ENERGY CONSERVATION AND MANAGEMENT

Electrical Energy Auditing & Energy Management

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Electrical Energy Auditing:
Potential areas for Electrical Energy Conservation in Various Industries - Energy Management Opportunities in Electrical Heating, Lighting System, Cable Selection - Energy Efficient Motors - Factors Involved in Determination of Motor Efficiency-Adjustable AC Drives, Application & its use Variable Speed Drives Belt Drives.

Energy Management:
Importance of Energy Management, Energy Economics - Discount Rate, Payback Period, Internal Rate of Return, Life Cycle Costing.

Definition & Objectives of Energy Management

The fundamental goal of energy management is to produce goods and provide services with the least cost and least environmental effect.

The term energy management means many things to many people. One definition of energy management is:

"The judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions"
(Cape Hart, Turner and Kennedy, Guide to Energy Management Fairmont press inc. 1997)

Another comprehensive definition is

"The strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total costs of producing the output from these systems"

The objective of Energy Management is to achieve and maintain optimum energy procurement and utilisation, throughout the organization and:

- To minimise energy costs / waste without affecting production & quality
- To minimise environmental effects.

Potential Areas for Electrical Energy Conservation in Industries

In the current energy scenario of the India, a fast and efficient solution is needed to review Industrial sector, manufacturing technologies and its energy (utilization) efficiency. The wastage of energy or loss in old and obsolete industrial technologies and machinery needs to be considered carefully as it has been noticed from the survey reports.

Energy Conservation potential in the industrial sector of our nation has been projected between 35 to 45 %. Energy conservation measures range from simple good house-keeping to modern state of art practices in plants and methodologies. To have proper understanding it is very essential to know what amount of energy is being consumed. Monitoring industrial energy utilization on continuous basis and relating it to the production is the first step of any energy conservation program. The agricultural sector is amongst the major energy consuming sectors followed by industrial sector. It is found that 50-55% of the energy consumption of the country is utilized for cooking activity – considering commercial as well as non-commercial energy.

INDIAN ENERGY SCENARIO

India being a developing country the energy generation and usage is as shown below. For any country the growth in over all can be understood from such data. The Fig1 and Fig 2 show the energy generation from different sources and sharing by central and state is mentioned. The energy generated from different sources give the insight to the usage of resources to meet the demand. RES includes all the renewable and new sources of generations. Fig 3 gives the statistics of energy over the years and energy units are in MU. As stated earlier the energy consumption is witnessing the country's growth in overall. Fig 4 shows per capita energy consumption of India. As India one of the growing country and it is clearly self explanatory. It is an indicator of either lesser production or practice of conservation measures.

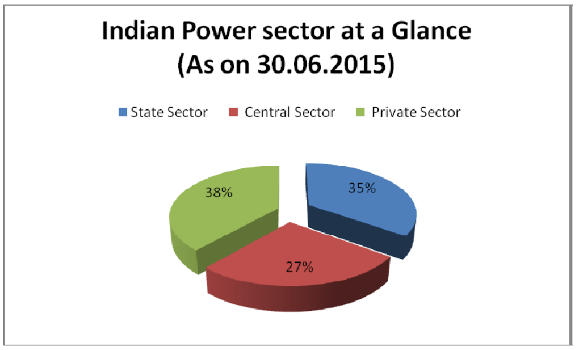


Fig 1

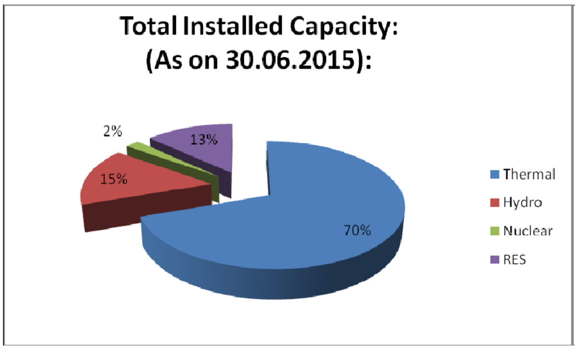


Fig 2

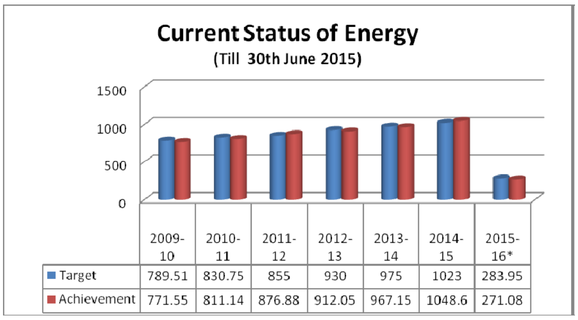


Fig 3

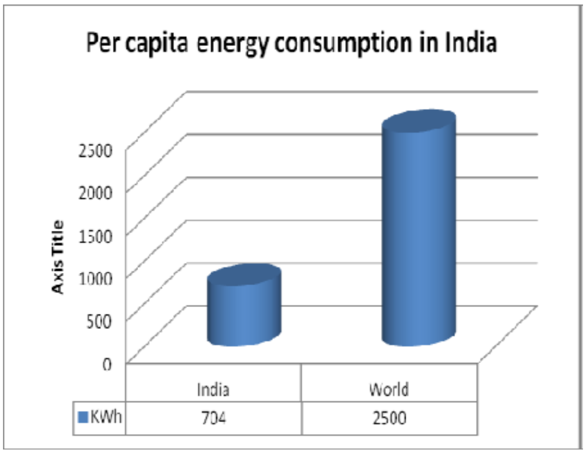


Fig 4

ENERGY CONSERVATION AND OPPORTUNITIES

Energy conservation is the scientific method of decreasing the quantity of energy used while achieving a similar outcome of end use. This practice enhances the national and personal security, human comfort and environmental value. Energy conservation is the most economical solution to energy shortages and more environmental friendly to benign with alternative to reduce energy production.

Energy conservation has been recognized as a national priority for saving energy and resources for the future use since a very long time. It is the lack of strong steps, seriousness, energy perspective and determination causing a minor short fall in the achievement of the country's target towards the same. The direct consumers like individuals and organizations need to conserve energy in order to reduce energy costs and promote economic, political and environmental state of the country. Industrial and commercial users need to find out solutions to increase efficiency and thus maximize profit by ultimate reduction in emissions. As energy conservation is an important part of reducing climate change thus incorporation of renewable energy systems adds the credits to the same.

Industrial Sector

Entire growth of a country mainly depends on industry and trading that result revenue to the country. The industrial sector is a major energy-consuming sector accounting nearly 45-50 % of the commercial energy available in the country. The general sources of energy for industries is from the coal accounts 56%, oil and gas about 40%, hydroelectric power of 3% and nuclear power 1%. Net industrial energy requirement is based on type of industry, capacity and location.

The industrial sector represents all production and processing of goods, including manufacturing, construction, farming, water management and mining. Typical components of the industries that consume power are represented in Fig 6. Increasing costs have forced energy-intensive industries to make substantial efficiency improvements in the past 30-35 years. A noticeable reduction in energy usage in steel and paper is about 35-45%, about 25% reduction in petroleum/aluminum refining and cement production. The reason for the reduction would be recycling the reusable/waste material and the practice of cogeneration equipment for electricity and heating. Fig. No: 5 shows electricity usage in Industrial sectors in India and Table 1 presents a possible opportunities in each of the industries.

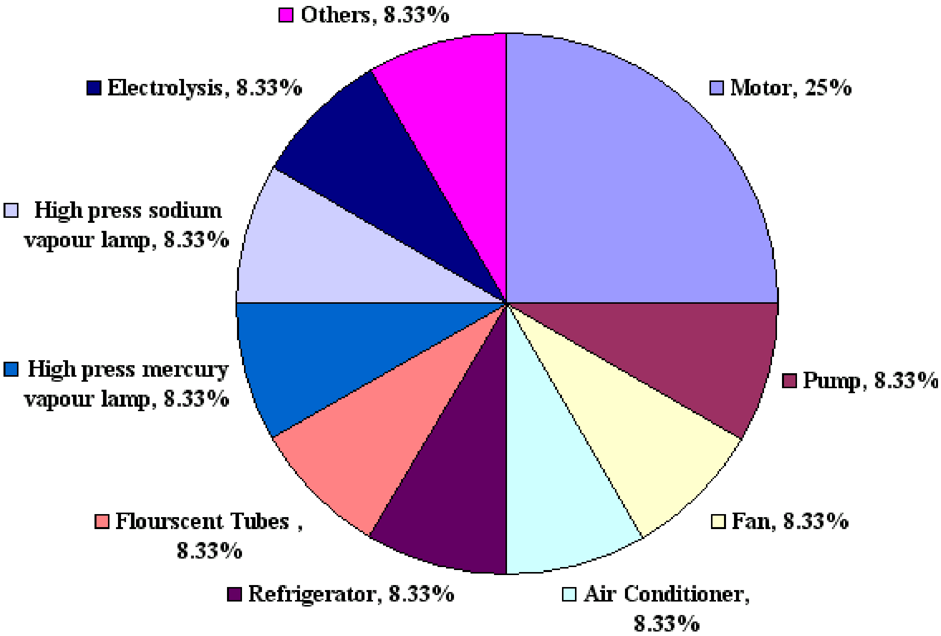


Fig 5

Table 1 Energy Conservation in Industrial Sector

Process	**Energy Saving Extent**
1 Choice location	Greater
2 Properly planned connected Capacity	Moderate
3 Standard of machines and equipments	Good
4 Sequence of operation	Good
5 Periodic calibration and maintenance	Good
6 Use of latest state of Technology, awareness of energy conservation measures/ Audit	Moderate

OBJECTIVE OF ENERGY MANAGEMENT

The objective of Energy Management is to achieve and maintain optimum energy procurement and utilization, throughout the organization and:

- To optimize specific energy consumption
- To minimize energy costs
- To minimise environmental effects.

Energy Audit

Energy Audit is the key to a systematic approach for decision making in the area of **energy management**.

It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility.

It quantifies energy usage according to its discrete functions.

Electrical Energy Auditing

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 "

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

Types of Energy Audits

1. Preliminary Energy Audit
2. Targeted Energy Audit
3. Detailed Energy Audit

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

Targeted Energy Audits

- 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.

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

The Ten Steps for Detailed Audit

Step No	PLAN OF ACTION	PURPOSE / RESULTS
Step 1	Phase I –Pre Audit Phase • Plan and organise • Walk through Audit • Informal Interview with Energy Manager, Production / Plant Manager	• Resource planning, Establish/organize a Energy audit team • Organize Instruments & time frame • Macro Data collection (suitable to type of industry.) • Familiarization of process/plant activities • First hand observation & Assessment of current level operation and practices
Step 2	Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.)	• Building up cooperation • Issue questionnaire for each department Orientation, awareness creation
Step 3	Phase II –Audit Phase Primary data gathering, Process Flow Diagram, & Energy Utility Diagram	• Historic data analysis, Baseline data collection • Prepare process flow charts • All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution. • Design, operating data and schedule of operation • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview)

Step 4	Conduct survey and monitoring	• Measurements : Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data.
Step 5	Conduct of detailed trials /experiments for selected energy guzzlers opportunities	• 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
Step 6	Analysis of energy use	• Energy and Material balance & energy loss/waste analysis
Step 7	Identification and development of Energy Conservation (ENCON)	• Identification & Consolidation ENCON measures • Conceive, develop, and refine ideas • Review the previous ideas suggested by unit personal • Review the previous ideas suggested by energy audit if any • Use brainstorming and value analysis techniques • Contact vendors for new/efficient technology
Step 8	Cost benefit analysis	• Assess technical feasibility, economic viability and prioritization of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step 9	Reporting & Presentation to the Top Management	• Documentation, Report Presentation to the top Management.
Step 10	Phase III –Post Audit phase Implementation and Follow-up	Assist and Implement ENCON recommendation measures and Monitor the performance • Action plan, Schedule for implementation • Follow-up and periodic review

Phase I -Pre Audit Phase Activities

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

Initial Site Visit and Preparation Required for Detailed Auditing

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

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

• Discuss with the site's senior management the aims of the energy audit.
• Discuss economic guidelines associated with the recommendations of the audit.
• Analyse the major energy consumption data with the relevant personnel.
• Obtain site drawings where available - building layout, steam distribution, compressed air distribution, electricity distribution etc.
• Tour the site accompanied by engineering/production

The main aims of this visit are: -

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

Phase II- Detailed Energy Audit Activities

Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out.

Whenever possible, checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.

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

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

1. Energy consumption by type of energy, by department, by major items of process equipment, by end-use
2. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)
3. Energy cost and tariff data
4. Process and material flow diagrams
5. Generation and distribution of site services (eg. compressed air, steam).
6. Sources of energy supply (e.g. electricity from the grid or self-generation)
7. Potential for fuel substitution, process modifications, and the use of co-generation systems (combined heat and power generation).

8. Energy Management procedures and energy awareness training programs within the establishment.

Existing baseline information and reports are useful to get consumption pattern, production cost and productivity levels in terms of product per raw material inputs. The audit team should collect the following baseline data:

- Technology, processes used and equipment details
- Capacity utilisation
- Amount & type of input materials used
- Water consumption
- Fuel Consumption
- Electrical energy consumption
- Steam consumption
- Other inputs such as compressed air, cooling water etc
- Quantity & type of wastes generated
- Percentage rejection / reprocessing
- Efficiencies / yield

DATA COLLECTION HINTS

It is important to plan additional data gathering carefully. Here are some basic tips to avoid wasting time and effort:

• measurement systems should be easy to use and provide the information to the accuracy that is needed, not the accuracy that is technically possible

• measurement equipment can be inexpensive (flow rates using a bucket and stopwatch)

• the quality of the data must be such that the correct conclusions are drawn (what grade of prod uct is on, is the production normal etc)

• define how frequent data collection should be to account for process variations.

• measurement exercises over abnormal workload periods (such as startup and shutdowns)

• design values can be taken where measurements are difficult (cooling water through heat exchanger)

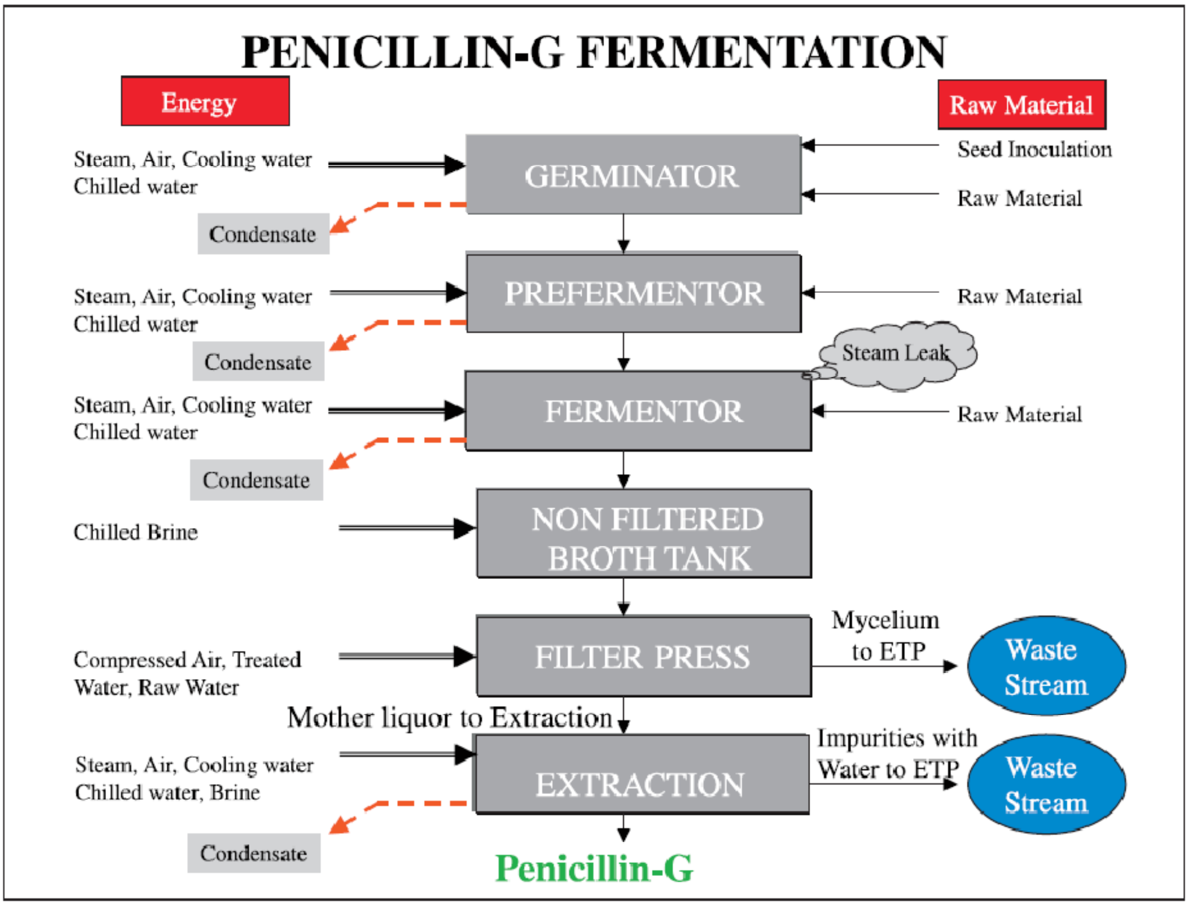
DO NOT ESTIMATE WHEN YOU CAN CALCULATE
DO NOT CALCULATE WHEN YOU CAN MEASURE

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

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

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

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



Identification of Energy Conservation Opportunities

Fuel substitution: Identifying the appropriate fuel for efficient energy conversion

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

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

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

Technical and Economic feasibility
The technical feasibility should address the following issues
• Technology availability, space, skilled manpower, reliability, service etc
• The impact of energy efficiency measure on safety, quality, production or process.
• The maintenance requirements and spares availability
The Economic viability often becomes the key parameter for the management acceptance. The economic analysis can be conducted by using a variety of methods. Example: Pay back method, Internal Rate of Return method, Net Present Value method etc. For low investment short duration

measures, which have attractive economic viability, simplest of the methods, payback is usually sufficient. A sample worksheet for assessing economic feasibility is provided below:

Sample Worksheet for Economic Feasibility
Name of Energy Efficiency Measure

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

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

Classification of Energy Conservation Measures

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

1. Low cost - high return;
2. Medium cost - medium return;
3. High cost - high return

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

Project Priority Guideline

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

Energy Audit Reporting Format

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

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

4.0 Detailed Process flow diagram and Energy& Material balance
- 4.1 Flow chart showing flow rate, temperature, pressures of all input- Output streams
- 4.2 Water balance for entire industry

5.0 Energy efficiency in utility and process systems
- 5.1 Specific Energy consumption
- 5.2 Boiler efficiency assessment
- 5.3 Thermic Fluid Heater performance 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

Energy Audit Instruments

The requirement for an energy audit such as identification and quantification of energy necessitates measurements; these measurements require the use of instruments. These instruments must be portable, durable, easy to operate and relatively inexpensive. The parameters generally monitored during energy audit may include the following:

Basic Electrical Parameters in AC &DC systems - Voltage (V), Current (I), Power factor, Active power (kW), apparent power (demand) (kVA), Reactive power (kVAr), Energy consumption (kWh), Frequency (Hz), Harmonics, etc.

Parameters of importance other than electrical such as temperature & heat flow, radiation, air and gas flow, liquid flow, revolutions per minute (RPM), air velocity, noise and vibration, dust concentration, Total Dissolved Solids (TDS), pH, moisture content, relative humidity, flue gas analysis - CO_2, O_2, CO, SO_x, NO_x, combustion efficiency etc.

Key instruments for energy audit are listed below.

The operating instructions for all instruments must be understood and staff should familiarize themselves with the instruments and their operation prior to actual audit use.

Electrical Measuring Instruments:

These are instruments for measuring major electrical parameters such as kVA, kW, PF, Hertz, kVAr, Amps and Volts. In addition some of these instruments also measure harmonics.

These instruments are applied on-line i.e on running motors without any need to stop the motor. Instant measurements can be taken with hand-held meters, while more advanced ones facilitates cumulative readings with print outs at specified intervals.

Combustion analyzer:

This instrument has in-built chemical cells which measure various gases such as O_2, CO, NO_X and SO_X.

Fuel Efficiency Monitor:

This measures oxygen and temperature of the flue gas. Calorific values of common fuels are fed into the microprocessor which calculates the combustion efficiency.

Fyrite:

A hand bellow pump draws the flue gas sample into the solution inside the fyrite. A chemical reaction changes the liquid volume revealing the amount of gas. A separate fyrite can be used for O_2 and CO_2 measurement.

Contact thermometer:

These are thermocouples which measures for example flue gas, hot air, hot water temperatures by insertion of probe into the stream.

For surface temperature, a leaf type probe is used with the same instrument.

Infrared Thermometer:

This is a non-contact type measurement which when directed at a heat source directly gives the temperature read out. This instrument is useful for measuring hot spots in furnaces, surface temperatures etc.

Pitot Tube and manometer:

Air velocity in ducts can be measured using a pitot tube and inclined manometer for further calculation of flows.

Water flow meter:

This non-contact flow measuring device using Doppler effect / Ultra sonic principle. There is a transmitter and receiver which are positioned on opposite sides of the pipe. The meter directly gives the flow. Water and other fluid flows can be easily measured with this meter.

Tachometer

Stroboscope

Speed Measurements:

In any audit exercise speed measurements are critical as thay may change with frequency, belt slip and loading.

A simple tachometer is a contact type instrument which can be used where direct access is possible.

More sophisticated and safer ones are non contact instruments such as stroboscopes.

Leak Detectors:

Ultrasonic instruments are available which can be used to detect leaks of compressed air and other gases which are normally not possible to detect with human abilities.

Lux meters:

Illumination levels are measured with a lux meter. It consists of a photo cell which senses the light output, converts to electrical impulses which are calibrated as lux.

Energy Management Opportunities in Electrical Heating, Lighting System, Cable Selection

Electrical Heating

Overview of the Process Heat Systems Audit Standard

Process Heat systems are used extensively to provide heating for various industrial processes — essential to the daily operation of many companies. Such systems include indirect heating steam boiler and hot water generator systems, as well as direct-heating systems such as gas-fired drying ovens.

This Audit Standard provides an approach to heating system auditing and analysis. The objectives of the standard are to:

a) provide the framework for the systematic collection of data relevant to the efficient operation of heating systems; and

b) enable the heating system auditor to analyse the performance of the system, identify potential energy savings and provide sound recommendations for implementation of energy efficiency initiatives.

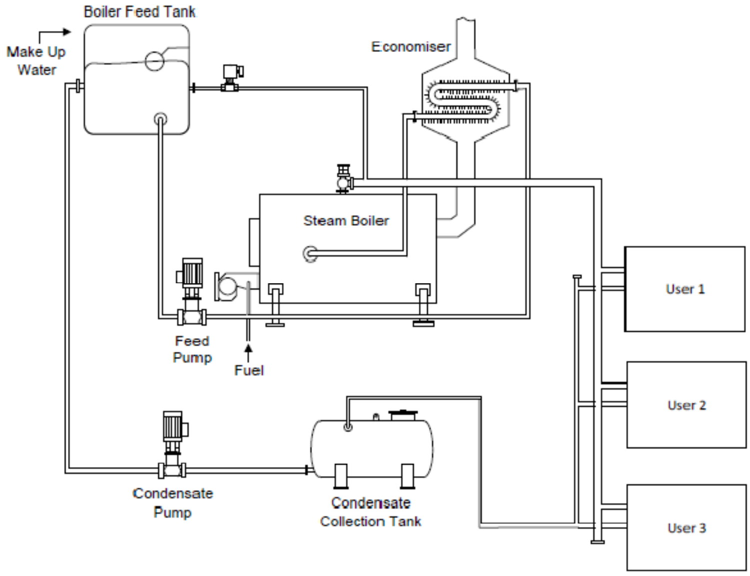
The scope of the Audit Standard is direct or indirect industrial heating systems, including distributed systems such as air, high-temperature fluids (e.g. thermal oil), steam and hot water systems, as well as direct process heating systems.

Assessing the efficiency of a heating system amounts to assessing the system's efficiency in *fulfilling the purpose that the heating process is serving.*

The boundary of the system concerned extends from the energy input to the heating system, whether via burning of a fuel or consuming electricity, to the point where the business purpose of generating the heat is achieved.

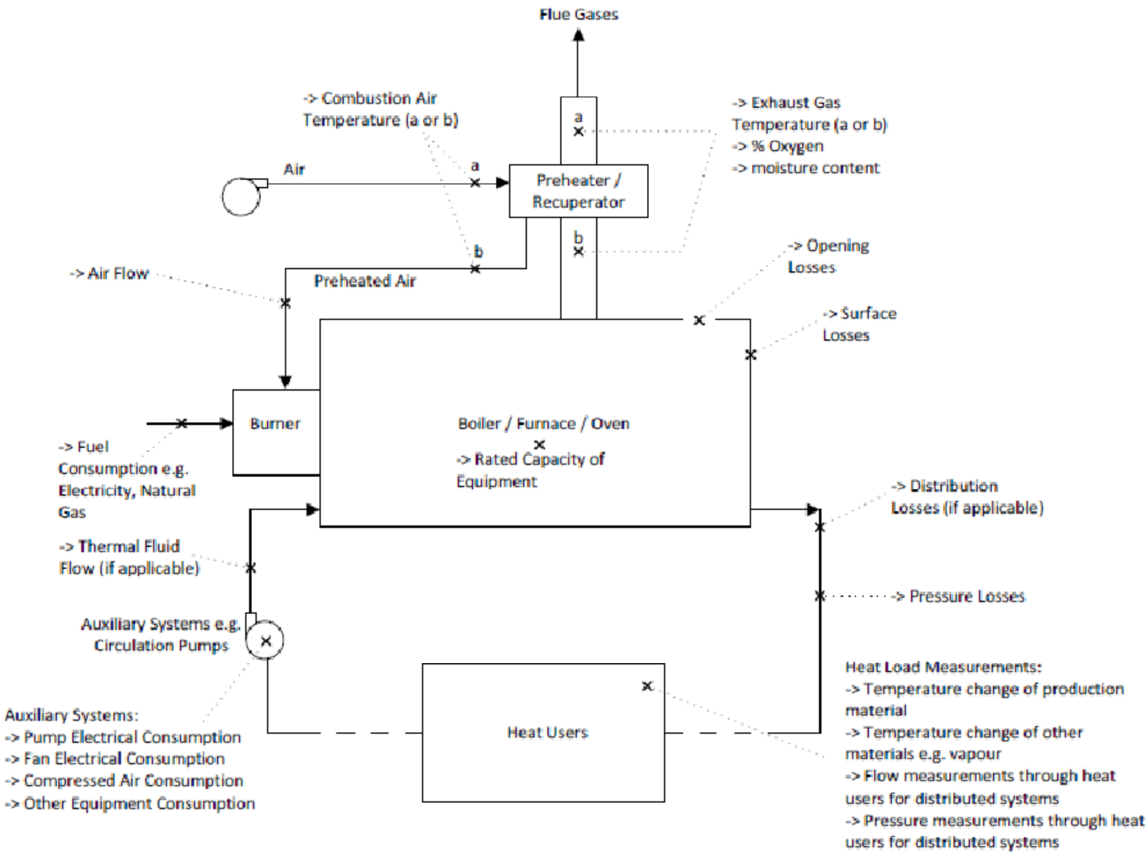
For example, that business purpose may be to provide heat for a cooking process (in the case of an oven) or to provide heat for a drying process (such as in the case of a lumber kiln) or to induce a chemical reaction. It is important to understand the ultimate goal of a process to ensure that any potential system changes are compatible.

The system boundary is therefore defined by the points beyond which any change to the system no longer has any effect on the business purpose that the system is serving. Figure shows the components within a typical system boundary, in this case a steam heating system.



Heating System Boundary (e.g. Steam)

Heating System Data Acquisition or Direct Measurement Suggestions



On-site Measurements and Data Collection

This section details the measurement requirements for a Process Heat system audit conducted to investment-level accuracy, and provides some guidance on what may be sufficient when auditing to the (lower) base level of accuracy.

In the first part, the measurement methods are outlined, followed by the measurement requirements for the site and systems being audited.

Measurement Methods

1 Pressure Measurements

Pressure measurement techniques vary depending on the part of the heating system being measured, the pressure ranges and therefore the accuracy of the measurement required. In general, there can be three levels of measurement with various measurement equipment depending on the application:

- Low Pressure (pressure<250Pa) —flow through a duct, furnace/oven or draft through a burner. Suitable measurement equipment includes an inclined manometer or digital manometer.
- Mid-range Pressure (pressure<7kPa) —combustion air and gaseous fuel flow. Suitable measurement equipment includes a liquid manometer or digital manometer.
- High Pressure (pressure>7kPa) —steam, fuel oil and compressed air. The pressure measurement for higher pressures requires the use of accurate calibrated gauges or pressure transducer.

It is important to note that low-quality pressure gauges are easily accessible and at low cost, but often will not provide the accuracy required for later analysis. Liquid-filled manometers are inherently accurate but can be impractical, while digital manometers are also accurate but require regular calibration to maintain their accuracy.

The accuracy of a pressure measurement instrument should be verified by comparison of its measurements with those from a gauge calibrated according to a standard such as AS 1349:1986 or BSI EN837.1.

For a base-level audit, it is recommended that values are noted if there are pressure gauges or transducers already in the network.

2 Flow Measurements

Knowledge of liquid or gas flows is important to understand a heating system's performance. Intrusive flow meters may be used, although installation can be difficult or disruptive to production. Non-intrusive ultrasonic flow meters are a useful tool in determining system characteristics, especially in the case of closed-loop hot-water systems.

Flow measurement varies depending on the part of the heating system being measured, whether the flow is gaseous or liquid, as well as the accuracy of the measurement required. Flow can generally be categorised into three main types, with various suitable measurement equipment depending on the application;

- Combustion Air or Gas Flow —several different devices are suitable depending on the application, including an orifice meter, differential manometer/pitot tube, inline turbines and a flow scope.
- Liquid Flow (e.g. water, fuel oil, other process liquids) —suitable devices include external clamp-on ultrasonic flow meters, electromagnetic flow, vortex meters, and inline turbine or roots flow meters.
- Steam Flow —there are various types of steam-flow meters that are often installed during the commissioning of a steam system. A common steam-flow meter is the simple orifice plate meter, although it has limited turndown so may not be suitable if a wide flow range. A

Variable Area meter, which has turndown of 100:1 is a good selection for measuring a wide flow range

Ideally, some of this equipment will already be installed onsite, as it may be difficult to install this equipment (especially intrusive meters) in an industrial setting due to production requirements. This highlights the need for advanced audit planning to ensure that all measurement requirements are met. This may require the installation of measurement devices outside regular production periods.

It is important to note that there are many factors that can influence a flow reading obtained from a meter, and the suitability and accuracy of each meter must be understood. Meter accuracy is generally affected by turbulence and so requires a certain length of straight pipe upstream and downstream; installation near valves or elbows, for instance, will negatively affect the accuracy of the readings from the meter. The condition of the heating medium may also affect readings, for example air bubbles in water flow, or condensate in steam flow. Density compensation is usually also required for gas and steam metering to ensure flows are accurate when pressure and temperature vary.

Because flows may be dynamic, periodic and transient, local flow measurements should be taken over a period that captures the full range of operating requirements. Periods of maximum and minimum demands need to be captured, as well as rates of change of flow.

3 Temperature Measurements

Knowledge of liquid or gas temperatures is crucial to understand a heating system's performance. Temperature measurements vary depending on the part of the heating system being measured, whether the flow is gaseous, liquid or solid, as well as the accuracy of the measurement required. Temperature measurements can be categorized into three groups based on the state of the substance being measured;

- Gas Temperature —several different devices are suitable depending on the temperature. For lower temperatures (<600°C), a thermocouple or resistance thermometer (RTD) is sufficient, while at higher temperatures (>600°C), where radiation is a large factor, suction pyrometers may be required.
- Liquid Temperature —for low-pressure situations a resistance thermometer (RTD) is sufficient, while at higher pressures or in abrasive environments thermometers must be in thermowells (often already installed at various locations throughout a distributed heating system).
- Solid Temperature —if temperatures are low enough and the solid surface is accessible, a thermocouple or resistance temperature detector (RTD) is recommended. However, for higher temperatures and less-accessible surfaces, thermal imaging cameras and/or optical pyrometers are very useful. Thermal imaging cameras are particularly useful for insulation surveys of the piping network of distributed systems. It is important to note that the emissivity of solid surfaces must be known, as this parameter is used by thermal imaging software to determine the temperature of a material's surface. Particular caution must be taken when measuring the temperature of surfaces with low emissivity, such as stainless steel, as this may lead to large measurement errors.

Most heating systems have in-built temperature measurement systems, as this is usually the most important variable that must be controlled within a heating process.

In all cases of temperature measurement, the most accurate measurement will be taken directly from gas or liquid flows or solid surfaces. If this is not possible, the surface temperature of piping or ducts can be used, and in this case RTDs or thermocouples must be covered by a piece of insulation.

Because temperatures often vary for a given process, local temperature measurements should be taken over a period that captures the full range of operating requirements, including periods of maximum and minimum demand.

4 Energy Usage Measurements

Electricity Usage

For investment-level audits, electricity usage should be measured at the terminals of the heating devices or at the terminals of motors driving auxiliary equipment such as fans and pumps. For each pump motor, a three-phase electricity meter (with data-logging) should be used to record kilowatt (kW) and kilowatt hour (kWh) usage. Particularly where the equipment exhibits variable demand characteristics, it is recommended that the power readings are logged at intervals of not greater than 10 seconds. For instance, electric resistive elements within an oven may switch on and off regularly to maintain changing temperature set points.

If the electricity line charges are based on kilovolt-ampere (kVA) measurement and the site does not have power factor correction upstream of the electrical users, kVA demand should be either directly measured or otherwise assessed.

Fuel Usage

Measuring the fuel consumption of different fuel-burning heating devices may be much more difficult than for electrical devices. A wide variety of fuels exist, including natural gas, different grades of oil and waste oil, biomass such as wood chip and sawdust, and different grades of coal. In some plants, fuel usage of different devices will be measured; however, in many cases this will not occur. For fluid fuels, refer to Section 2 for flow measurement techniques. To measure solid-fuel usage, direct observation of the consumption should take place if the consumption is not already monitored.

Measurements of electricity and fuel usage should be taken for a period of time sufficient to capture the weekly operational pattern of the heating system. For instance, electrical loggings of a boiler can be useful by showing the cycling of the burner, though temperature loggings will be required to determine if the boiler is in high-fire or low-fire if it is a two-stage system. In addition, in order to put the weekly profile into an annual usage context, it is necessary to obtain an annual profile of production and/or energy use. Investment-level accuracy of the annual usage estimate requires consideration of both the weekly and annual profile data.

5 Electricity Cost Estimation

Wherever the audit findings are likely to be used in any investment analysis undertaken by the client, the electricity costs used in valuing the electricity consumption of the heating system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

Annual average prices can generally be used unless there are considerable seasonal variances in production (heating system consumption) patterns. Any seasonal electricity price variations should be recognised in any calculation of production-weighted annual average prices.

The effect of any demand and/or capacity charges should also be accounted for. Where differences in electricity use are being valued, the valuation needs to consider that some elements of the delivered electricity price may be independent of the consumption level. Any fully fixed elements of the electricity price need to be removed from the cost used to value a consumption difference.

For the purposes of a base-level audit, if the client does not have a standard electricity cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average electricity cost (total cost divided by total energy consumed) for the valuing of electricity use.

If relevant, the effect of power factor on delivered electricity costs to the heating system should be recognised. On most electricity distribution networks, a premium is chargeable if a power factor of less than 0.95 is measureable at the site-entry metering point. The audit should identify if the site would benefit from the installation of power factor correction equipment at the main switchboard (or any sub-board for the supply of heating systems), as that information is important to the assessment of existing and future delivered electricity costs for the site concerned.

The absence of power factor correction equipment on the site would normally result in a recommendation to the client to investigate the economics of correcting that situation.

6 Fuel Cost Estimation

As for electricity consumption, wherever the audit findings are likely to be used in any investment analysis undertaken by the client, the costs used in valuing the fuel consumption of the heating system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

Annual average prices can generally be used unless there are considerable seasonal variances in production (heating system consumption) patterns.

Fuel consumption differs from electricity consumption in that combustion efficiency and thermal efficiency must also be taken into account to determine the true fuel cost (or 'effective energy cost'). For example, in the case of a steam boiler system, combustion analysis of the burner may reveal a fuel combustion efficiency of 80% during typical operating conditions and the thermal efficiency of the boiler as 95%. For a fuel cost of $0.04/kWh, the effective energy cost for any user of the steam produced is therefore $0.053/kWh ($0.04/{0.80x0.95}). There are also several other factors to consider when determining the true cost of heat use, especially for complex dynamic systems.

For the purposes of a base-level audit, if the client does not have a standard fuel cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average fuel cost (total cost divided by total energy consumed) for the valuing of fuel use, and typical combustion and thermal efficiencies can be assumed.

7 Works Cost Estimates

Particularly where the audit is undertaken for investment proposal purposes, the findings will include recommendations for works to be performed to exploit efficiency opportunities.

With guidance from the client with regard to whom to consult with, it is expected that compiling budget estimates for such will require consultation with a range of equipment suppliers or maintenance engineering companies. The level of accuracy of the cost estimates should meet the client's requirement. For investment proposal purposes, the accuracy expectation will typically be in the order of ±15%.

<u>Demand Data-Collection and Measurements</u>

For each system being audited, record characteristics of the heat-transfer medium, how it is being transferred and how it is being used or misused, including:

- nature of the heat-transfer medium, including properties that influence the requirements and performance of the system;
- heat-use isolation practices;
- peak-load shedding practices for electrical equipment;
- identification of inappropriate uses of the heat (and hence questionable demand);
- the nature of product handling and scheduling in the case of batch systems;
- pressure measurements, including the pressure of the heat-transfer medium through major heat users;
- flow measurements, including the flow of the heat-transfer medium through major heat users, and flow through auxiliary equipment such as pumps or fans;
- temperature measurements, including the temperature of products, the inside of furnaces and ovens, or the heat-transfer medium through major heat users;
- heat-transfer medium leakage (e.g. steam leakage), estimating each leak rate where possible;

- temperature measurement of solid surfaces to determine heat losses associated with heat users or the heat containment effectiveness of ovens and furnaces.

<u>Network Data-Collection and Measurements</u>

In the case of indirect heating systems, network measurements must also be considered. Record key characteristics of the network delivering and returning the heat-transfer medium, including:

- pipework or ducting configuration and sizing;
- areas of high pressure/frictional losses including under-sized pipework;
- the level of network maintenance practiced;
- the effects of any valves, meters and filters, particularly any misuses;
- the effects of any alterations made to the heating system network's original design;
- steam trap conditions;
- pressure measurements, including the pressure losses across major network components;
- flow measurements, including the flow of the heat-transfer medium through major sections of the network;
- temperature measurements, including the temperature of the heat-transfer medium at different points throughout the network;
- temperature measurement of solid surfaces to determine heat losses from pipework or other components. This is useful for later analysis of potential insulation initiatives.

Note that identifying areas of high pressure loss and frictional loss in indirect distributed systems may require additional software assistance. There are several software packages that may aid in identifying potential network inefficiencies.

<u>Generation Data-Collection and Measurements</u>

Record the key characteristics of the generation side of the heating system, including:

- nameplate information of heating device, including model, type, capacity etc.;
- burner information, including kW rating, control and likely efficiency;
- electric element and motor information, including kW rating and control;
- heat generator energy logging for the period specified through the audit scoping;
- heat generator flow or temperature logging for the period specified through the audit scoping (if an electrical logging does not provide sufficient information);
- the level of maintenance which takes place;
- heat-generation control method and extent of use of the control (expected to be observed through power, temperature, or flow logging);
- pressure measurements, the supply pressure of the delivery medium (such as steam pressure);
- flow measurements, including flow of exhaust gas and fuel consumption;
- temperature measurements, including temperature of input and exhaust gases;
- obtain any previous combustion analysis data from prior tests, which are often readily available;
- temperature measurement of the body of the heat generation device to determine heat losses and therefore the heat containment effectiveness;
- flue gas composition with the use of current measurement systems or via combustion gas analyser;
- the performance of existing heat recovery systems such as boiler economisers;
- blowdown control in the case of steam systems;
- heat-generation plant control practices;

- auxiliary system control such as pumps and fans, including Variable Speed Drive (VSD) information. Note that there are other auditing standards for fans and pumps which outline the optimum control methods for such systems.

Heating Systems Data Analysis

With respect to indirect heating systems, particular focus will be given to steam and hot water systems as together they are the most common forms of indirect systems. Despite this, many of the analysis principles can be applied to all other forms of distributed heating systems with different heat-transfer media such as thermal oil.

Likewise, many of the analysis principles discussed with respect to indirect distributed heating systems can also be applied to direct heating systems.

Process heating systems come in a wide variety of forms. Systems can range from direct heating of a product with a flame to complex processes involving highly controlled temperatures such as for annealing. Because process heating systems encompass such a diverse collection of technologies, this audit standard cannot provide in-depth guidance for all systems, but will cover broad principles that should be evaluated when assessing a system.

It is important to note that any assessment should focus first on the demand side of a system before any optimisation of the supply side. Often, supply-side measures are investigated without first considering potential measures to reduce the demand, and this is not ideal. For this reason, demand-side analysis is initially covered in following Sections followed by system network (distribution) analysis, finally system heat generation (supply-side) analysis, the last section covers waste heat recovery analysis.

Demand-Side Assessment

Analysis of heating demand throughout a heating system requires the optimisation of heat use. Solutions to improve the efficiency of this use include, but are not limited to:

- manual or automated isolation of heat users
- scheduling of electrical heating system operation outside electricity network peak charge periods
- reduction of heat or temperature consumption by users
- reduction of pressure requirements by users
- reduction of flow requirements by users
- reduction in leaks, particularly relevant to steam leakage, direct heating and indirect high-temperature fluids such as thermal oil
- improvement of heat-exchange surface
- ensuring all system components are adequately insulated
- utilisation of lash steam within the heating system

Any improvement in the use of heat on the demand side ultimately reduces the energy input required from the system's heating device. Calculations of fuel or power consumption reductions must take into account combustion and thermal efficiency. For base-level audits, reduction in fuel or power consumption can be calculated based on assumed combustion and thermal efficiency.

Potential recommendations should be assessed and evaluated using both technical and economic considerations. Where possible, recommendations should be selected and reported to the client before the supply-side study is undertaken so that feedback from the client with respect to the likelihood of any implementation can be factored into any supply side study.

Indirect (Distributed) System Network

Analysis of a heating system network requires the determination of the heating fluid's delivery efficiency. This requires the measurement of pressure losses and flow through different sections of the network.

Solutions to improve the efficiency of heat distribution fluid delivery include:

- reducing pressure drops across incorrectly installed valves
- reducing system pressure drops as a result of excessive frictional losses (often caused by undersized pipework)
- the optimising of pipe configuration
- improved network maintenance
- maintenance of steam traps, incorporating a regular testing programme or continuous monitoring, with follow up repair or replacement (for steam systems)
- optimise system air removal (particularly in the case of steam systems)
- optimise system separator operation

It is very difficult to determine the effectiveness of fluid delivery without accurate measurements of flow and pressure, let alone calculate potential energy savings.
If it is noted that network maintenance practices are poor, it is suggested that a percentage improvement in system energy efficiency can be expected as a result of improved practices.

Heat Generation

Analysis of a heating system's generation side requires the optimisation of burner and boiler or heating plant suitability, combustion efficiency and system control. Again, this may be difficult to determine without accurate measurements, although assumptions can be made to estimate potential energy savings. Solutions to improve the heat generation efficiency include:

- replacing a heating system with one more optimally sized for the demand
- improve burner/boiler maintenance
- improve burner combustion efficiency via excess air control or oxygen enrichment
- improve flame patterns for more effective heating
- ensure electrical elements are in good condition
- improve generation plant control, in particular capacity control and standby control
- improve auxiliary system operation control, ideally automating when these systems switch on or off, or vary in supply depending on wider system variables such as temperature
- optimise the boiler's water treatment plan and control systems and therefore minimise blowdown frequency
- change to a cheaper fuel source
- ensure the boiler, kiln or oven body is well insulated

Analysis of the heat-generation side requires the optimisation of several facets of the heating system, each interrelated to the other. As for demand-side analysis, it is important to keep in mind the effects that each improvement may have on other parts of the system, ensuring a holistic approach is maintained.

Heat Recovery

Analysis of a heating system's heat recovery opportunities involves determination of the current heat loss associated with a process, the heat generation system, or other utilities. Heat recovered within the process itself is discussed in Section 4.1.2. This requires the measurement of temperature and flow through different sections of the system.
Potential heat recovery options include:

- condensate return (steam systems only)
- flash steam heat recovery (steam systems only)
- blowdown heat recovery (steam systems only)
- boiler economiser for in-feed pre-heating
- waste heat recovery (e.g. air compressors or refrigeration compressors)
- heat storage, i.e. batch processes that by nature expend heat energy during a cycle may be modified so that some heat is externally stored for re-use by another batch

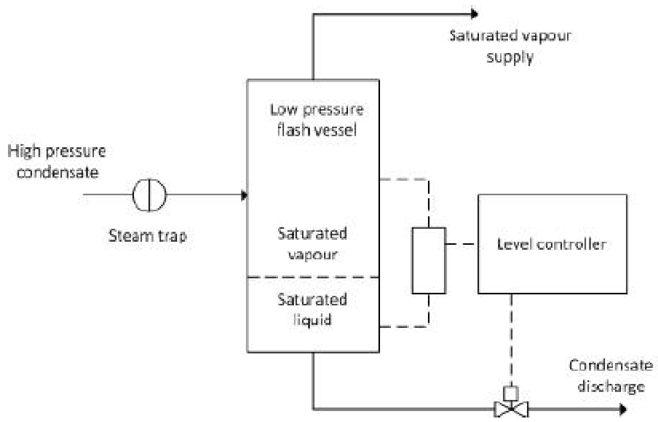
- waste heat use for absorption cooling or for low-grade plant or product heating

Heat recovered from any part of the system can be used within another part of the process (demand side), such as product in-feed preheating, or can be used within the generation system (supply side), such as for combustion air preheating. Pinch analysis is a useful method for determining heat recovery opportunities and optimising current systems.
Current site heat recovery systems should also be assessed to determine their effectiveness, then in some cases further improved.
For base-level assessments it may be difficult to determine the heat available for recovery without accurate measurements of flow, temperature and pressure, let alone calculate potential energy savings. Consequently, large assumptions are often required, as well as auditing experience.

Heat Generation Heat Recovery

Heat generation heat recovery refers to heat recovery from the heating system itself. There are several heat recovery opportunities for both direct and indirect systems. These opportunities should be analysed to determine the potential system-wide efficiency improvement and therefore energy savings. Some of these opportunities include, but are not limited to:

- Blowdown heat recovery — can be achieved by using this water to preheat feedwater via a fouling-resistant heat exchanger or by flash-steam heat recovery. Assessing the amount of heat-recovery potential involves quantifying the volume of blowdown that takes place. It is important to note that the blowdown system should be optimised first before estimating potential heat recovery.
- Economiser heat recovery — an economiser is a heat exchanger in a burner’s exhaust that can be used to preheat low-temperature materials. A common application is to preheat boiler feedwater. Assessing the amount of heat-recovery potential involves measuring exhaust gas flow and temperature. It is important to note that the combustion efficiency should be optimised first before estimating potential heat recovery, as improving combustion efficiency reduces stack temperatures.
- Return heat recovery — most heating systems have return systems (e.g. condensate return for steam systems) since there is such a large amount of energy contained in the return. Assessing the amount of heat-recovery potential of an open system that does not have return heat recovery involves measuring discharge volumes and temperatures.
- Flash-steam heat recovery — low-pressure steam is flashed from high-pressure condensate. This is particularly viable when it is not economically feasible to return high-pressure condensate to the boiler. A flash-steam recovery vessel allows the low-pressure steam to be separated from the condensate, as shown in Figure.



Waste Heat Recovery

Waste heat recovery refers to heat recovery from other utilities onsite. There are several waste heat recovery opportunities for both direct and indirect systems. These opportunities should be analysed to determine the potential system-wide efficiency improvement and therefore energy savings. Some of the sources of waste heat include:

- air conditioning exhaust air
- refrigeration4 compressors
- air compressors

This waste heat can be recovered in several ways, such as:

- boiler feedwater pre-heating
- combustion air preheating — can often just be a simple redirecting of HVAC exhaust air towards a burner inlet
- process heating e.g. product preheating
- use of thermal storage
- direct heating of heat-transfer medium such as hot water or steam
- cascading — multiple processes with successively lower heating requirements can use the heat waste from the process at a higher temperature.

Whole-system Considerations

Each part of the Process Heat system analysis may include findings that can have some relation to another part of the system.

Consequently, the analysis needs to identify 'dependent' and 'mutually exclusive' opportunities across the whole system, to ensure that the most cohesive and well-specified recommendation set is made to the client.

Where two opportunities are dependent (one must be implemented in order for the other one to be possible), they may be presented as one saving with one total associated cost. For example, if an oven typically consumes 10kW of fuel and reductions of 30% of the demand for heating and 20% burner efficiency improvements can be made, they should be applied as follows:

Power use after demand reduction = 10kW x 0.7 = 7kW

Power use after burner improvement = 7kW x 0.8 = 5.6kW (or 56% of the original consumption)

If the savings had both been applied to the original 10kW, total savings of 5kW or 50% would have been calculated, overestimating savings by 6% of the original energy use.

Example Data Collection Form

Network Schematic			
System Reference			
note: include all relevant system components such as burners, boilers, pumps, fans, heat users, heat exchangers, direct injection systems, heat recovery systems and valves			
Heat Generation Information			
Heat-generation Type		Heat Generator Condition	
Fuel Type		Burner Condition	
Heat-transfer Medium		System Pressure/Temperature	
System Operation		Feedwater Treatment (Steam)	
Auxiliary Equipment/Operation		Blowdown Operation (Steam)	
Heat Recovery Information			
Current Heat Recovery Technology Utilised		Effectiveness of Heat Recovery Units	
Potential Heat Recovery Opportunities			
Network Information (if applicable)			
Supply Pipework		***Condensate Pipework***	
Material / Size		Material / Size	
Insulation Condition		Insulation Condition	
Other Information		Other Information	
Valves / Outlets			
Valve / Outlet Types		General Condition	
Insulation Condition		Operation	
Demand Information			
Heat User Name	Description / Comments / General Condition		Pressure / Temperature Requirements

One per heating system

Baseline Consumption Table					
Heating System	Description				
Thermal Energy Use Details					
Fuel Type	Fuel Cost				
Equipment ID	*Make / Model*	*Rated kW (thermal)*	*Load Factor*	*Annual Run Hours*	*Annual Energy Consumption*
Total Thermal Energy Use					
Annual Thermal Energy Operational Cost					
Electricity Energy Use Details					
Electricity Cost					
User ID	*Make / Model*	*Rated kW (electrical)*	*Load Factor*	*Annual Run Hours*	*Annual Energy Consumption*
Total Electrical Energy Use					
Annual Electrical Energy Operational Cost					
Total System Energy Use Data					
Total Heating System Energy Use					
Total Heating System Energy Cost					
Relevant Production Measure (e.g. units produced)					
Estimated Annual Production Throughput					
Estimated Heating System Energy Intensity (HEI)					

Steam System Checklist

	Assessment Checklist	Potential for Efficiency Improvement				
	Efficiency Opportunity Element	N / A	LOW	MED	HIGH	Further Comments
DEMAND	Steam user isolation					
	Appropriate use of steam					
	Steam user insulation					
	Pressure / temperature requirements					
	Steam use / process efficiency					
	Steam leaks					
	Heat exchange surface condition					
NETWORK	Pipe design					
	Network condition					
	Supply pipe insulation					
	Condensate pipe insulation					
	Fitting / valve removable insulation					
	Steam trap testing / maintenance					
	System air removal					
GENERATION	Boiler condition					
	Burner condition Combustion testing and control					
	Supply-side insulation					
	Standby losses					
	Blowdown optimisation					
	Internal water treatment					
	External water treatment					
	Plant operation					
	Steam supply pressure					
	Fuel quality					
	Oxygen enrichment					
	Fuel change					
	Auxiliary equipment operation					
HEAT RECOVERY	Condensate return Flash steam					
	Process					
	Blowdown Economiser (feedwater)					
	Combustion air preheating					
	Absorption cooling potential					
	Thermocompressor potential					

Other Heating System Checklist

	Assessment Checklist	Potential for Efficiency Improvement				
	Efficiency Opportunity Element	**N / A**	**LOW**	**MED**	**HIGH**	**Further Comments**
DEMAND	Heat user isolation Appropriate use of heat					
	Heat containment					
	Temperature requirements					
	Heat use efficiency					
	Fluid leaks					
	Heat exchange surface condition					
	Process time optimisation					
	Product loading and scheduling optimisation					
	Peak load shedding opportunity					
NETWORK	Pipe design and configuration					
	Network condition and maintenance					
	Pipe / fitting / valve insulation					
HEAT GENERATION	Water heater condition					
	Electrical element condition					
	Burner condition					
	Combustion testing and air/fuel ratio					
	Fuel quality and distribution					
	Fuel change opportunity					
	Standby losses Alternative heating for smaller loads Combined heat and power opportunity Plant operation and scheduling					
	FD / ID fan control					
	Motor efficiency auxiliary equipment					
	Auxiliary equipment operation					
HEAT RECOVERY	Heat storage potential					
	Return loop conversion					
	Process heat recovery					
	Economiser Combustion air preheating					
	Absorption cooling potential					

LIGHTING SYSTEM

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.

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.

Lamp Types and their Features

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

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

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 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, sterilising, washing, preparation of solutions, filling,capping, wrapping, hardening	300–500–750
Fine chemical manufacturers	
Exterior walkways, platforms, stairs and ladders	30–50–100

Process plant	50–100–150
Fine chemical finishing	300–500–750
Inspection	300–500–750
Soap manufacture	
General area	200–300–500
Automatic processes	100–200–300
Control panels	200–300–500
Machines	200–300–500
Paint works	
General	200–300–500
Automatic processes	150–200–300
Control panels	200–300–500
Special batch mixing	500–750–1000
Colour matching	750–100–1500

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 1 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 2 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.

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:

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.

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

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

CABLE SYSTEM

Selection of Power Cables

Selection of Power cables for given purpose depends on a number of factors. Hence selection of it is never a simple task. Selection is also made difficult as there is such a large variety of cables available in the market.

We will see some of the important factors that determine selection of Power Cables.

Rated Voltage

It is necessary to select a power cable capable of supporting a particular system voltage. In case of AC system, the rated voltage of power cable should always be equal to or greater than the system voltage.

To determine rated voltage consider following formula:

If V0 is the rated cable voltage between each conductor and earth, Then, V is the cable rated voltage between phase conductors, expressed as:

$$V = \sqrt{3}\, V0$$

The exact rated voltage selection of power cable depends on earth fault withstand limits and specifications considerations that are made by the power system designers.

As per IEC (International Electrotechnical Commission) standards following three classifications exist:

Category A: The earth fault must be cleared within 1 second

Category B: Earth fault cleared within 1 hour for IEC-183 type cables, and cleared within 8 hours for IEC-502 type cables

Category C: All systems not covered under A and B

For categories A and B – cables with same rated voltage as system voltage can be chosen. However, for Category C, the rated voltage of cable should be higher than system voltage.

e.g. for 3.3 kV system voltage, a 6.6 kV rated voltage cable should be selected.

Current Carrying Capacity

Each power cable is designed to operate under certain temperature conditions.

Current carrying capacity of power cable is also dependent on conductor material (Copper / Aluminium) and insulation type.

Thus, Copper conductor cable has greater current carrying capacity than Aluminium.

XLPE (XLPE stands for cross-linked polyethylene) insulation is better than PVC, hence the current carrying capacity of XLPE cable is more than that of PVC insulated cable.

Operating a cable continuously beyond its rated current carrying capacity shortens the lifespan of the cable, as the insulation becomes prone to failure.

The current carrying capacity is also dependent on operating temperature. Higher the temperature, lower is the current carrying capacity of the cable and vice versa.

Derating Factor

A power cable designed with standard operating conditions may not operate so in practical. Therefore, the current carrying capacity may get impacted due to this.

Some examples of this:

Cables installed deep under the ground will have reduced current carrying capacity than cables installed in air. This is impacted due to multiple factors like soil temperature, soil thermal resistivity etc.

In order to deal with this, a Derating Factor is associated with cables to arrive at actual value of current carrying capacity.

Actual Current Carrying Capacity = Derating Factor x Cable current carrying capacity under std. conditions.

Thus for a 100 A cable with a derating factor of 0.8 the actual current carrying capacity would be: 0.8 x 100 = 80 A

Voltage Drop

A power cable manufacturer provides this as part of their data sheet. A voltage drop across the length of the power cable is very important. It is expressed as: mV / A-m.

The voltage drop per unit length of cable should as minimum as possible so as to get voltage at delivery end approximately same as supply side.

Short circuit Withstand

A power cable in case of short circuit event should be able to withstand the high current values without any damage to the cable and insulation.

The selection of short circuit current withstand capacity of a power cable is directly dependent on the specification of connected protection device.

E.g. if a breaker connected to a power cable is set to trip at 1000 A in 1 second then we need to select appropriate cable that can withstand the high current of 1000 A for a period of 1 second.

Availability of Cables

This needs to be checked with manufacturer or the dealer of a particular cable. Cables are manufactured in certain minimum length segments. Therefore, it will be difficult to procure a 30 meter length of 300 sq-mm cable than a 300 meter length of same cable. Also, the costing may vary largely between the two quantities.

Bending Radius

This can be a practical problem during installation. Large sized multi-core cables have bigger bending radius than small sized. Therefore a same size of multi-core XLPE cable has more bending radius than a PVC.

In order to overcome this, a contractor might have to opt separate single core cables.

Other Factors

Care needs to be taken while dealing with Aluminum conductor cables, as the metal tends to oxidize very fast when exposed to air and develops a thin film of dielectric coating. Aluminum conductor cables are not used in case of generating stations, substations installations.

Aluminum is preferred for other application areas due to its high conductivity-to-weight ratio.

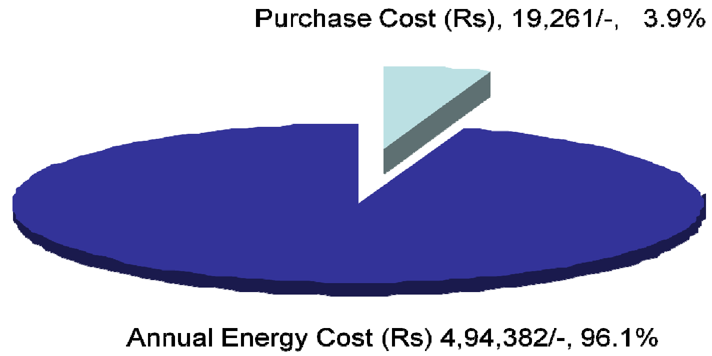
Large sized cables are quite rigid and difficult to bend, install and terminate.

Energy Efficient Motors - Factors Involved in Determination of Motor Efficiency

- Save energy – this is a national priority
- Reduce operating cost
- Reduce harmful greenhouse gas emissions
- 70 % of all electrical energy consumed in India is used for driving electric motors
- 55 % of which is consumed by industrial motors

Initial Cost of an 11 kW motor is only 3.9% in the first year of operation

Assumptions: Efficiency Eff2 : 89.0% (BBL)
Energy cost: Rs 5 per kWH
Working: 8000 hrs pa



- In one year, a motor consumes energy equivalent to 10 to 25 times its purchase price

- Many consumers in India especially OEMs purchase cheap motors having low efficiency values

National Standard for Energy Efficient Motors

- IS 12615: 2004 (First Revision)
  Energy Efficient Induction Motors — Three Phase Squirrel Cage
- IS 12615 covers Energy Efficient motors from 0.37kW to 160kW (up to Fr. 315L)
- IS 12615 specifies two efficiency levels - eff2 and eff1

IS 12615: 2004 (First revision) - superior to existing Std. IS 8789

- To be considered as energy efficient, a motor must conform to one of the following efficiency levels specified in IS 12615:
  - Improved Efficiency (eff2)
  - High Efficiency (eff1)
- eff1 efficiency levels are higher than those of eff2
- Both eff1 & eff2 are higher than the nominal values specified in IS 8789: 1996

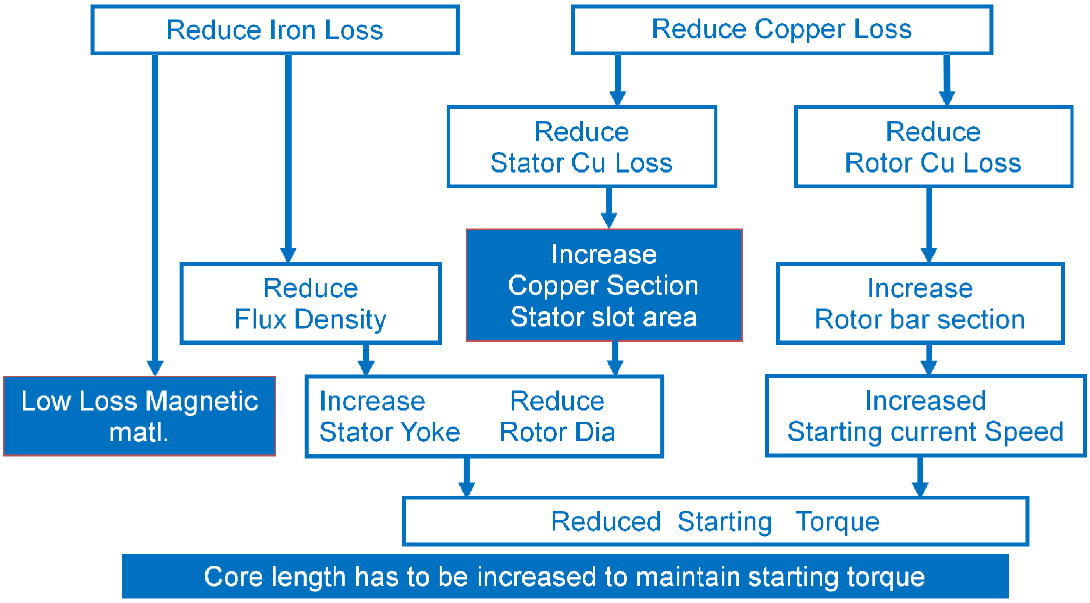
Why 2 Efficiency levels?

- User has the option to go for eff1 motor and save energy but at higher initial cost. It is strongly recommended to go for eff1 motor when utilization is high
- The standard is hence user friendly since it has provided two levels of efficiency. This in line with other international standards like CEMEP

Comparison of efficiencies of Standard & Energy Efficient Motors

Output 4 Pole	IS 8789	eff2 as per IS 12615	eff1 as per IS 12615
0.75 kW	71.0%	73.0%	82.5%
1.5 kW	76.0%	78.5%	85.0%
3.7 kW	83.0%	84.0%	88.3%
11 kW	85.5%	88.4%	91.0%
18.5kW	87.0%	90.0%	92.2%
37 kW	88.5%	92.0%	93.6%
75 kW	Not specified	93.6%	94.7%
110 kW	Not specified	94.4%	95.2%
160 kW	Not specified	95.0%	95.8%

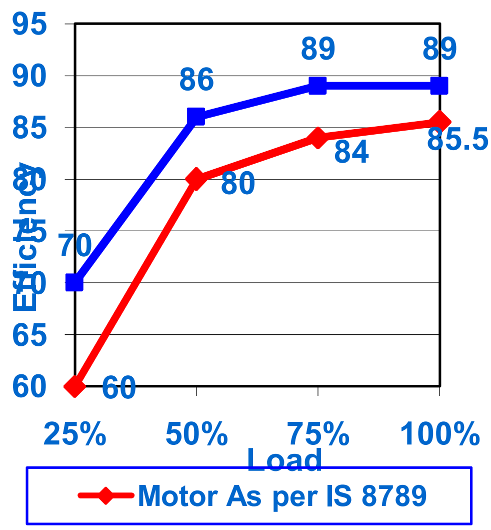
- eff1 motors are generally priced 5 - 15 % higher than eff2 motors
- More laminations - longer core length and/or
- High Grade (low loss) laminations
- More Copper



Energy Efficient Motors have a Flat Efficiency Vs Load Characteristic

- Motor rating is selected for max. load conditions and next preferred rating
- Most motors operate on an average around 75% load

Efficiency is almost same from 60% to 100% load in a well designed EE motor



eff2 motor gives savings over an IS 8789 motor

	IS 8789	eff2
Purchase Price of 11kW/4P motor Rs	17510	19261
Efficiency	85.5%	89.0%
Energy consumption p.a. for 8000 Hrs @ Rs 5 per kWh	5,14,620	4,94,382
Energy Saving p.a. Rs	20,238	
Additional purchase price Rs	1751	

Pay Back Period of eff2 motor is 1.0 month for a 10% price increase over an IS 8789 motor

eff1 motor gives further savings over an eff2 motor

	eff2	eff1
Purchase Price of 11kW/4P motor Rs	19261	22149
Efficiency	89.0%	91.5%
Energy consumption p.a. for 8000 Hrs @ Rs 5 per kWh	4,94,382	4,80,874
Energy Saving Rs	13,507	
Additional purchase price Rs	2888	

Pay Back Period of eff1 motor is 2.6 months for a 15% price increase over eff2 motor

Energy Efficient Motors- Speed and Starting current

- Due to reduced rotor losses, speed is higher.(5-15rpm)
  - The driven equipment (fan / pump) should be designed accordingly

- Due to reduced rotor and stator resistance, starting current is higher. This can go to 700 % in eff1 motors.
  - When used with a VVVF drive, this does not matter as the drive takes care.
  - In other cases, this should be taken care during system design.