rs.500 crore per annum [2].

Several measures can be adopted for reducing energy losses in Induction motors and improving energy conservation. The recommended ways to achieve this are:

(i) By design modifications
(ii) By constructional modifications
(iii) By efficient operation

1.2.1 Design Modifications

Numerous noteworthy works have been carried out in the area of Induction motor design. One of the earliest was that of Erlicki and Applebaum [3] whose work focused on parameter optimization with relevance to consumer and national economy. The parameters so determined could ensure minimum cost_only and not the machine properties. Ramarathnam, et.al [4] optimized the Induction motor design, taking into account the active material cost alone. He used non – linear programming approach with different optimizing techniques. Chaoyang li and Arifur Rahman [5] presented a modified form of the Hooks and Jeeves approach. In most of the available literature, the main focus has been on the cost of the active material and not much on the operating cost. Bhimsing, et.al [6] have done optimization of Induction motor for various objective functions viz cost of active material, annual operating cost, overall cost, efficiency, power factor and the product of efficiency and power factor. In 1995, J.W. Nims. et.al [7] did a work on Power Transformer design using Genetic Algorithm. In 1997, Kenneth Price and Rainer Storn[8] highlighted the potential of Differential Evolution for fast optimization.

1.2.2 Constructional Modifications

Developing Induction motors is a standard technology with existing manufacturing infrastructure. They are preferred for their higher reliability and maintenance free operation. However, they have the disadvantages of decrease in speed with increase in load, slip-dependent rotor copper loss and low power-factor of operation. On the other hand, Synchronous motors have constant speed operation and better power-factor. But, they require DC excitation and extra starting arrangement. Permanent Magnet Induction - Synchronous Motor (PMISM) combines the advantages of both the above mentioned conventional motors. Permanent Magnet AC motors are attracting growing international attention for a wide variety of industrial applications, ranging from general-purpose line-start pump/fan drives [9] to high performance machine tool servos [10]. New development of more powerful and cost-effective PM materials is serving to accelerate those motor development efforts [11]. Combination of squirrel cage rotor with interior permanent magnet geometry provides possibilities for efficient steady state operation and robust line-starting [12,13]. Different models of PMISM were tried by various groups [14, 15, 16].

The conventional submersible motor pumping systems are inefficient due to the limitation in speed and usage of higher number of stages in deep wells [17]. The performance of the pumping system can be improved considerably when operated at higher speeds i.e. more than 3000 rpm (synchronous), which is the limiting speed for a 50 Hz motor with 2-pole construction. Running the motor pump at a higher speed can be realized by increasing the supply frequency, which yields reduction in number of stages in pump and volume of active material used in motor [18].

1.2.3 Efficient Operation

Variable voltage operation of partly loaded Induction motor attracted the attention of many researchers as a means of energy saving in this context [19-22]. In earlier works, the control strategy employed is basically a search technique, where the stator voltage is decreased in steps, until the motor current settles down to the lower value, for a given load. The search technique takes more time for reaching the optimum point than can normally be allowed. Also, no clear-cut design procedure for the controller is presented. Many step changes in motor voltage lead to poor dynamic response and also takes more time for reaching the optimum point. The fuzzy logic control approach is very useful for Induction motor drives since no exact mathematical model of the Induction motor or closed-loop system is required [23].

1.3 SCOPE OF THE THESIS

This thesis deals with the investigation that has been carried out with the aim of energy conservation in electric drives. Development of different prototype energy efficient electric drives fulfills the aim. Also, a novel method for predicting energy efficient operation of 3-phase Induction motor is established.

With the aim of developing Energy Efficient Induction Motor (EEIM) , design optimization is proposed to be carried out . Optimal design problem is considered as a non-linear multi – variable constrained problem. Imposition of a multitude of constraints makes optimization tedious. In this work, the following well established robust and optimization techniques are proposed for developing EEIM:

* Genetic Algorithm Technique
* Differential Evolution Technique

Based on the optimal design results obtained by Genetic Algorithm Technique, two EEIMs are proposed to be developed. Their ratings are 11 kW and 3.7 kW, 415 V, 3-phase, 50 Hz, 4-pole.

Another 11 kW, 415 V, 3-phase, 50 Hz, 4-pole EEIM is also proposed to be developed with the results obtained by Differential Evolution Technique.

For most of the industrial applications, Induction motors are preferred due to their robust construction, higher reliability and maintenance free operation. However, they have the disadvantages of decrease in speed with increase in load and low power factor. To overcome the above disadvantages it is proposed to develop a Permanent Magnet Induction – Synchronous Motor (PMISM). The proposed PMISM integrates the features of Permanent Magnet (PM) motors with those of conventional Induction and Synchronous motors. Combination of squirrel cage rotor with interior permanent magnet geometry provides possibilities for efficient steady state operation and good line starting. The synchronous operation eliminates the rotor copper loss which leads to improvement in efficiency. A prototype 1-phase, 0.75 kW, 230 V, 50 Hz, 2-pole PMISM is intended to be developed.

Attention was also given to Induction motors employed in agricultural pumping sector. In order to utilize the available ground water below 120 m depth, efficient bore-hole multistage submersible pumps are required. Due to the limitations in the diameter, the number of stages required in the conventional pumping system is very large for the high head applications (12–24). This leads to more moving parts and low efficiency. The performance of the pumping system can be improved considerably when operated at higher speeds i.e. more than 3000 rpm, which is the limiting speed for a 50 Hz motor with 2-pole construction as already mentioned. It is proposed to develop single stage submersible motor pumps of 2.2 kW for 100 mm size and 9.3 kW for 150 mm size bore wells for heads of 60 m, 2.0 lps and 120 m, 4.0 lps respectively in stainless steel body. They are to be operated with a microprocessor based controller capable of varying frequency up to 200 Hz . When the rotor speed is increased, say to 11 000 rpm, the rise in each stage is found to be very high. This will lead to reduction of number of stages to either 1 or 2.

Variable voltage operation of partly loaded Induction motor has attracted the attention of many researchers as a means of energy conservation . In a lightly loaded Induction motor , a large amount of energy is wasted which can be conserved by voltage control. There is a distinct stator voltage for each load condition for optimum performance. The fuzzy logic control approach is found to be very useful for Induction motor drives since no exact mathematical model of the Induction motor or the related closed loop system is required . A laboratory prototype fuzzy logic controller is proposed to be designed, developed and tested with 0.37 kW , 3-phase , 50 Hz , 4-pole Induction motor . The fuzzy logic controller will adjust the terminal voltage of the motor continuously, based on sampled values of current feedback , to maximize the efficiency of operation at any given load.

Modern computer and telecommunication systems place heavy demands on the availability and quality of the power supply . Invariably Uninterruptable Power Supply (UPS) system is used everywhere as a power conditioner. This work proposes the augmentation of solar photovoltaic supply with Electricity Board (EB) supply through supervisory controllers for energy conservation . A battery monitoring circuit in the proposed controller will sample the battery voltage , solar panel voltage and the EB supply in order to switch over between two modes (stand alone mode or grid interface mode) or sound an alarm if both the primary source (EB supply / solar photovoltaic supply) and secondary source (battery) fails. Energy conservation can be achieved by the proposed controller.

A novel prediction method for energy efficient operation of 3-phase Induction motors is also proposed which will greatly simplify the concept of voltage control in partly loaded condition. The prediction method is based on the standard approximate equivalent circuit model of 3-phase Induction motor. The variation of shunt branch elements of the equivalent circuit with the supply voltage is taken care of. New equation for slip at which the motor operates at its maximum efficiency (S_{em}) for a given input voltage is to be arrived at. With this equation, the voltage required to be applied to the motor for any desired power output can be predicted for energy efficient operation.

1.4 ORGANISATION OF THE THESIS

Following the introductory remarks and scope of the thesis in the present chapter, Chapter 2 deals with design, development and testing of energy efficient Induction motor implementing the powerful optimization techniques namely GA and DE at the design stage. Comparison of main dimensions and performance of the proposed motors with that of conventional motors of similar ratings are also presented.

Obtaining energy efficiency by constructional modification is presented in Chapter 3, with the design, development and testing of a prototype permanent magnet Induction Synchronous motor.

In Chapter 4, development works related to high frequency, energy efficient submersible motor pump system with suitable controller is discussed.

Chapter 5 deals with development of prototype fuzzy logic controller for energy efficient operation of partly loaded 3-phase Induction motor. The test results showing the improvement in efficiency are also provided.

Energy conservation procedure through solar power aided UPS with the developed controller is presented in Chapter 6.

In Chapter 7, a novel prediction method for energy efficient operation of 3-phase Induction motors is presented. A new equation for slip at which the motor operates at its maximum efficiency for a given input voltage is derived. Test results, obtained from several motors validating the newly derived formula, are also presented.

Summarization of the investigations carried out in this thesis is provided in Chapter 8.