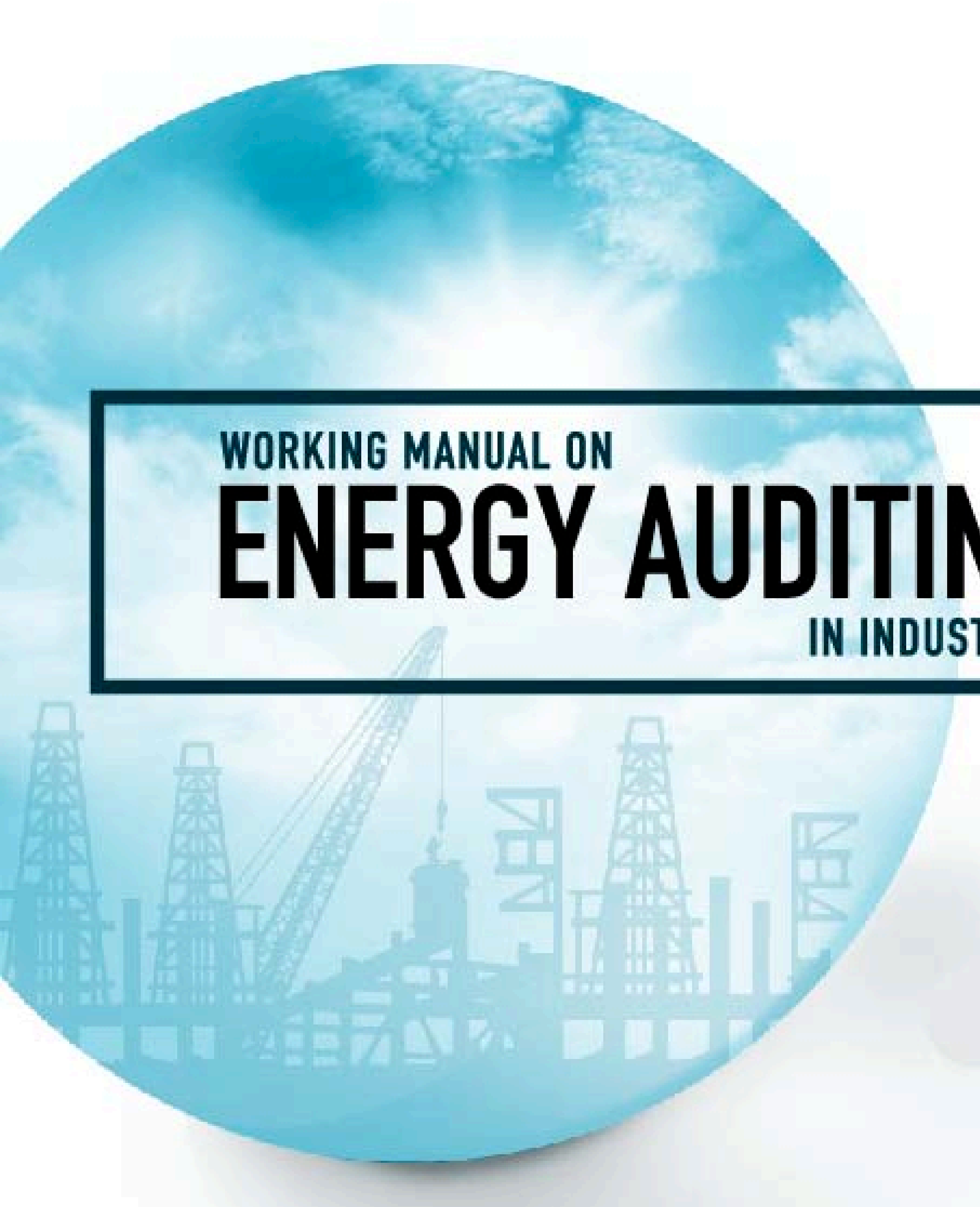

WORKING MANUAL ON

ENERGY AUDITING

IN INDUSTRIES

Asian Productivity Organization
2008

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CONTENTS

FOREWORD

With the rising costs of energy and concerns about global warming, it is imperative that countries adopt the most efficient energy conservation measures and technologies. Energy conservation must evolve as a way of life in developing countries in the Asia-Pacific region given the limited availability of resources. If we are to share commercial energy equitably across all sections of society, it is necessary to conserve energy and use it efficiently. Industries can become globally competitive when their products are energy efficient and their production processes consume the least amount of energy.

For this purpose, energy audits and conservation studies must be conducted at regular intervals in all industries. One of the main bottlenecks in conducting these studies is the lack of technical information on various types of equipment and how energy performance should be measured.

The *Working Manual on Energy Auditing* is an outcome of the workshop on Energy Efficiency and Green Productivity organized by the Asian Productivity Organization (APO) and National Productivity Council (NPC) in New Delhi, India, and subsequent Web-based project on Energy Management organized by APO and conducted by the author in 2007, during which the practical difficulties in conducting energy audits were discussed. The manual explains briefly the necessity for energy audits, their step-by-step methodology, and the instrumentation required for undertaking detailed energy audits in industries. It also contains worksheets for performance assessment of various types of equipment generally found in industries. The publication is intended to be a one-stop guide for managers interested in conducting energy audits.

This manual is the result of efforts by the Energy Management Group of the National Productivity Council (NPC), India. The inputs were drawn from interaction with the participants during the above workshops, energy audit studies conducted by the NPC over the past four decades and extensive literature survey. Their liberal use in the manual helped to make it more practice oriented.

The *Working Manual on Energy Auditing* was developed by the APO to promote the concept and fundamentals of energy conservation so that industries in the region can become more competitive and improve their bottom lines. I hope that it will find wide acceptance among industry professionals in the Asia-Pacific.

Shigeo Takenaka
Secretary-General

Tokyo, July 2008

CHAPTER 1
ENERGY AUDIT AND MANAGEMENT

1.1 Introduction

Energy is one of the major inputs for the economic development of any country. The energy sector assumes a critical importance in view of the ever-increasing energy needs requiring huge investments to meet them.

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

- Primary and Secondary energy
- Commercial and Non-commercial energy
- Renewable and Non-Renewable energy

1.2 Primary and Secondary Energy

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources include nuclear energy from radioactive substances, thermal energy from the earth's interior, and potential energy due to the earth's gravity. The major primary and secondary energy sources are shown in Figure 1.1.

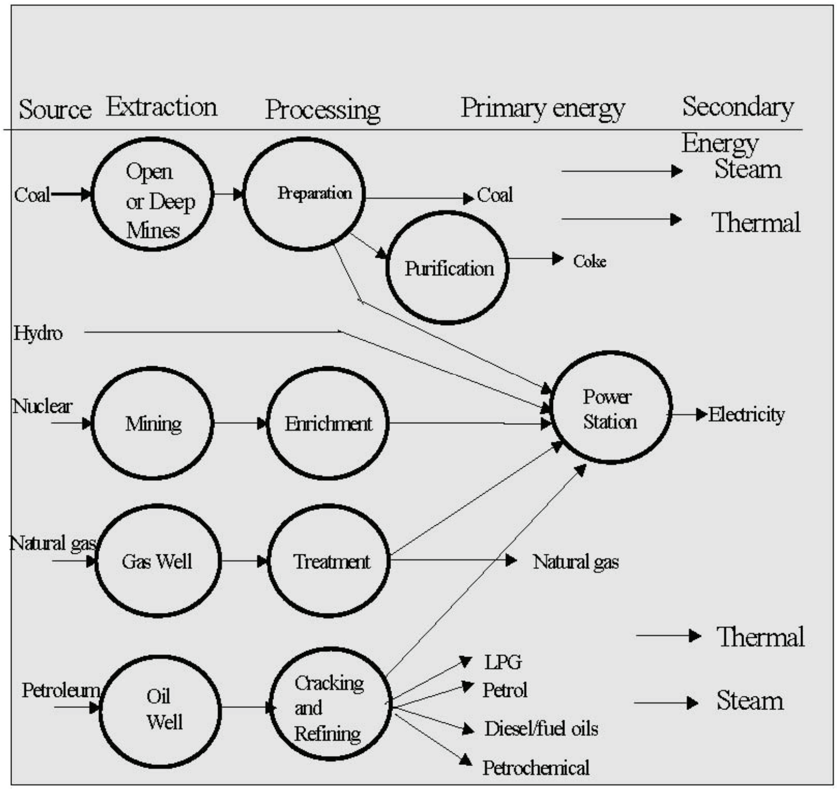


Figure 1.1 Major Primary and Secondary Sources

Primary energy sources are mostly converted in industrial utilities into *secondary energy* sources; for example coal, oil, or gas converted into steam and electricity.

Primary energy can also be used directly. Some energy sources have non-energy uses; for example, coal or natural gas can be used as a feedstock in fertilizer plants.

1.3 Commercial Energy and Non-Commercial Energy

Commercial Energy

Energy sources that are available on the market for a price are known as *commercial energy*. By far the most important forms of commercial energy are electricity, coal, and refined-petroleum products. Commercial energy forms the basis of industrial, agricultural, transport, and commercial development in the modern world. In industrialized countries, commercialized fuels are the predominant source not only for economic production, but also for many household tasks of the general population.

Examples: Electricity, lignite, coal, oil, and natural gas.

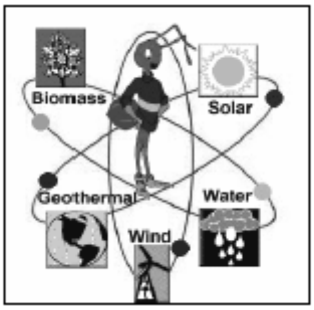
Non-Commercial Energy

Energy sources that are not available on the market at a price are classified as *non-commercial energy.* Non-commercial energy sources include such fuels as firewood, cattle dung, and agricultural waste, which are traditionally gathered and not bought at a set price especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.

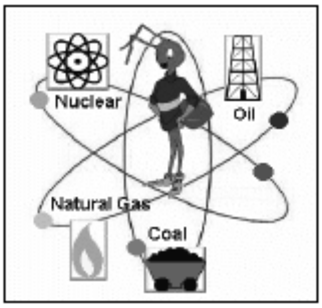
Examples: Firewood and agro-waste in rural areas; solar energy for water heating, electricity generation, and for drying grain, fish, and fruits; animal power for transport, threshing, lifting water for irrigation, and crushing sugarcane; wind energy for lifting water and electricity generation.

1.4 Renewable and Non-Renewable Energy

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power, and hydroelectric power (Figure 1.2). The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants. *Non-renewable energy* includes conventional fossil fuels such as coal, oil, and gas, which are likely to be depleted over time.



Renewable



Non-Renewable

Figure 1.2 Renewable and Non-Renewable Energy

1.5 Global Primary Energy Reserve

Coal

Proven global coal reserves were estimated at 984.453 billion tons by the end of 2003. The U.S. had the largest share (25.4%) followed by Russia (15.9%), and China (11.6%). India was fourth on the list with 8.6%.

Oil

Global proven oil reserves were estimated at 1.147 trillion barrels by the end of 2003. Saudi Arabia had the largest share with almost 23%. (One barrel of oil is approximately 160 liters.)

Gas

Global proven gas reserves were estimated at 176 trillion cubic meters by the end of 2003. The Russian Federation had the largest share of the reserves with almost 27%.

(Source: BP Statistical Review of World Energy, June 2004)

1.6 Global Primary Energy Consumption

The global primary energy consumption at the end of 2003 was equivalent to 9,741 million tons of oil equivalent (Mtoe). Figure 1.3 shows in what proportions the sources mentioned above contributed to this global figure.

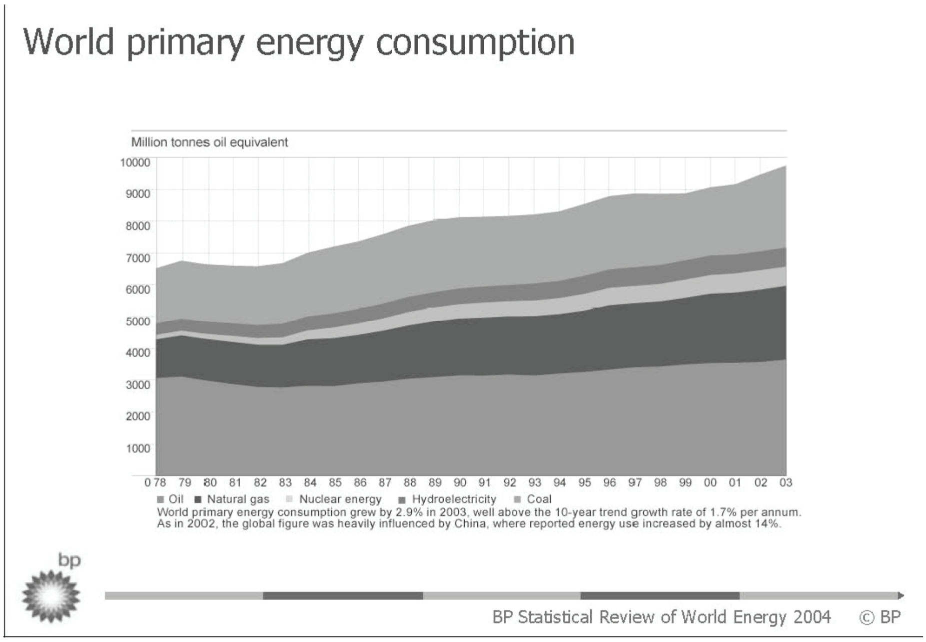


Figure 1.3 Global Primary Energy Consumption

The levels of consumption of primary energy sources by a selection of developed and developing countries are shown in Table 1.1.

Table 1.1 Primary Energy Consumption by Fuel (2003)

In million tons, oil equivalent

Country	Oil	Natural gas	Coal	Nuclear energy	Hydro-electric	**Total**
U.S.	914.3	566.8	573.9	181.9	60.9	**2,297.8**
Canada	96.4	78.7	31.0	16.8	68.6	**291.4**
France	94.2	39.4	12.4	99.8	14.8	**260.6**
Russian Federation	124.7	365.2	111.3	34.0	35.6	**670.8**
United Kingdom	76.8	85.7	39.1	20.1	1.3	**223.2**
China	275.2	29.5	799.7	9.8	64.0	**1,178.3**
India	113.3	27.1	185.3	4.1	15.6	345.3
Japan	248.7	68.9	112.2	52.2	22.8	**504.8**
Malaysia	23.9	25.6	3.2	–	1.7	**54.4**
Pakistan	17.0	19.0	2.7	0.4	5.6	**44.8**
Singapore	34.1	4.8	–	–	–	**38.9**
TOTAL WORLD	**3,636.6**	**2,331.9**	**2,578.4**	**598.8**	**595.4**	**9741.1**

1.7 Global Environmental Issues

As early as 1896, the Swedish scientist Svante Arrhenius had predicted that human activities would interfere with the way the sun interacts with the earth, resulting in global warming and climate change. His prediction has become true and climate change is now disrupting global environmental stability. The last few decades have seen many treaties, conventions, and protocols for the cause of global environmental protection.

A few examples of environmental issues of global significance are:

- Ozone layer depletion
- Global warming
- Loss of biodiversity

One of the most important characteristics of this environmental degradation is that it affects all mankind on a global scale without regard to any particular country, geographic region, or race. The entire world is a stakeholder and this raises issues on who should do what to combat environmental degradation.

1.8 Ozone Layer Depletion

Earth's atmosphere is divided into three regions, namely the troposphere, stratosphere, and mesosphere (Figure 1.4). The stratosphere extends 10 to 50 km above the Earth's surface. This region holds a concentration of ozone, a slightly pungent-smelling, faintly blue gas. The ozone gas is made up of molecules each containing three atoms of oxygen, expressed by the chemical formula O_3. The ozone layer in the stratosphere acts as an efficient filter for harmful ultraviolet B (UV-B) solar rays.

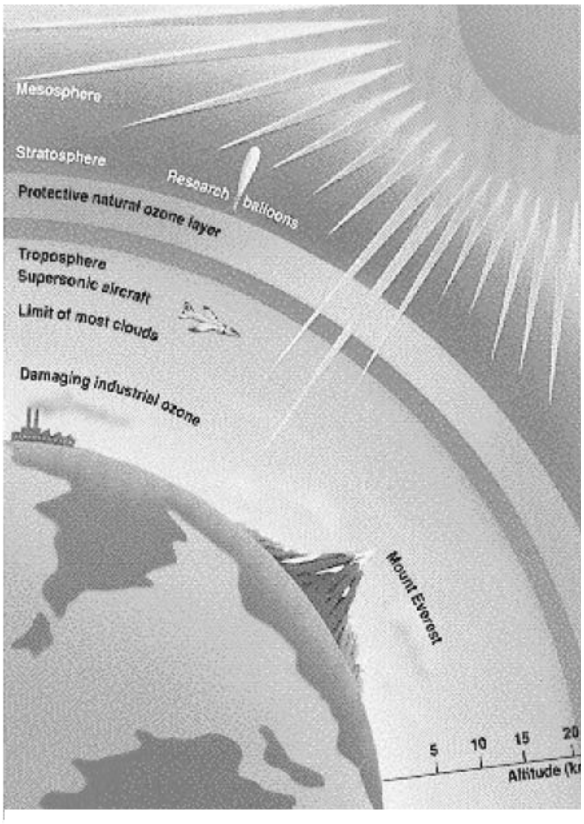


Figure 1.4 Ozone Layer

Ozone is produced and destroyed naturally in the atmosphere and until recently, this resulted in a well-balanced equilibrium (Figure 1.5). Ozone is formed when oxygen molecules absorb ultraviolet radiation with wavelengths less than 240 nanometers and is destroyed when it absorbs ultraviolet radiation with wavelengths greater than 290 nanometers. In recent years, scientists have measured a seasonal thinning of the ozone layer primarily at the South Pole. This phenomenon is referred to as the "ozone hole."

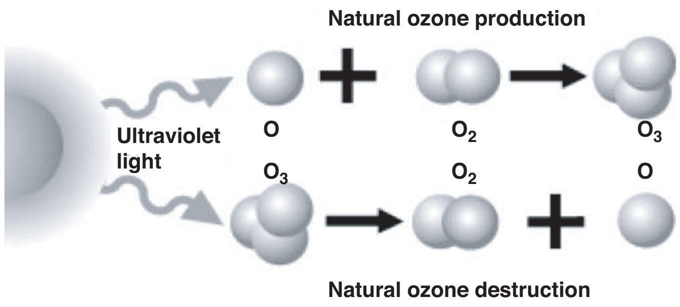


Figure 1.5 Ozone Production and Destruction Process

Ozone is highly reactive and easily broken down by man-made chlorine and bromine compounds. These compounds are found to be responsible for most of the ozone layer depletion.

Ozone Depletion Process

The ozone depletion process begins when chlorofluorocarbon (CFC) refrigerants (previously used in refrigerators and air conditioners but now increasingly outlawed) and other ozone-depleting substances (ODS) are released into the atmosphere. Winds efficiently mix and evenly distribute the ODS in the troposphere. These ODS compounds do not dissolve in rain, are extremely stable, and have a long life span. After several years, they reach the stratosphere by diffusion.

Strong UV light breaks apart the ODS molecules. CFCs, HCFCs, carbon tetrachloride, and methyl chloroform release chlorine atoms, and halons and methyl bromide release bromine atoms. It is the chlorine and bromine atom that actually destroy ozone, not the intact ODS molecule. It is estimated that one chlorine atom can destroy from 10,000 to 100,000 ozone molecules before it is finally removed from the stratosphere.

Chemistry of Ozone Depletion

When ultraviolet light waves (UV) strike CFC* ($CFCl_3$) molecules in the upper atmosphere, the carbon-chlorine bond breaks, producing a chlorine (Cl) atom. The chlorine atom then reacts with an ozone (O_3) molecule breaking it apart and so destroying the ozone. This forms an ordinary oxygen molecule (O_2) and a chlorine monoxide (ClO) molecule. Then a free oxygen** atom breaks up the chlorine monoxide. The chlorine is free to repeat the process of destroying more ozone molecules. A single CFC molecule can destroy 100,000 ozone molecules. The chemistry of ozone depletion process is shown in Figure 1.6.

* CFC – chlorofluorocarbon, containing chlorine, fluorine and carbon atoms.
** UV radiation breaks oxygen molecules (O_2) into single oxygen atoms.

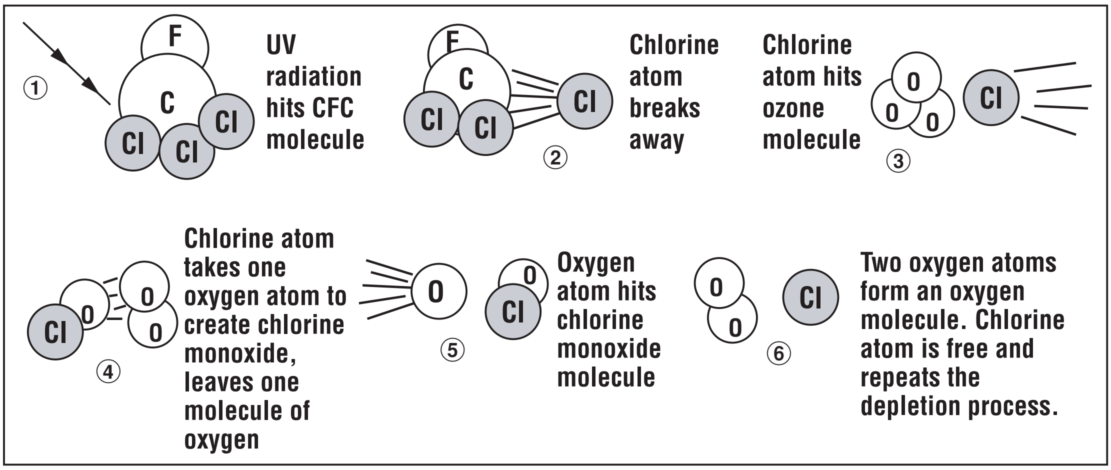


Figure 1.6 Chemistry of Ozone Depletion Process

The chemical equation is
$CFCl_3$ + UV Light ==> $CFCl_2$ + Cl
Cl + O_3 ==> ClO + O_2
ClO + O ==> Cl + O_2

The released chlorine atom is then free to attack another ozone molecule
Cl + O_3 ==> ClO + O_2
ClO + O ==> Cl + O_2

and again ...
Cl + O_3 ==> ClO + O_2 ClO + O ==> Cl + O_2

and again... for thousands of repetitions.

Scientist measure the ozone layer thickness by analyzing how much ultraviolet radiation reaches the ground, using a Dobson ozone spectrophotometer. The thickness is expressed in Dobson units. The higher the number, the thicker the ozone layer. Since the 1970s, gases produced for commercial purposes have been destroying the ozone layer, upsetting the natural equilibrium that previously existed. It was planned that by 2005 in developed countries and by 2015 in developing countries, the use of ozone depleting gases, such as CFCs, would be phased out.

Effects of Ozone Layer Depletion

Effects on Human and Animal Health: Increased penetration of solar UV-B radiation is likely to have high impact on human health with potential risks of eye diseases, skin cancer, and infectious diseases.

Effects on Terrestrial Plants: In forests and grasslands, increased radiation is likely to change species composition thus altering bio-diversity in various ecosystems. It could also affect the plant community indirectly resulting in changes in plant form, secondary metabolism, etc.

Effects on Aquatic Ecosystems: High levels of radiation exposure in the tropics and subtropics may affect the distribution of phytoplankton, which forms the foundation of the aquatic food chain. It can also cause damage to early development stages of fish, shrimp, crab, amphibians, and other living things, the most severe effects being decreased reproductive capacity and impaired larval development.

Effects on Bio-geo-chemical Cycles: Increased solar UV radiation could affect terrestrial and aquatic bio-geo-chemical cycles thus altering both the sources and sinks of greenhouse and important trace gases, e.g., carbon dioxide (CO_2), carbon monoxide (CO), carbonyl sulfide (COS), etc. These changes would contribute to biosphere-atmosphere feedbacks responsible for the atmospheric build-up of these greenhouse gases.

Effects on Air Quality: Reduction of stratospheric ozone and increased penetration of UV-B radiation result in higher photo-dissociation rates of the molecules of key trace gases that control the chemical reactivity of the troposphere. This can increase both production and destruction of ozone and related oxidants such as hydrogen peroxide, which are known to have adverse effects on human health, terrestrial plants, and nature in its many interrelated respects.

The ozone layer, therefore, is highly beneficial to plant and animal life on earth filtering out the dangerous aspects of the sun's radiation and allowing only the beneficial rays to reach earth. Any disturbance or depletion of this layer would result in an increase of harmful radiation reaching the earth's surface leading to dangerous consequences.

Ozone Depletion Counter-measures

- International cooperation, agreement (Montreal Protocol) to phase out ozone-depleting chemicals since 1974
- Tax imposed for ozone depleting substances
- Ozone friendly substitutes — Hydrochlorofluorocarbons (HCFC) (less ozone-depleting potential and shorter life)
- Containment and recycling of CFCs and halons

1.9 Global Warming and Greenhouse Gases

Before the industrial revolution, human activities released very few gases into the atmosphere and all climate changes happened naturally. After the industrial revolution, through fossil fuel combustion, changing agricultural practices and deforestation, the natural composition of gases in the atmosphere began to be increasingly affected and climate and environment began to alter significantly.

Over the last 100 years, it has been determined that the earth is becoming warmer and warmer, unlike the previous 8,000 years when temperatures remained relatively constant. The present average temperature is 0.3 to 0.6°C warmer than it was just a century ago.

CFCs, even though they exist in relatively small quantities, are significant contributors to global warming as already discussed. In terms of environmental damage the escaped refrigerant chemical takes a back seat, however, to carbon dioxide, the worst of the greenhouse gases. Carbon dioxide has two major anthropogenic (human-caused) sources: the combustion of fossil fuels and changes in land use. Net releases of carbon dioxide from these two sources are believed to have contributed to the rapid rise in atmospheric concentrations since the industrial revolution. Because estimates indicate that approximately 80% of all anthropogenic carbon dioxide emissions currently come from fossil fuel combustion, world energy use has emerged at the center of the climate change debate.

Sources of Greenhouse Gases

Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone (Figure 1.7). Certain human activities, however, add to the levels of most of these naturally occurring gases.

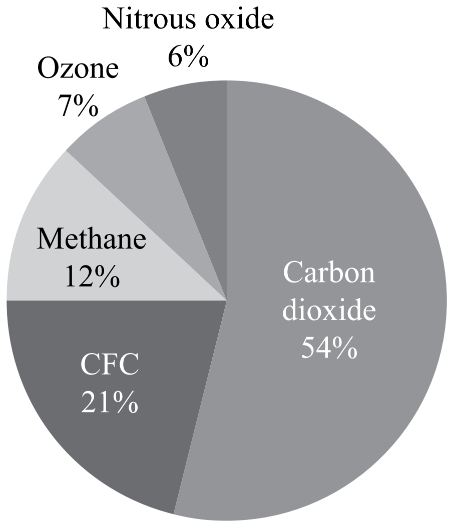


Figure 1.7 Share of Greenhouse Gases

Carbon dioxide is released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned.

Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from the decomposition of organic wastes in municipal solid waste landfills, and the raising of livestock. Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels.

Very powerful greenhouse gases that are not naturally occurring include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), which are generated in a variety of industrial processes.

Global Warming Potential

Often, estimates of greenhouse gas emissions are presented in units of millions of metric tons of carbon equivalents (MMTCE), which weighs each gas by its Global Warming Potential (GWP) value.

Although there are a number of ways of measuring the strength of different greenhouse gases in the atmosphere, GWP is perhaps the most useful.

GWPs measure the influence greenhouse gases have on the natural greenhouse effect, including the ability of greenhouse gas molecules to absorb or trap heat and the length of time greenhouse gas molecules remain in the atmosphere before being removed or breaking down. In this way, the contribution that each greenhouse gas has towards global warming can be assessed.

Each greenhouse gas differs in its ability to absorb heat in the atmosphere. HFCs and PFCs are the most heat-absorbent. Methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide. Conventionally, the GWP of carbon dioxide, measured across all time horizons, is 1. The GWPs of other greenhouse gases are then measured relative to the GWP of carbon dioxide. Thus the GWP of methane is 21 while the GWP of nitrous oxide is 270.

Other greenhouse gases have much higher GWPs than carbon dioxide, but because their concentration in the atmosphere is much lower, carbon dioxide is still the most important greenhouse gas, contributing about 60% to the enhancement of the greenhouse effect.

Global Warming (Climate Change) Implications

- **Rise in global temperature**
  Observations show that global temperatures rose by about 0.6°C during the past century. There is strong evidence now that most of the observed warming over the last 50 years is caused by human activities. Climate models predict that the global temperature will rise about 6°C by the year 2100.

- **Rise in sea level**
  In general, the faster the climate change, the greater will be the risk of damage. The mean sea level is expected to rise 9 to 88 cm by the year 2100, causing disastrous flooding of low-lying areas and other damage.

- **Food shortages and hunger**
  Water resources will be affected as precipitation and evaporation patterns change around the world. This will affect agricultural output. Food security is likely to be threatened and some regions are likely to experience acute food shortages and hunger.

1.10 Loss of Biodiversity

Biodiversity refers to the variety of life on earth, and its biological health. The number of species of plants, animals, micro organisms, the enormous diversity of genes in these species, the different ecosystems on the planet, such as deserts, rain forests, and coral reefs, are all a part of a biologically diverse earth. Biodiversity actually boosts ecosystem productivity whereby each species, no matter how small, all have an important role to play and that it is in this combination that enables the ecosystem to possess the ability to prevent and recover from a variety of disasters.

It is now believed that human activity is changing biodiversity and causing mass extinctions. The World Resource Institute reports that there is a clear link between biodiversity and climate change. Rapid global warming can affect the ability of ecosystems to adapt naturally. Over the past 150 years, deforestation has contributed an estimated 30% of the atmospheric build-up of CO_2. It is also a significant driving force behind the loss of genes, species, and critical ecosystem services.

Link between Biodiversity and Climate change

- Climate change is affecting species already threatened by multiple threats across the globe. Habitat fragmentation due to colonization, slash and burn land clearing, logging, agriculture, and mining is contributing to further destruction of terrestrial habitats.
- Individual species may not be able to adapt. The species most threatened by climate change typically have small ranges, low population densities, restricted habitat requirements, and patchy distribution.
- Ecosystems will generally shift northward or upward in altitude, but in some cases they will run out of space – as a 1°C change in temperature corresponds to a 100 km change in latitude, hence, the average shift in habitat conditions by the year 2100 will be on the order of 140 to 580 km.
- Coral reef mortality may increase and erosion may be accelerated. Increases in the level of carbon dioxide adversely impact the coral building process (calcification).
- Sea level may rise, engulfing low-lying areas causing disappearance of many islands, and extinction of endemic island species.
- Invasive species may be aided by climate change. Exotic species can out-compete native wildlife for space, food, water, and other resources, and may also prey on native wildlife.
- Droughts and wildfires may increase. An increased risk of wildfires due to warming and drying out of vegetation is likely.
- Sustained climate change may change the competitive balance among species and might lead to the widespread destruction of forests.

1.11 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 different things to different people. One definition of energy management is:

"The judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions."

(Capehart, 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 utilization throughout the organization and:

- To minimize energy costs / waste without affecting production and quality
- To minimize environmental effects.

1.12 Energy Audit: Types and Methodology

The "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 their use, and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. An industrial energy audit is an effective tool in defining and pursuing a comprehensive energy management program within a business.

As per the Energy Conservation Act, 2001, passed by the government of India, *energy audit* is defined as "the verification, monitoring and analysis of use of energy including submission of technical reports containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption."

1.12.1 Need for Energy Audit

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labor, and materials. In most assessments of the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction. A well done energy audit will always help managers understand more about the ways energy and fuel are used in their industry, and help to identify areas where waste can occur and where scope for improvement exists.

The energy audit would give a positive orientation to the energy cost reduction, preventive maintenance, and quality control programs which are vital for production and utility activities. Such an audit program will help to keep focus on variations that occur in the energy costs, availability, and reliability of supply of energy, help decide on the appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment, etc.

In general, the energy audit is the translation of conservation ideas and hopes into reality, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame.

The primary objective of the energy audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. The energy audit provides a benchmark, or reference point, for managing and assessing energy use across the organization and provides the basis for ensuring more effective use of energy.

1.12.2 Types of Energy Audits

The type of energy audit to be performed depends on:

- Function and type of industry
- Depth to which a final audit is needed, and
- Potential and magnitude of cost reduction desired

Thus energy audits can be classified into the following two types:

- Preliminary audit
- Detailed audit

1.12.3 Preliminary Energy Audit Methodology

The preliminary energy audit uses existing or easily obtained data. It is a relatively quick exercise to:

- Determine energy consumption in the organization
- Estimate the scope for saving
- Identify the most likely (and easiest areas) for attention
- Identify immediate (especially no-cost/low-cost) improvements/savings
- Set a reference point
- Identify areas for more detailed study/measurement

1.12.4 Detailed Energy Audit Methodology

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

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

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

Detailed energy auditing is carried out in three phases:

Phase I – Pre-Audit
Phase II – Audit
Phase III – Post-Audit

A Guide for Conducting Energy Audit at a Glance

Industry-to-industry, the methodology of energy audits needs to be flexible.

A 10-step summary for conducting a detailed energy audit at the field level is listed below. The energy manager or energy auditor may follow these steps to start with and add/change as per their needs and the industry type.

10 Steps for a Detailed Energy Audit

Step	Action	Purpose
1	**Phase I – Pre-Audit** • Plan and organize • Walk-through audit • Informal interviews with energy manager, production/plant manager	• Resource planning; establish/organize energy audit team • Organize instrumentation & 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
2	• Conduct briefing/ awareness session with all divisional heads and persons concerned (2–3 hrs)	• Building up cooperation • Issue questionnaire for each department • Orientation, awareness creation
3	**Phase II –Audit** Primary data gathering, process flow diagram, & energy utility diagram	Historic data analysis; baseline data collection Prepare process flowchart(s) All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air and steam distribution.) Design, operating data and schedule of operation Annual energy bill and energy consumption pattern (refer to manuals, log sheets, equipment spec sheets, interviews)
4	Conduct survey and monitoring	Measurements: Motor survey, insulation, and lighting survey with portable instruments to collect more and accurate data. Confirm and compare actual operating data with design data.
5	Conduct detailed trials / experiments for biggest energy users / equipment	Trials/experiments: – 24-hr power monitoring (MD, PF, kWh, etc.). – Load variation trends in pumps, fans, compressors, heaters, etc. – Boiler efficiency trials (4 – 8 hrs) – Furnace efficiency trials – Equipment performance experiments, etc.

10 Steps for a Detailed Energy Audit (continued)

Step	Action	Purpose
6	Analysis of energy use	Energy and material balance & energy loss/waste analysis
7	Identification and development of energy conservation (ENCON) opportunities	Identification & consolidation of ENCON measures Conceive, develop, and refine ideas Review ideas suggested by unit personnel Review ideas suggested by preliminary energy audit Use brainstorming and value analysis techniques Contact vendors for new/efficient technology
8	Cost-benefit analysis	Assess technical feasibility, economic viability, and prioritization of ENCON options for implementation Select the most promising projects Prioritize by low-, medium-, long-term measures Documentation, report presentation to top management
9	Reporting & presenting to top management	Documentation, report presentation to top management
10	**<u>Phase III –Post-Audit</u>** Implementation and follow-up	Assist and implement ENCON measures and monitor performance Action plan, schedule for implementation Follow-up and periodic review

Phase I – Pre-Audit Activities

A structured methodology to carry out the energy audit is necessary for efficient implementation. An initial study of the site should always be carried out, as the planning of the audit procedures is of key importance.

Initial Site Visit and Preparation Required for Detailed Auditing

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

During the initial site visit the energy auditor/manager 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
- Analyze the major energy consumption data with relevant personnel
- Obtain site drawings where available – building layout, steam distribution, compressed air distribution, electricity distribution, etc.
- Tour the site accompanied by engineering/production staff

The main aims of this visit are:

- To finalize energy audit team
- To identify the main energy-consuming areas/plant items to be surveyed during the audit
- To identify any existing instrumentation or additional metering that may be required
- To decide whether any meters will have to be installed prior to the audit; e.g., kWh, steam, oil, or gas meters.
- To identify the instrumentation required for carrying out the audit
- To plan the time frame
- To collect macro data on plant energy resources, major energy consuming centers
- To create awareness through meetings/program

Phase II – Detailed Energy Audit Activities

Depending on the nature and complexity of the site, a detailed energy 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 conducted 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 departments 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 additional capital investment.

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 (e.g., compressed air, steam)
6. Sources of energy supply (e.g., electricity off 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 understand consumption patterns, production cost, and productivity levels in terms of product per raw material inputs. For this the audit team should collect the following baseline data:

- Technology, processes used, and equipment details
- Capacity utilization
- 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 information to the level of accuracy that is actually 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 correct conclusions are drawn (what the grade of product is in production, is the production normal, etc.)
- Define how frequent data collection should be to account for process variations.
- Measurement exercises over abnormal workload periods (i.e., startup and shutdown)
- Design values can be taken where measurements are difficult (i.e., cooling water through a heat exchanger)

Process flow diagram to identify waste streams and 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 Figure 1.8. Existing drawings, records, and a shop floor walk-through will help in making this flowchart. Simultaneously the team should identify the various inputs and output streams at each process step.

Example: A flowchart of a production line for penicillin is given in Figure 1.8. Note that a waste stream (Mycelium) and obvious energy losses such as condensate drainage and steam leakages are identified in this flowchart**.**

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

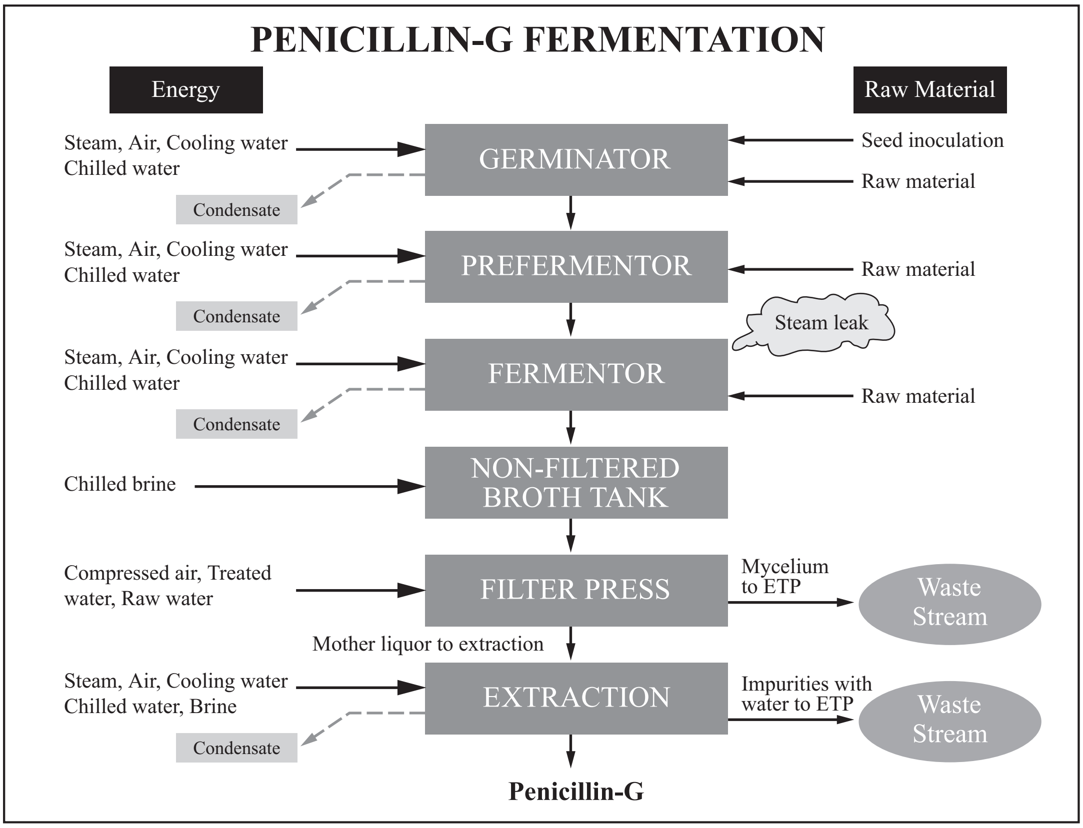


Figure 1.8 Process Flow Diagram

Identification of Energy Conservation Opportunities

Fuel substitution: Identifying alternative fuels for efficient energy conversion

Energy generation: Identifying efficiency opportunities in energy conversion equipment/utilities such as captive power generation, steam generation in boilers, thermic fluid heating, optimal loading of diesel generator sets, minimum excess air combustion with boilers/thermic fluid heating, optimizing existing efficiencies, efficient energy conversion equipment, biomass gasifiers, cogeneration, high efficiency diesel generator sets, etc.

Energy distribution: Identifying efficiency opportunities networks 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 one of the major opportunities for improvement and many of them are hidden. Process analysis is a useful tool for process integration measures that can greatly improve energy efficiency.

Technical and economic feasibility

Technical feasibility assessment should address the following issues:

- Technology availability, space, skilled manpower, reliability, service, etc.
- The impact of energy efficiency measures on safety, quality, production, or process
- Maintenance requirements and availability of spare parts and components

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

Sample Worksheet for Economic Feasibility
Energy Efficiency Measure:

1. Investment	**2. Annual operating cost**	**3. Annual savings**
Equipment	Cost of capital	
Civil works	Maintenance	Thermal energy
Instrumentation	Manpower	Electrical energy
Auxiliaries	Energy	Raw material
	Depreciation	Waste disposal

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

Classification of Energy Conservation Measures

Based on the energy audit and analysis 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 to Table 1.2 for project priority guidelines.

Table 1.2 Project Priority Guidelines			
Priority	**Economic Feasibility**	**Technical Feasibility**	**Risk / Feasibility**
A: Good	Well defined and attractive	Existing technology adequate	No Risk/ Highly feasible
B: Maybe	Well defined and only marginally acceptable	Existing technology may be updated, lack of confirmation	Minor operating risk/May be feasible
C: Hold	Poorly defined and marginally unacceptable	Existing technology is inadequate	Doubtful
D: No	Clearly not attractive	Needs a major breakthrough	Not feasible

CHAPTER 2
ENERGY AUDIT REPORTING

2.1 Energy Audit Reporting Format

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

DETAILED ENERGY AUDIT

TABLE OF CONTENTS

5.1 Specific energy consumption
5.2 Boiler efficiency assessment
5.3 Thermic fluid heater performance assessment
5.4 Furnace efficiency analysis
5.5 Cooling water system performance assessment
5.6 DG set performance assessment
5.7 Refrigeration system performance
5.8 Compressed air system performance
5.9 Electric motor load analysis
5.10 Lighting system

6.0 Energy Conservation Options & Recommendations

6.1 List of options in terms of no cost/low cost, medium cost, and high investment cost, annual energy & cost savings, and payback
6.2 Implementation plan for energy saving measures/projects

ANNEXURE

A1. List of Energy Audit Worksheets
A2. List of Instruments
A3. List of Vendors and Other Technical details

The following worksheets (Tables 2.1 and 2.2) can be used as guides for energy audit assessment and reporting.

Table 2.1 Summary of Energy-Saving Recommendations

Energy-saving recommendations		Annual energy (fuel/electricity) savings (kWh/MT or kl/MT)	Annual savings (USD)	Capital investment	Simple payback period (months)
1					
2					
Total					

Table 2.2 Type and Priority of Energy-Saving Measures

	Type of energy-saving options	Annual energy (fuel/electricity) savings	Annual savings	Priority
		kWh/MT (or) kl /MT	(USD)	
A	No Investment (Immediate) • Operational improvement • Housekeeping			
B	Low Investment (Short to medium term) • Controls • Equipment modification • Process change			
C	High Investment (Long term) • Energy efficient devices • Product modification • Technology change			

Sample Reporting Format for Energy Conservation Recommendations		
A: Title of Recommendation	:	Combine DG set cooling tower with main cooling tower
B: Description of Existing System and its Operation	:	Main cooling tower is operating at 30% of capacity. The rated cooling water flow is 5000 m^3/hr. Two cooling water pumps are in operation continuously at 50% of rated capacity. A separate cooling tower is also operating for DG set operation continuously.
C: Description of Proposed System and its Operation	:	The DG Set cooling water flow is only 240 m^3/h. Adding this flow into the main cooling tower will eliminate the need for separate cooling tower operation for the DG set, besides improving the % loading of main cooling tower. It is suggested to stop DG set cooling tower operation.
D: Energy Saving Calculations:		
Capacity of main cooling tower	=	5000 m^3/ hr
Temperature across cooling tower (design)	=	8°C
Present capacity	=	3000 m^3/ hr
Temperature across cooling tower (operating)	=	4°C
% loading of main cooling tower	=	(3000 × 4)/(5000 × 8) = 30%
Capacity of DG set cooling tower	=	240 m^3/ hr
Temperature across tower	=	5°C
Heat load (240 × 1000 × 1 × 5)	=	1,200,000 K.Cal/hr
Power drawn by DG set cooling tower:	=	(22 × 2 + 7.5 × 2) × 0.80 = 47 kW
No. of pumps / rating	=	2 × 7.5 kW
No. of fans / rating	=	2 × 22 kW

Sample Reporting Format for Energy Conservation Recommendations (continued)		
E: Cost Benefits		
Annual Energy Saving Potential	=	40kW × 8,400 hrs = 336,000 units/year
Annual Cost Savings	=	336,000 × INR 4.00 = INR 134400 per year
Investment (only cost of piping)	=	INR 150000 (1 USD = 42 INR)
Simple Payback Period		**Less than 2 months**

2.2 Understanding Energy Costs

Understanding energy cost is a vital factor for awareness creation and savings calculation. In many industries adequate meters may not be available to measure all the energy being used. In such cases, invoices for fuel and electricity will be useful. The annual company balance sheet is another source where fuel cost and power are given with production-related information.

Energy invoices can be used for the following purposes:

- They provide a record of energy purchased in a given year, which gives a baseline for future comparisons
- Energy invoices may indicate the potential for savings when related to production requirements or to air conditioning / space heating requirements, etc.
- When electricity is purchased on the basis of maximum demand tariff
- They can suggest where savings are most likely to be made
- In later years invoices can be used to quantify the energy and cost savings made through energy conservation measures

Fuel Costs

A variety of fuels are available for thermal energy supply. These include:

- Fuel oil
- Low sulphur heavy stock (LSHS)
- Light diesel oil (LDO)
- Liquefied petroleum gas (LPG)
- Natural gas
- Coal
- Lignite
- Wood

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

- Price at source, transport charge, type of transport
- Quality of fuel (contamination, moisture, etc.)
- Energy content (calorific value)

Power Costs

Many factors are involved in deciding final cost of purchased electricity such as:

- Maximum demand charges, kVA
  (i.e., **how fast** is the electricity used?)
- Energy charges, kWh
  (i.e., **how much** electricity is consumed?)
- Time-of-day charges, peak/non-peak periods
  (i.e., **when** electricity is utilized?)
- Power factor charge (PF)
  (i.e., **actual power use versus apparent power use factor**)
- Other incentives and penalties applied from time to time
- High tension tariff and low tension tariff rate changes
- Slab rate cost and its variations
- Type of tariff clause and rate for various categories such as commercial, residential, industrial, government, agricultural, etc.
- Tariff rate for developed and underdeveloped areas/states
- Tax exclusions for new/energy saving projects

Example: Monthly utility bills

A typical summary of energy expenses based on monthly utility bills

Table 3.4 Total of Monthly Utility Bills

Type	Unit	Unit Cost	Monthly Cost (INR)
Electricity	500,000 kWh	INR 4.00/kWh	2000000
Fuel oil	200 kL	INR 10,000/kL	2000000
Coal	1,000 tons	INR 2,000/ton	2000000
Total			6000000

(1USD = INR42)

2.3 Benchmarking and Energy Performance

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

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

- Scale of operation
- Vintage of technology
- Raw material specifications and quality
- Product specifications and quality

Benchmarking energy performance permits:

- Quantification of fixed and variable energy consumption trends vis-à-vis production levels
- Comparison of industry energy performance with respect to various production levels (capacity utilization)
- Identification of best practices (based on external benchmarking data)
- Scope and margin available for energy consumption and cost reduction
- Basis for monitoring and target-setting exercises

Benchmark parameters can include:

- Gross production related
  - kWh/MT clinker or cement produced (cement plant)
  - kWh/kg yarn produced (textile unit)
  - kWh/MT, kCal/kg, paper produced (paper plant)
  - kCal/kWh Power produced (Heat rate of a power plant)
  - Million kilocals/MT urea or ammonia (fertilizer plant)
  - kWh/MT of liquid metal output (foundry)

- Equipment and utility related
  - kW/ton of refrigeration (air conditioning plant)
  - Thermal efficiency (%) (boiler plant)
  - Cooling tower effectiveness (%)

- kWh/NM^3 of compressed air generated
- kWh/litre in plant using diesel power generation

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

- For cement plant – the Blaine number (particle fineness) and the type of cement (i.e., Portland cement or wet mix) should be stated with kWh/MT
- For textile unit – average count and type of yarn (i.e., polyester/cotton) should be stated with kWh/m^2
- For paper plant – paper type, raw material (recycling extent), and GSM quality are among important factors to be stated with kWh/MT, kCal/Kg
- For power plant / cogeneration plant – plant percentage loading, condenser vacuum, inlet and cooling water temperature are important factors to be stated with the heat rate (kCal/kWh)
- For fertilizer plant – capacity utilization (%) and on-stream factor are inputs worth comparing while mentioning specific energy consumption
- For foundry unit – melt output, furnace type, composition (mild steel, high carbon steel/cast iron, etc.), raw material mix, and number of power trips are useful operating parameters to include with specific energy consumption data
- For air conditioning plant – Chilled water temperature level and refrigeration load (TR) are crucial for comparing kW/TR
- For boiler plant – fuel quality, type, steam pressure, temperature, and flow are useful comparators alongside thermal efficiency and more importantly, whether thermal efficiency is on a gross or net calorific value basis or whether the computation is by direct method or indirect heat loss method
- Cooling tower effectiveness – ambient air wet/dry bulb temperature, relative humidity, and air and circulating water flows are required to be reported to make meaningful sense.
- Compressed air specific power consumption – should be compared at similar inlet air temperatures and generated pressure levels
- Diesel power plant performance – should be compared at similar load percentage, steady run conditions, etc.

Plant Energy Performance

Plant energy performance (PEP) is the measure of whether a plant is now using more or less energy to manufacture its products than it did in the past, as a measure of how well the energy management program is doing. It compares the change in energy consumption from one year to another considering production output. Plant energy performance monitoring compares plant energy use from a reference year with subsequent years to determine the extent of improvement that has been made.

However, plant production output may vary from year to year and the output has a significant bearing on the plant's energy use. For a meaningful comparison, it is necessary to determine the energy that would have been required to produce a target year's (for instance, the preceding 12 months) production output, if the plant had operated in the same way as it did during the reference year. This calculated value can then be compared with the actual value to determine the improvement or deterioration that has taken place since the reference year. This requires calculating the production factor.

Production factor

The production factor is used to determine the energy that would have been required to produce this year's production output if the plant had operated in the same way as it did in the reference year. It is the ratio of production in the current year to that in the reference year.

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

Reference Year Equivalent Energy Use

The reference year's energy use that would have been needed to produce the current year's production output can be called the "reference year energy use equivalent" or "reference year equivalent" for short. The reference year equivalent is obtained by multiplying the reference year energy use by the production factor (obtained above).

$$\text{Reference year equivalent} = \text{Reference year energy use} \times \text{Production factor}$$

The improvement or deterioration from the level of the reference year is called "energy performance" and is a measure of the plant's energy management progress. It is the reduction or increase in the current year's energy use over the reference, and is calculated by subtracting the current year's energy use from the reference year's equivalent. The result is then divided by the reference year equivalent and multiplied by 100 to obtain a ratio.

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

The energy performance is the ratio of energy saved at the current rate of use compared to the reference year rate of use. The greater the improvement, the higher the ratio will be.

Monthly Energy Performance

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

CHAPTER 3
INSTRUMENTS USED IN THE ENERGY AUDIT

3.1 Energy Audit Instruments

The requirement for an energy audit such as identification and quantification of energy necessitates various 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 the energy audit may include the following:

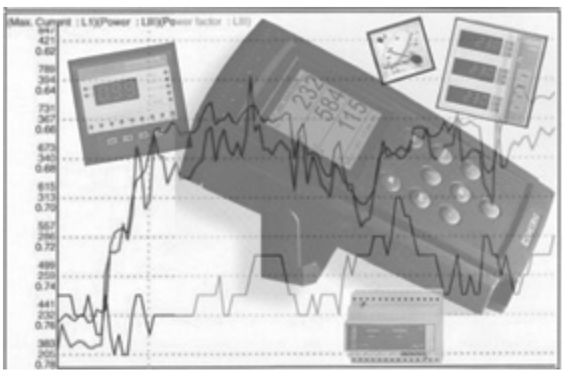
Basic Electrical Parameters in AC & DC systems – Voltage (V), Current (I), Power factor, Active power (kW), Apparent power (demand) (kVA), Reactive power (kVAr), Energy consumption (kWh), Frequency (Hz), Harmonics, etc.

Parameters of importance other than electrical such as temperature and heat flow, radiation, air and gas flow, liquid flow, revolutions per minute, air velocity, noise and vibration, dust concentration, total dissolved solids, pH, moisture content, relative humidity, flue gas analysis – CO_2, O_2, CO, SO_X, NO_X, combustion efficiency etc.

Typical instruments used in energy audits

The below are some of the typical instruments utilized depending on the process or system being audited.

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 stopping the motor. Instantaneous measurements can be taken with hand-held meters, while more advanced models facilitate cumulative readings with printouts at desired intervals.

Combustion Analyzer

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

The Fyrite® is another example of a portable combustion analyzer. A hand pump draws a sample of flue gas into a container of test solution. A chemical reaction occurs, which alters the liquid volume to indicate the level of gas in the sample. A separate Fyrite can be used for O_2 and CO_2 measurement.

Fuel Efficiency Monitor

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

Contact thermometer

This is a thermocouple that measures the temperature, for example, of flue gas, hot air, and hot water by inserting the probe into the stream.

For surface temperatures, 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 a temperature readout. 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 uses the Doppler effect/ultrasonic principle. It has a transmitter and receiver that are positioned on opposite sides of the pipe and detects the flow of the liquid inside. The meter directly gives the flow level. Water and other fluids can be easily measured with this meter.

Tachometer

Stroboscope

Speed Measurement

In any audit exercise, speed measurements are critical as speeds can change with frequency, belt slippage, and loading.

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

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

Leak Detector

Ultrasonic instruments are available that can be used to detect leaks of compressed air and other gases which are normally not possible to detect through touch, sound or other human senses**.**

Lux Meter

Illumination levels are measured with a lux meter. It consists of a photo cell that senses the light output, converting it to electrical impulses that are calibrated as lux and indicated by a digital meter.

CHAPTER 4
AUDIT WORKSHEETS FOR VARIOUS TYPES OF EQUIPMENT

4.1 Fuel & Combustion

4.1.1 Excess Air Calculation

No	Parameter	Formula	Unit	Value
1	Carbon (C)		% by weight	
2	Hydrogen (H)		% by weight	
3	Oxygen (O_4)		% by weight	
4	Nitrogen		% by weight	
5	Sulphur		% by weight	
6	H_2O		% by weight	
7	Ash		% by weight	
8	GCV of fuel		kCal/kg	
9	Oxygen required for burning carbon (O_1)	C_X (32/12)	kg/100 kg of fuel	
10	Oxygen required for burning hydrogen (O_2)	H_X (32/4)	kg/100 kg of fuel	
11	Oxygen required for burning sulfur (O_3)	S_X (32/32)	kg/100 kg of fuel	
12	Total oxygen required (O)	$O_1 + O_2 + O_3 - O_4$	kg/100 kg of fuel	
13	Stochiometric amount of air required (SA)	O / 0.23	kg/100 kg of fuel	
14	Excess air (EA)		%	
15	Actual amount of air required	$S.A_X$ (1+ EA/100)	kg/100 kg of fuel	

4.2 Boiler

4.2.1 Boiler Performance

No.	Parameter reference	Unit	Reading
1	**Ultimate Analysis**		
	Carbon	%	
	Hydrogen	%	
	Oxygen	%	
	Sulfur	%	
	Nitrogen	%	
	Moisture	%	
	Ash	%	
2	GCV of fuel	KCal/kg	
3	Oxygen in flue gas	%	
4	Flue gas temperature (T_f)	ºC	
5	Ambient temperature (T_a)	ºC	
6	Humidity in air	Kg/kg of dry air	
7	Combustibles in ash	%	
8	GCV of ash	KCal/kg	
9	Excess air supplied (EA) $(O_2 \times 100)/(21 – O_2)$	%	
10	Theoretical air requirement (TAR) $[11 \times C + \{34.5 \text{ x } (H_2 – O_2/8)\} + 4.32 \times S]/100$	Kg/kg of fuel	
11	Actual mass of air supplied {1 + EA/100} x theoretical air	Kg/kg of fuel	
12	Percentage heat loss due to dry flue gas $\{k \times (T_f – T_a)\}$ / % of CO_2 Where, k (Seigert constr.) = 0.65 for coal = 0.56 for oil = 0.40 for NG	%	
13	Percentage heat loss due to evaporation of water formed due to H_2 in fuel $[9 \times H2 \{584 + 0.45(T_f – T_a)\}]$/ GCV of fuel	%	

No.	Parameter reference	Unit	Reading
14	Percentage heat loss due to evaporation of moisture present in fuel [M × {584 + 0.45 × (T_f – T_a)}] / GCV of fuel	%	
15	Percentage heat loss due to moisture present in air {AAS × Humidity × 0.45 (T_f – T_a) × 100} / GCV of Fuel	%	
16	Percentage heat loss due to combustibles in ash {Ash × (100 – comb. in ash) × GCV of ash × 100} / GCV of fuel	%	
17	Total losses	%	
18	Efficiency	%	

4.2.2 Data Collection Sheet for Boiler

No.	Parameter reference	Unit	Reading
1	Type of boiler		
2	Quantity of steam generated	TPH	
3	Steam pressure	Kg/cm^2 (g)	
4	Steam temperature	ºC	
5	Fuel used (coal/oil/gas, etc.)		
6	Quantity of fuel consumed	TPH	
7	GCV of fuel	kCal/kg	
8	Feed water temperature	ºC	
9	Oxygen in flue gas	%	
10	Flue gas temperature (T_f)	ºC	
11	Ambient temperature (T_a)	ºC	
12	Humidity in air	Kg/kg of dry air	
13	Combustibles in ash	%	
14	GCV of ash	KCal/kg	

4.2.3 Fuel Analysis Sheet

No.	Parameter reference	Unit	Reading
1	**Ultimate Analysis**		
	Carbon	%	
	Hydrogen	%	
	Oxygen	%	
	Sulfur	%	
	Nitrogen	%	
	Moisture	%	
	Ash	%	
2	GCV of fuel	KCal/kg	

4.3 Steam Distribution & Utilization

4.3.1 Technical Specifications of Steam Traps

Section No.	Trap ref. No.	Trap type	Trap size	Location ref. (plant dept/block)	Type of discharge (continuous/ semi-continuous/ intermittent)	Trap capacity (kg condensate/hr)

4.3.2 Steam Trap Audit

Section No.	Trap ref. (No.)	Trap type	Trap size	Trap pressure kg/cm^2	Trap location	Application of trap	Functional status of trap	Diagnosis of situation	Status of trap fittings	Remarks

4.3.3 Insulation Losses

No.	Location	Equipment reference	Outer diameter	Surface temperature	Insulation thickness

4.4 Waste Heat Recovery

4.4.1 Heat Recovery Questionnaire

1. From which equipment do you want to recover heat? Oven, furnace, etc.

- Oven
- Flue gas
- Dryer
- Bake oven
- Furnace
- Paint dryer
- Kiln
- Melting furnace
- Boiler
- Die cast machine
- Cupola
- Exhaust air
- Other (specify)

2. Hot Side Flows
   a. At what temperature does hot exhaust leave this equipment?
   b. What is the quantity of this hot exhaust?

3. Is this hot exhaust gas clean (natural gas, propane, No. 2 fuel oil) or does it contain contaminates or corrodents such as sulfur, chlorides, etc.?

Clean:
Exhaust is from:
_________ Air
_________ Natural gas
_________ Propane
_________ Fuel oil
_________ Electricity
_________ Other

Dirty:
Exhaust is from and/or contains:
_____________ Fuel oil
_____________ Coal
_____________ Sulfur ______%
_____________ Chloride ______%
_____________ Paint vapor ______%
_____________ Other ______%

4. Cold Side Flows

Entering Fluid Temperature	ºC	
Entering fluid volume	ºC	
Leaving Fluid Temperature desired	ºC	
Energy to be recovered	kJ/hr	
Available flow	L/s	

5. Fuel cost: (USD/kg)

6. Operating hours

4.5 Electric Motors

4.5.1 Motor Data Collection

No.	Motor reference	Motor Tag No.	HT/LT	kW	Voltage	FLA (Amp)	Power factor	Speed (RPM)	Insulation class	Service factor	Frame size	Manufacturer

4.5.2 Motor Load Analysis

No.	Motor reference	Motor ID	Rated power (KW)	Rated efficiency	Actual measured values				Motor loading %
					Voltage (KV)	Current (Amp)	Power factor	Input power (KW)	

4.6 Compressed Air System

4.6.1 Compressor Master Data

Air compressor reference	**Unit**	**1**	**2**	**3**	**4**
Make	--				
Type	--				
No. of stages	--				
Discharge capacity	Nm^3/min				
Discharge pressure	$kg/cm^2 \cdot g$				
Speed	Rpm				
Receiver capacity	m^3				
Motor rating					
Power	kW				
Full-load current	A				
Voltage	V				
Power factor	PF				
Speed	rpm				
Frequency	Hz				
Specific power consumption	kW/m^3/min				

4.6.2 Leakage Test in Compressed Air System

Item	Unit	Remarks
Compressed air users	No.	Mention area of plant
Load time (t1)	Sec	Measured
Unload time (t2)	Sec	Measured
Capacity of compressor	Nm^3/min	Rated
Leakage = [t1/(t1+t2)] x 100	%	Estimated
Leakage cfm = % Leakage × Capacity of compressor		Estimated

Procedure:

- Leakage test is conducted when entire plant is shut down or when all compressed air users are not working. It would be advantageous if separate sections could be isolated from one another by isolating valves.
- A dedicated compressor is switched on to fill the system network with compressed air.
- Since there are no compressed air users, the air compressor will unload the moment the system pressure reaches the set point (say, 8 $kg/cm^2 \cdot g$).
- If the system has no leaks, the air compressor will remain unloaded indefinitely.
- However, since there are bound to be system leaks, the receiver pressure gradually begins to drop, until the lower set point is reached, at which point the air compressor is loaded again and begins to generate compressed air.
- Load and unload times are measured using a stopwatch over 5–6 cycles, and average load and unload times are worked out.
- Compressed air leakage (%) and quantity are then evaluated.

4.6.3 Capacity Testing of Compressor

Air compressor reference	Unit	1	2	3	4
Receiver volume plus volume of pipeline between receiver and the air compressor	m^3				
Receiver temperature	°C				
Initial receiver pressure (P_1)	$kg/cm^2 \cdot a$				
Final receiver pressure (P_2)	$kg/cm^2 \cdot a$				
Time taken to fill receiver from P_1 to P_2 (t)	min				
Atmospheric pressure (P_o)	$kg/cm^2 \cdot a$				
Air compressor capacity (free air delivery) Q	Nm^3/min				

Note: Each compressor must have its own receiver.

Procedure:

1. The air compressor being tested for capacity is first isolated from the rest of the system, by operating the isolating non-return valve.
2. The compressor drive motor is shut-off.
3. The receiver connected to this air compressor is emptied.
4. The motor is re-started.
5. The pressure in the receiver begins to rise. Initial pressure, say 2 kg/cm^2, is noted. The stopwatch is started at this moment.
6. The stopwatch is stopped when receiver pressure has risen to, say, 9 kg/cm^2.
7. Time elapsed is noted.
8. Compressor capacity is evaluated as:

$$(Nm^3/min) = \left(\frac{P_2 - P_1}{P_o}\right) \times \left(\frac{V_R}{t}\right) \times \left(\frac{273}{273 + T}\right)$$

4.7 Refrigeration & Air Conditioning

4.7.1 Refrigeration and AC System Rated Specifications

Section No.	Refrigeration compressor	Unit	Machine reference			
			1	2	3	4
1	Make					
2	Type					
3	Capacity (of cooling)	TR				
4	**Chiller:**					
a	No. of tubes	—				
b	Dia. of tubes	m				
c	Total heat transfer area	m^2				
d	Chilled water flow	m^3/hr				
e	Chilled water temp. difference	°C				
5	**Condenser:**					
a	No. of tubes					
b	Dia. of tubes					
c	Total heat transfer area	m				
d	Condenser water flow	m^3/hr				
e	Condenser water temp. difference	°C				
6	**Chilled water pump:**					
a	Nos.	—				
b	Capacity	m^3/hr				
c	Head developed	mWC				
d	Rated power	kW				
e	Rated efficiency	%				
7	**Condenser water pump:**					
a	No.	—				
b	Capacity	m^3/hr				
c	Head developed	mWC				
d	Rated power	kW				
e	Rated efficiency	%				

4.7.2 Refrigeration Plant Performance

No.	Parameter reference	Unit	Refrigeration compressor reference			
			1	2	3	4
1	Chilled water flow (using a flow meter or assessed by level difference)	m^3/hr				
2	Chilled water pump motor input power	kW				
3	Chilled water pump suction pressure	kg/cm^2g				
4	Chilled water pump discharge pressure	kg/cm^2g				
5	Chiller water inlet temperature to chiller	°C				
6	Chiller water outlet temperature from chiller	°C				
7	Condenser water inlet temperature	°C				
8	Condenser pump suction pressure	kg/cm^2				
9	Condenser pump discharge pressure	kg/cm^2				
10	Condenser water outlet temperature	°C				
11	Chiller (evaporator) outlet refrigerant temperature	°C				
12	Refrigerant pressure	kg/cm^2 (or psig)				
13	Condenser inlet refrigerant temperature	°C				
14	Refrigerant pressure	kg/cm^2 (or psig)				
15	Actual cooling capacity [(1) ∗ (6 – 5) / 3024]	TR				
16	COP [11 / (10 – 11)]	—				
17	Compressor motor input power	kW				
18	Specific energy consumption	kW/TR				
19	Input power to CT fan	kW				
20	Input power to chilled water pumps in operation	kW				
21	Input power to condenser water pumps in operation	kW				
22	Overall system specific power consumption [(2 + 17 + 19 + 20) / 15]	kW/TR				

4.8 Fans & Blowers

4.8.1 Fans and Blowers Specification Data

No.	Parameter	Unit	Fan / Blower No.		
			1	2	3
1	Make				
2	Type (Axial/Centrifugal)				
3	Discharge flow	m^3/hr			
4	Head developed	mmWC			
5	Fluid handled				
6	Density of fluid	kg/m^3			
7	Dust concentration	kg/m^3			
8	Temperature of fluid	°C			
9	Flow control type				
10	Flow control range	%			
11	Fan input power	kW			
12	Fan speed	RPM			
13	Fan rated efficiency	%			
14	Specific power consumption	kW/(m^3/hr)			
15	Fan motor				
	Rated power	kW			
	Full load current	Amp			
	Rated speed	RPM			
	Supply voltage	Volts			
	Rated efficiency	%			
	Rated power factor				
	Supply frequency	Hz			
16	Bearing type				
	Fan (driving end)				
	Fan (non-driving end)				
	Motor (driving end)				
	Motor (non-driving end)				
17	Lubricant grade				

4.8.2 Fan and Blower Efficiency Calculation

No.	Parameter	Unit	Fan / Blower reference		
			1	2	3
1	Fluid (medium) flow (Q) (measured using pitot tube at fan discharge)	m^3/sec			
2	For suction pressure (measured at fan inlet using U-tube manometer)	mmWC			
3	For discharge pressure (measured at fan discharge using U-tube manometer)	mmWC			
4	Total Static Pressure (ΔP) [3–4]	mmWC			
5	Total Differential Pressure (dP) (measured by pitot tube by taking measurement at number of points over the duct cross section)	mmWC			
6	Pitot tube constant (Cp)				
7	Duct cross sectional area (A)	m^2			
8	Temperature of fluid medium (measured at fan inlet using thermometer)	°C			
9	Density of fluid medium handled (r) (taken from standard data and corrected to operating temperature/pressure conditions)	kg/m^3			
10	Motor input power (P) (measured at motor terminals or switchgear using panel or portable energy meter/power analyzer)	kW			
11	Power input to shaft (P1) (P × motor efficiency × transmission efficiency)	%			
12	Supply frequency	Hz			
13	Pump input power	kW			
14	Air/Gas velocity (V) [= (Cp × √(2 × 9.81 × dP × r)]/r	m/sec			
15	Flow rate (Q) (= V x A)	M^3/sec			
16	Fan mechanical efficiency (ηF) (Q × ΔP)/(102 × P1) x 100	%			
17	Specific power consumption (P/Q)	kW/(m^3/sec)			
18	% motor loading with respect to power	%			
19	% fan loading with respect to flow	%			
20	% fan loading with respect to total static pressure	%			

4.9 Pump & Pumping System

4.9.1 Pump Specification Data

No.	Parameter	Unit	Pump No.		
			1	2	3
1	Make				
2	Type (reciprocating/centrifugal)				
3	Discharge capacity	m^3/hr			
4	Head developed	mmWC			
5	Fluid handled				
6	Density of fluid	kg/m^3			
7	Temperature of fluid	^{0}C			
8	Pump input power	kW			
9	Pump speed	RPM			
10	Pump rated efficiency	%			
11	Specific power consumption	kW/(m^3/hr)			
12	Pump motor				
	Rated power	kW			
	Full load current	Amp			
	Rated speed	RPM			
	Supply voltage	Volts			
	Rated efficiency	%			
	Rated power factor				
	Supply frequency	Hz			
13	Bearing type				
	Pump (driving end)				
	Pump (non-driving end)				
	Motor (driving end)				
	Motor (non-driving end)				
14	Lubricant grade				

4.9.2 Pump Efficiency Calculation

No.	Parameter	Unit	Pump No.		
			1	2	3
1	Fluid flow measured or estimated (Q)	m^3/sec			
2	Suction head (including head correction due to pressure gauge location)	m			
3	Discharge head (including head correction due to pressure gauge location)	m			
4	Total dynamic head (TDH)	m			
5	Density of fluid (γ)	kg/m^3			
6	Motor input power (P)	kW			
7	Supply frequency	Hz			
8	Pump input power	kW			
9	Hydraulic power (Ph) $Q \times H \times \gamma \times 9.81/1000$	kW			
10	Combined efficiency (ηc) Ph/P × 100	%			
11	Pump efficiency (ηp) (ηc/motor efficiency) × 100	%			
12	Specific power consumption P/Q	kW/(m^3/sec)			
13	% motor loading with respect to power	%			
14	% pump loading with respect to flow	%			
15	% pump loading with respect to total dynamic head (TDH)	%			

4.10 Cooling Tower

4.10.1 Key Technical Specification

No.	Parameter	Unit	Cooling tower reference	
			CT 1	CT 2
1	Type of cooling tower			
2	Number of tower			
3	Number of cells per tower			
4	Area per cell			
5	Water flow	m^3/hr		
6	Pumping power	kW		
7	Pumping head	m		
8	Fan power	kW		
9	Design hot water temperature	°C		
10	Design cold-water temperature	°C		
11	Design wet bulb temperature	°C		

4.10.2 Cooling Tower Performance

No.	Parameter reference	Unit	Cooling tower (CT)	
			CT 1	CT 2
1	Dry bulb temperature	°C		
2	Wet bulb temperature	°C		
3	CT inlet temperature	°C		
4	CT outlet temperature	°C		
5	Range	°C		
6	Approach	°C		
7	CT effectiveness	%		
8	Average water flow	kg/hr		
9	Average air quantity	kg/hr		
10	Liquid/gas (L/G) ratio	kg water/kg air		
11	Evaporation loss	m^3/hr		
12	CT heat loading	kCal/hr		