Module 1

FUNDAMENTALS OF ENERGY MANAGEMENT AND ENERGY AUDIT

SREDA
Sustainable and Renewable Energy Development Authority

Sustainable and Renewable Energy Development Authority

Power Division

Second Edition'2021

Preamble

In order to ensure energy efficiency and conservation and to determine the future course of action, Sustainable and Renewable Energy Development Authority (SREDA) has developed the Energy Efficiency & Conservation Master Plan up to 2030 in 2016. According to this plan, the target of energy saving has been set 20% per GDP by 2030 which will be achieved by the use of energy efficient machinery and equipment as well as by improving energy management system.

In order to achieve the above mentioned target & to ensure the energy efficiency and conservation in industrial & commercial sector, SREDA has formulated the Energy Audit Regulation'2018. Based on this regulation, SREDA will conduct the Energy Auditor Certification Examination to create energy auditors and energy managers in Bangladesh.

SREDA has prepared the following modules as reading material for four paper examinations in cooperation with various National and Foreign partner organizations.

Module No	Examination Paper	Subject
Module 01	Paper 01	Fundamentals of Energy Management and Energy Audit
Module 02	Paper 02	Energy Efficiency in Thermal Systems
Module 03	Paper 03	Energy Efficiency in Electrical Systems
Module 04	Paper 04	Energy Performance Assessment for Equipment and Utility Systems

This module 01 on Fundamentals of Energy Management and Energy Audit is the reading material for the preparation of Paper 01 Examination for prospective candidates.

We hope that these modules will also act as valuable resource for practicing engineers in comprehending and implementing energy efficiency measures in the facilities.

It is the first iteration of these modules. It will be a living document which can be reviewed and revised time to time according to the evolution of the technology and industry. Any suggestion and comments (please email to ad.eaa@sreda.gov.bd) on the contents of those modules will be highly appreciated.

Table of Contents

Chapter 1: Introduction to ENERGY

1.1 Basics of Energy and its Various Forms

1.1.1 Introduction

Energy is described as the ability to do work or as the ability to carry a heat transfer. Energy is required for doing work or involving in a heat transfer. A body is said to possess energy when it has the capacity to do work or the capacity to carry a heat transfer with another body. Work and heat transfer are the transfer of energy from one body to another-so they are called transitory energy. In practical terms energy is what we use to manipulate the world around us, whether by exciting our muscles, by using electricity or by using mechanical devices such as automobiles. Broadly, energy can be classified as potential (stored) energy and kinetic (working) energy.

Potential Energy

Potential energy is the energy a body possesses because of its position or configuration. For example, driving head of a pile driver has potential energy of position when raised above. On release, driving head comes down to do the piling work. Stretched rubber band or compressed steel spring possesses potential energy of configuration. Both have ability to do work because of their tendency to return to their normal position. Potential energy exists in various forms: chemical energy, nuclear energy, stored mechanical energy, gravitational energy etc.
Potential energy stored in a body due to its height above a datum level is expressed by:

Potential energy (E_P) = mass x gravitational acceleration x height= m g h.

Chemical Energy

Chemical energy is the energy stored in the bonds of atoms and molecules and released as heat in a chemical reaction. This is specific to each reaction and is usually given as energy per unit mass (e.g. kJ/ kg) or number of molecules (e.g. kJ/mol). Biomass, petroleum, natural gas, propane and coal are examples of stored chemical energy.

Nuclear Energy

Nuclear energy is the energy stored in the nucleus of an atom - the energy that holds the nucleus together. The nucleus of an Uranium atom releases nuclear energy when its' fission (split in two parts) results in a loss of mass and the corresponding loss of mass(m) is converted to nuclear energy by the following famous equation of Einstein:

Nuclear energy (EJ = mass x speed of light squared = m c^2 (where c = 3 x 10^8 m/s)

Stored Mechanical Energy

Stored mechanical energy is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of stored mechanical energy.

Gravitational Energy

Gravitational energy is the energy of place or position. Water in a reservoir behind a hydropower dam is an example of gravitational energy. When the water is released to spin the turbines, it becomes motion energy in the form of mechanical power-which drives the Generators/Alternators to produce electrical energy.

Kinetic Energy

It is the energy a body possesses by virtue of motion or velocity. For example, a moving vehicle, a flowing fluid and moving parts of machinery all have kinetic energy because of their motion. It exists in various forms: radiant energy, thermal energy, electrical energy, motion energy, sound energy etc.

Kinetic energy $E_k = \frac{1}{2}mv^2 = \text{half} * \text{mass} * \text{velocity squared}$

Radiant Energy

Radiant energy is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays and radio waves. Solar energy is an example of radiant energy.

Thermal Energy

Thermal energy is the internal energy in substances - the vibration and movement of atoms and molecules within substances. Geothermal energy is an example of thermal energy.

Motion energy

The movement of objects or substances from one place to another is motion. Wind and hydropower are manifestations of motion energy.

Sound energy

Sound is the movement of energy through substances in longitudinal (compression/rarefaction) waves.

Electrical Energy

Electrical energy is the movement of electrons. Lightning and electricity are examples of electrical Energy.

1.1.2 Work, Energy and Power

Work

The unit of work or energy is the joule (J) where one joule is one Newton meter. The joule is defined as the work done or energy transferred when a force of one Newton is exerted through a distance of one meter in the direction of the force. Energy is the capacity for doing work.

Thus, Work done on a body, in Joules W= Fs

Where, F is the force in Newtons and s is the distance in meters moved by the body in the direction of the force.

In case of rotating body work done is expressed in Joules as: W= T*Θ
Where T is the Torque in Newton-Meter and Θ is the angle in radian the body rotated.

Kilojoule (1 kJ = 1000J) is more common among engineers. Even kilojoule is too small a unit when considering national or global amounts of energy. In such cases Mega joule (10^6 J), Gigajoule (10^9 J), terra joule (10^{12} J) and petajoule (10^{15} J) are used.

Energy and Power

Energy represents potential to do work. To actually do the work, one has to use energy of one form at a given rate and convert it to another form. Power is defined as the rate of doing work or rate at which energy is used and converted.

The unit of power is Watt (W), where one Watt is one Joule per second.
Thus, power in Watts, P = W/t

Where, W is the work done or energy transferred in Joules and t is the time in seconds.

Thus, energy, in joules, W = Pt
1 kWh = 3600KJ =3.6MJ

In case of rotating body, power in Watts, P=T*w= (2πr*T*N)/60,

Where T is the Torque applied in Newton-Meter, w is angular velocity in radian/sec. and N is the revolution per minute (RPM).

Example 1.1

A portable machine requires a force of 200 N to move it. How much work is done if the machine is moved 20 m and what average power is utilized if the movement takes 25 s?

Solution

Work done = force x distance
= 200 N X 20 m
= 4000 Nm or 4 k]
Power = Work done / time taken = 4000 J /25 s = 160 J/s =160 W

1.1.3 Electricity Basics

Direct Current (DC)

A current which is a non-varying, unidirectional current, e.g. current produced by batteries.

Alternating Current

A current which reverses in regularly recurring intervals of time and which has alternate positive and negative values occurring specified number of times, e.g. current from utilities. In 50 Cycle (Hertz) AC, current reverses direction 100 times per second i.e. two times in one cycle.

Amps or Ampere (A)

Current is the rate of flow of charge. Ampere is the basic unit of electric current.

Voltage or Volts (V)

It is a measure of electric potential or electromotive force. A potential of one Volt (V) appears across a resistance of one Ohm when a current of one Ampere flows through the resistance. In case of Alternating Current (AC) —the Voltage or Current value normally mentioned is Root Mean Squared (RMS) value so that we can use the same formula for calculating power just like a Direct Current (DC) application.

Resistance and Conductance

The unit of electric resistance is the ohm (Q) where one ohm is one volt per ampere. It is defined as the resistance between two points in a conductor when a constant electric potential of one volt applied at the two points produces a current flow of one ampere in the conductor. Thus, resistance, in ohms R = Volts /Amp = V/I

Where V is the potential difference across the two points in volts and I is the current flowing between the two points in amperes.

The reciprocal of resistance is called conductance and is measured in Siemens (S). Thus, conductance, in mho or Siemens G = 1/R, where R is the resistance in ohms.

Frequency (Hertz)

The supply frequency is the number of cycles at which alternating current changes. The unit of frequency is cycles / second or Hz. In Bangladesh the normal supply frequency by utilities is at 50 Hz.

Electrical Energy

When a direct current (DC) of I amperes is flowing in an electric circuit and the voltage across the circuit is V volts, then,

Power, in Watts P = VI
Electrical energy = Power x time
= V x I x t Joules

The same formulae can be used in AC applications as well (since voltage and current are normally expressed in RMS values for AC applications)
Although the unit of energy is the Joule, when dealing with large amounts of energy, the unit used is the kilowatt hour (kWh) where

1 kWh = 1000 Watt hour
= 1000 x 3600 Watt seconds or Joules
= 3,600,000 J

Example 1.2

An electric heater consumes 1.8 MJ when connected to a 250 V supply for 30 minutes. Find the power rating of the heater and the current taken from the supply?

Solution
Energy = power x time,
Power = Energy / time
=1.8x106J/30x60s
=1000 J/s =1000 W
i.e., Power rating of heater = 1 kW
Power P= VI thus, I = P/ V= 1000/250 = 4A
Hence, the current taken from the supply is 4 A.

Example 1.3

A 100 W electric light bulb is connected to a 250 V supply. Determine (a) the current flowing in the bulb, and (b) the resistance of the bulb

Solution
Power P = V X I from which, current I = P/V
(a) Current, I = 100/250 =0.4 A
(b) Resistance, R = V/I =250/0.4 = 625 Ω

Example 1.4

An electric kettle has a resistance of 30 Ω. What current will flow when it is connected to a 240 V supply? Find also the power rating of the kettle.

Solution
Current, I = V/R = 240/30 = 8 A
Power, P = VI = 240 x 8 = 1920 W
= 1.92 kW
= Power rating of kettle

Example 1.5

An electric heater of 230 V, 5 kW rating is used for hot water generation in an industry. Find electricity consumption per hour (a) at the rated voltage (b) at 200 V.

Solution

(a) Electricity consumption (kWh) at rated voltage = 5 kW x 1 hour = 5 kWh.
(b) Electricity consumption at 200 V (kWh) = (200/ 230)2X 5 kW x 1 hour = 3.78 kWh.

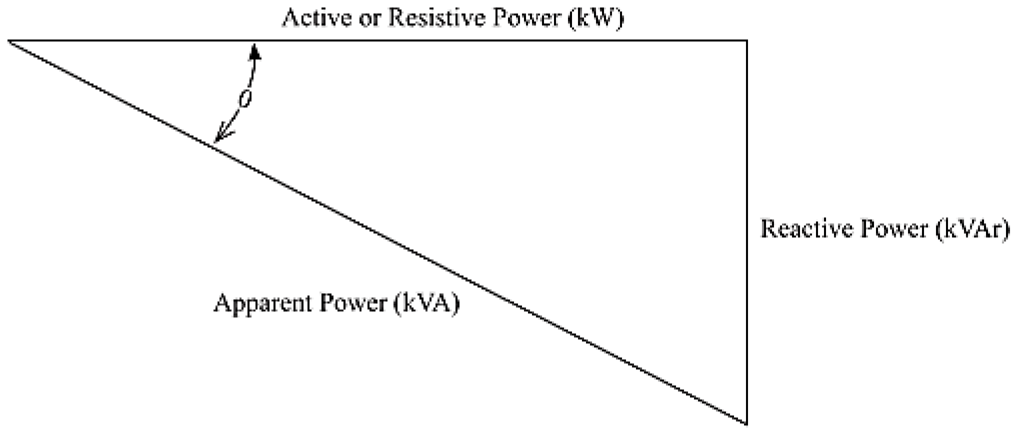
Power Factor

The total power requirement is comprised of two components, as illustrated in the power triangle. This triangle (given below) shows the resistive portion or kilowatt (kW), 90° out of phase with the reactive portion, kilovolt ampere reactive (kVAR). The reactive current is necessary to build up the flux for the magnetic field of inductive devices, but otherwise it is non-usable. The resistive portion is also known as the active power which is directly converted to useful work. The hypotenuse of the power triangle is referred to as the kilovolt ampere or apparent power (kVA). The angle between kW and kVA is the power factor angle.

$$kW = kVA\ cos\theta$$
$$kVA = kW / cos\ \theta$$
$$kVAR = kVA\ sin\ \theta$$
$$PF = cos\ \theta$$

PF is referred to as the power factor.

Only power portions in same phase with each other can be combined. For example: resistive portions of one load can be added to resistive portions of another. The same will hold for reactive loads also.



Relationships between Power, Voltage, and Current

For a balanced three-phase load,
Power, Watts $= \sqrt{3}\, V_L \times I_L Cos\theta$
For a balanced single-phase load,
Power, Watts $= V_L \times I_L\ Cos\theta$

Where,

V_L = Line Voltage
I_L = Line current.

Which applications use single-phase power in an industry?

Single-phase power is mostly used for lighting, fractional HP motors and electric heater applications.

Example 1.6

A 400 Watt mercury vapor lamp was switched on for 10 hours per day. The supply volt is 230 V. Find the energy consumption per day? (Volt = 230 V, Current = 2 amps, PF = 0.8)

Solution
Electricity consumption (kWh) = $V \times I \times Cos\,\phi\; x\; No\; of\; Hours$
= 0.230 x 2 x 0.8 x 10 = 3.7 kWh or Units

Motor Loads

Each electrical load in a system has an inherent power factor. Motor loads are usually specified by horse power ratings. These may be converted to kVA, by use of Equation

$$kVA = (HP\; x\; 0.746)/(\eta\; x\; PF)$$

Where,
$\eta = Motor\; efficiency$
$P.F. = Motor\; power\; factor$
$HP = Motor\; horsepower\; (i.e. Rated\; Output\; power)$.

Most motor manufacturers can supply information on motor efficiencies and power factors. Smaller motors running partly loaded are the least efficient and have the lowest power factor.

Example 1.7

A 3-phase AC induction motor (20 kW capacity) is used for pumping operation. Electrical parameters such as current, volt and power factor were measured with power analyzer. Find the energy consumption of motor in one hour? (Volts. = 440 V, current = 25 amps and PF = 0.90).

Solution
Measured Energy consumption = $\sqrt{3} \times 0.440 \times 25 \times 0.90 \times 1 = 17.15\; kWh$

Motor loading calculation
The name plate details of motor, KW or HP indicates the output of the motor at full load the other Parameters such as volt, amps, PF are the input condition of motor at full load.

Example 1.8

A 3-phase 10 kW motor has the name plate details as 415 V, 18.2 amps and 0.9 PF. Actual input measurement shows 415 V, 12 A and 0.7 PF which was measured with power analyzer during motor running. Find out the motor loading and actual input power of the motor.

Solution
Rated output at full load = 10 KW
Rated input at full load = $1.732 \times 0.415 \times 18.2 \times 0.9 = 11.8\ kW$
The rated efficiency of motor = 10/11.8 = 85%
Measured (Actual) input power = $1.732 \times 0.415 \times 12 \times 0.7 = 6.0\ kW$

Motor loading (%) = Measured kW = 6.0 x 100 = 51.2 %
Rated Input kW 11.8

1.1.4 Thermal Energy Basics

Temperature

Temperature is a physical property that quantitatively expresses the common notions of hot and cold. Objects of low temperature are cold, while various degrees of higher temperatures are referred to as warm or hot.

Temperature is measured with thermometers, which may be calibrated to a variety of temperature scales. Much of the world uses the Celsius scale for most temperature measurements. In Fahrenheit scale (British system), the freezing point of water is 32°F and the boiling point of water is 212°F at atmospheric pressure.

The Kelvin scale is the temperature standard for scientific or engineering purposes. It has the same incremental scaling (1°) as the Celsius scale, but fixes its origin, or null point, at absolute zero ('K = -273.15°C)

Conversion of the degree Celsius into Fahrenheit = $(degrees\ C\ x\ 1.8) + 32$
Conversion of the Fahrenheit into degree Celsius = $(degrees\ F - 32)$ / 1.8
Degrees Celsius (C) to degrees Kelvin (K) = $(C) + 273 = (K)$

Pressure
It is the force per unit area applied to outside of a body.

$$P = F/A = ma/A = mg/A\ (when\ g = a)$$

Where,

$P\ is\ the\ pressure\ in\ N/m^2\ or\ Pascals$
$F\ is\ the\ force\ in\ Newtons\ (N)$
$a\ is\ the\ acceleration\ in\ m/s^2$
$g\ is\ the\ acceleration\ due\ to\ gravity\ in\ m/s^2$

Absolute pressure

The absolute pressure (ps) is total or true pressure. It is measured relative to the absolute zero pressure - the pressure that would occur at absolute vacuum. All calculation involving the gas laws requires pressure to be in absolute units and temperature in Kelvin.

Gauge Pressure

Gauge pressure (pg) is the pressure indicated by a gauge. All gauges are calibrated to read zero at atmospheric pressure. Gauges indicated the pressure difference between a system and the surrounding atmosphere. The gauge pressure can be expressed as

$$pg = ps - pa$$

Where,

$pg = gauge\ pressure$
$ps = system\ pressure\ (absolute)$
$pa = atmospheric\ pressure$

Atmospheric Pressure

Atmospheric pressure (pa) is pressure in the surrounding air at the surface of the earth. The atmospheric pressure varies with temperature and altitude above sea level.

Standard Atmospheric Pressure

Standard Atmospheric Pressure (atm) is used as a reference for gas densities and volumes. The Standard Atmospheric Pressure is defined at sea-level at 273°K (0°C) and is 1.01325 bar or 101325 Pascal (absolute). The temperature of293°K (20°C) is also used.

$$1\ \text{atm} = 1.01325\ \text{bar} = 101.3\ \text{kPa} = 760\ \text{mmHg} = 10.33\ \text{meter}\ H_20 = 1.013\ \text{mbar} = 1.0332\ \text{kgf/cm}^2$$

Heat

Heat is transferred from one body to another body at a lower temperature by virtue of temperature difference i.e. Heat is energy in transition or transitory energy.

The quantity of heat depends on the quantity and type of substance involved.

Calorie is the unit for measuring the quantity of heat. It is the quantity of heat, which can raise the temperature of 1 g of water by 1°C.

Calorie is too small a unit for many purposes. Therefore, a bigger unit Kilocalorie (1 Kilocalorie = 1000 calories) is used to measure heat. 1 kilocalorie can raise the temperature of 1000g (i.e. 1kg) of water by 1°C.

However, nowadays generally Joule as the unit of heat energy is used. It is the internationally accepted unit. Its relationship with calorie is as follows:

$$1\ \text{Calorie} = 4.187\ \text{J} \sim 4.2\ \text{J}$$

Specific Heat

If the same amount of heat energy is supplied to equal quantities of water and milk, their temperature goes up by different amounts. This is due to different specific heats of different substances. Specific heat is defined as the quantity of heat required to raise the temperature of 1kg of a substance through 1°C or 1 K. Specific heat is expressed in terms of kcal/kg^{0}C or J/kg K. Specific heat varies with temperature. In case of gases-there are an infinite number of processes in which heat may be added to raise gas temperature by a fixed amount and hence a gas could have an infinite numbers of specific heat capacities. However-only two specific heats are defined for gases i.e. specific heat at constant pressure, cp and specific heat at constant volume, cv. For solids and liquids, however, the specific heat does not depend on the process.

The specific heat of water is very high as compared to other common substances; it takes a lot of heat to raise the temperature of water. Also, when water is cooled, it gives out a large quantity of heat. The specific heats of common substances are given in Table 1.1.

Table 1.1: Specific Heat of Some Common Substances

Substance	Specific heat (J/kg°C)
Lead	130
Mercury	140
Copper	390
Aluminium	910
Water	4200
Alcohol	2400
Iron	470

Sensible Heat

The amount of heat which when added to any substance causes a change in temperature. The changes in temperature that do not alter the moisture content of air. It is expressed in calories or Joules.

Sensible heat = mass x specific heat x change in temperature

$$Q = m\, C_p\, \Delta T$$

Phase Change

The change of state from the solid state to a liquid state is called fusion. The fixed temperature at which a solid changes into a liquid is called its melting point.

The change of a state from a liquid state to a gaseous is called vaporization. The fixed temperature at which a liquid changes into a vapour is called its boiling point. The change of a state from gaseous state to a liquid state is called condensation.

Latent heat

It is the change in heat content of a substance, when its physical state is changed without a change in temperature.

Latent heat of fusion

The latent heat of fusion of a substance is the quantity of heat required to convert 1 kg solid into liquid state without change of temperature. It is represented by the symbol h_{if}. Its unit is Joule per kilogram (J/Kg) Thus, Q_L (ice) = 335 KJ/kg. The change in phase occurs in either direction at the fusion temperature i.e. liquid to solid and solid to liquid. The temperature and quantity of heat to bring about the change will be the same in either case and can be determined from the following equation:

$$Q_L = m \times h_{if}$$

Where $Q_L = The\ quantity\ of\ latent\ heat\ in\ kilojoules$
$m = The\ mass\ in\ kg$
$h_{if} = The\ latent\ heat\ of\ fusion\ in\ kJ/kg$

Example 1.10

If the latent heat of fusion of water is 335 kJ/kg, determine the quantity of latent heat given up by 10 kg of water at 0°C when it freezes into ice at 0°C.

$$Q_L = 10\ kg\ x\ 335\ kJ/kg = 3350\ kJ$$

Example 1.11

If 20 kJ of heat is supplied to 25 kg of ice at 0°C, how many kilograms of ice will be melted into water?

$$m = Q_L/h_{if} = 20\ KJ/335\ kJ/kg = 0.06\ kg$$

Latent Heat of Vaporization

The quantity of heat that a 1 kg mass of liquid will absorb in going from the liquid phase to the vapour phase, or give up in going from the vapour phase to the liquid phase, without change in temperature, is called latent heat of vaporization.

It is also denoted by the symbol Q_L and its unit is J/kg. The latent heat of vaporization of water is 2257 KJ/kg. When 1 kg of water at 100°C vaporizes to form steam at 100°C, it absorbs 2257 kcal/kg (540 kcal/kg) of heat.

$$Q_L = m \times h_{fg}$$

Where,
$Q_L = The\ quantity\ of\ latent\ heat\ in\ kilojoules$
$m = The\ mass\ in\ kg$
$h_{fg} = The\ latent\ heat\ of vaporization\ in\ kJ/kg$

Condensation

Condensation is the change by which any substance is converted from a gaseous state to liquid state without change in temperature. When 1 kg of steam at 100 condenses to form water at 100°C, it gives out 2260 kJ of heat.

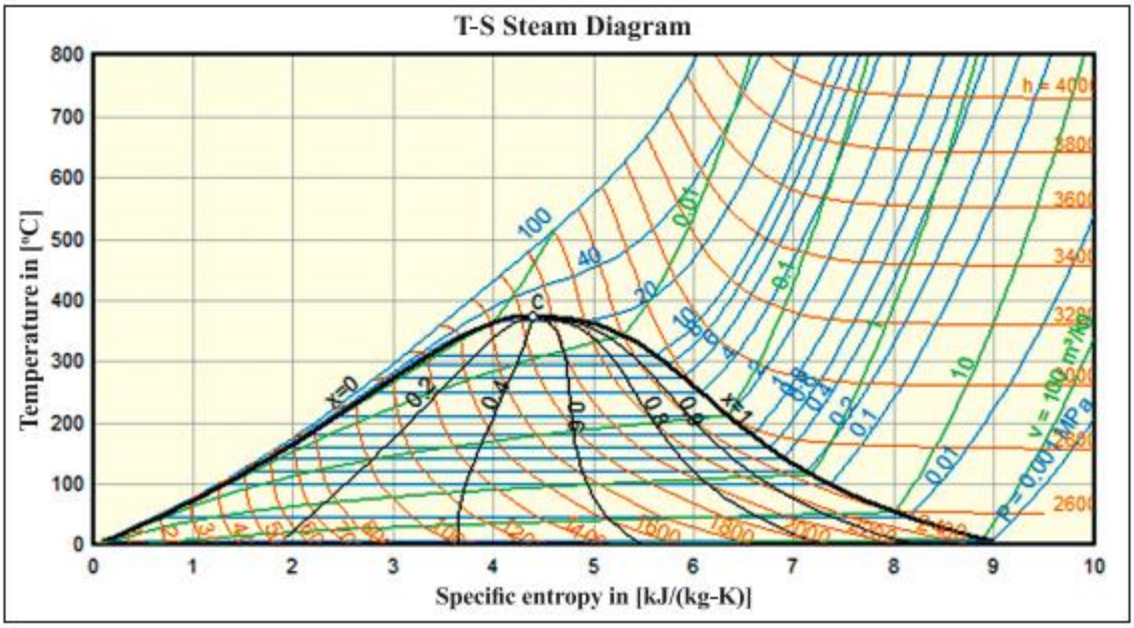
Example 1.12

Determine the quantity of heat required to vaporize 2 m^3 of water at 100°C if the latent heat of vaporization of water at that temperature is 2257 kJ/kg

$$QL = 2000\ kg\ X\ 2257\ kJ/kg = 4514000\ kJ$$

Super Heat

Super heating is the heating of vapour, particularly saturated steam to a temperature much higher than the boiling point (also called saturation temperature) at the existing pressure. This is done in power plants to improve efficiency and to avoid condensation in the turbine. Here it is noteworthy to mention that higher the pressure of water-higher the saturation temperature at corresponding pressure. This property of water can be depicted by the following Temperature-entropy (T-S) diagram:



Entropy in horizontal axis is commonly understood as a measure of disorder of a substance.

The area under the dome is the binary phase i.e. water and steam mixture. The blue lines are constant pressure line and these lines under the dome represent the latent heat region (i.e. constant temperature and pressure heating resulting into phase change from water to steam).

X=dryness factor of steam=in 1 kg of water-steam mixture, x kg is mass of steam and (l-x) kg is mass of water.

Thus the zone in right side of X=l .0 line represents the superheated region of steam.

Humidity

Moisture contained in air is expressed as Humidity. Saturated air holds all the moisture it can at that temperature and pressure.

The unit for humidity is kg of moisture / kg of dry air.

Dew Point

It is the temperature at which water vapor in the air becomes saturated with moisture and the moisture starts to condense into water droplets. It is equal to the saturation temperature at the partial pressure of the water vapour in the mixture.

Specific Humidity or Humidity Ratio

It is the mass (kg) of the water vapor in each kg of dry air (kg/kg).

Relative Humidity (RH)

It is the ratio of mass of water vapour actually held by the air in a given volume to that which air could hold at the same temperature if the air were saturated. It is expressed as a percentage. Warmer air will hold more water vapour and saturated air cannot hold any more water vapour.

Relative humidity affects comfort conditions. An air sample that is at 50% RH is holding half the moisture it is capable of holding at the same temperature (at dew point or saturated).

Dry bulb and Wet bulb Temperatures

Dry bulb measures sensible heat content in air-vapour mixtures. Dry bulb temperature is not influenced by RH. It is the temperature recorded by the thermometer with a dry bulb.

Wet bulb thermometer has wick saturated with distilled water enveloping the bulb of the thermometer. The evaporation of water lowers temperature, taking the latent heat from the water-soaked wick-thus decreasing the temperature recorded. Wet bulb temperature takes into account RH.

If relative humidity is 100%, dew point, wet bulb and dry bulb temperatures are all the same.

Enthalpy of air

It is the measure of total heat content of air and water vapour mixture measured from pre-determined base point. It is expressed as 1(kCal/kg. Enthalpy of air stream can be determined by measuring dry and wet bulb temperature and referring the psychometric chart.

Fuel Density

Density is the ratio of the mass of the fuel to the volume of the fuel at a stated temperature. Density is expressed in kg/m^3.

Specific gravity of fuel

The specific gravity of fuel is the ratio of density of fuel to that of water. The specific gravity of water is defined as 1. As it is a ratio there are no units. Higher the specific gravity, higher will be the heating values. Specific gravity has no dimensions.

Viscosity

The viscosity of a fluid is a measure of its internal resistance to flow. All liquid fuels decrease in viscosity with increasing temperature.

Viscosity is measured in Stokes / Centistokes. Sometimes viscosity is quoted in Engler, Saybolt or Redwood.

Energy Content in Fuel

Energy content (**Calorific Value**) in an organic matter can be measured by burning it and measuring the heat released. This is done by placing a sample of known mass in a bomb calorimeter, a device that is completely sealed and insulated to prevent heat loss. A thermometer is placed inside (but it can be read from the outside) and the increase in temperature after the sample is burnt completely is measured. From this data, energy content in the organic matter can be found out.

The heating value of fuel is the measure of the heat released during the complete combustion of unit weight of fuel. It is expressed as Gross Calorific Value (GCV) or Net Calorific Value (NCV). The difference between GCV and NCV is the heat of vaporization of the moisture and atomic hydrogen (conversion to water vapour) in the fuel. Typical GCV and NCV for heavy fuel oil are 44100 J/kg (10,500 kcal/kg) and 41160 J/kg (9,800 kcal/kg).

Heat transfer

Heat will always be transferred from hot to cold independent of the mode. The energy transferred is measured in Joules. The rate of energy transfer, more commonly called heat transfer, is measured in Watts (J/s)

Heat is transferred by three primary modes:

- Conduction (Energy transfer in a solid)
- Convection (Energy transfer in a fluid)
- Radiation (doesn’t need a material to travel through)

Conduction is the primary mode of heat transfer through solid. Conduction occurs by two mechanisms

- ✓ V Molecular Motion. Molecules of higher energy (motion) impart that energy to adjacent molecules of lesser energy.
- ✓ Migration of free electrons. This is primarily associated with pure metals

Convection occurs when a fluid exchanges energy with an adjacent solid. The fluid motion adjacent to the solid surface assists in the transfer of energy.

There are two types of convection heat transfer:

- ✓ Forced convection - Fluid motion is induced by an external source such as a fan or pump
- ✓ Natural convection - Heating a fluid results in natural convection heating. Air will circulate due to natural convective heating. The temperature gradient in the fluid

creates variations in density within the fluid. The colder fluid (heavier) will sink, and the hotter fluid (lighter) will rise.

Radiation mode heat transfer requires no medium for the transport of heat. Energy can be radiated from a body over a wide range of wavelengths. Thermal radiation is only a small portion of the electromagnetic spectrum shown and it encompasses infrared light to ultraviolet light. Radiant energy that strikes a surface can be reflected, absorbed and transmitted.

Steam Properties Evaporation

When a liquid evaporates it goes through a process where

- ✓ The liquid heats up to the evaporation temperature
- ✓ The liquid evaporate at the evaporation temperature by changing state from fluid to gas
- ✓ The vapor heats above the evaporation temperature - superheating

The heat transferred to a substance when temperature changes is often referred to as sensible heat. The heat required for changing state as evaporation is referred to as latent heat of evaporation.

The most common vapour is evaporated water - steam.

Enthalpy of steam

Enthalpy of a system is defined as the mass of the system - m - multiplied by the specific enthalpy - h – of the system and can be expressed as:

$$H = m\,h$$

Where,
H = enthalpy (kl)
m = mass (kg)
h = specific enthalpy (kl/kg)

Specific Enthalpy

Specific enthalpy is a property of the fluid and can be expressed as:

$$h = u + pv$$

Where,

u = internal energy (kJ/kg)
p = absolute pressure (N/m^2)
V = specific volume (m^3/kg)
Part of the water vapor - steam - properties can be expressed in a table as:

p (bar)	t_s (°C)	v_f (m^3/kg)	v_g (m^3/kg)	u_f (kJ/ kg)	u_g (kJ/ kg)	h_f (kJ/kg)	h_g (kJ/ kg)	s_f (kJ/ kg.K)	s_g (kJ/ kg.K)
0.006112	0.01	0.0010002	206.1	0	2,375	0.0006	2,501	0	9.155
0,010	7.0	0.0010001	129.2	29	2,385	29	2,514	0.106	8.974
1.01325	100.0	0.001044	1.673	419	2,507	419	2,676	1.307	7.355
220	373.7	0.00269	0.00368	1,949	2,097	2,008	2,178	4.289	4.552
221.2	374.15	0.00317	0.00317	2,014	2,014	2,084	2,084	4.430	4.430

- *s* is the steam entropy
- suffix - *f* - referrer to saturated liquid
- suffix - *g* - referrer to saturated vapor – steam
- *p (bar) in terms of absolute pressure i.e pg +pa*

Specific Enthalpy of Saturated Water

Specific enthalpy of saturated water - h_f - can be obtained from tables as above. The value depends on the pressure.

For saturated water at standard atmosphere -the specific enthalpy - h_f - is 419 kJ/kg. At standard atmosphere - 1 bar (I4. 7psi) - water starts boiling at 100 0C (212 °F).

The specific enthalpy of water (in SI units) can be calculated from:

$$h_f = c_w (t_f - t_0)$$

Where,

$h_f = enthalpy\ of water\ (kJ/kg)$
$c_w = specific\ heat\ of water = 4.19\ (kJ/kg.°C)$
$t_f = saturation\ temperature\ (°C)$
$t_o = refer\ temperature = 0\ (°C)$

Specific Enthalpy of Saturated Steam

Specific enthalpy of saturated steam - h_g - can be obtained from tables as above. The value depends on the pressure.

For saturated steam at standard atmosphere - the specific enthalpy - h_g - is 2676 kJ/kg.

The specific enthalpy of evaporation can be calculated from:

Where,

h_e = specific evaporation enthalpy (kJ/kg)
Specific evaporation enthalpy for water at standard atmosphere is:

$$h_e = h_g - h_f$$

Specific Enthalpy of Superheated Steam

The specific enthalpy of superheated steam can be calculated from:

$$h_s = h_g + c_{ps}\,(t_s - t_f)$$

Where,

$h_s = Enthalpy\ of\ superheated\ steam\ (kJ/kg)$
$c_{ps} = Specific\ heat\ of\ steam\ at\ constant\ pressure = 1.860\ (kJ/kg\ °C)$
$t_f = Saturation\ temperature\ (°C)$
$t_s = Superheated\ steam\ temperature\ (°C)$
$C = 1.860\ (kJ/kg\ °C)\ at\ standard\ atmosphere. Note\ that\ c\ varies\ with\ temperature.$

The laws of thermodynamics

Thermodynamics is the study of heat and work, and the conversion of energy from one form into another. There are actually three laws of thermodynamics, although the majority of thermodynamics is based on the first two laws.

The first law of thermodynamics

The first law of thermodynamics is also known as the law of conservation of energy. It states that the energy in a system can neither be created nor destroyed. Instead, energy is either converted from one form to another, or transferred from one system to another. The term 'system' can refer to anything from a simple object to a complex machine. If the first law is applied to a heat engine, such as a gas turbine, where heat energy is converted into mechanical energy, then it tells us that no matter what the various stages in the process, the total amount of energy in the system must always remain constant.

The second law of thermodynamics

While the first law of thermodynamics refers to the quantity of energy that is in a system, it says nothing about the direction in which it flows. It is the second law which deals with the natural direction of energy processes. For example, according to the second law of thermodynamics, heat will always flow only from a hot object to a colder object.

Another term arising from the second law of thermodynamics is the term 'entropy' which means disorder. Entropy can be used to quantify the amount of useful work that can be performed in a system. In simple terms, the more chaotic or disorderly a system, the more difficult it is to perform useful work.

It is the second law of thermodynamics that accounts for the fact that a heat engine can never be 100% efficient. Some of the heat energy from its fuel will be rejected to the surroundings, with the result that it will not be converted into mechanical energy.

The third law of thermodynamics

The third law of thermodynamics is concerned with absolute zero (i.e.$-273\ C$). It simply states that it is impossible to reduce the temperature of any system to absolute zero.

1.1.5 Energy Units and Conversions

SI system has 6 base units on which other units are derived. The base units are:

Base quantity	***Name***	***Symbol***
Length	meter	m
Time	Second	S
Electric current	Ampere	A
Temperature	Kelvin	K
Amount of substance	Mole	mol
Luminous intensity	Candela	cd

The examples of derived units from base units are:

Derived quantity	**Name**	**Symbol**
Area	Square meter	m^2
Volume	Cubic meter	m^3
Acceleration	Meter per second Squared	m/s^2
Mass density	Kilogram per cubic meter	kg/m^3
Specific volume	Cubic meter per kilogram	m^3/kg
Luminance	Candela per square meter	Cd/m^2

SI derived units are given special names and symbols for better understanding. Some derived SI units relevant to Energy Management & Audit are listed below:

Derived quantity	**Name**	**Symbol**	**Expression in terms of other units**	**Expression in terms of base unit**
Frequency	Hertz	Hz	-	s^{-1}
Force	Newton	N	-	$m \cdot kg \cdot s^{-2}$
Pressure	Pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
Energy, work, quantity of heat	Joule	J	N-m	$m^2 \cdot kg \cdot s^{-2}$
Power	Watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
Electric potential difference, electromotive force	Volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
Capacitance	Farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	Ohm		V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	Siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
Celsius temperature	degree Celsius	°C	-	K
luminous flux	lumen	lm	cd·sr [c]	$m^2 \cdot m^{-2} \cdot cd = cd$
Illuminance	lux	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$

Temperature Units

Conversion of the degree Celsius into Fahrenheit = degrees C X 1.8 + 32
Conversion of the Fahrenheit into degree Celsius = (degrees F - 32.) / 1.8

Degrees Celsius (C) to degrees Kelvin (K) = (C) + 273.15 = (K)

Pressure Units

1 atm	760 mm Hg	atmosphere (standard)
1 atm	101325 Pa	atmosphere (standard)
1 bar	100000 Pa	bar
1 cmHg (0 °C)	1333.22 Pa	centimetre of mercury (0 °C)
1cm H_2O	98.0638 Pa	centimeter of water (4 °C)
1 kgf/cm²	98066,5 Pa	kilogram force per square centimetre
1 kgf/m²	9,80665 Pa	kilogram force per square meter
1 kPa	1000 Pa	kilopascal
1 MPa	1000000 Pa	megapascal
1 mbar	100 Pa	millibar
1 N/m²	1 Pa	pascal
1 lbf/ft²	6894,76 Pa	pound force per square inch

Energy Units and Conversions

1 Joule	= 1 Watt/s
1 kW	= 1000 W
1 kWh	= 3.6 x 10^6 J = 3.6 million Joules
1 Mega-joule	= 278 Wh
1 Watt-hour (Wh)	= 3600 Joules
1 British thermal unit (BTU)	= 252 Cal
1 BTU	= 1055 J
1 Btu/h	= 0.293071 Wh
1 Kilocalorie/hour (kcal/h)	= 1163 Wh
1 HP	= 745.7 Watts

1.2 Renewable Energy Sources

1.2.1 Concept of Renewable Energy

Renewable energy is energy obtained from sources that are essentially inexhaustible such as sun and wind. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power, bio-energy (bio-fuels grown sustainably) and hydropower. A renewable energy system converts the energy found in sunlight, wind, falling-water, sea-waves, geothermal heat, or biomass into a form, we can use such as heat or electricity. Another important feature of renewable energy is that it can be used without the release of harmful pollutants. Renewable energy is also known as non-conventional energy. Renewable energy sources are essentially flows of energy unlike the fossil and nuclear fuels which are considered stocks of energy.

1.2.2 Fundamentals of Solar Energy

Solar radiation is radiant energy emitted by the sun comprising of ultra-Violet, visible and infra-red radiation. The amount of solar radiation that reaches any given location is dependent on several factors including the geographic location, time of day, season, landscape, and local weather. Because the earth is round, the sun strikes the surface at different angles ranging from 0° (just above the horizon) to 90° (directly overhead). When the sun's rays are vertical, the earth's surface gets maximum energy possible. The more slanted the sun's rays are, the longer they travel through the atmosphere, becoming more scattered and diffuse.

Solar Constant

Solar constant is the rate at which solar energy, at all wavelengths, is received per unit area at the top level of Earth's atmosphere. The solar constant actually varies by about 0.3% over the 11-year solar cycle but averages about 1,368 W/m^2. Each planet has its own planetary solar constant.

Solar Insolation

Solar Insolation is the amount of solar energy that strikes a square metre of the earth's surface in a single day. Insolation is greatest when the surface is normal to the Sun. As the angle increases beyond a direction normal to the surface and the sunlight, the insolation is reduced in proportion to the cosine of the angle. The average incoming radiation is known as solar insolation and is one-fourth the solar constant, or 342 W/m^2.

Solar Window is the period, typically 9 AM- 3 PM, when maximum sunlight is available.

By knowing the insolation levels of a particular area, required size of solar collector and energy output can be calculated. An area with poor insolation levels will need a larger collector than an area with high insolation levels. The values are generally expressed in kWh/ m^2/day. Bangladesh receives solar energy in the region of 4.5 to 6 kWh/m^2 for 300 to 330 days in a year. This energy is sufficient to set up 70 MW solar power plant per square kilometre land area.

Solar energy can be used through two different routes, namely, Solar Thermal Energy and Solar Electric (Solar Photovoltaic) Energy. Solar thermal systems uses the sun's heat and convert it into heat energy while solar photovoltaic systems uses sun's heat to produce electricity.

1.2.3 Solar Thermal Energy

Solar collectors are the main component of most of solar energy systems. The collector absorbs the sun's energy and converts it into heat energy. This energy is then transferred to a fluid or air which is used to heat water, generate electricity, dry materials, distil water or cook food. When used for heating purpose, solar thermal system can partially or fully replace the conventional fuels such as coal, oil and electricity.

Various applications of solar thermal energy discussed are

- ✓ Solar Water Heating System (Flat—plate collector & Evacuated tube collector)
- ✓ Solar Thermal Power Systems (Power tower, parabolic trough collector)

Solar Water Heating System

A solar water heating system (Figure 1.1) consists of a flat plate or evacuated tube solar collector, a storage tank and connecting pipes. The system is generally installed on the roof or on open ground, with the collector facing the sun and connected to a continuous water supply. The collectors are generally mounted on a north-facing roof (in southern hemisphere). Water stored in the tank remains hot overnight as the storage tank is insulated and heat losses are small.

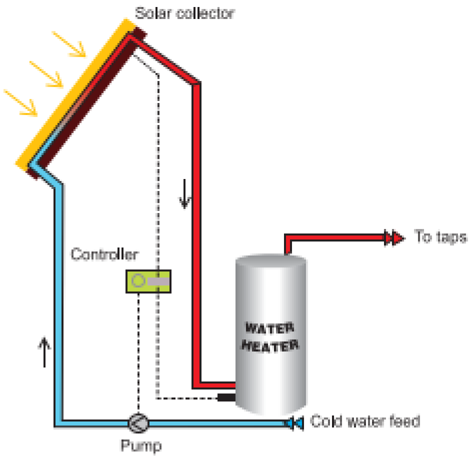


Figure 1.1: Solar Water Heating System

Solar Flat Plate Collector

The most common collector is called a flat-plate collector. Flat-plate collectors heat the circulating fluid to a temperature of about 40-60°C. Flat plate collector is highly dependent upon ambient temperatures. It has good efficiency if ambient temperature is high. Consequently, heat output is higher during summer months than winter months in a flat plate collector.

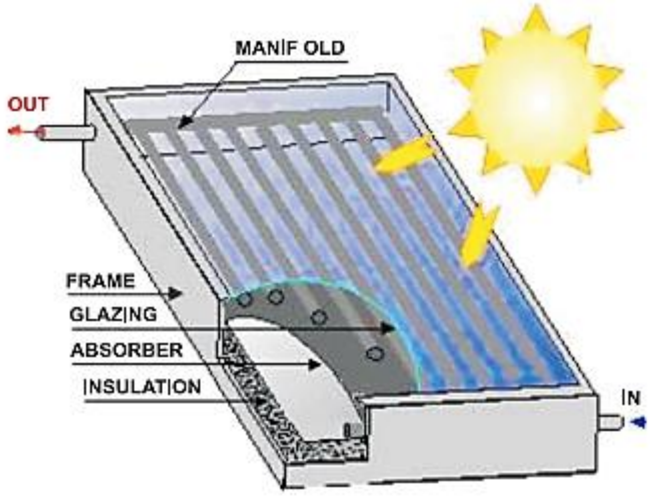


Figure 1.2: Solar Flat Plate Collector

The flat plate collector (Figure 1.2) usually comprises of copper tubes welded to copper sheets (both coated with a highly absorbing black coatings) with toughened glass sheet on top for cover and insulating material at the bottom. The entire assembly is placed in a flat box.

Evacuated Tube Collector

For higher temperatures, evacuated tube collectors are used. Evacuated tube collector is less dependent upon ambient temperature unlike flat plate collector and its efficiency does not drop with ambient temperature.

Figure 1.3: Evacuated Tube Collector

In this type of solar collector, evacuated glass tubes are used instead of copper in which case a separate cover sheet and insulating box are not required. Water flows through the tubes, absorbs solar heat and is stored in a tank. This type of solar collector can reach high temperatures up to 150°C. Evacuated tube collector is shown in Figure 1.3. Evacuated tube collector comprises of two concentric glass tubes fused in the ends as shown in Figure 1.4. The air is evacuated from the gap between the tubes. The evacuated double-walled glass tube provides thermal insulation similar to that of thermally insulated "Thermos" bottle. The outer glass tube is clear, and the surface of the inner glass tube is coated with a special heat material that absorbs the sun's energy.

Sun rays penetrate the outer clear glass and heat energy is absorbed by the inner coated glass. The vacuum permits the heat radiation to enter the outer tube. The absorbent coating on the inner tube converts short wave radiation to long wave radiation thus preventing re-radiation to atmosphere. Since conduction cannot take place in vacuum, heat loss due to conduction back to atmosphere is also prevented. Because of this principle, more heat is trapped compared to a flat plate collector. The heat loss in Evacuated tube collector is less than 10% compared with 40% for a flat plate collector. Water flows in through a third, innermost concentric feeder tube and hot water flows out in the annulus outside the feeder tube in contact with the absorber tube surface.

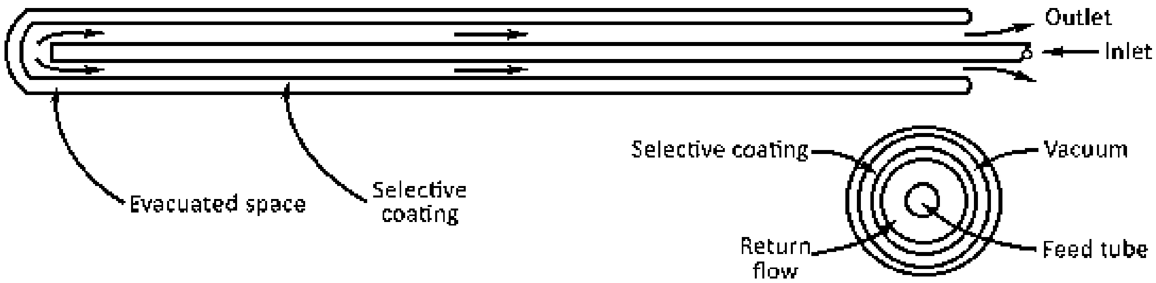


Figure 1.4: Cut view of Evacuated Tube Collector

1.2.4 Solar Electrical Energy

There are broadly two ways of generating electrical energy from solar power; the thermal route and direct conversion route through photovoltaic. There are two basic types of solar thermal power stations:

1. power tower and
2. parabolic trough collector.

Power Towers

A typical power tower (see Figure 1.5) operation is described as follows:

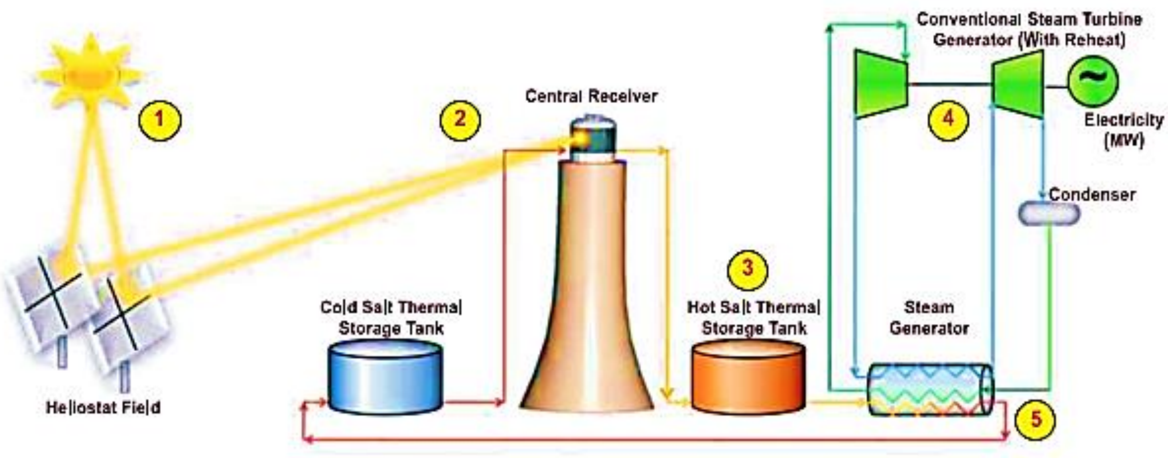


Figure 1.5: Solar Thermal Power Stations

1. Sunlight is concentrated and directed from a large field of heliostats (mirrors) to a receiver on a tall tower.
2. Molten salt (for example liquid sodium) from the cold salt tank is pumped through the central receiver where it is heated to 566°C).
3. The heated salt from the receiver is stored in the hot salt thermal storage tank.
4. Molten salt is pumped from the hot salt tank through a steam generator that creates steam, which drives a steam turbine, generating electricity.
5. Cold salt at 288°C flows back to the cold salt thermal storage tank and is re-used.

[Molten salt is a mixture of 60% sodium nitrate and 40% potassium nitrate. It is preferred as it provide an efficient low-cost medium to store thermal energy and it is non-flammable and nontoxic.]

Parabolic Trough Collector

Parabolic Trough Collector is currently the most proven solar thermal electric technology. This system uses a series of specially designed parabolic curved, trough shaped reflectors that focus the sun's energy onto a receiver tube running at the focus of the reflector as shown in Figure 1.6. Because of their parabolic shape, troughs can focus the sun at 30-60 times its normal intensity on the receiver pipe. Heat transfer fluid (such as water) in the receiver is heated to a temperature of about 400°C.

Large arrays of these collectors are coupled to provide high temperature water for driving a steam turbine. The collectors are aligned on an east-west axis and the troughs are rotated to follow the sun to maximize the sun's energy input to the receiver tube. Such power stations can produce many megawatts (MW) of electricity, but are confined to areas where there is sufficient solar insolation.

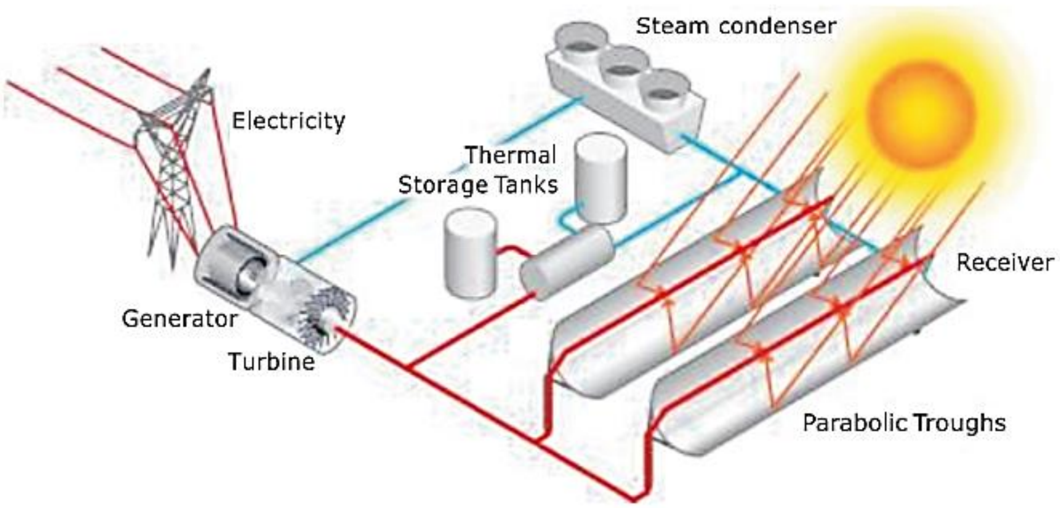


Figure 1.6: Parabolic Trough Collector

Solar Photovoltaic Technology

Direct conversion of solar energy to electricity takes place through photoelectric effect. The photoelectric or photovoltaic effect is the process in which the two dissimilar materials in close contact produce an electrical voltage when struck by light or radiant energy. Discrete packets of light energy known as photons, strike the Photovoltaic (PV) cell, knocking the electrons in

the silicon material out of their normal energy state, putting them in a position to be conducted as electricity (Refer Figure 1.7).
The photoelectric effect only occurs when a photon which has the correct amount of energy strikes an atom in the solar cell.

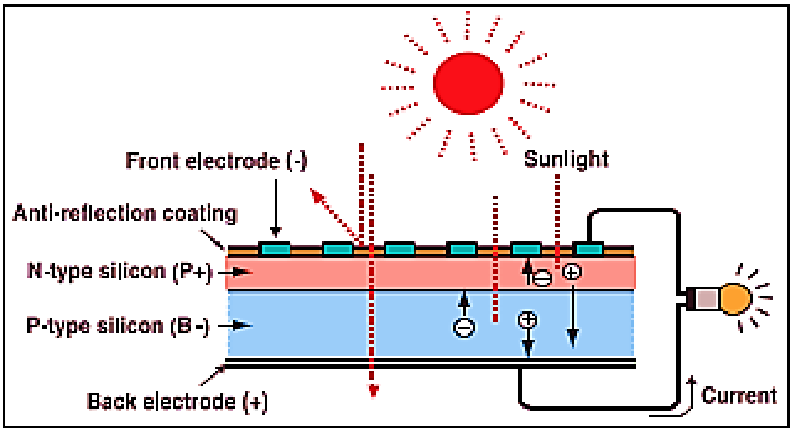


Figure 1.7: Solar Photovoltaic Effect

The amount of energy needed is dependent on the material the solar cell is made from. This means that the solar cell is not able to convert all the different wavelengths of light which are hitting it. Because of this, solar cells are "tuned" during their manufacturing to absorb the spectrum of sunlight that is most intense. This phenomenon is exploited to form the individual solar cells on wafers of silicon. Since Silicon is naturally reflective in nature, each photovoltaic cell is typically covered with an anti-reflective coating to minimize any loss from reflection.

PV panels comprise of PV cells. Solar cells are connected in series and parallel combinations to form modules that provide the required power. PV cells have been made with silicon (Si), gallium arsenide (GaAs), copper indium diselenide (CIS), cadmium telluride (CdTe), and a few other materials. A Photovoltaic (PV) module comprise of PV panels (also known as solar panels), battery system, charge controller, inverter as shown in Figure 1.8.

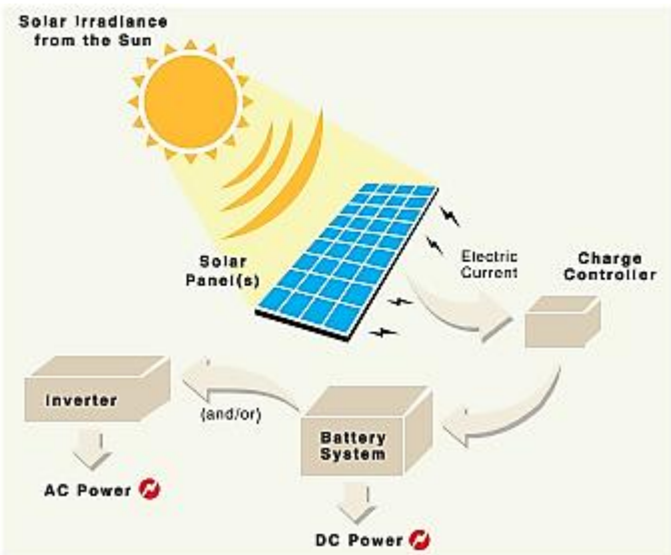


Figure 1.8: PV System

One silicon cell generally produces 0.5 Volts. 36 such cells connected together are called a PV module and it has enough voltage to charge 12 V battery and run pump and motor. Modules can be connected together to form an array and generate more power.

The wattage output of a PV module is rated in terms of peak Watt (Wp). The peak Watt output power from a module is defined as the maximum power output that the module could deliver under standard test conditions. Single PV module can be manufactured with capacity ranging from 5 Wp to 120 Wp.

Stand-alone SPV Power Plant: These systems are used where conventional grid supply is not available, or is irregular. In an SPV power plant, electricity is centrally generated and made available to users through a local grid in a 'stand-alone mode'. The most common use for such plants is the electrification of remote villages, power for hospitals, hotels, communication equipment, railway stations, border outposts etc.

Grid connected Solar System: Grid connected solar system (Figure 1.9) use an inverter that synchronizes with the utility power. These systems do not generally require batteries, although batteries can be used to provide backup power if the utility power goes out. Grid connected solar is easier to install and maintain than stand-alone system.

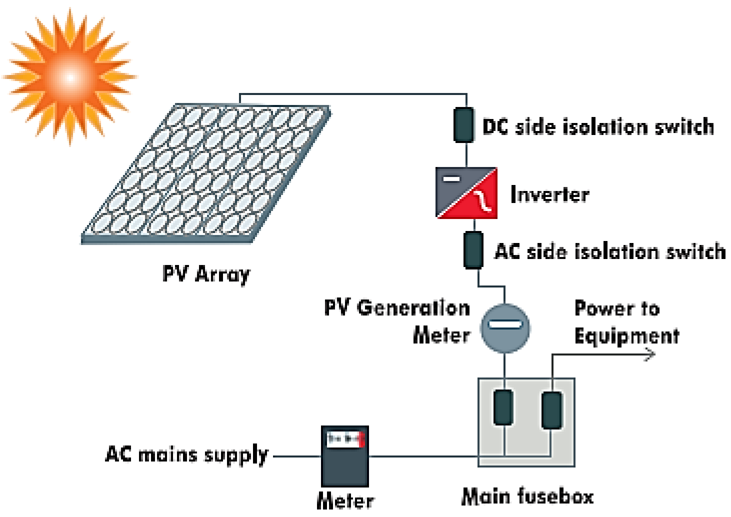


Figure 1.9: Grid Connected Solar

How much of Solar Energy is converted into Electrical Energy in Photovoltaic Cells?

The energy conversion efficiency is a measure of how much of the solar energy is converted into electrical energy. The calculation for the energy conversion factor is,

$$\eta = (Pm/(E * A)) * 100$$

Where,

$\eta =$ *Energy conversion factor, percent.*
$Pm =$ *Maximum power output, watts.*
$E =$ *Solar energy, insolation, watts per square meter.*
$A =$ *Area of the solar cell, square meters.*

For example, what is the energy conversion efficiency of a 175-Watt solar panel that measures 0.75 X 1.50 meters, if the solar insolation is 1,000 W/m^2?

Since the area of the solar cell is 0.75 * 1.50 = 1.125 m^2, the efficiency is,

$$\eta = (175 / (1.125 * 1{,}000)) * 100$$

$$\eta = 15.6\%.$$

This particular unit converts 15.6% of the available solar energy into electrical energy.

Building-integrated PV Systems: In building-integrated photovoltaic (BIPV) system, PV panels are integrated into the roof or facade of a building as shown in Figure 1.10.

Figure 1.10: BIPV

BIPV provides photovoltaic power as well as weather proofing and glazing of buildings. SPV panels generate electricity during the daytime, which is used to meet a part of the electrical energy needs of the building. Since PV cells are integrated into the buildings, no separate costly mountings are required.

1.2.5 Wind Energy

The use of wind energy is not new and has been used for thousands of years for applications such as water pumping, milling grains, mechanical power, sailing etc. However, it is the use of wind energy for electricity generation that is receiving most attention today. Modern windmills are normally called as wind turbines as their functions are similar to gas and steam turbines. They are also called as wind energy conversion systems (WECS), and those used to generate electricity are described as wind generators.

How Wind is created?

As the earth orbits the sun daily, it receives light and heat. The majority of the heat from the sun is received at the equator and it gradually reduces towards both poles. Across the earth these heat differences help create wind. In warmer regions of the earth the air is hot and is therefore at a high pressure, compared to colder regions, where the air is at a low pressure. Wind is the movement of air from areas of high pressure to low pressure. Ideally, wind should flow from equator to the direction of either pole if earth is not rotating.

However, rotation of earth creates a force known as Coriolis force. The Coriolis force is swirling action on the Winds because of earth rotation. This causes series of wind circulations in both northern and southern latitude as shown in Figure 1.11.

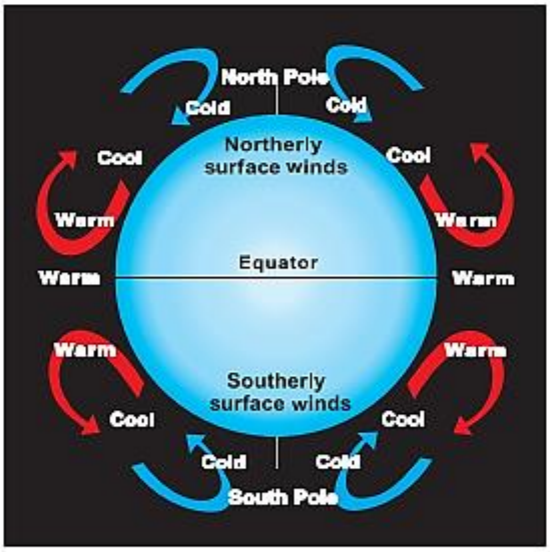


Figure 1.11: Global Wind Flow

The local Winds are largely affected by earth terrain. The earth has large flat plains (desert regions), areas covered with plant life (rainforests), very uneven regions (mountain ranges) and very smooth regions (seas and oceans), all of which affect the wind near the surface of the earth to varying levels. Sea breeze is set up when hot air rises from land, which is heated faster than sea, rises into the sky where it cools off. High in the sky, the cooled air now moves towards the sea and sinks pressing cold air from sea towards land.

Variability in Wind Speed and its Effect

Wind speed and direction are continuously fluctuating. The wind will vary over few hours with weather system. Generally, tropics have steady moderate winds all year, temperate latitudes have much more variation in wind speed and in particular more high wind speed occurrences. Sites with more wind speed will generate more power. The Table 1.2 gives a guideline of different wind speeds and their potential in producing electricity.

Table 1.2: Wind Speed vs Power Generation Suitability

Average Wind Speed m/s (km/h)	Suitability for Power generation
Upto 4 (15)	No good
5 (18)	Poor
6 (22)	Moderate
7 (25)	Good
8 (29)	Excellent

Operating Characteristics of Wind Turbine

A few of the important operating characteristics of a wind turbine include the cut-in speed, rated speed, cut-out speeds, power output and capacity factor. Refer Figure 1.12.

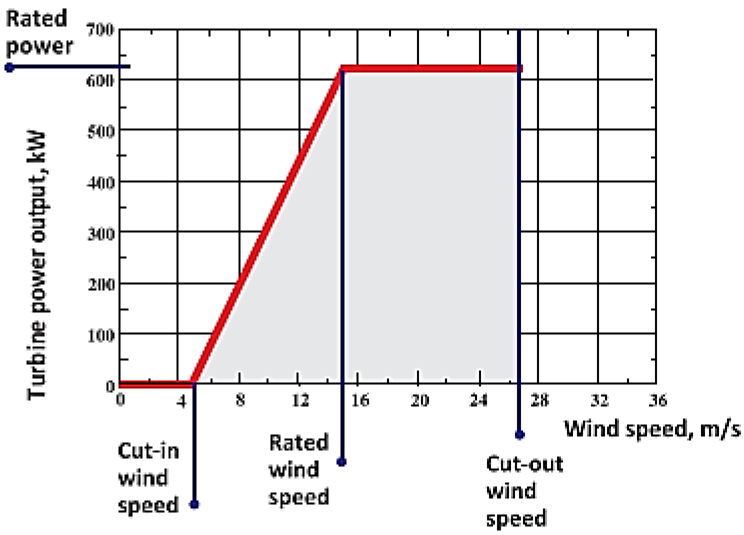


Figure 1.12: Idealised Power Curve for a Wind Turbine

Cut-in Speed: There is a minimum speed at which a Wind turbine can reliably produce useable power. This is known as the cut-in speed which is generally around 5 m/s.

Rated Speed: Most wind turbines are designed to generate maximum power at a fixed wind speed. This is known as rated power and the minimum wind speed at which it is achieved is the rated wind speed. The rated wind speed is chosen to fit the local site and wind regime and is often 1.5 times the site mean wind speed.

Cut-out Speed (Furling Speed): Above a certain speed beyond the rated speed, the wind turbine will need to shut down and stop operation to prevent damage to the unit. Cut-out speeds vary by manufacturer from about 20 to 30 m/s. The wind speed at which shut down occurs is called the cut-out speed. Cut- out speed is also known as furling speed.

Betz Limit: It is impossible for the blades of a wind turbine to be 100% efficient since some of the wind energy must pass through the blades to make the turbine turn. Air flowing over the blades and through the rotor area makes a Wind turbine function. The Wind turbine extracts energy by slowing down the wind. The theoretical maximum amount of energy in the wind that can be collected by a wind turbines rotor is approximately 59%. This value is known as the Betz limit. Considering the Betz limit and the efficiency losses through the generator, gearbox, etc., will result in only about 15-25% of the wind energy being converted into useful power.

Rotor Efficiency: The ability of a turbine rotor to extract the wind's power depends upon its "efficiency". Thus to express the power output of the turbine, a non-dimensional coefficient of performance of the blades (C_p) is included.

The coefficient of performance of blades (C_p) varies with speed and generally varies between 0.33-0.59.

Power Available from the wind turbine: Power extracted by wind turbine is proportional to the cross sectional area of the wind intercepted by wind turbine and cube of the Wind speed.

The power generated by a wind turbine can be found using the following formula:
Kinetic Energy from the wind $= \frac{1}{2} \times\ Mass \times\ Velocity^2$

$$\mathrm{Mass}\ =\ \mathrm{p}\ *\mathrm{A}\ *\ \mathrm{V}$$

$$\mathrm{P} = 0.5\ *\mathrm{p}\ *\mathrm{A} *\ \mathrm{C_p}\ *\mathrm{N_g} *\mathrm{N_b}\ *\mathrm{V}^3$$

Where,
$P\ =\ Power\ produced\ by\ the\ generator, watts$
$p\ is\ air\ density\ in\ kg/m^3$
$A\ is\ cross\ sectional\ area\ of the\ wind\ intercepted\ by\ the\ wind\ turbine, m2$
$C_p\ =\ Coefficient\ of performance\ of\ the\ blades$
$N_g\ =\ Generator\ efficiency$
$N_b\ =\ Gearbox\ efficiency$
V is Wind speed in metres/sec

Power generated is highly dependent upon wind speed. Doubling the wind speed increases the power by eight times, but doubling the turbine area only doubles the power. Thus optimizing the siting of wind turbines in the highest wind speed areas has significant benefit and critical for the best economic performance.

For example, consider a wind turbine with 6 m diameter rotor, a coefficient of performance of 0.30, generator efficiency 0f 0.8, a gearbox efficiency of 0.90, and a wind speed of 11 m/s. What is the expected power output in watts?

$$\mathrm{P} =\ 0.5\ *\ 1.2\ *\ 3.14/4\ *\ 6^2\ *\ 0.30\ *\ 0.8\ *\ 0.9\ *11^3$$

$$\mathrm{P}\ =\ 4875\ \text{watts, or } 4.875\ \text{kW}$$

Capacity Factor: The capacity factor of a wind turbine is the actual energy output of a Wind turbine during a given time period, usually one year, compared to its theoretical maximum energy output.

The capacity factor (CF) is,
CF = kWh produced / (8760 * Nameplate rating of the wind turbine, kW)

Typical capacity factors are 20-40% with values at the upper end of the range in particularly favourable sites.

A 2.5 MW Wind turbine could produce theoretical maximum of 21,900,000 kWh's per year (2.5 * 1,000 *8760).

However, due to the variability of the wind the unit has actually produced 5,000,000 kWh per year. In this example, the capacity factor is,
CF = 5,000,000 / (2.5 * 1,000 *8760)
CF = 22.8%

1.2.6 Biomass Energy

Biomass is basically organic matter such as wood, straw, crops, algae, sewage sludge, animal waste and/or other biological waste. Bioenergy is the energy derived from biomass. In energy terms, biomass can be viewed as a form of stored solar energy. The sun's energy is captured and stored (Via photosynthesis) in the biomass material. The carbon dioxide released during the burning of biomass when used as fuel is largely balanced by the absorption capture of carbon dioxide during its growth. Hence it is considered ‘carbon neutral’

Biofuels from Biomass

Biomass can be converted into liquid fuels such as Ethanol and Biodiesel to partially replace the conventional petroleum fuels.

Ethanol is commonly produced by the fermentation of molasses, a by-product in sugar manufacture.

It is also produced by fermenting any biomass feedstock rich in carbohydrates (starch, sugar or cellulose). e.g.: Sugar beet, Sweet corn and Ligno-cellulosic materials (straw and wood waste), which are much cheaper than molasses, are now being considered for manufacturing ethanol. Ethanol is used as a fuel additive to cut down vehicle’s carbon monoxide and other smog causing emissions. Flexible fuel vehicles, which run on mixture of gasoline, use up to 85% ethanol.

Biodiesel is a good alternative for diesel. The most economical way of producing biodiesel is by transesterification of extracted oil (e.g. Jatropha seeds oil) with alcohol such as methanol. Jatropha is a non-edible tree-borne oilseed which grows in dry and arid land. Biodiesel can be used as an additive to reduce vehicle emissions (typically 20%) or in its pure form as a renewable alternative fuel for diesel engines. All oils extracted from plant origin, waste cooking oil and animal fat can be used as raw materials for biodiesel production. The biodiesel cycle is shown in Figure 1.13.

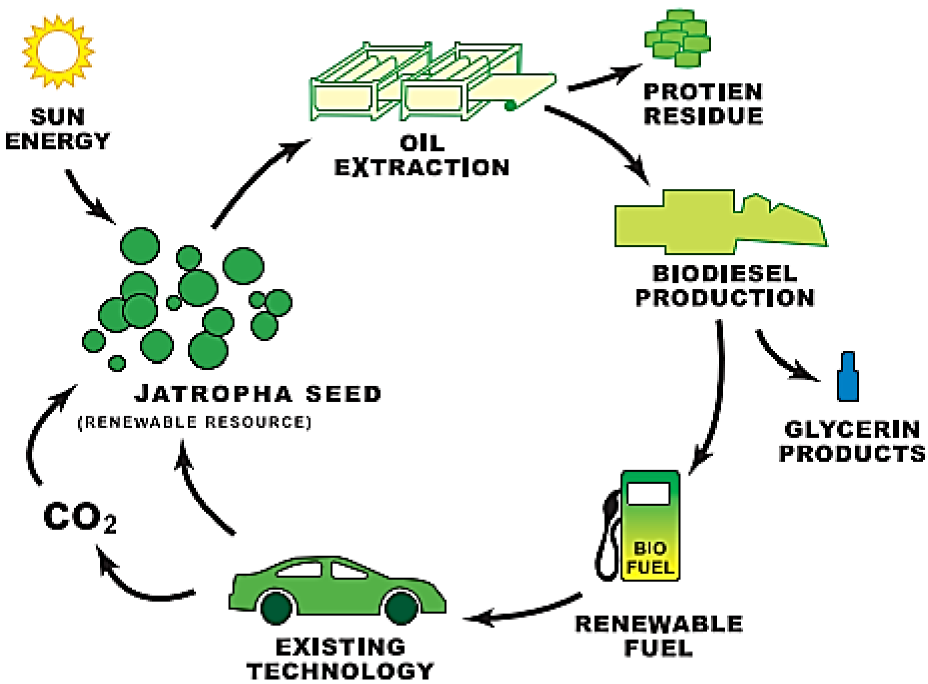


Figure 1.13: Biodiesel Cycle

1.2.7 Hydro Power

Water power can be harnessed in many ways; the most common way is to use a turbine which is turned by water moving in a controlled manner. Large dams hold water which can be used to provide energy for industry and grid electrification systems. Smaller systems can provide energy to remote regions without the need to build dams.

Micro-hydro power is the small-scale harnessing of energy from falling water; for example, harnessing enough water from a local river to power a small factory or village. The Figure 1.14 shows the main components and layout of a run-of-the-river micro-hydro scheme. This type of scheme requires no water storage but instead diverts some of the water from the river which is channelled along the side of a valley before being 'dropped' into the turbine via a penstock.

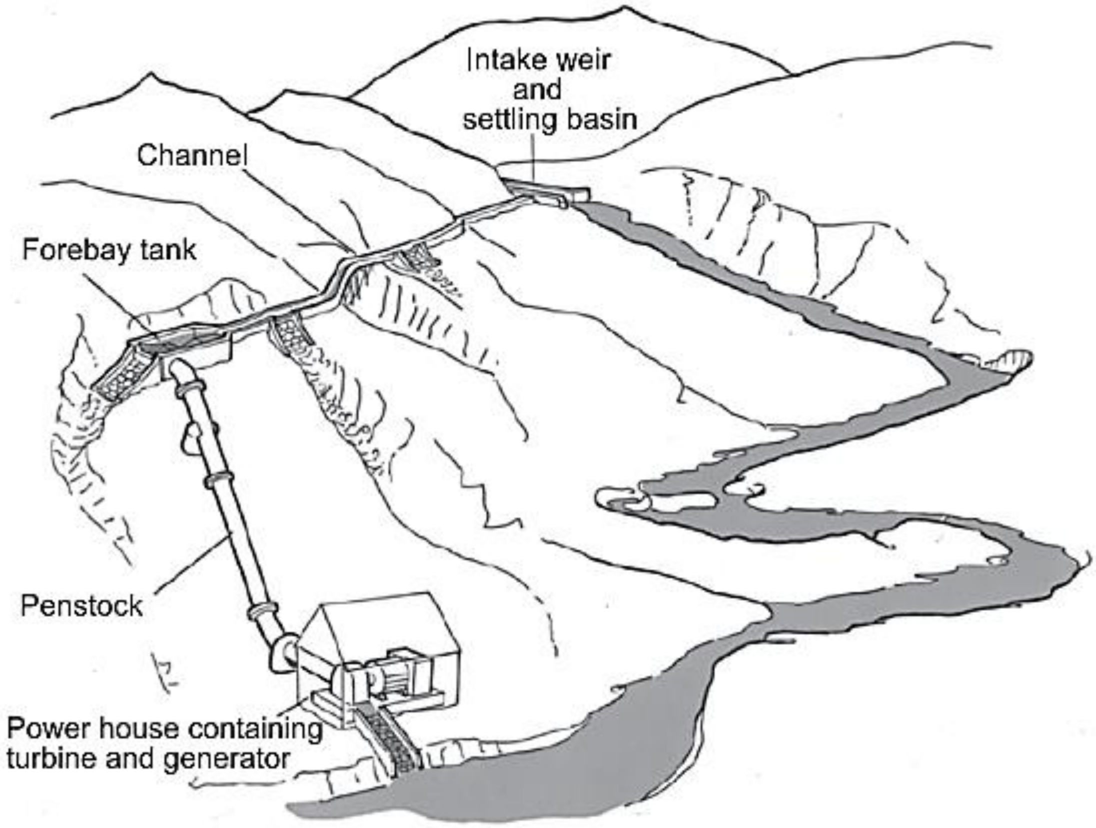


Figure 1.14: Main Components and Layout of a run-of-the river Micro-hydro Scheme

Water into Watts

To determine the power potential of the water flowing in a river or stream it is necessary to determine both the flow rate of the water and the head through which the water can be made to fall. The potential power can be calculated as follows:

$\text{Theoretical power (P)} = \text{Flow rate (Q) x Head (H) x Gravity (g)}$
$\text{Where, Q is in cubic metres per second, H in metres and g} = 9.81\ \text{m/s2 then,}$
$P = 9.81\ xQxH(kW)$

Small water turbines rarely have efficiencies better than 80%. Power will also be lost in the pipe carrying the water to the turbine, due to frictional losses. A rough guide used for small systems of a few kW rating is to take the overall efficiency as approximately 50%. Thus, the theoretical power must be multiplied by 0.50 for a more realistic figure.

Example 1.13

A turbine generator set operating at a head of 10 metres with flow of 0.3 cubic metres per second will deliver approximately, (9.81 x 0.5 x 0.3 x 10 =) 14.715 kilo Watts of electricity.

Example 1.14

How much power generation potential is available in a run of river mini hydropower plant for flow of 20 litres/second with a head of 12 metres? Assume system efficiency of 60%.

$$Power = Head\ x\ Flow\ x\ Gravity$$
$$= \frac{12\ x\ 20\ x\ 9.81\ x\ 0.6}{1000} = 1.4\ kW$$

1.2.8 Fuel Cell

Input to a Fuel Cell is hydrogen. Hydrogen combines with oxygen to produce electricity through an electrochemical process with water and heat as by-products. Since conversion of the fuel to energy takes place using an electrochemical process (not combustion process), fuel cell is a clean, quiet and highly efficient process. Although there are many types of fuel cells, the principle of operation is similar.

Operation of Fuel Cell

A Fuel Cell (Figure 1.15) consists of two catalyst coated electrodes surrounding an electrolyte. One electrode is an anode and the other is a cathode. The process begins when hydrogen molecules enter the anode. The catalyst coating separates hydrogen's negatively charged electrons from the positively charged protons. The electrolyte allows the protons to pass through to the cathode, but not the electrons. Instead the electrons are directed through an external circuit which creates electrical current. While the electrons pass through the external circuit, oxygen molecules pass through the cathode. The oxygen and the protons combine with the electrons after they have passed through the external circuit producing water and heat.

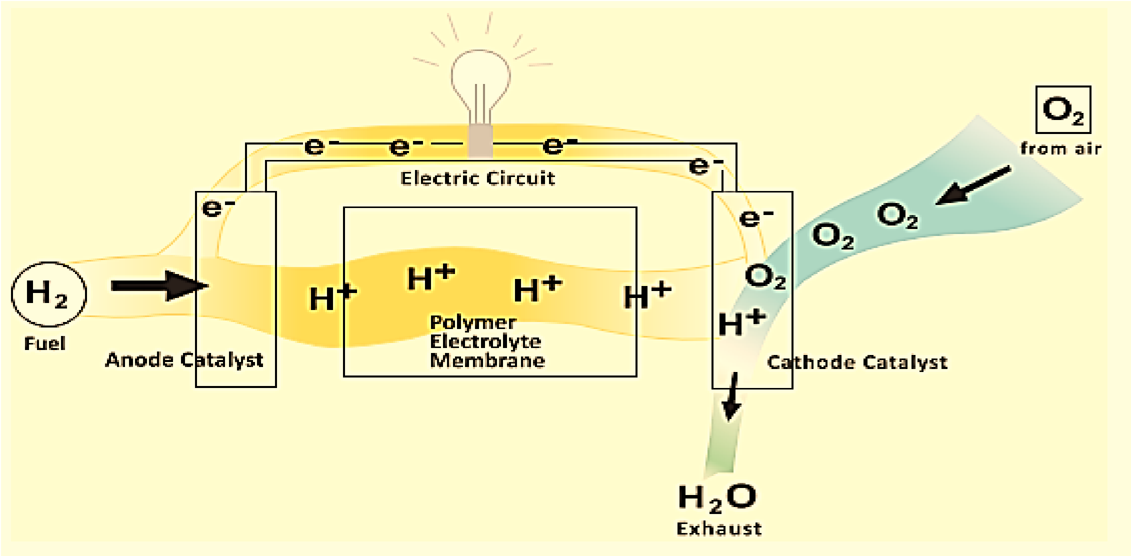


Figure 1.15: Fuel Cell

Individual fuel cells can then be placed in a series to form a fuel cell stack. The stack can be used in a system to power a vehicle or to provide stationary power to a building.

In general all fuel cells have the same basic configuration - an electrolyte and two electrodes. Whatever be the type of fuel cell, all require hydrogen as fuel. Hydrogen is a secondary energy resource, meaning it must be made from another fuel. Hydrogen can be produced in a variety of ways such as steam reforming of natural gas, electrolysis of water, gasification of biomass, etc. The biggest hurdle to large scale commercial exploitation of fuel cell is the cost of production of hydrogen which is now very high.

Table 1.3: Types of Fuel Cells

S. No.	Type	Anode	Cathode	Electrolyte	Remarks
1	Proton Exchange Membrane Fuel Cell (PEMFC)/ Polymer Electrolyte Membrane Fuel Cell	Hydrogen	Oxygen	Water based, acidic polymer membrane	• High-temperature variants use a mineral acid-based electrolyte and can operate up to 200°C. • Electrical output can be varied, ideal for vehicles • Use a platinum-based catalyst on both electrodes • Have high power density
2	Direct Methanol fuel cells-DMFC	Methanol	Oxygen	Polymer membrane (like PEMFC)	• Use a platinum-ruthenium catalyst on the anode and a platinum catalyst on the cathode

					• Operate in the range from 60°C to 130 °C • Direct use of methanol avoids use of fuel vaporizers, heating and humidification requirements • DMFC are convenient for portable power applications with outputs generally less than 250 W
3	PAFC-Phosphoric Acid Fuel Cells	Hydrogen	Oxygen	Liquid Phosphoric acid in a bonded silicon carbide matrix	• Use a finely dispersed platinum catalyst on carbon • Quite resistant to poisoning by carbon monoxide • Operate at around 180 °C. • Electrical efficiency is relatively low, but overall efficiency can be over 80% if the heat is used • Used in stationary power generators (100 kW to 400 kW)
4	AFC-Alkaline Fuel Cells	Hydrogen	Oxygen	Alkaline solution such as potassium hydroxide in water	• Commonly use a nickel catalyst • Generally fuelled with pure hydrogen and oxygen as they are very sensitive to poisoning • Typical operating temperatures are around 70 °C • Can offer high electrical efficiencies • Tend to have relatively large footprints • Used on NASA shuttles throughout the space programme
5	SOFC-Solid Oxide Fuel Cells	Synthesis gas (Hydrogen & carbon	Oxygen	Solid ceramic, such as stabilised	• Has solid state anode and cathode • Can run on hydrocarbon fuels such

		monoxide)		zirconium oxide	as methane • Operate at very high temperatures, around 800 °C to 1,000 °C • Best run continuously due to the high operating temperature • Popular in stationary power generation
6	MCFC-Molten carbonate Fuel Cells	Synthesis gas (Hydrogen & carbon monoxide)	Oxygen & Carbon Dioxide	A molten carbonate salt suspended in a porous ceramic matrix	• Can run on hydrocarbon fuels such as methane • Operate at around 650 °C • Best run continuously due to the high operating temperature • Most fuel cell power plants of megawatt capacity use MCFCs. as do large combined heat and power plants

Applications of Fuel Cells

The type of fuel cells used is decided by the application in which it is used. Since fuel cells are capable of producing power anywhere in the 1 Watt to 10 Megawatt range, they can be applied to almost any application that requires power.

The low power range fuel cells can be used as source of power for personal electronics applications such as charging of cell phones, personal computers etc. The high power fuel cells (1 kW — 100 kW range) fuel cell can be used to power vehicles. The megawatt range fuel cells can be used to convert energy for distributed power uses. Application of fuel cells in the transportation sector has significant advantages like reduced complexity of design.

1.2.9 Energy from Wastes

Energy can be recovered from wastes (trash) via combustion of waste in incinerators and generating power. A typical Waste-to-Energy power plant using direct combustion is explained in Figure 1.16.

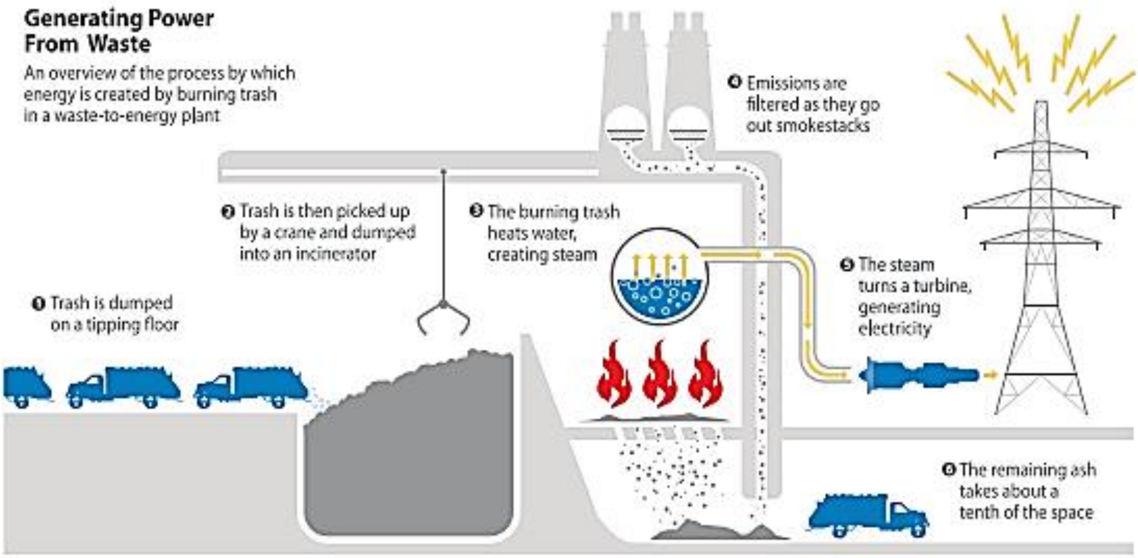


Figure 1.16: Energy from Wastes

Power generation from landfill gas

Biogas produced from landfill is known as Landfill gas (Figure 1.17). This process is also an anaerobic digestion process as bacteria decompose organic matter naturally in absence of oxygen over time. Landfill gas is composed mainly of methane and carbon dioxide. The methane gas produced in landfill sites normally escapes into the atmosphere and contributes to greenhouse gas emissions. However, if perforated pipes are inserted into the landfill, the landfill gas will travel through the pipes under natural pressure to be used as energy source.

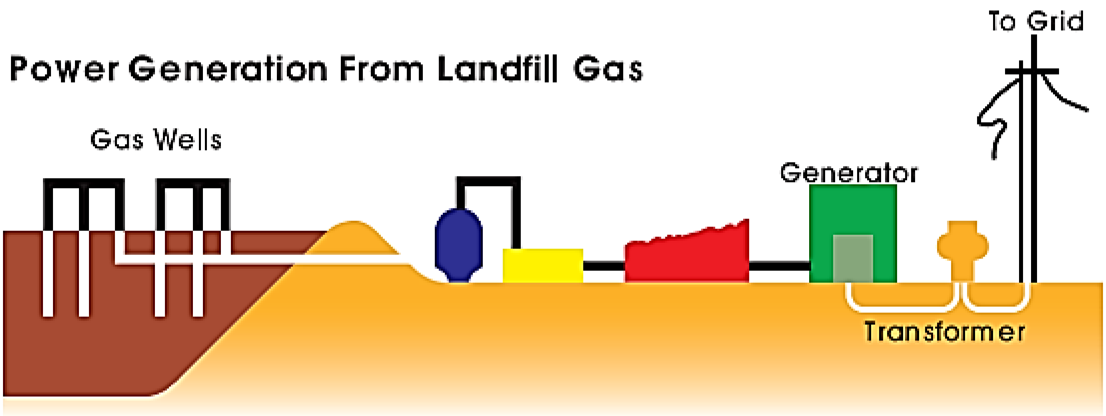


Figure 1.17 Power Generation from Landfill Gas

Chapter 2: Energy Scenario in Bangladesh

2.1 Introduction

Fossil fuels such as oil, natural gas, and coal have been the world's primary energy source for several decades. Currently, conventional fossil fuels supply about 83% of the global primary energy consumption for industrial, transportation, commercial and residential uses. Total primary energy consumption comprising commercially–traded fuels including renewable energy was 13389.3 million tonnes oil equivalent (MTOE) in 2020. The world primary energy consumption by fuel type/source is shown in Figure 2.1.

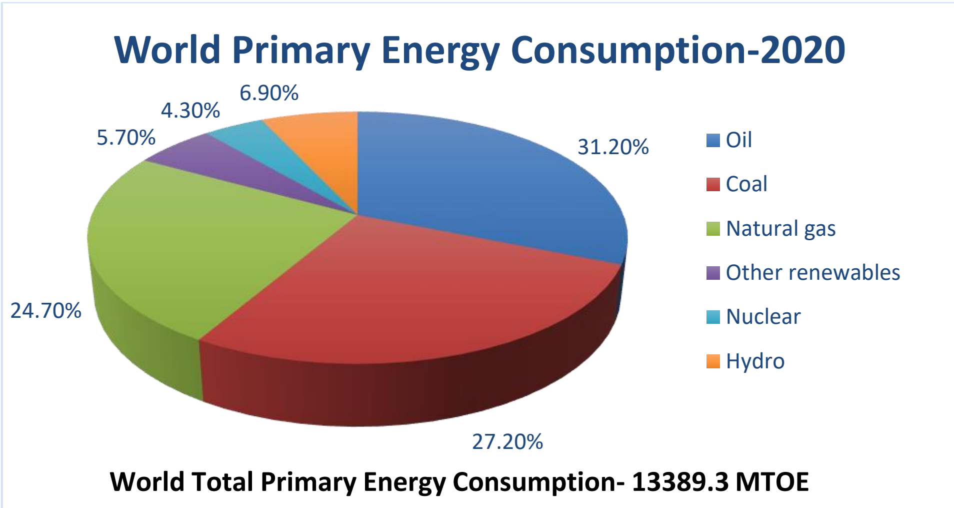


Figure 2.1: Breakup of World Primary Energy Consumption by Fuel / Source

(Source: BP Statistical Review of World Energy 2021)

The world is facing the reality that fossil fuels will be exhausted soon as the global consumption rate is outpacing the discovery and exploitation of new reserves, and that the global environment is worsening due to increasing greenhouse gas (GHG) emissions caused by fossil fuels. The world primary energy consumption trend is shown in Figure 2.2.

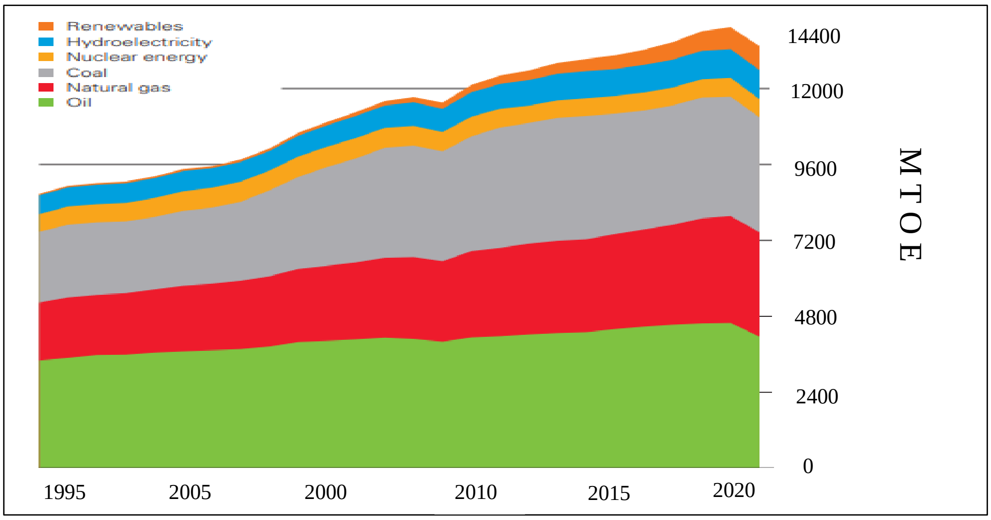


Figure 2.2: World Primary Energy Consumption Trend

(Source: BP Statistical Review of World Energy 2021)

Among the fossil fuels, natural gas share of the primary energy mix has seen the highest growth rate internationally. Unconventional gas, shale and coal bed methane (CBM) are also available as LNG in the regional gas markets. Natural gas has the potential to play an important role in the transition to a cleaner, more affordable and secure energy future. Natural Gas offers a much cleaner alternative to coal for power generation and produces only around half of the carbon dioxide (CO_2) emissions of coal when burned to generate power.

Demand of Primary energy in Bangladesh has been increasing steadily, at around 8% per year. Its primary energy supply was about 55 million tonnes oil equivalent in the year 2019-20 and final energy consumption was about 42 million tonnes oil equivalent, which is about 0.3% of the world's consumption. The energy consumption is growing rapidly and its economy faces significant challenges in meeting energy needs in the coming decades. The increasing energy needs coupled with declining domestic energy production mainly natural gas has meant that bulk of energy will have to be met by increasing exports. Bangladesh primary energy supply by energy source/type is shown in the Figure 2.3.

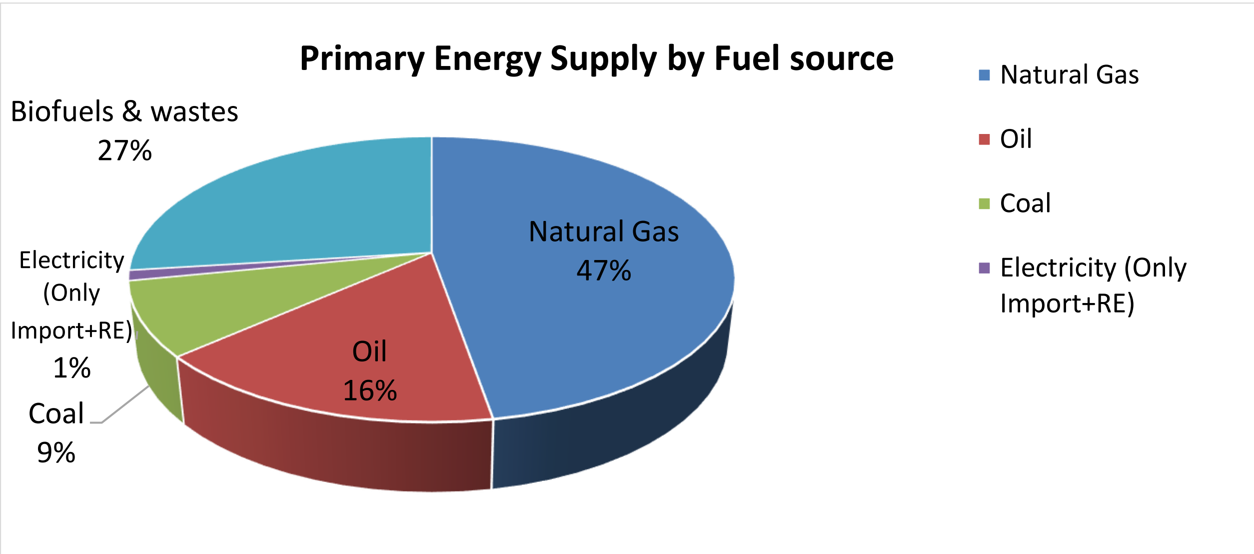


Figure 2.3: Primary Energy Supply by Fuel source in Bangladesh
(Source: National Energy Balance 2019-20)

As seen from the graph, Gas (47%), Biofuels & wastes (27%) and Petroleum (16%) are the main sources of primary energy to meet the energy demand of Bangladesh.

The Bangladesh's growth of primary energy supply over the last decade is illustrated in Figure 2.4.

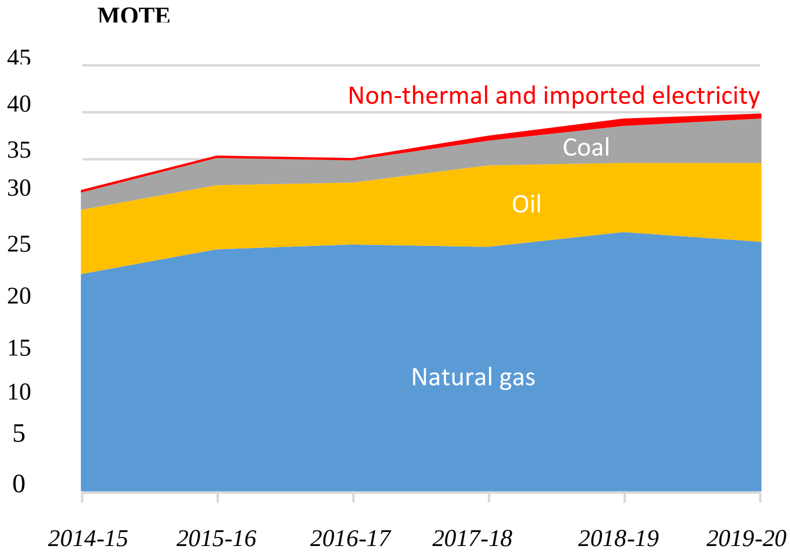


Figure 2.4: Primary Energy Supply Trend of Bangladesh

(Source: National Energy Balance 2019-20)

2.2 Natural Gas

Natural gas is the major fuel in Bangladesh. Natural gas produced in Bangladesh contains 95-99% methane and all others are hydrocarbon components. It contains almost no other impurities such as hydrogen sulphide, carbon dioxide and/or nitrogen. To date, 26 gas fields have been discovered in Bangladesh and natural gas reserve is estimated at 0.2 trillion cubic meters which is about 0.1% of the world reserves. Reserve/Production (R/P) ratio is estimated at only 6.7 years as of end of 2017.

Around three-fourth of the total primary energy consumption comes from natural gas. Bangladesh share of world consumption is only 0.7% and almost all the natural gas domestic consumption (26.6 Billion cubic metres) is met by domestic production (2017). The shares of industrial and residential sector are 15.66% and 13.36% respectively (2019-2020). The distribution of gas consumption is shown in the Table 2.1.

Table 2.1: Gas Consumption

	Industry	*Fertilizer*	*Transport*	*Domestic*	*Commercial*	*Tea*	*Captive Power*	*Grid*
Gas	***15.66%***	***5.48%***	***3.63%***	***13.36%***	***0.67%***	***0.11%***	***15.24%***	***45.85%***

(Source : National Energy Balance 2019-20)

Domestic gas supply has reached peak production and it is expected to decline and the demand will exceed the supply. This means the demand and supply gas must be filled by LNG imports.

Bangladesh's LPG demand is expected to grow drastically as an alternative for households' cooking fuel (currently domestic natural gas) and transportation fuel. Government wants to promote LPG as an alternative to conventional biomass as LPG is widely available, highly energy efficient, and less CO_2 and air-polluting particles emission than combustion of conventional solid biomass and less risk of deforestation by overexploitation of forest resources. The current price of LPG is two to three times higher than that of the piped gas supply. To meet the increasing demand, LNG terminals are being setup. Currently there are five import terminals and nine LPG private operators in Bangladesh, who deals with LPG import, shipping and distribution. Also the government has guaranteed to issue licenses to more new private operators.

GTCL (Gas Transmission Company Limited) was setup with the objectives of centralized operation and maintenance of national grid, and expanding the system as required, ensuring balanced supply and usage of natural gas in all regions of the country. GTCL transports almost 70 % of gas produced to various regions of Bangladesh.

2.3 Oil

Oil remains the world's leading energy source, accounting for about 31.2% of total global energy consumption in 2020. In recent years, supply of unconventional oil (shale oil, oil sands, natural gas liquid, liquid fuels derived from coal and gas) along with increased crude production both from mature oil fields has supported oil demand.

Bangladesh share of world oil consumption is 0.2% which was about 146 thousands of barrels per day (2017). Bangladesh produces a small amount of condensates (about 7,800 barrels per day as of December 2014), from natural gas fields. Condensates are fractionated to petroleum products, such as liquefied petroleum gas (LPG) and motor gasoline and are marketed in the domestic oil market. The domestic condensate supplies only about 5% of the total domestic oil demand in Bangladesh, and most of the oil demand is met with import from abroad.

The growing mobility and increasing demands for passenger and freight movement has increased the consumption of petroleum products in the road transport sector. The transport sector has the largest share (54%) in petroleum (oil) consumption, followed by agriculture (15%) and residential sectors (18% in the form of kerosene oil). The distribution of oil consumption is shown in Table 2.2.

Table 2.2: Petroleum Consumption

	Industry	*Transport*	*Residence*	*Commercial*	*Agriculture*	*Power generation*
Oil	***6%***	***54%***	***18%***	***1%***	***15%***	***6%***

(Source : National Energy Balance 2019-20)

Bangladesh's current oil annual demand is around 5 million tons, and the self-sufficiency rate is only 5%. However, Bangladesh expects continuous economic development, and the industry sector and transport sector demand will lead drastic oil demand growth: 6 times higher in 2041 than in 2016 (average growth rate 7.4% p.a.), even under the "Energy Efficient and Conservation Scenario".

The country has only one refinery in Chittagong; but its refining capacity is not sufficient to meet the country's total oil demand, and the country imports oil products for the remaining demand. Oil refining throughput was 28 thousand barrels daily as against capacity of 43 thousand barrels daily (2017).

Bangladesh has several plans to increase capacity of existing refineries or newly develop oil refineries.

2.4 Coal

Globally, coal is the predominant of the three major fossil fuels and most widely distributed with reserves in over 100 countries. World proved coal reserves are currently sufficient to meet 136 years of global production, which means that Reserve/Production (R/P) ratio is much higher than that of oil and gas.

In Bangladesh, coal is generally characterized as having low ash content and low sulphur content that are in favour of the environment. It is basically bituminous coal. Another grade of coal, which is classified into coking coal for iron production whose commodity value is very high in the market, is also available. Small amounts of coking coal are also produced in Bangladesh, which are being exported and the associated middling is being supplied to a domestic coal fired power station.

2.5 Nuclear Power

The development of nuclear power is today concentrated in a relatively small group of countries namely China, Korea, India and Russia. As of January 2015, the total identified resources of uranium are considered sufficient for over 100 years' of supply based on current requirements.

The nuclear is increasingly seen as a means to add large scale base load power generation while limiting the amount of GHG emissions. The low share of fuel cost in total generating costs makes nuclear the lowest-cost base load electricity supply option. Uranium costs account for only about 5% of total generating costs and thus protect plant operators against fuel price volatility.

Bangladesh is introducing nuclear energy as a safe, environmentally friendly and economically viable source of electricity generation. The plant in Rooppur, 160 kilometres north-west of Dhaka, will consist of two units, with a combined power capacity of 2400 MW(e). It is being built by a subsidiary of Russia's State Atomic Energy Corporation ROSATOM. The first unit is scheduled to come online in 2023 and the second in 2024.

2.6 Renewable Energy

Bangladesh has currently 776 MW installed renewable energy capacity which only about 3.06% of the total share. The Government has plans to generate 10% electricity of total installed generation capacity from Renewable Energy sources. Installed renewable energy capacity (as of 21 October, 2021) is given in Table 2.3.

Table 2.3: Installed Renewable Energy Capacity in MW (as of 21 October, 2021)

S.L.	*Technology*	*Off-Grid*	*On-Grid*	*Total*
1	***Solar***	***347.07***	***194.93***	***542.01***
2	***Wind***	***2***	***0.90***	***2.90***
3	***Hydro***	***-***	***230***	***230***
4	***Biogas to Electricity***	***0.69***	***-***	***0.69***
5	***Biomass to Electricity***	***0.40***	***-***	***0.40***
	Total	***350.16***	***425.83***	***776***

(Source: SREDA, http://www.sreda.gov.bd/index.php/site/re_present_status)

Site-specific wind data collection has been started in 4 coastal areas at the initiative of SREDA to facilitate site selection and bidding process for IPP based wind power plants. Five (05) wind power projects with an aggregated capacity of 245 MW are under implementation. Government is eying to generate more than1500 MW electricity from wind energy by 2030.

Renewable Energy contribution in power mix is illustrated in the following chart.

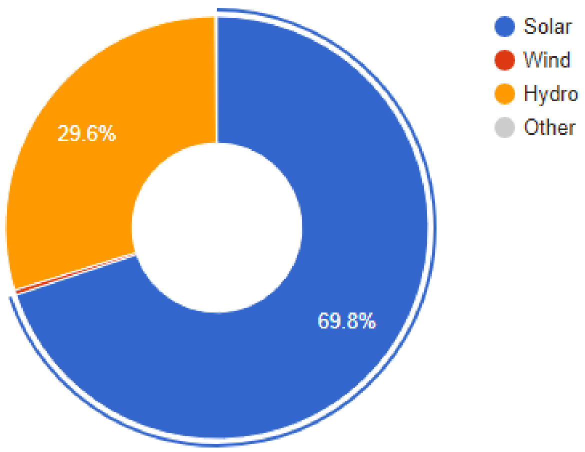


Figure 2.5: Renewable Energy Share

(Source: SREDA)

2.7 Electricity Supply Trend

Average electricity demand is growing at over 10% per year, owing to rapid economic growth, industrialization, expansion in grid connection and inclusion of new electrical devices and appliances.

Bangladesh's share of gas-fired capacity accounted for about 61% of total installed electricity capacity which reached 11.46 Giga Watts (GW) in 2021. In recent years, diesel or fuel oil based units have come into operation. According to the government of Bangladesh, about 62% of the population has access to electricity. The peak load deficit which resulted in regular load shedding during the peak hours were however minimized by substantial increase in generation

along with infrastructure development in recent years.
The government seeks to replace older, inefficient units and increase electricity generation capacity to match the electrification rates of other developing countries. Bangladesh plans to more than double power generation capacity to 24 GW by 2021, primarily through the use of coal and natural gas.

Table 2.4 shows the present installed generation capacity by different sectors and figures 2.6 & 2.7 shows the installed capacity of power generation by fuel type and plant type. The present energy mix for electricity generation is dominated by natural gas followed by petroleum (HFO/HSD).

Table 2.4 : Present Installed Generation Capacity (MW) as on September, 2021

Public Sector	*Installed Generation Capacity (MW)*
BPDB	***6013***
APSCL	***1444***
EGCB	***957***
NWPGCL	***1401***
RPCL ***BPDB-RPCL JV***	***182*** ***149***
Subtotal	*10146 (46%)*
Joint Venture	
BCPCL (JV of NWPGCL & CMC, China)	***1244 (6%)***
Private Sector	
IPPs	***8042***
SIPPs (BPDB)	***99***
SIPPs (REB)	***251***
15 YR. Rental	***169***
3/5 YR. Rental	***920***
Subtotal	*9481 (43%)*
Power Import	***1160 (5%)***
TOTAL	*22,031*
Captive Power & Renewable Energy	*2800 + 404*
Grand Total	*25,235 MW*

(Source: www.bpdb.gov.bd)

BPDB: Bangladesh Power Development Board (BPDB)
APSCL: Ashuganj Power Station Company Limited
EGCB: Electricity Generation Company of Bangladesh
NWPGCL: North West Power Generation Company Limited
RPCL: Rural Power Company Limited

IPPs: Independent Power producers (IPP, SIPP & Rental)

The Bangladesh Power Development Board (BPDB) is responsible for the major portion of generation and distribution of electricity mainly in urban areas of the country. The Board is now under the Power Division of the Bangladesh Ministry of Power, Energy and Mineral Resources. The main fuel used for power generation in BPDB plants is indigenous natural gas. BPDP operations also include projects that utilize renewable power sources including offshore wind power generation. Out of 100% total installed generation, 52% is by the public sector power plants operated by BPDB & others and balance 48% by private sector as per 2018. Under the existing generation scenario of Bangladesh, Renewable Energy has a very small share to the total generation. The present Government is placing priority on developing Renewable Energy resources to improve energy security and to establish a sustainable energy regime alongside of conventional energy sources.

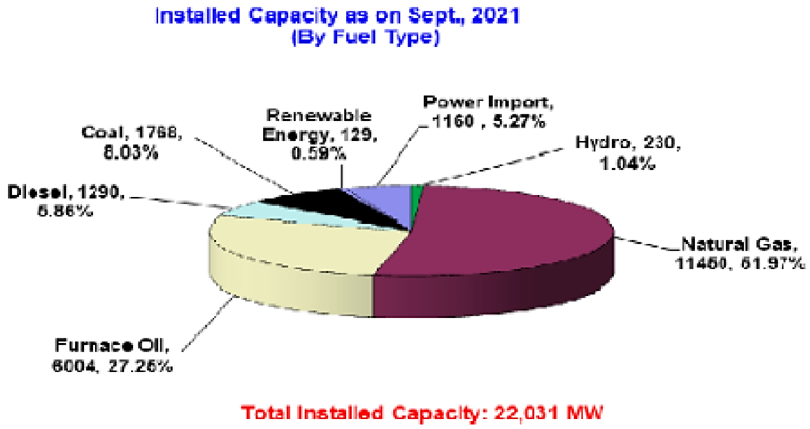


Figure 2.6: Installed Capacity by Fuel Type

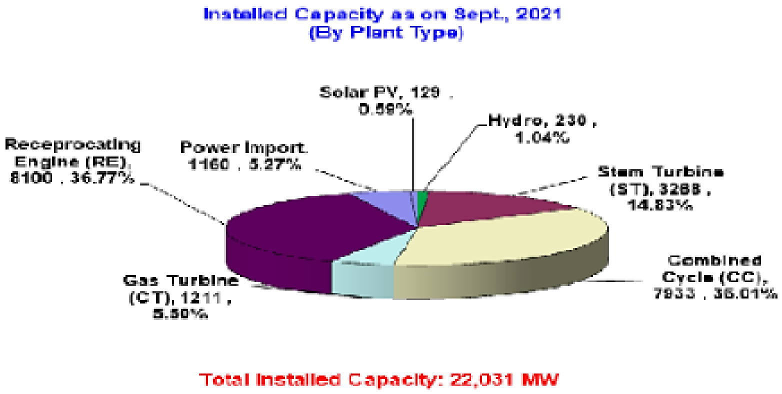


Figure 2.7: Installed Capacity by Plant Type

The power plants in the country are mostly gas-fired and with decline in gas supply projected from 2018 onwards, Bangladesh may not go for further gas fired power plants without sourcing LNG supply or discovering new gas reserve. Alternative sources of power generation through coal, oil, renewable and new energy sources (such as nuclear and hydro power generation) are being explored. The Government has drafted Power System Master Plan 2010 (PSMP) to improve and expand electricity supply.

2.8 Final Energy Consumption by Sector

Final energy basis data below show that industry sector consumes almost a half (48%) of the entire energy (excluding biomass). Composition of residential sector is approximately one third, at 29%.

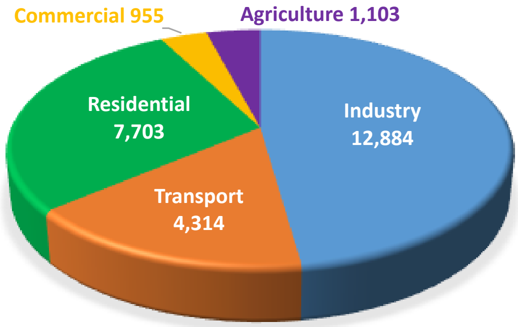


Figure 2.8: Energy Consumption by sector (Final Energy basis)

Primary energy basis chart below visualises the fact that the importance of residential sector energy consumption increases when considering the data on primary energy basis.

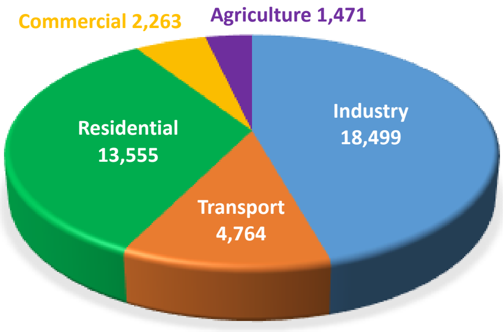


Figure 2.9: Energy Consumption by sector (Primary Energy basis)

Note
* Excludes biomass.
* Commercial and public services = compilation of commercial, building and others

(Source: SREDA compilation based on readily-available national energy data-National Energy Balance 2019-20)

2.9 Energy Balance in Bangladesh

The national energy balance is a presentation of a set of energy data to exhibit the overall pattern of energy supply, transformation and consumption pattern among the major sector and by source of energy. It can also be described as the input-output data, or a balance sheet table of energy supply to consumption within the country.

Based on readily-available national energy supply, transformation efficiency and consumption data, an updated energy balance calculation was conducted at SREDA. Table 2 on the next two-pages spread is the country's national energy balance table for FY 2019-20. The visual presentation focusing of the flow of energy by sector and source, based on the table is as shown in Figure 5. It should be noted here that the energy consumption in national energy balance is the final consumption basis, not in primary energy basis. It should also be noted that the national energy balance table and the visual presentation contain ambiguity which require to be solved once comprehensive official data become available.

The striking characteristics of the national energy balance structure of Bangladesh is that the captive power generation comprises a significant portion of energy transformation. It also shows that approximately a half of the natural gas is being fed into power generation (including captive power generation). Captive power generation is contributing a significant portion of electricity supply to the industry sector (approximately 40%).

Further, looking at fuel source-wise consumption, natural gas is the major source for industry and residential sectors. It should also be noted that the imported coal, imported petroleum products also comprise an important portion of the primary energy supply. Electricity is the most consumed form of energy in industry, residential and commercial & public service (building) sectors.

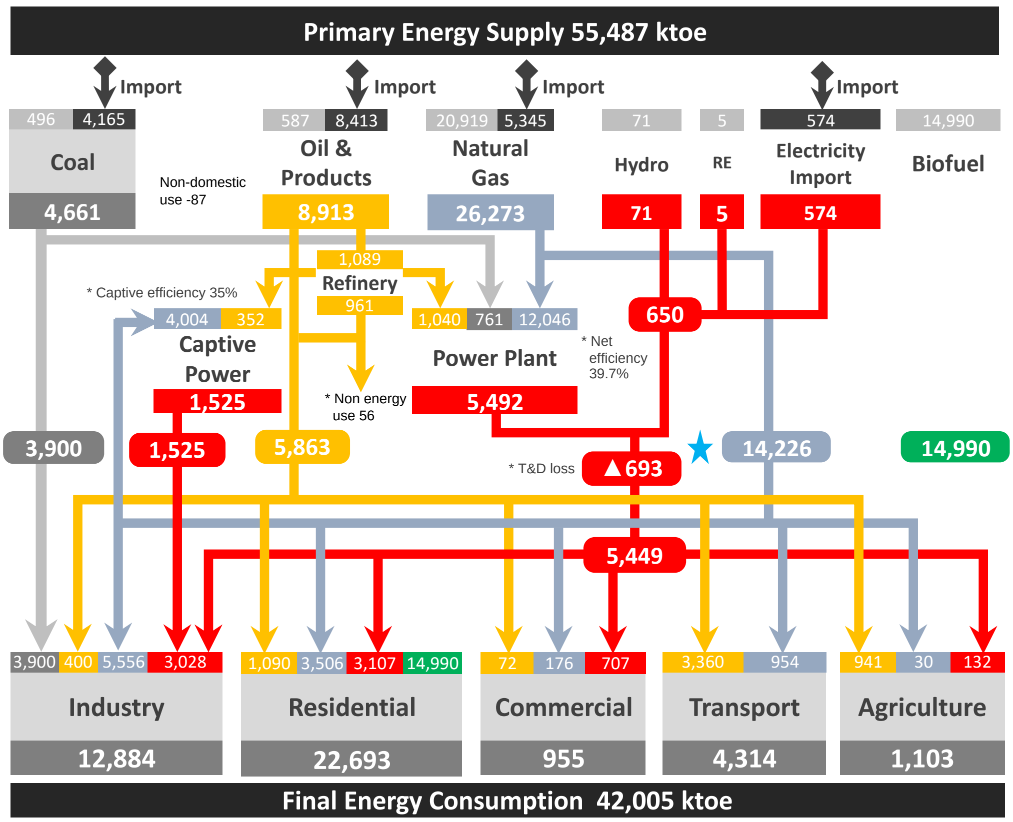


Figure 2.10: Energy Balance in Bangladesh (FY 2019-20)

Note: Unit = ktoe

Seven boxes on the top (in five colours) are Primary Energy Supply by fuel source.
Middle thee boxes (power plant, refinery, captive) are energy transformation means.
Bottom five boxes are final consumption by sector.

(Source: Compiled from HCU, BPC, BCMCL, Petrobangla, ERL and BPDB data-National Energy Balance 2019-20)

2.10 Energy Efficiency and Conservation Program (EE&C)

Bangladesh has set the following targets

10% (2000 MW) of total Electricity Generation will be from RE by 2020
15% & 20% reduction in Primary Energy Consumption per GDP by 2021 & 2030 respectively.

It is expected that in the EE&C scenario (20% energy efficiency improvement by 2030), the electricity demand by 2030 will result in avoided generation of 7 GW compared to the BAU case. This will also lead to reduce the import of primary fuel for power generation as well. EE&C potential in various sectors namely industrial,

EE&C Potential

EE&C potential is defined as an expected amount of energy reduction, gained by introducing more effective energy management, energy efficient equipment, insulation and solar energy nationwide. EE&C potentials by sector were estimated as follows.

Industrial Sector

Manufacturing industries are not efficient in energy use, because of the continuous usage of old/poorly-maintained machines and poor energy management. It is estimated that, through energy intensity comparison and actual on-site energy audits, the accumulating EE&C potential in industrial sub-sectors amount to around 21% of the entire industrial sector consumption. Considering the fact that about 50% of national primary energy is consumed in the industrial sector, the potential reduction due to various EE&C measures is estimated at about 10.5% of the total energy consumption (Figure 2.10).

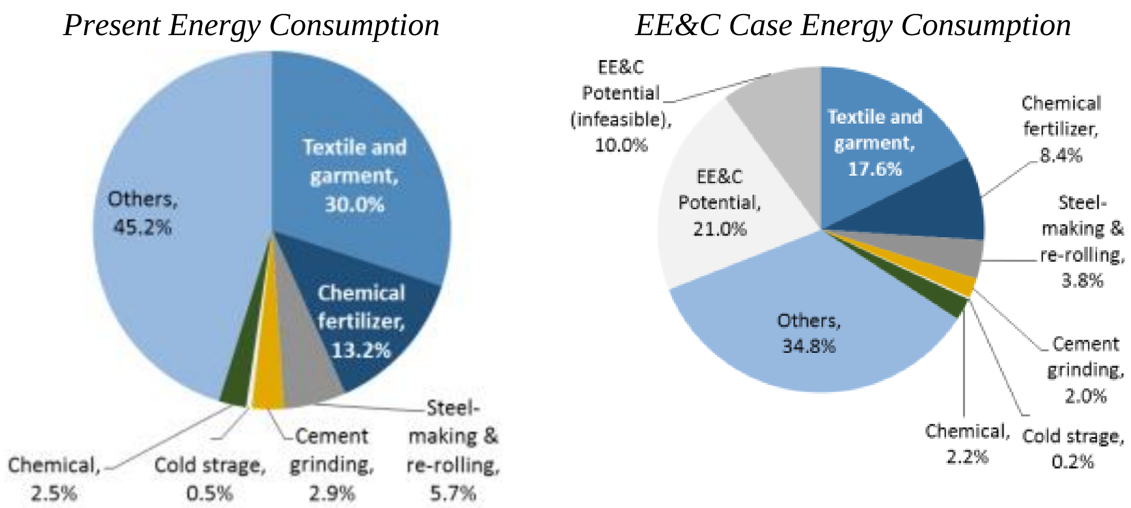


Figure 2.11: EE&C Potential in Industrial Sector

(Source: SREDA, Energy Efficiency & Conservation Master Plan up to 2030)

Gas use efficiency is one of the critical issues that need to be introduced. “Cheap gas” will not be available in the future and gas users need to enhance their efficiency to save the country’s indigenous gas resources. Both the Urea Manufacturing Sector and Power Sector are major gas users and have a significant impact on the overall gas consumption.

Urea is manufactured from natural gas. The world benchmark efficiency for Urea Manufacturing is 25mcf/ton, while average efficiency in Bangladesh was 44 mcf/ton as of 2014 FY, which is much higher than that of the international benchmark. If international benchmark is adopted in the country, 130 mmscfd of gas would be saved in manufacturing 2,375,000 tons in 2014 and this figure would translate into the power plant equivalent of 1000 MW.

Gas Consumption for the Power Sector (under BPDB) was 337.4 BCF in FY 2014 while Power Generation Capacity was 8,340 MW and Generated Power was 42,200 GWh. The current power generation efficiency is around 38%. If the efficiency can be raised to 45%, which is considered the international benchmark for a gas based power plant, Energy gas consumption will be reduced to 285 BCF, and the difference of 52 BCF can be said to be wasted. This is equivalent to 1,300 MW in power plant annual operation.

Residential Sector (Electric Home Appliances)

If all the existing home appliances in residences are to be replaced by higher efficiency products, huge energy reduction can be achieved. Considering the fact that about 30% of national primary energy is consumed in the residential sector, the potential reduction in energy consumption due to EE&C measures is estimated at almost 8.6% of the total energy consumption (Figure 2.11).

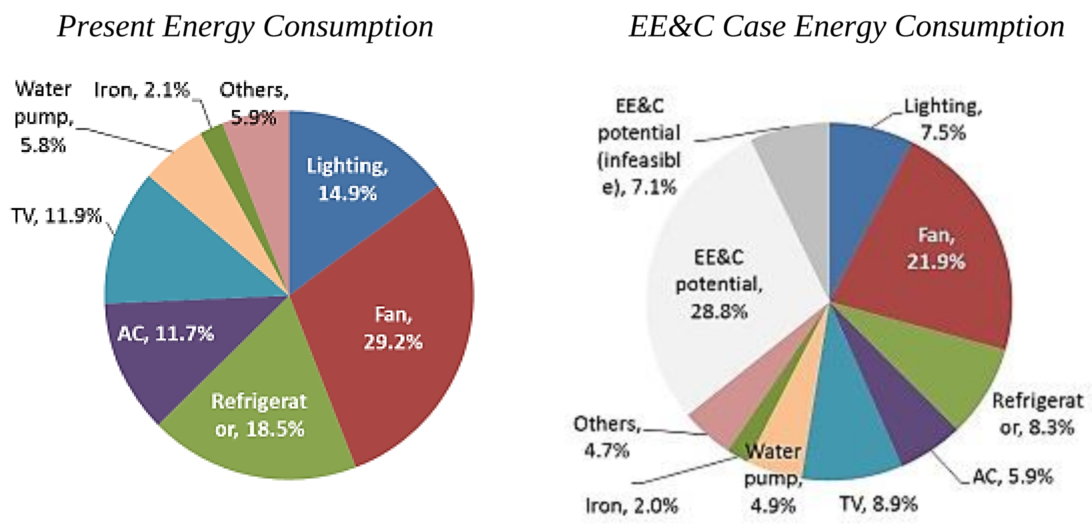


Figure 2.12: EE&C Potential in Residential Sector

(Source: SREDA, Energy Efficiency & Conservation Master Plan up to 2030)

Commercial Sector (Buildings)

Electricity is the main mode of energy in commercial buildings and almost 50% of the total energy is consumed by ACs and 10-30% by lighting systems. It is expected that a simple replacement of ACs and lighting systems with high energy efficiency equipment and systems can save about 50% of total electricity consumptions in the commercial sector. EE&C potential for buildings is estimated at about 10%.

Agricultural Sector

Electricity (including captive power) is the main mode of energy in agricultural sector and the largest energy is used for irrigation pumps. EE&C potential for existing pumps is expected around 20%.

2.11 Targets and Action Plans

The various indicators to evaluate the improvement of future national energy efficiency are as follows:

a) The actual reduction amount of energy consumption,
b) Reduction ratio (value) for future BAU value,
c) Energy consumption per capita and
d) Energy consumption per Gross Domestic Product (GDP), etc.

Out of these indicators, energy consumption per GDP which considers both energy efficiency and national economic growth is the most appropriate for Bangladesh. In this EECMP, **"primary energy consumption per GDP"** is chosen as the indicator to set EE&C target and evaluate future national energy efficiency.

It is proposed to achieve EE&C targets in a phased manner through combination of regulatory measure and incentive mechanisms with nationwide action plans to reduce "primary energy consumption per GDP'. The targets for 2021 and 2030 are set at 15% and 20% reduction, compared with 2013 value. The various action plans for achieving targets are summarized in the following Table: 2.5.

Table: 2.5 Summary of EE&C programs in Action Plans

Program	*Target*	*Methodology*
Energy Management Program (EMP)	***Large Industrial Energy Consumers***	• *Large energy consumer designation* • *Energy Manager, Certified Energy Auditor and Accredited Energy Auditor certification with qualification and examination system* • *Energy audit (mandatory/voluntary)* • *Energy consumption reporting (mandatory)* • *Benchmarking*
EE Labeling Program (EELP)	***Residential Consumers***	• *Label certification / Laboratory accreditation system* • *Standardization of EE measurement method and Star Label Rating criteria* • *Star Label Standardization (Unification)*

		• *Participation of manufactures, importers and retail shops (mandatory/voluntary)* • *MEPS (Minimum Energy Performance Standard)* • *Effective means to be developed to stop entry of bellow standard and energy inefficient products/items in the market.*
EE&C Finance Incentive Program	***Private Companies***	• *Low-interest loan for EE&C investment* • *Preferential taxation on high efficiency equipment/appliances and/or EE&C investment* • *Subsidy for EE&C investment* • *Other incentive mechanisms*
Government's Own Initiatives	***Government***	• *Green Purchase Program for Eco-friendly public procurement* • *Obtain ISO14001 and 50001 certification*
Energy Consumption Data Collection	***Government***	• *Energy consumption data by fuel* • *Energy consumption data by sector and sub-sector* • *Energy intensity data*
Global Warming Countermeasure	***All***	• *Formulation and quantification of national carbon market* • *Carbon abatement project as capacity development* • *Awareness raising*

2.12 Policies relevant to Renewable Energy and Energy Efficiency & Conservation

1. National Energy Policy
2. Action Plan for Energy Efficiency & Conservation, 2013
3. Renewable Energy Policy of Bangladesh, 2008
4. Energy Efficiency and Conservation Master Plan up to 2030
5. Energy Efficiency and Conservation Rules, 2016
6. Power System Master Plan (PSMP) -2016
7. Energy Audit Regulation, 2018
8. Net Metering Guideline, 2018
9. Building Energy Efficiency and Environment Rating (BEER) System (Draft)
10. Standard and Labeling Regulation (Draft)

All Policies can be found in SREDA Website: www.sreda.gov.bd

Chapter 3: Energy Management and Audit

3.1 Introduction

Energy such as electricity, oil, coal, and natural gas is being consumed in all facilities for its operations. If energy is not efficiently used and managed, it will increase operational and maintenance costs besides polluting the environment.

Energy management can be defined as:

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

Organizations that successfully manage energy have business processes to plan, monitor, and control energy use, just as they do for other corporate priorities, such as labor, materials, and other costs. For these organizations, energy management is "business as usual".

Successful energy management need an effective strategy and involves all employees. Energy audit is the key to a systematic approach for decision making in the area of energy management.

The objectives of Energy Management include,

- ✓ To achieve and maintain optimum energy procurement and utilisation, throughout the organisation
- ✓ To minimize energy costs/waste without affecting production and quality
- ✓ To minimise environmental effects

An energy audit is an investigation of all facets of a facility's historical and current energy use with an objective of identifying and quantifying areas of energy wastage in its activities. The outcome is the identification of viable and cost effective energy saving measures to reduce energy consumption per unit of product output thereby lowering the operating costs.

Energy audit serves as the 'foundation' on which successful energy management programme can be built in an organisation. Energy audit also provides a 'benchmark' for managing energy and planning a more effective use of energy throughout the facility.

3.2 Scope of Energy Audit

Typically the scope of an energy audit includes an examination of the following areas:

- Energy conversions in equipment such as boilers, furnaces, transformers, pumps, fans, compressors etc.
- Energy distribution (electricity, steam, condensate, compressed air, water etc.)
- Energy utilisation efficiency of equipment
- Production planning, operation, maintenance, and housekeeping
- Management aspects (information flow, data collection and analysis, feedback, achievements, training of employees, motivation, etc.)
- Other related areas such as water audit & conservation, waste minimization studies are sometimes included as part of an energy audit.

3.3 Types of Energy Audit

The type of energy audit depends on factors such as function, size, and type of facility and depth of the study. Energy audit is classified broadly into two types: preliminary energy audit and detailed energy audit.

Preliminary energy audit	*Detailed energy audit*
• *Short time frame, say few days to one week.*	• *Longer time frame, say 15–30 days*
• *Uses readily available data for quick analysis and results are general*	• *Uses operating data, detailed observations, measurements, energy and mass balance to assess energy performance*
• *Focus on common opportunities for energy efficiency*	• *More specific recommendations for energy improvements covering all areas*
• *Economic analysis is mostly limited to calculation of simple payback period*	• *Economic analysis may include internal rate of return, net present value, life cycle cost, as well as simple payback period*
• *Broad recommendations*	• *Detailed energy audit accounts for and evaluates all major energy using equipment and systems and provides specific recommendations with comprehensive implementation plan.*

3.4 Detailed Energy Audit Methodology

The detailed audit is typically carried out in following stages:

a) Initiating the audit
b) Preparing the audit
c) Executing the audit
d) Reporting the audit
e) Implementing the audit

A step-by-step guidance to conduct of energy audit at site is presented in the following Table. Energy auditors may follow these steps and amend them as per their needs and facility being audited.

Step-by-Step Guidance for Detailed Energy Audit

Step	*Plan of Actions*	*Results*
	a) INITIATING THE AUDIT	
Step 1	• ***Understand client needs and expectations.*** • ***Gather main data prior to site visit.*** • ***Define audit criteria and scope of audit.***	• ***Overall operational strategy, major equipment/process and key technologies.*** • ***Historical and current data such as annual production, energy consumption, water consumption, performance indicators i.e. typical figures normally referred or quoted.*** • ***Decision on type of audit i.e. preliminary or detailed***
	b) PREPARING THE AUDIT	
Step 2	• ***Plan resources for audit.*** • ***Prepare audit checklist.***	• ***Resources (total time for the audit including timeline for each step).*** • ***Audit team and composition, responsibility of each team member.*** • ***Energy audit instruments needs.***
Step 3	• ***Conduct opening meeting.*** • ***Establish common understanding of audit process (auditors and client).***	• ***Safety briefing.*** • ***Company philosophy towards investment for energy savings.*** • ***Facility layout or plan.***
	c) EXECUTING THE AUDIT	
Step 4	• ***Walk-through audit*** • ***Interview key facility personnel.*** • ***Gather on-site data.***	• ***Plant/process activities, current operating practices, metering, monitoring and energy reporting system.*** • ***Broad process flow diagram.*** • ***Energy utility diagram.***
Step 5	• ***Gather additional information through tailor-made questionnaire for each department.*** • ***Evaluate collected information and identify focus areas for detailed investigation.***	• ***Energy tariffs and bills*** • ***Month wise current and historical energy and related production data (1-3 years).*** • ***Proportionate share of different energy sources when compared with total energy consumption for current year in a pie-chart.*** • ***Production performance and related energy consumption under varying conditions: days, months, seasons.*** • ***Design data, operating data, and schedule of operation of various equipment.*** • ***Breakdown of energy consumption by department/section as a pie-chart.*** • ***Baseline energy consumption.***
Step 6	• ***Conduct onsite measurements and performance surveys using portable instruments, and panel mounted instruments (if available).*** • ***Conduct detailed performance trials for major energy equipment /systems.***	• ***Comparison of operating / measurement data with design data (motor survey, lighting survey, fluid flow rates, temperatures).*** • ***Analysis of variation and trends (24 hours) of kVA, PF, kWh etc.*** • ***Efficiencies of major equipment such as boiler, furnace, chillers etc.*** • ***Load variations and trends in pumps, fan, chillers, refrigerators, cooling towers, compressors etc.***

Step 7	• ***Analyze use of energy, material and water use.***	• ***Energy &material balance and assessment of energy losses/wastes.*** • ***Water conservation opportunities.***
Step 8	• ***Identify, develop and refine ENCON (Energy Conservation) opportunities using brainstorming, vendor inputs etc.***	• ***List of ENCON measures.*** • ***Technology options and budgetary offers from vendors.***
Step 9	• ***Evaluate ENCON opportunities (Cost-benefit analysis)***	• ***Technical and financial feasibility of various ENCON measures.*** • ***Selected ENCON measures for implementation as short, medium, and long-term measures.*** **(Some short term measures may be implemented immediately at site and impact on energy savings can be demonstrated to the client.)**
	d) REPORTING THE AUDIT	
Step 10	• ***Prepare a draft or working report for presentation to facility management.*** • ***Conduct closing meeting after submission of final report (soft copy).***	• ***Highlights of the audit with key findings and ENCON measures.*** • ***Concurrence of draft report from all concerned or functional managers and modifications as required.*** • ***Submission of fine-tuned report (if required) as soft and hard copy.*** • ***Presentation to the facility management as the final appraisal.***
	e) IMPLEMENTING THE AUDIT	
	Implementing the audit findings is not normally the scope of an energy auditor. The client may seek implementation assistance particularly for technical inputs, evaluating the equipment supplier offers and for monitoring of the implementation of the projects. This may also be assigned as an extension of energy audit. The client can also seek the help of ESCOs in implementing ENCON options and monitoring the performance.	
Step 11	• ***Prepare action plan for Implementation and follow-up.***	• ***Action plan for implementation of ENCON options (DPR for major project) by facility management or through ESCO.*** • ***Monitoring and review by ESCO or facility management assisted by energy auditor.*** • ***Measurement and Verification.***

Some of the salient points in the energy audit methodology are elaborated as follows:

Audit Criteria and Scope

These define purpose, depth, and methodology to be adopted by energy auditor for the given audit. In case of mandatory energy audit or compliance audit, the client defines the criteria and scope and provides basic energy data with raising of Expression of interest (EOI) or Request for proposal (RFP). Sustainable and Renewable Energy Development Authority (SREDA), GOB has outlined a detailed audit methodology to be followed, and it is available in the SREDA website.

Sample Scope of Work (commercial buildings)

The energy audit consultancy organisation, based on site visits and diagnostic studies, shall cover all forms of energy i.e. both thermal and electrical for all systems and equipment.

A)	*Electrical Distribution System*
(i)	*Review electrical distribution like single line diagram for transformer loading, cable loading, normal and emergency loading, and also electrical distribution in various areas.*
(ii)	*Study reactive power management and option for power factor improvement.*
(iii)	*Study power quality issues like harmonics, current imbalance, voltage imbalance, etc.*
(iv)	*Explore energy conservation options in electrical distribution system.*
B)	*Motor Load Survey*
(i)	*Conduct motor load survey of all drives to estimate % loading.*
(ii)	*Explore ENCON options in motor driven equipment and system.*
C)	*Heating, Ventilation, & Air Conditioning System (HVAC System)*
(i)	*Review present HVAC system like central AC, split AC, package AC, water coolers, and air heaters.*
(ii)	*Assess performance of split AC and package AC system.*
(iii)	*Assess performance of air handling units (AHUs) and central AC system.*
(iv)	*Compare HVAC performance such as KW/TR, specific energy consumption (SEC) of chilled water pumps, condenser water pumps, AHUs with the design data.*
(v)	*Explore energy conservation options (ENCON) in HVAC system.*
D)	*Water Pumping Systems*
(i)	*Review water pumping, storage, and distribution systems.*
(ii)	*Conduct water balance studies.*
(iii)	*Assess performance of all major water pumps i.e. power consumption vs. flow delivered, determination of pump efficiency etc.*
(iv)	*Explore Energy Conservation Options (ENCON) in water pumping system.*

E)	*Lighting System*
(i)	*Examine present lighting system in all areas and assess lighting load (lighting inventory, lighting equipment, type, rating, nos and corresponding control gears)*
(ii)	*Measure lux levels at various locations and analyse lighting performance indices like lux/m^2, lux/watt, lux/watt/m^2 and compare with norms*
(iii)	*Evaluate possibilities to reduce energy use by incorporating energy efficient lighting system, equipment's including lay out changes*
(iv)	*Explore Energy Conservation Options (ENCON) in lighting system.*
F)	*Others*
(i)	*Assess scope for integrating renewable energy into existing building.*
(ii)	*Cost benefit analysis indicating investment, energy saving, and payback period.*

Initial Site Visit and Preparation

An initial site visit may be planned before the audit to give the energy auditor an opportunity to meet the top management and other department heads, to familiarize with the site, and to assess the procedures necessary to carry out energy audit. During the initial site visit, the energy auditor carries out the following actions:

- *Discuss with the site's senior management the goals of the energy audit*
- *Obtain major energy consumption and production data*
- *Discuss the economic guidelines associated with the recommendations of the audit*
- *Tour the site accompanied by engineering/production staff*
- *Interview key personnel (energy manager/maintenance manager/finance manager/floor supervisors/operating staff)*
- *Identify major energy consuming areas/process to be audited*
- *Identify existing instruments and data available in the facility*
- *Identify list of parameters to be measured and the instruments needed during the energy audit*
- *Create awareness through a meeting/programme.*

Selection of Energy Audit Team

The selection and composition of energy auditing team depends upon the type of industry to be audited. The audit team can be drawn from varied disciplines like mechanical, electrical, and chemical engineering. The areas having high potential for energy savings are identified and responsibilities and tasks of each audit member are defined.

Detailed Energy Audit Activities

Depending on the nature and complexity of the site, the detailed audit takes from several weeks to few months to complete. Energy and material balances for specific plant departments or items of process equipment are carried out. If required, checks of plant operations are carried out over extended periods of time, at nights, and at weekends to ensure that nothing is overlooked.

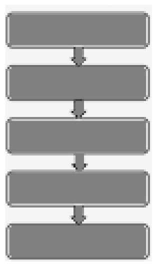
Information to be collected during detailed energy audit

- Plant layout
- Sources of energy supply (e.g. electricity from the grid or self-generation)
- Energy cost and tariff data (month wise energy consumption data for 1–3 years)
- Production data (1–3 years)
- Energy consumption by type of energy, by department, by major items of process equipment, by end-use
- Production process description with energy interaction
- Process flow diagram with energy and material flows
- Generation and distribution of site services diagram (e.g. compressed air, steam, chilled water, cooling water, etc.)
- 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.)
- Energy management procedures and existing energy awareness training programmes.

The audit team should collect the following baseline data:

• Technology, processes used and equipment details • Capacity utilisation • Amount and type of input materials used • Water consumption • Fuel consumption	• Electrical energy consumption • Steam consumption • Type and quantity of wastes generated • Percentage rejection/reprocessing • Efficiencies/yield

Preparation of Process Flow Diagram and Listing Process Steps



An overview of unit operations, key process steps, areas of material and energy use, energy losses and waste generation are identified. Existing drawings, records and shop floor walk-through assist in preparing the flow chart. The inputs and outputs at each process step are identified and depicted in the flow chart.

Performance Evaluation and Trials for Major Equipment/Processes

Depending on the type of industry, data collection and trials cover areas such as air conditioning and refrigeration system, lighting, ventilation system, motors, pumps, fans, boilers, furnaces, compressors and other specialized equipment. The monitored parameters vary from one plant to another because of differences in designs and operations.

Energy Audit Instruments

Instruments for energy audit should be portable, durable, and easy to use. Energy audit instruments must be used only for measurements and not for calibrating panel instruments. Typical energy audit instruments include the following:

• Power analyser–3ϕ and 1ϕ (data logger optional) • Combustion analyser / Flue gas analyser • Power quality analyser / Harmonic analyser • Lux meter • Contact thermometers • Infrared non-contact temperature sensor • Manometers • Pitot tube with micro manometer or Digital manometer	• Vane anemometer • Tachometers-Stroboscopic tachometer • Ultrasonic Flow Meter • Anemometer • Psychrometer (Humidity measurements) • Temperature Probe • Ultrasonic steam trap tester • Thermal imaging devices • Miscellaneous instruments–leak detectors, pH meter, and TDS meter

Data Analysis

The field data collected during the audit has to be refined to enable analysis. Some of the steps involved in data analysis are listed as follows:

Computation of various parameters

The parameters not directly metered are computed using the measured data. Some examples include cooling load, which is computed using chilled water flow, chilled inlet and outlet temperatures. Similarly, chiller efficiency is computed using the actual cooling load and compressor motor power.

Tabulation and plotting of data

If the data is tabulated or plotted, operating trends and characteristics are easily interpreted. For example, variation of cooling load, voltage, kW, kVA, PF, % transformer loading with corresponding time (hourly reading over 24 hours) are plotted as a graph.

Comparing performance with design specifications

Performances of equipment or systems are compared with the design data so that gaps or possible improvements are identified. Following are some examples where actual performances are compared with design values:

• *Chiller capacity and COP* • *Boiler capacity and efficiency* • *Chilled water flow* • *Chilled water supply and return temperatures*	• *Cooling tower capacity and performance* • *Pump flow, head, and motor power* • *Fan flow, static pressure, and motor power*

• *Condenser water flow* • *Condenser water supply and return temperatures*	• *Air handling unit (AHU) cooling capacity, supply, and fresh air flow* • *Motor power* • *Ventilation rates*

Identification of Energy Conservation Opportunities

Fuel substitution

This involves identifying appropriate fuel for efficient energy conversion as well as lower cost, scope for introducing solar energy for hot water generation, drying, etc.

Energy generation

This involves identifying efficiency opportunities in energy conversion equipment/utility such as captive power generation, boilers, thermic fluid heaters, furnaces, cogeneration, energy-efficient DG sets, optimal loading of DG sets, and combustion with minimum excess air in boilers/thermic fluid heating, biomass gasifiers etc.

Energy distribution

This involves identifying efficiency opportunities in electrical distribution system such as transformers, cables, and switch gears, plant utility systems such as chilled water, cooling water, hot water, and compressed air.

Energy usage by processes

This consists of optimizing energy at end-use equipment such as steam using equipment, electrical end-use equipment such as fans, pumps, compressors, chillers. These are the areas where the opportunities for improvement are more.

Technical and Economic Feasibility

The technical feasibility addresses the following issues:

- The technology availability, space, skilled manpower, reliability, service.
- The impact of energy efficiency measures on safety, quality, production or process.
- The maintenance requirements and spares availability.

The financial viability often becomes the key for management acceptance of ENCON measures. Cost estimation is usually done by listing the scope of work necessary for each ENCON measures and using unit rates for the different tasks (if available), or by obtaining quotations from suitable contractors. Once the cost and saving for each measure is computed, the financial viability is considered based on agreed financial criteria. The various financial criteria for evaluating energy management projects are simple payback period, return on investment (ROI), net present value (NPV), and internal rate of return (IRR).

Classification of Energy Conservation Measures

Based on the energy audit and analyses, various energy saving projects are identified. These projects may be classified into three categories:

a) Category I: measures involving housekeeping measures which are improvements with practically no cost investment and no disruption to the facility operation.

b) Category II: measures involving changes in operation measures with relatively low cost investment.

c) Category III: measures involving relatively higher capital cost investment to attain efficient use of energy.

Presenting Energy Audit Findings to Management

The limited time for onsite audit may not allow the auditor to carry out a detailed analysis of information collected during the audit. Before leaving the site, the key audit findings as a draft or working report are presented to the senior management as an acknowledgment of energy saving measures identified at site.

Submission of Energy Audit Report

After leaving the site, the data collected during the field study are used to refine the ENCON measures and produce accurate estimates of savings from energy projects. Another presentation to the client as the final appraisal may be required. The fine-tuned energy audit report is presented as soft and hard copy. The report is authorized by the certified energy auditor or accredited energy auditor (for designated consumers).

Structure of Energy Audit Report

The table of contents of a typical energy audit report is as follows:

TABLE OF CONTENTS (Generic Energy Audit Report)

1.5 Major energy use and areas
1.6 Baseline scenario

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 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 Measures & Recommendations

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

*****A detailed template of Energy Audit Report can be found in the form 6 of Energy Audit Regulation' 2018

ANNEXURES

A1. List of energy audit worksheets
A2. List of instruments
A3. List of vendors and other technical details

The common energy audit reporting formats with the useful tables are presented as follows:

Table 3.1 shows summary of baseline energy and resource consumption and Table 3.2 shows energy saving options at a glance and recommendations as part of executive summary.

Table 3.1: Summary of Baseline Energy and Resource Consumption

Baseline Energy Data	*Electricity*	*Natural Gas*	*Diesel, HFO, etc.*	*Water*	*GHG*
Consumption / Year					
Cost / Year					

Table 3.2: Energy Saving Options at a Glance and Recommendations

S. No.	*Description of energy saving measure*	*Annual Energy (Fuel & Electricity) Savings (kWh/MT or KL/MT*	*Annual Savings BDT. Million*	*Capital Investment (BDT. Million)*	*Simple Payback period*
1.					
2.					
3.					
Total					

The table 3.3 shows prioritizing energy saving measures as no investment (quick returns), low investment (short to medium term return) and high investment (long term return) types.

Table 3.3: Types and Priority of Energy Saving Measures

Category	*Type of Energy Saving Options*	*Annual Electricity / Fuel Savings kWh/MT or KL/MT*	*Annual Savings (BDT. Million)*	*Priority*
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***			

3.5 Implementing Energy Efficiency Measures

On completion of energy audit, the management team reviews the report and decides on the course of action. At this point, the facility is ready to prioritise and implement various ENCON measures and tool such as ISO 50001 is highly useful.

Role of ESCO

ESCO is an organisation engaged in a performance based contract with a client firm to implement measures which reduce energy consumption and costs in a technically and financially viable manner. ESCO can be engaged to conduct detailed energy audit from the beginning or can be involved later in implementation of detailed energy audit measures. The ESCO evaluates the detailed energy audit in order to offer a comprehensive efficiency solution that captures all energy efficiency opportunities and not just the obvious ones. This is carried out by preparing a detailed project report (DPR).

3.6 Detailed Project Report (DPR)

Detailed project report (DPR) is prepared for investment decision-making approval and execution of project. The project can be any of the following: setting up new equipment, new process, facility upgrades and even maintenance-driven issues promoting energy conservation and efficiency.

A typical DPR includes the following:

- Examination of technological parameters
- Description of the technology to be used
- Broad technical specification
- Evaluation of existing resources
- Project schedule/execution plan
- General layout
- Volume of work

3.7 Understanding Energy Costs

Energy cost is needed for saving calculations and awareness creation. In many industries sufficient meters may not be available to measure all the energy used. In such cases, invoices for fuels and electricity are used. The annual company balance sheet is another source to get fuel and power cost along with production related information.
Energy invoices can be used for the following purposes:

- They give details of energy used and costs.
- Energy purchased in a given year can be used as a baseline for setting targets.

- Energy data can be related to production or any other variable affecting energy consumption to establish performance indicators
- Invoices over the years can point out energy and cost savings made through energy conservation measures
- They can suggest where energy savings are most likely to be made.

Fuel costs

A wide variety of fuels are available for thermal energy supply namely,

- Fuel oil
- Low Sulphur Heavy Stock(LSHS)
- Light Diesel Oil(LDO)
- Natural gas
- Liquefied Petroleum Gas(LPG)
- Coal
- Lignite
- Wood etc.

Fuel is normally purchased in Tons or Kilolitres. The following factors should be considered during procurement of fuel:

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

The final cost of electricity (power) involves the following factors:

- Maximum demand charges, KVA/kW (i.e. rate at which electricity is used?)
- Energy Charges, kWh (i.e., How much electricity is consumed?)
- Time of Day (TOD) Charges, Peak/Non-peak period (i.e. When electricity is utilized?)
- Power factor Charge, P.F. (i.e., Real power use/Apparent power use)
- High tension (HT) tariff and low tension (LT) tariff rates
- Slab rate cost and its variation
- Applicable incentives and penalties
- Consumer categories such as commercial, residential, industrial, Government, agricultural, etc.
- Tariff rate for developed and under developed area/States

3.8 Benchmarking and Energy Performance

Benchmarking of energy consumption is a powerful tool for performance assessment and improvement. Historical data shows energy consumption and cost year-wise, month-wise and day-wise. Analyzing trends of energy consumption, energy cost and relevant production, specific energy consumption helps to understand the effects of capacity utilizations on energy use efficiency and costs.

External benchmarking relates to inter-unit comparison across similar units. Similarities should be confirmed as otherwise findings can be grossly misleading. Few comparative factors to be considered for external benchmarking are:

- Scale of operation
- Vintage of technology (new or old technology)
- Raw material specifications and quality
- Product specifications and quality
- Benchmarking energy performance allows:
- Quantification of fixed and variable energy consumption trends against production levels
- Comparison of the industry energy performance with respect to various production levels (capacity utilization)
- Identification of best practices (based on the external benchmarking data)
- Scope and margin available for energy consumption and cost reduction
- Basis for monitoring and target setting exercises.
- Examples of benchmarking parameters for various sectors, industries and equipment are listed as follows:

Gross production related:

Cement plant	*kWh/MT clinker or cement produced*
Textile unit	*kWh/kg yarn produced*
Paper plant	*kWh/MT, kCal/kg, paper produced*
Power plant	*Heat rate, kCal/kWh Power produced*
Ammonia (Fertilizer plant)	*Million kilocals/MT Urea*
Foundry	*kWh/MT of liquid metal output*

Equipment / utility related:

Air conditioning plant	*kW/TR (tons of refrigeration)*
Boiler plant	*% thermal efficiency*
Cooling tower	*% cooling tower effectiveness*
Compressor	*kWh/NM^3 of compressed air generated*
Diesel power generation plant	*kWh/litre*

While assessing benchmarks, related process parameters should also be collected for comparison between industries of the same sector namely,

Cement plant	*Type of cement, blaine number (fineness) i.e. Portland and process used (wet/dry) are to be reported along with kWh/MT.*
Textile unit	*Average count, type of yarn i.e. polyester/cotton, are to be reported along with kWh/square meter.*
Paper plant	*Paper type, raw material (recycling extent), GSM quality are reported along with kWh/MT, kCal/Kg*

Power plant / cogeneration plant	*Plant % loading, condenser vacuum, inlet cooling water temperature is mentioned along with heat rate (kCal/kWh).*
Fertilizer plant	*Capacity utilization (%)and on-stream factor are compared along with specific energy consumption.*
Foundry unit	*Melt output, furnace type, composition (mild steel, high carbon steel/cast iron etc.), raw material mix, number or power trips are operating parameters reported along with specific energy consumption data.*
Air conditioning (A/c) plant	*Chilled water temperature level and refrigeration load (TR) are crucial for comparing kW/TR.*
Boiler plant	*Fuel quality, type, steam pressure, temperature and flow are reported along with thermal efficiency. Also, whether thermal efficiency is on gross calorific value basis or net calorific value basis or whether the computation is by direct method or indirect heat loss method is significant in benchmarking exercise.*
Cooling tower effectiveness	*Ambient air wet/dry bulb temperature, relative humidity, air and circulating water flows are reported to make meaningful comparison.*
Compressed air specific power consumption	*Inlet air temperature and pressure of generation*
Diesel power plant performance	*Similar loading %, steady run condition*

3.9 Plant Energy Performance

Plant energy performance is the measure of whether a plant is now using more or less energy to manufacture its products than it did in the past. In short, it tells us how well energy management programme is doing.

It compares the change in energy consumption from one year to another year considering production output. Plant energy performance monitoring compares plant energy use at a reference year with the subsequent years to determine the improvement that has been made. However, plant production is likely to vary from year to year and has effect on energy consumption.

For a meaningful comparison, the energy that would have been required to produce this year production output, if the plant had operated in the same way as it did during the reference year is calculated. This calculated value can then be compared with the actual value to determine the improvement or deterioration that has taken place since the reference year.

Production Factor

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

$$\text{Production Factor} = \frac{\text{Current year production}}{\text{Reference year production}}$$

Reference Year Equivalent Energy Use

Reference Year Equivalent Energy Use or reference year equivalent in short is the reference

year's energy use that would have been used to produce current year production output.
The reference year equivalent is obtained by multiplying the reference year energy use by the production factor (obtained above).

Reference year equivalent = Reference year energy use * Production factor

The plant energy performance is calculated using the following relation:

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

The energy performance is the percentage of energy saved or lost at the current rate of use compared to the reference year rate of use.

The integrated paper plant has produced 119366 MT of paper during the year 2015-16. The management has implemented various energy conservation measures and had reduced the specific energy consumption from 53 GJ/ tonne of product to 50 GJ/tonne of product in the assessment year (2017-18). The corresponding production in assessment year was 124141 MT. Calculate the plant energy performance and states your inference.

Reference year production = 119366 MT
Reference year specific energy consumption = 53 GJ/tonne of product
Assessment year production = 124141 MT
Assessment year specific energy consumption = 50 GJ/tonne of product

$$\boldsymbol{Production\ Factor\ = \frac{Assessment\ year\ production}{Reference\ year\ production}}$$

Production factor = (124141 / 119366) = 1.04

$$\text{Reference year energy consumption, GJ}$$
$$= \text{Reference year specific energy consumption,} \frac{\text{GJ}}{\text{MT}} \text{ x Reference year production, MT}$$

= 53 x 119366 = 6326398 GJ

$$\text{Assessment year energy consumption, GJ}$$
$$= \text{Reference year specific energy consumption,} \frac{\text{GJ}}{\text{MT}} \text{ x Assessment year production, MT}$$

=50 x 124141 = 6207050 GJ

$$\text{Reference year equivalent energy use, GT}$$
$$= \text{Reference year energy consumption, GJ x Production Factor}$$

= 6326398 GJ x 1.04 =6579454 GJ

$$\text{Plant energy performance, \%} = \frac{\text{Reference year equivalent energy} - \text{Assessment year energy}}{\text{Reference year equivalent energy}} \text{ X } 100$$

= ((6579454 - 6207050) / 6579454) x 100

= 5.66%

$$\text{Plant energy performance, \%} = 5.66$$

Inference: plant energy performance is positive and hence the plant is achieving energy savings.

Monthly Energy Performance

Plant energy performance is based on yearly energy information, progressive management asks for monthly information

Once the plant has started measuring yearly energy information, management may ask for monthly information and use it as a tool to control energy use on an on-going basis.

3.10 Matching Energy Usage to Requirement

If the capacity of the equipment is much larger than use requirements, the equipment operates at part-load leading to inefficiency and wastage. This type of situations normally happens at design stage. Energy manager has to looks for ways to match energy equipment capacity to end-use needs. Some examples are:

Pump capacity (flow) more than required and throttled: Energy manager can eliminate throttling of a pump by impeller trimming, installing variable frequency drive, replacing existing pump with a smaller pump.

Similarly for a centrifugal fan operated with a damper for flow control can be operated with impeller trimming, installing variable frequency drive, pulley modification (Fan-motor pulley driven system), replacing existing fan with a smaller fan.

For a chiller with excess capacity, chilled water temperature can be controlled to meet process chilling need.
Energy (steam) loss in a pressure control valve (PRV) can be recovered with a back pressure turbine (micro turbine) adoption.

Task lighting can be adopted in place of area lighting to avoid lighting over an entire area.

3.11 Maximising System Efficiency

Once the energy source and usage is matched, next step is to operate the equipment efficiently using best operation and maintenance practices. Some examples are:

- Eliminate steam leakages by steam trap maintenance
- Maximise condensate recovery

- Adopt combustion controls for maximizing combustion efficiency in boilers/furnaces
- Reduce air leaks in compressed air system
- Periodically clean and maintain air filters in air cooling system

3.12 Instruments and Metering for Energy Audit

The quantification of energy use in an energy audit requires the use of various instruments for monitoring and measurements. These instruments must be portable, durable, easy to operate and relatively inexpensive. 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. The key instruments for energy audit are listed in the following Table:

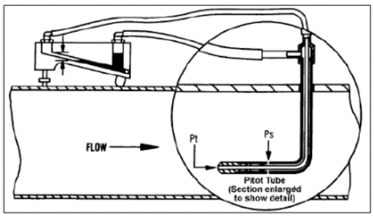
Table 3.4: Key Instruments for Energy Audit

No.	Name of the Instrument	Features and Typical Applications
1.	*Power & Harmonic Analyser* 	*Measures all Electrical and Harmonic Parameters namely, V, A, PF, KW, kVA, kVAr, Hz, and first 50 Harmonics.* *These instruments can be 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 printouts at specified intervals say every 1/2 hr over a shift or a day.*
2.	*Tachometer (Contact-type)* 	*A tachometer is an instrument used to measure the rotational speed of a shaft or wheel in revolutions per minute (rpm). By measuring speed, energy auditor is able to find out belt slip if any and loading.* *A contact type tachometer can be used where direct access is possible.*
3.	*Non-Contact Tachometer / Stroboscope* 	*Non-contact tachometer allows the users to measure the rotational speed without contacting the object.* *Non-contact instruments are sophisticated and safer. These instruments can measure speed for objects that are visible but not accessible.* *A stroboscopic tachometer employs a variable-frequency, flashing light which makes the rotating component appear to stand still when the frequencies match.*
4.	*Lux meter*	*A lux meter is a device for measuring illumination or lighting levels. The lux is a unit of measurement of illuminance (brightness).*

		*A lux meter works by using a photo cell to capture light. The light is then converted to an electric current and corresponding lux value.*
5.	*Thermometer*  	*These thermocouples measures temperatures of flue gas, hot air, hot water by insertion of appropriate probe into the stream. Different types include Fluid Filled, Resistance, Thermocouple and Thermistor.* *Most HVAC applications require a thermometer with temperature of -50^0C to 175^0C.Boiler and oven stacks require thermometers able to measure up to about 500^0C.* *By knowing the process temperature, the auditor can determine process equipment efficiency. It also helps us to waste heat recovery potential.* *For surface temperature, a leaf type probe is used with the same instrument.*
6.	*Combustion / Flue Gas Analysers* 	*Combustion analyser measures the composition of flue gases in percentage (% O_2 (or) % CO_2), and flue gas temperature.* *The instrument estimates the combustion efficiency of furnaces, boilers and other fossil fuel-fired devices with an inbuilt programme.* *Two types are available: digital analyzers and manual combustion analysis kits. Digital combustion analysis equipment performs the measurements and reads out combustion efficiency in percentage.* *The manual combustion analysis kits typically require multiple measurements including exhaust stack: temperature, oxygen content, and carbon dioxide content. The efficiency of the combustion process can be calculated after determining these parameters. The manual process is tedious and is frequently subject to human error.*
6.	*Thermometer*	*These thermocouples measures temperatures of flue gas, hot air, hot water by insertion of appropriate probe into the stream. Different types include Fluid Filled, Resistance, Thermocouple and Thermistor.* *Most HVAC applications require a thermometer with temperature of -50^0C to 175^0C.Boiler and oven stacks require thermometers able to measure up to about 500^0C.*

	 	*By knowing the process temperature, the auditor can determine process equipment efficiency. It also helps us to waste heat recovery potential.* *For surface temperature, a leaf type probe is used with the same instrument.*
7.	*Fyrite Gas Analyzer* 	*This instrument is used for measuring and analyzing carbon dioxide or oxygen. The instrument contains absorbing fluid which is selective in the chemical absorption of carbon dioxide or oxygen, respectively. Fyrite readings are unaffected by the presence of most background gases in the sample.* *Fyrite accuracy is sufficient for most industrial applications and test procedure is simple.*
8.	*Infrared Thermometer (Non-contact type)* 	*The instrument is basically non-contact type which is able to measure temperature from a distance. Non-contact infrared thermometers, also known as heat guns, are very useful for measuring surface temperatures of steam lines, boiler surfaces, processes temperatures, etc.* *An infrared thermometer infers temperature from a portion of the thermal radiation sometimes called blackbody radiation emitted by the object being measured (as radiation is characteristic of their temperature). By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can be determined.* *The heart of the infrared thermometer is the detecting surface, which absorbs infrared energy and converts it to an electrical voltage or current.* *These instruments typically cover a range from 30^0C to 2000^0C.*
9.	*Thermal Imaging Devices*	*Thermal cameras are instruments that create pictures of heat rather than light. They measure infrared (IR) energy and convert the data to corresponding images of temperatures.*

		*Non-contact infrared imagers provide fast, safe, accurate measurements for objects that are:* ▪ *Moving or very hot* ▪ *Difficult to reach* ▪ *Impossible to shut-off* ▪ *Dangerous to contact* ▪ *Where contact would damage, contaminate or change temperature.*
10.	*Ultrasonic Flow Meter* 	*Water and other fluid flows in pipelines can be easily measured using ultrasonic sensors mounted on the pipelines. This instrument is used to estimate the flow rates entering or leaving a pump. The meters are used to determine the fluid flow in terms of velocity and flow rate (given the diameter of pipe).* *This non-contact flow measuring device uses Doppler effect / Ultra sonic principle. A transmitter and a receiver are positioned on opposite sides of the pipe. Modes of operation and measurement are either by Doppler effect (or) Transit Time.*
11.	*Thermo-anemometer* 	*This instrument is used for measuring air velocity in ventilation, air-conditioning and refrigeration systems etc.*
12.	*Thermo-hygrometer* 	*This instrument measures humidity and temperature for determination of dew point and calculation of heat being carried away by outgoing gases where product drying requires hot air.*
13.	*Pitot Tube and manometer (Inclined /Digital manometer)*	*Air velocity in ducts can be measured using a pitot tube and an inclined manometer for further calculation of flows.* *The principle is based on measuring the differential (velocity) pressure at various points (traverse points) across the cross-section of the duct.*

	 	*In addition to velocity pressure, this instrument can also determine Static and Total pressures.*
14.	*Ultrasonic Steam Trap Tester* 	*These instruments operate as electronic stethoscopes. They are able to pick up the very high-pitched sound indicative of freely blowing steam (condensate draining makes a lower-pitched sound).* *The advantage of ultrasonic testers is that they can listen to one pipe and detect if any of the nearby steam traps have failed.* *Ultrasonic detecting devices can also be used to identify any type of gas or fluid leaks e.g. compressed air leaks.*
15.	*Leak Detectors*  	*Compressed air is one of the most costly utilities in a facility today. A simple program of leak inspection and repair helps greatly to reduce energy costs.* *Ultrasonic Leak Detector has an high quality flexible sensor is mounted on the end of a flexible steel pipe so the ultrasonic sound sensor can access hard to reach areas. The unit converts the ultrasonic noise of a leak into a sound a human can hear such as some beeping sound or LED display.* *Features of this instrument are* • *Detects the location of leaks* • *Detects almost any leak because* – *Short distance/access not needed* – *High pressure not needed* – *Sensitive to sound* – *Filters background noises* *This instrument does <u>not</u> measure the size of the leak.*
16.	*Conductivity Meter*	*This instrument is used for spot analysis of the amount of total dissolved solids (TDS) in water especially in case of boiler blow down. An accurate measurement of TDS is*

		*required to maintain blow down rate in boilers and optimize energy consumption.* *TDS meter measures the conductivity of the solution then converts that value to an equivalent TDS reading.*
17.	*pH meter* 	*pH meter is used for spot analysis of acidity or alkalinity of a solution/water..* *The meter uses the property of certain types of electrodes to exhibit electrical potential when immersed in a solution.*
18.	*Thermal Insulation scanner*	*This instrument measures loss of energy in kCal per unit area from hot/cold insulated surfaces. The total heat loss can be obtained by multiplying the value with total surface area.*

Chapter 4: Material and Energy Balance

4.1 Introduction

A material balance in its most broad definition is the application of the law of conservation of mass, which states matter is neither created nor destroyed. Matter may flow through a control volume and may be reacted to form another species, however, no matter is ever lost or gained. The same is true for energy. As with material balances, we can apply the law that energy is neither created nor destroyed, it is simply converted into another form of energy. The law of conservation of mass and energy leads to what is called a mass (material) and energy balance.

Material balances, as they pass through processing operations, can describe material quantities. If there is no accumulation, what goes into a process must come out. This is true for batch operation. It is equally true for continuous operation over any chosen time interval. Material balances are fundamental to the control of processing, particularly in the control of yields of the products. Material balance can be determined from conceptual stage to final production stage. Initially, material balance is estimated during the planning stage of a new process or equipment. This estimate is improved while material balance is verified during commissioning stage and carrying out pilot scale tests related to the new process. This finally used as a control measure during actual production stage.

Purpose of Material and Energy Balance

- ✓ To assess the input, conversion efficiency, output and Losses
- ✓ To quantify all material, energy and waste streams in a process or a system
- ✓ Powerful tool for establishing basis for 1mprovement and potential savings

Energy balances are means for industry to examine ways of reducing energy consumption in processing because of increasing energy cost. Energy balances are used in the examination of the various stages of a process, over the whole process and even extending over the total production system from the raw material to the finished product.

4.2 Components of Material and Energy Balance

Typical components of material and energy balance for a process or unit operation is shown in Figure 4.1. It may be noted that recycle stream is shown along with input side.

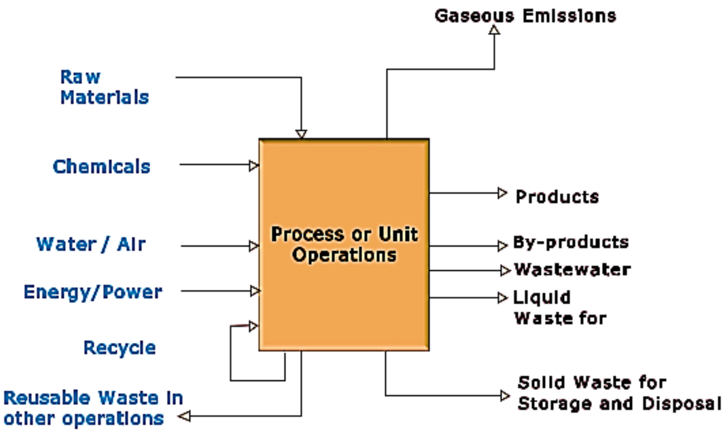


Figure 4.1: Components of Material and Energy Balance of a Process or Unit Operation

4.3 Basic Principles of Material and Energy Balance

If the unit operation, whatever its nature is seen as a Whole it may be represented diagrammatically as a box, as shown in Figure. 4 .2. The mass and energy going into the box must balance with the mass and energy coming out.

The law of conservation of mass leads to what is called a mass or a material balance.

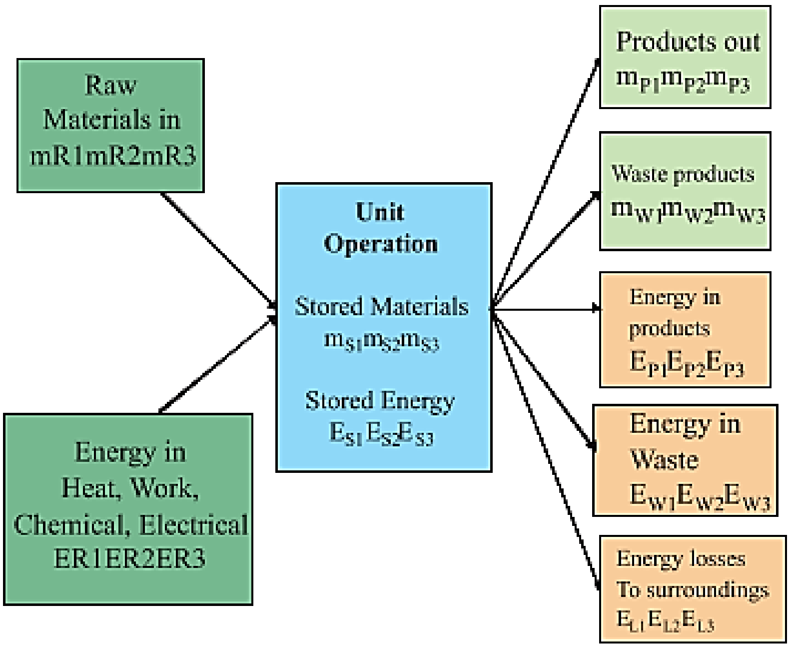


Figure 4.2: Mass and Energy Balance

Mass In = Mass Out + Mass Stored

Raw Materials = Products + Wastes + Stored Materials.

$$\sum m_R = \sum m_P + \sum m_W + \sum m_S$$

(Where, ∑ (sigma) denotes the sum of all terms).

$$\sum m_R = \sum m_{R1} + \sum m_{R2} + \sum m_{R3} = Total\ Raw\ Materials$$
$$\sum m_P = \sum m_{P1} + \sum m_{P2} + \sum m_{P3} = Total\ Products$$
$$\sum m_S = \sum m_{S1} + \sum m_{S2} + \sum m_{S3} = Total\ Stored\ Products$$

If there are no chemical changes occurring in the plant, the law of conservation of mass will apply also to each component, so that for component A:

mA in entering materials = mA in the exit materials + mA stored in plant.

For example, in a plant that is producing sugar, if the total quantity of sugar (mA) going into the plant is not equalled by the total of the purified sugar (mAp) and the sugar in the waste liquors (mAw) and accumulated in the process (mAs), then there is something wrong. Sugar is either being burned (chemically changed) or else it is going unnoticed down the drain somewhere. In this case:

$mA=(mA_P+mA_W+mA_S+mA_U)$

Where, m_{AU} is the unknown loss and needs to be identified. So the material balance is now:

Raw Materials = Products + Waste Products + Stored Products + Losses

Where, Losses are the unidentified materials.

Just as mass is conserved, energy is conserved in process operations. The energy coming into a unit operation can be balanced with the energy coming out and the energy stored.

Energy In = Energy Out + Energy Stored

$$\sum \boldsymbol{E_R} = \sum \boldsymbol{E_P} + \sum \boldsymbol{E_W} + \sum \boldsymbol{E_L} + \sum \boldsymbol{E_S}$$

Where,

$\Sigma E_R = E_{R1} + E_{R2} + E_{R3} +.$ = Total Energy entering with raw materials

$\Sigma Ep = E_{P1} + E_{P2} + E_{P3} +.$ = Total Energy leaving with products

$\Sigma E_W = E_{W1} + E_{W2} + E_{W3} +.$ = Total Energy leaving with waste materials

$\Sigma E_L = E_{L1} + E_{L2} + E_{L3} +.$ = Total Energy lost to surroundings

$\Sigma E_S = E_{S1} + E_{S2} + E_{S3} +.$ = Total Energy stored

Energy balances are often complicated because forms of energy can be inter-converted, for example Mechanical energy to heat energy, but overall the quantities must balance.

4.4 Classification of Processes

Process can be viewed overall or as a series of units. Each unit is a unit operation that can be represented by a box as shown in Figure 4.3. Raw materials and energy go into the box and desired products, by- products, wastes and energy come out of the box. The mass in and out of a control box must be equal. The equipment within the box will make the required changes with little waste and energy as possible. =There are different types of process.

A) Based on how the process varies with time

Steady-state process is one where none of the process variables change with time

Unsteady-state process is one where the process variables change with time

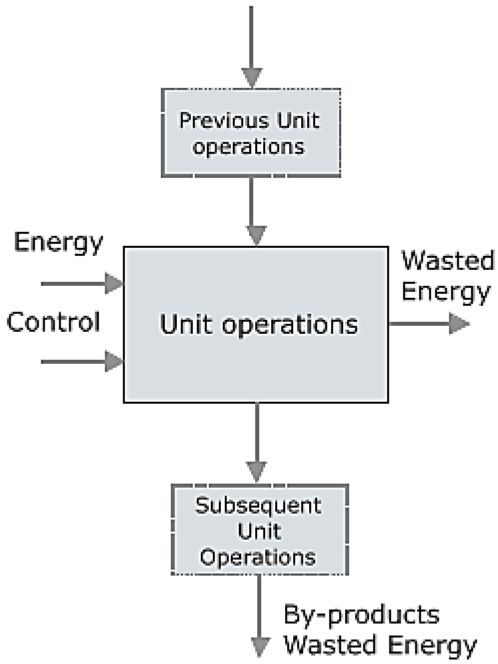


Figure 4.3 Representation of Process

B) Based on how the process was built to operate

A continuous process is one that has the feed streams and product streams moving into and out of the process all the time. Examples are oil refinery, distillation process etc.

A batch process is one where the feed streams are fed to the process to get it started. The feed material is then processed through various process steps and finished products are taken out at specific times. Steps:

- Feed is charged into vessel
- Process is started
- No mass is added or removed from vessel (process parameters are usually monitored and controlled)
- At some conditions or after fixed time, products are removed.

4.5 Material Balance

Levels of Material Balance

The material balances can be developed at various levels:

Overall Material balance: This involves input and output steams for complete plant

Section wise Material balances: This involves M&E balances to be made for each section/department/ cost centre. This would help to prioritise focus areas for efficiency improvement.
Equipment-wise Material balances: Material balances for key equipment would help assess performance of equipment, which would in turn help identify energy and material losses.

The choice among the types of material balance depends on the reasons for making the balance. The major factor is the cost of the materials and so costly materials are more likely considered than cheaper ones and products more than waste materials

Material Balance Procedure

First step is to identify materials in, materials out and material stored. Next step is to consider whether materials in each category have to be treated as whole (gross material balance) or whether individual constituents in the material should be treated separately. For example, we can do material balance for dry solids alone as opposed to total material. This means separating the material into two constituents, non-water and water.

Typical steps are as follows:

a) **Define basis & units**: Choose a basis of calculations on quantity (mass for batch process) or flow rate (mass per hour for continuous process) of one of the process streams. Convenient Units are then chosen as mass can be expressed in various ways: weight/weight (w/w), weight/volume (w/v), molar concentration (M), mole fraction.

- ✓ The weight/weight concentration is the weight of the solute divided by the total weight of the solution and is the fractional form of the percentage composition by weight.
- ✓ The weight volume concentration is the weight of solute in the total volume of the solution. With gases, concentrations are primarily measured in weight concentrations per unit volume, or as partial pressures.
- ✓ The molar concentration is the number of molecular weights of the solute expressed in kg in 1 m^3 of the solution.
- ✓ The mole fraction is the ratio of the number of moles of the solute to the total number of moles of all species present in the solution.

b**) Draw a flowchart:** Establish a boundary so that the flow streams in and out can be identified. The identification and drawing up a unit operation/process is prerequisite for energy and material balance. Flow charts are schematic representation of the production process, involving various input resources, conversion steps and output and recycle streams. The process flow may be constructed stepwise i.e. by identifying the inputs / output / wastes at each stage of the process, as shown in the Figure 4.4.

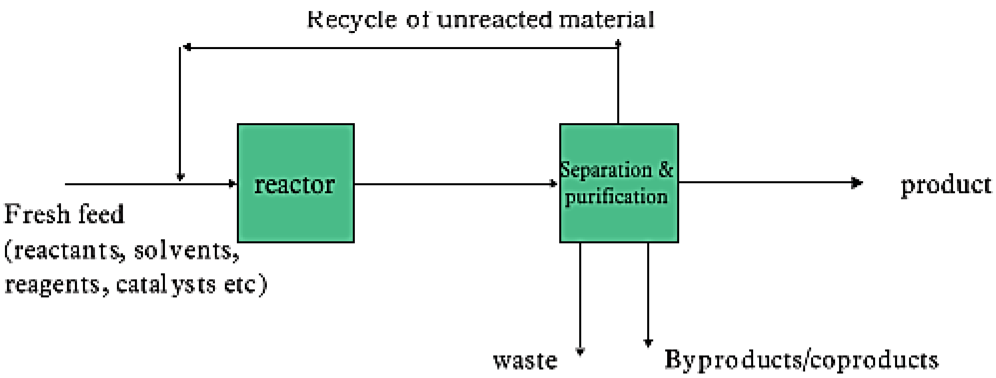


Figure 4.4: Typical Arrangement of a Process Flowchart

- ✓ Inputs of the process could include raw materials, water, steam, energy (electricity, etc);
- ✓ Process Steps should be sequentially drawn from raw material to finished product. Intermediates and any other by-product should also be represented. The operating process parameters such as temperature, pressure, % concentration, etc. should be represented.
- ✓ The flow rate of various streams should also be represented in appropriate units like m^3/h or kg/h. In case of batch process the total cycle time should be included.
- ✓ Wastes / by products could include solids, water, chemicals, energy etc. For each process steps (unit operation) as well as for an entire plant, energy and mass balance diagram should be drawn.
- ✓ Output of the process is the final product produced in the plan

c) **Write Material Balance Equations:** The following examples are illustration for writing the material balance equations

Example 4.1

A solution which contains 10% solids is mixed with 25% solid solution. A single output which is 20% solid is removed. If the 10% solution enters at 5.0 kg/s, what are the other rates? (Assume no accumulation)

Solution

Basis:
Solution A (INPUT) = 5 kg/s
Solution B (INPUT) = x kg/s
Solution C (OUTPUT) = y kg/s
Therefore A + B = C
5 + X = Y.................. EQ-1

Since solution A contains 10% solids, solution B contains 25% solids and solution C contains 20% solids the equation can be written as

Solids 0.1 *5 +0.25 * X = 0.2 * Y.................. EQ -2
Liquids 0.9 *5 +0.75*X = 0.8 * Y.................... EQ -3

Substituting value of Y from EQ -1 in EQ-2

0.5 + 0.25 X = 0.2 * (5 + X)
0.05 X = 0.5
X = 10 kg/s,
Substituting X in EQ-l, Y= 15 kg/s

Example 4.2

A solution which is 80% oil, 15% usable by-products and 5% impurities, enters a refinery. One output is 92% oil and 6% usable by-products. The other output is 60% oil and flows at the rate of 1000 lit/hr assume no accumulation, percent by volume)

- What is the flow rate of input?
- What is the percent composition of the 1000 lit/hr output?
- What percent of the original impurities are in the 1000 lit/hr output?

Solution
Basis:
Input Stream A = X lit/hr
Output Stream B = Y lit/hr
Output Stream C = 1000 lit/hr

Material balance equations

1) Total: X = Y + 1000 ....EQ-l
2) Oil: 0.8 * X = 0.92 * Y + 0.6 * 1000 ....EQ-2
3) UBP: 0.15 *X=0.06*Y+v*1000.................EQ-3
4) IMP: 0.05 * X = 0.02 * Y + w *1000..................EQ-4
5) OUTPUT impurities & UBP: V + W = 0.4 ....EQ-5

Solving Equations 1 and 2; substituting value of X in EQ-2

0.8 (Y +1000) = 0.92 * Y + 600
0.8 Y + 800 =0.92 Y + 600, Y = 1666 lit/hr

Substituting Y in EQ-l
X = 1666 + 1000 = 2666 lit/hr = Flow rate of input stream
Substituting value of X and Y in EQ-3, v = 30%
Substituting value of v in EQ-S, w = 10%

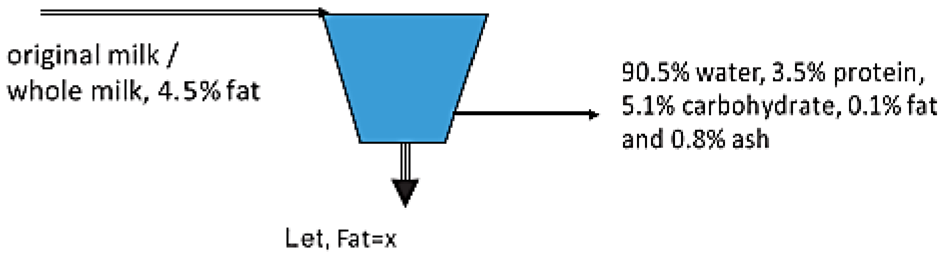
Thus composition of 1000 lit/hr output stream is 60% oil, 30% usable by products and 10% impurities
Impurities in input stream = 0.05 * 2666 = 133.3 lit/hr
Impurities in 1000 lit/hr stream (10%) =100 lit/hr

Therefore impurities in 1000 lit/hr stream as % input stream = 100/133.3 = 75%

Example 4.3 Constituent balance

Skim milk is prepared by the removal of some of the fat from whole milk. This skim milk is found to contain 90.5% water, 3.5% protein, 5.1% carbohydrate, 0.1% fat and 0.8% ash. If the original milk contained 4.5% fat, calculate its composition assuming that fat only was removed to make the skim milk and that there are no losses in processing.

Solution:



Basis: 100 kg of skim milk.
This contains, therefore, 0.1 kg of fat. Let the fat which was removed from it to make skim milk
be X kg.

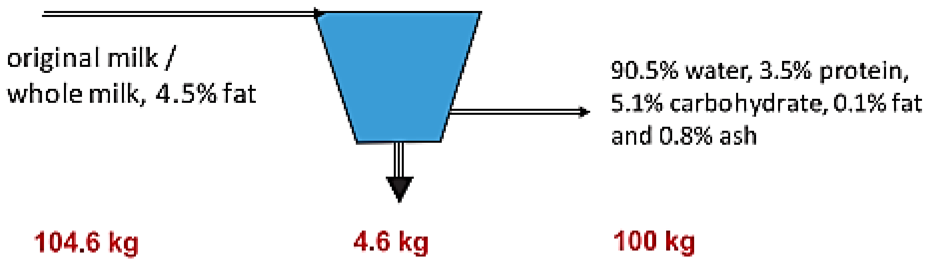
Total original fat = (x + 0.1) kg
Total original mass = (100 + x) kg

and as it is known that the original fat content was 4.5% so

$$\frac{(x + 0.1)}{(100+X)} = 0.045$$

$$x + 0.1 = 0.045(100 + x)$$
$$x = 4.6 \text{ kg}$$

So the composition of the whole milk is then fat = 4.5%, water = 90.5/104.6 = 86.5 %, protein = 3.5/104.6 = 3.3 %, carbohydrate: 5.1/104.6 = 4.9% and ash = 0.8%



Example 4.4 Continuous Process balance

In a continuous centrifuging of milk, if 35,000 kg of whole milk containing 4% fat is to be separated in a 6 hour period into skim milk with 0.45% fat and cream with 45 % fat, what is the flow rate of the two output streams from the continuous centrifuge which accomplishes the separation?

In continuous processes, time also enters into consideration and the balances are related to unit time. Thus in considering a continuous centrifuge separating whole milk into skim milk and cream, if the material holdup in the centrifuge is constant both in mass and in composition, then the quantities of the components entering and leaving in the different streams in unit time are constant and a mass balance can be written on this basis. Such an analysis assumes that the process is in a steady state, that is flows and quantities held up in vessels do not change with time.

Solution
Basis:
Total mass input per hour = 35000/6 =5 833 kg
Total mass output for skim milk = Y
Total mass output for cream = z

Material Balance Equations:

1) Mass In = Mass Out: 5833 = Y + Z (i.e. Z = 5833-Y) EQ-l
2) Fat In = Fat Out: 0.04 * 5833 = 0.0045 * Y+ 0.45 * Z EQ-2

Substituting Z from EQ-l to EQ-2

0.04 * 5833 = 0.0045 Y + 0.45 * (5833 - Y)
Y = 5369 kg/hr
Substituting Y in EQ -1
Z = 464 kg/hr

Example 4.5 Concentrations

A solution of common salt in water is prepared by adding 20 kg of salt to 100 kg of water, to make a liquid of density 1323 kg/m3. Calculate the concentration of salt in this solution as a (a) weight fraction, (b) weight/volume fraction, (c) mole fraction, (d) molal concentration.

Solution
(a) Weight fraction: 20/ (100 + 20) = 0.167
% weight / weight = 16.7%

(b) Weight/volume:

A density of 1323 kg/m3 means that 1 m3 of solution weighs 1323 kg, but 1323 kg of salt solution contains (20 kg of salt x 1323 kg/m3) / (100 + 20) kg = 220.5 kg salt / m3
1 m3 solution contains 220.5 kg salt.
Weight/volume fraction = 220.5 / 1000 = 0.2205
And so weight / volume = 22.1%

c) Moles of water = 100/ 18 = 5.56

Moles of salt = 20/ 58.5 = 0.34
Mole fraction of salt = 0.34 / (5.56 + 0.34) = 0.058

d) The molar concentration (M) is 220.5/58.5 = 3.77 moles in m^3

Note that the mole fraction can be approximated by the (moles of salt/moles of water) as the number of moles of water is dominant, that is the mole fraction is close to 0.34 / 5.56 = 0.061. As the solution becomes more dilute, this approximation improves and generally for dilute solutions the mole fraction of solute is a close approximation to the moles of solute / moles of solvent.

Example 4.6

In a textile mill, an evaporator concentrates a liquor containing solids of6% by w/w (weight by weight) to produce an output containing 30% solids w/w. Calculate the evaporation of water per 100 kg of feed to evaporator?

Solution

Inlet solid contents	= 6%
Outlet solid contents	= 30%
Feed	=100 kg
Solid content in kg in feed	= 100 * 0.06 = 6 kg
Since mass in	= mass out, the outlet solid content should be 6 kg
Output	= (100/30)*6 = 20 kg
Quantity of water evaporated	= [100 - 20] = 80 kg

Example 4.7 Air Composition

If air consists of 77% by weight of nitrogen and 23% by weight of oxygen calculate:
(a) The mean molecular weight of air,
(b) The mole fraction of oxygen,
(c) The concentration of oxygen in mole/m3 and kg/m3 if the total pressure is 1.5 atmospheres and the temperature is 25^0C

Solution

(a) Taking the basis of 100 kg of air: it contains 77/28 moles of N_2 and 23/32 moles of O_2

Total number of moles	= 2.75 + 0.72 = 3.47 moles.
So mean molecular weight of air	= 100 / 3.47 = 28.8
Mean molecular weight of air	= 28.8

b) The mole fraction of oxygen = 0.72 / (2.75 + 0.72) = 0.72 / 3.47 = 0.21
Mole fraction of oxygen = 0.21

(c) In the gas equation, where n is the number of moles present: the value of R is 0.08206 m3 atm/ mole K and at a temperature of 25^0 C = 25 + 273 = 298 K, and where V= l m^3
pV = nRT
and so, 1.5 x 1 = n x 0.08206 x 298
n = 0.061 mole/m^3
weight of air = n x mean molecular weight
= 0.061x 28.8 =1.76 kg / m^3
and of this 23% is oxygen, so weight of oxygen = 0.23 x 1.76 = 0.4 kg in 1 m3
Concentration of oxygen = 0.4 kg/m^3
or 0.4 / 32 = 0.013 mole / m^3

When a gas is dissolved in a liquid, the mole fraction of the gas in the liquid can be determined by first calculating the number of moles of gas using the gas laws, treating the volume as the volume of the liquid, and then calculating the number of moles of liquid directly.

Example 4.8 Gas composition

In the carbonation of a soft drink, the total quantity of carbon dioxide required is the equivalent of 3 volumes of gas to one volume of water at 0 °C and atmospheric pressure. Calculate (a) the mass fraction and (b) the mole fraction of the CO_2 in the drink, ignoring all the components other than CO_2 and water.

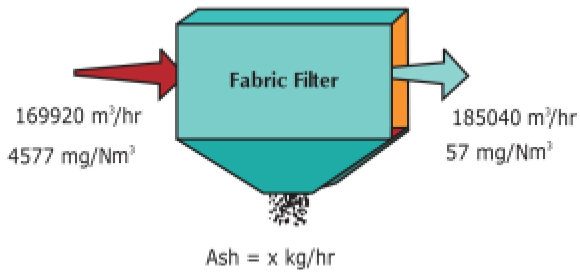
Solution
Basis 1 m^3 of water = 1000 kg
Volume of carbon dioxide added = 3 m^3
From the gas equation, pV = nRT
1x 3 = n x 0.08206 X 273
n = 0.134 mole.
Molecular weight of carbon dioxide = 44
And so weight of carbon dioxide added = 0.134 x 44 = 5.9 kg
(a) Mass fraction of carbon dioxide in drink = 5.9 / (1000 + 5.9) = 5 .9 x 10^{-3}
(b) Mole fraction of carbon dioxide in drink = 0.134 / (1000/18 + 0.134) = 2.41 x 10^{-3}

Example 4.9 Dust balance

A bag filter is used to remove the dust from the inlet gas stream to meet the emission standards in cement, fertilizer and other chemical industries.

Inlet gas to a bag filter is 1, 69,920 m^3/hr and the dust loading is 4577 mg/m^3. Outlet gas from the bag filter is 1, 85,040 m^3/hr and the dust loading is 57 mg/m^3. What is the maximum quantity of ash that will have to be removed per hour from the bag filter hopper based on test results?

Solution
Dust balance, Mass $_{(in)}$ = Mass $_{(out)}$
Inlet gas dust = Outlet gas dust + Hopper Ash



1. Calculation in/ out dust quantity
Inlet dust qty =169920 (m^3/hr) x 4577 (mg/m^3) x 1/1000000 (kg/mg) = 777.7 kg/hr
Outlet dust qty = 185040 (m^3/hr) x 57 (mg/m^3) x 1/1000000 (kg/mg) = 10.6 kg/hr

2. Calculate ash qty (to be removed from the hopper)

Hopper ash = Inlet dust qty—Outlet dust qty = 777.7 kg/hr—10.6 kg/hr = 767.1 kg/hr

4.6 Energy Balance

Energy is the capacity to do work or to transfer heat. The law of conservation of energy states that energy can neither be created nor destroyed. The total energy in the materials entering the processing plant, plus the energy added in the plant must equal the total energy leaving the plant. This is a more complex concept than the conservation of mass, as energy can take various forms such as kinetic energy. Potential energy, heat energy, chemical energy, electrical energy and so on. During processing, some of these forms of energy can be converted from one to another; say for instance mechanical energy in a fluid can be converted through friction into heat energy. It is the sum total of all these forms of energy that is conserved.
For example, in the pasteurizing process for milk, the milk is pumped through a heat exchanger and is first heated and then cooled. The energy affecting the product is the heat energy in the milk. Heat energy is added to the milk by the pump and by the hot water passing through the heat exchanger. Cooling water then removes part of the heat energy and some of the heat energy is also lost to the surroundings. The heat energy leaving in the milk must equal the heat energy in the milk entering the pasteurizer plus or minus any heat added or taken away in the plant.

Heat energy leaving in milk = initial heat energy + heat energy added by pump + heat energy added in heating section - heat energy taken out in cooling section - heat energy lost to surroundings.

The law of conservation of energy can also apply to part of a process. For example, considering only the heating section of the heat exchanger in the pasteurizer, the heat lost by the hot water must be equal to the sum of the heat gained by the milk and the heat lost from the heat exchanger to its surroundings.

Conservation of Energy

In a system, if the storage does not change, the ingoing and outgoing energy must be equal (Figure 4.5 a). If the storage changes, this must be reflected in the energy balance and the energy input to a system might not balance the energy that goes out. For instance as in Figure 4 .5 b, the input is 75 units of energy but only 60 units go out. Since the first law requires that the energy be conserved, system had to gain 15 units of energy. In the Figure 4.5 c, the input is short by 15 units of energy so it can be inferred that the system must have lost 15 units.

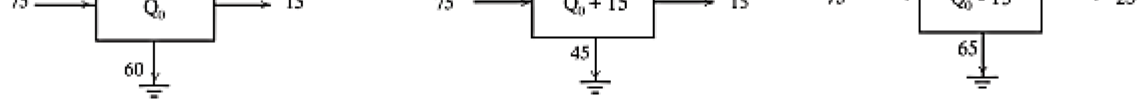


Figure 4.5: a) No Storage ***b) Storage Increased*** ***c) Storage Decreased***

The sinks are depositories of leakage or rejected energy. It is usually low-grade heat, as in, radiation losses from boilers or heat carried away by cooling water. The outputs represent useful work.

The Figure 4.6 below illustrates power cycle schematic. In this input heat energy (Q_{in}) resulting from combustion of fuel is transferred to water in a steam generator (boiler). The fluid feed water is pumped using input energy Win. The steam is used to drive the turbine and perform useful work WM,- and the steam is condensed in condenser giving its heat energy Q_{out} The working fluid is feed water which changes its state from water to steam and back to condensate.

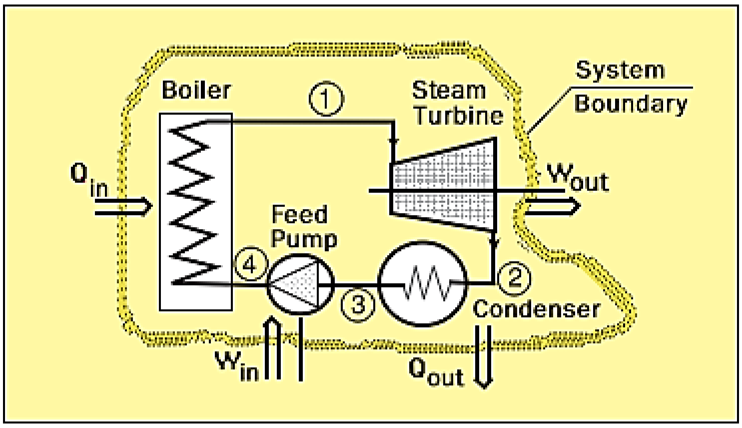


Figure 4.6: Energy Balance in Power Plant Cycle

Applying the law of conservation of energy, if a system undergoes a process by heat and work transfer, then the net heat supplied, Q plus the net work input, W. is equal to the change of intrinsic (internal) energy, DU of the working fluid, i.e.

$$\sum Q + \sum w = \Delta U$$

Applying this general principle to a thermodynamic cycle, when the system undergoes a complete cycle. i.e. change in internal energy, $\Delta U = 0$.
$\sum Q + \sum w = 0$

Where,
$\sum Q$ = The algebraic sum ofthe heat supplied to (+) or rejected from (-) the system.
$\sum W$ = The algebraic sum of the work done by surroundings on the system (+) or by the system on surroundings (-).

Applying the rule to the power plant gives:

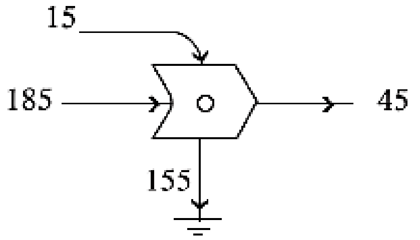
$$\sum Q = Q_{in} - Q_{out}$$
$$\sum W = W_{in} - W_{out}$$

$$Q_{in} + W_{in} - Q_{out} - Wout = 0$$

$Q_{in} = Heat\ supplied\ to\ the\ system\ through\ boiler$
$W_{in} = Feed - pump\ work$
$Q_{Out} = Heat\ rejected\ from\ the\ system\ by\ condenser$
$W_{out} = Turbine\ work$

Efficiency

The (thermodynamic) efficiency of a process is the ratio of useful output to input and is always less than 100%. In the energy balance shown in Figure 4.7, there is no internal storage, so the sum of the inputs must equal the outgoing energy. The efficiency of the process is 22.5% and the energy 1^{st} in the system is 100 - 22.5 = 77.5%.



Input = 15 + 185

Output + Sink= 45 + 155

Eff = Output / Input

= 45/(15+185) = 45/200 = .225

Figure 4.7: Efficiency and Losses

How can energy be lost in a system?

Energy can manifest itself in many forms such as heat, kinetic energy, chemical energy, potential energy but because of inter-conversions, it is not always easy to isolate separate constituents of energy balances. Energy is "lost" really means it changes into a form that is not counted. Most often the "uncounted' energy is work done against friction. This work changes other forms of energy into heat and wear. No energy is lost in the end, only the forms have changed.

This loss of usable energy is due to many causes

- ✓ In mechanical systems it is friction
- ✓ In electrical systems it is resistance
- ✓ In fluid systems it is turbulence, viscosity or mixing

Practically, approach to energy balance takes into account only "heat balances' ignoring internal energies. When we are unfamiliar with the relative magnitudes of the various forms of energy (oil, gas, coal, steam, chilled water or electricity) entering and exiting a particular processing situation, it is best to put them all down and convert them to equivalent "Heat Energy".

Heat Balances

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

Enthalpy (H) is always referred to some reference level or datum, so that the quantities are relative to this datum. Working out energy balances is then just a matter of considering the various quantities of materials involved, their specific heats, and their changes in temperature or state i.e. latent heat.

4.7 Facility as an Energy System

In a production facility, the energy in form of coal, oil, gas and electricity enters the facility and is converted to more convenient forms of energy such as steam, compressed air, chilled water etc. The outgoing energy is usually in the form of heat and motion.

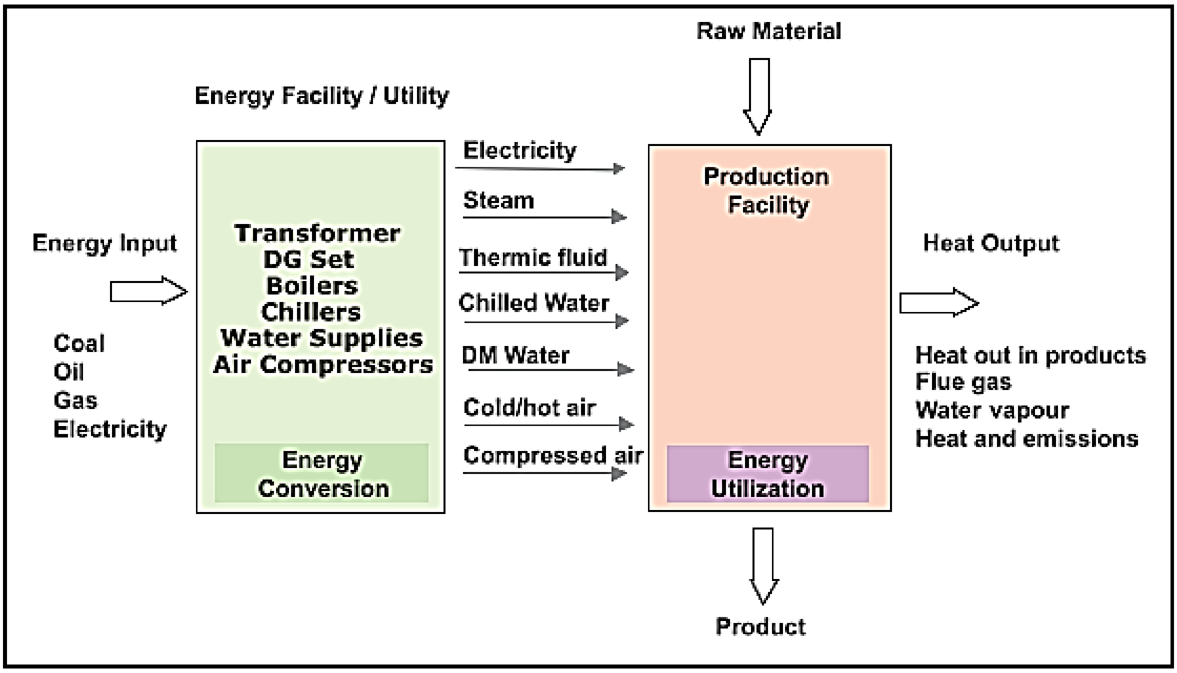


Figure 4.8: Plant Energy Systems

The energy usage in the overall plant can be split up into various forms such as (Figure 4.8):

- ✓ Electrical energy, which is usually purchased as HT and converted into LT supply for end use.
- ✓ Some plants generate their own electricity using DG sets or captive power plants.
- ✓ Fuels such as furnace oil, coal are purchased and then converted into steam or electricity.
- ✓ Boiler generates steam for heating and drying demand
- ✓ Cooling tower and cooling water supply system for cooling demand
- ✓ Air compressors and compressed air supply system for compressed air needs

All energy/utility system can be classified into three areas like generation, distribution and utilisation for the system approach and energy analysis.

Example 4.10 Furnace

A furnace shell has to be cooled from 90°C to 55°C. The mass of the furnace shell is 2 tonnes; the specific heat of furnace shell is 0.2 kcal/kg °C. Water is available at 28°C. The maximum allowed increase in water temperature is 5°C. Calculate the quantity of water required to cool the furnace. Neglect heat loss.

Solution
Energy Stream #1

Mass of furnace shell (m) = 2000 kg
Specific heat (C_p) = 0.2 kcal/kg °C
Initial furnace temperature (T_1) = 90°C
Desired furnace shell temperature (T_2) = 55°C
Total heat that has to be removed from the furnace = $m \times C_p \times (T_1 - T_2) = 2000 \times 0.2 \times (90 - 55)$

Energy Stream #2

Quantity of water required =X kg
Specific heat of water = 1 kcal/kg °C
Inlet cooling water temperature (T_3) = 28°C
Maximum cooling water outlet temperature (T_4) = 33°C
Heat removed by water $X \times 1 \times (33 - 28) = 5X\ kcal$
For energy balance:

Energy Stream #1 = Energy Stream #2
or Quantity of water required (X) = 14000/5 = 2800 kg

Example 4.11 Dryer heat balance

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

Solution
1) Initial moisture in wet cloth =60 x 0.55 = 33 kg moisture
2) Bone dry cloth = 60 X (1-0.55) =27 kg bone dry cloth
3) Final product moisture content 10% = 27/9 = 3 kg
4) So moisture removed /hr = 33 - 3 = 30 kg/hr
5) Latent heat of evaporation = 2257 kJ/kg
6) Heat used for drying cloth = 30 X 2257 = 6.8 x 10^4 kJ/hr
7) Assuming the natural gas to be at standard temperature and pressure at which 1 mole occupies 22.4 liters
8) Rate of flow of natural gas = 4 m3/hr = (4 x 1000)/22.4 = 179 moles/hr
9) Heat available from combustion 179 x 800 =14.3 x 10^4 kJ/hr
10) Approximate thermal efficiency of dryer = heat needed I heat used = 6.8 x 10^4 /14.3 x 10^4 = 48%

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

Example 4.12 Evaporation Rate

Production rate from a paper machine is 340 tonnes per day (TPD). Inlet and outlet dryness to paper machine is 40% and 95% respectively. Evaporated moisture temperature is 80 °C. To evaporate moisture, the steam is supplied at 35 kg/cm^2. Latent heat of steam at 35 kg/cm2 is 513 kcal/kg. Assume 24 hours/day operation a) Estimate the quantity of moisture to be evaporated b) Input steam quantity required for evaporation (per hour). Consider enthalpy of evaporated moisture as 632 kCal/kg.

Solution

Production rate from a paper machine: 340 TPD or 14.16 TPH (tonnes per hour)
Inlet dryness to paper machine: 40%
Outlet dryness from paper machine: 95%
Estimation of moisture to be evaporated
Paper weight in final product: 14.16 x 0.95 = 13.45 TPH
Weight of moisture before dryer: [(100-40)/ 40] X 13.45 = 20.175 TPH
Weight of moisture after dryer: 14.16 X 0.05 = 0.707 TPH
Evaporated moisture quantity: 20.175 - 0.707 =19.468 TPH

Input steam quantity required for evaporation
Evaporated moisture temperature: 80 °C
Enthalpy of evaporated moisture: 632 kcal/kg
Heat available in moisture (sensible & latent): 632 X 19468 = 12303776 kcal/h

For evaporation minimum equivalent heat available should be supplied from steam
Latent Heat available in supply steam at 3.5 kg/cm2 = 513 kcal/kg
Quantity of steam required: 12303776/513= 23984 kg or 23.98 MT/hour

4.8 Energy Analysis and the Sankey Diagram

The basic data needed for an energy analysis is an energy balance of each process section. The objective is to define in detail the energy input, energy utilized, and the energy dissipated or wasted. This is best represented by a Sankey diagram. The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment or system such as boiler generation, fired heaters, and furnaces after carrying out energy balance calculation. Usually the flows are represented by arrows. The width of the arrows is proportional to the size of the actual flow. Better than numbers, tables or descriptions, this diagram represents visually various outputs (benefits) and losses so that energy managers can focus on finding improvements in a prioritized manner.

Sankey Diagram

The Figure 4.9 shows a Sankey diagram for an Internal Combustion engine. From the Figure, it is clear that exhaust flue gas losses are a key area for priority attention. Since the engines operate at high temperatures, the exhaust gases leave at high temperatures resulting in poor system efficiency. Hence a heat recovery device such as a waste heat boiler has to be necessarily part of the system. The lower the exhaust temperature, higher is the system efficiency. Further improvements can be thought of by utilising the heat in the cooling water circuit for a vapour absorption refrigeration system.

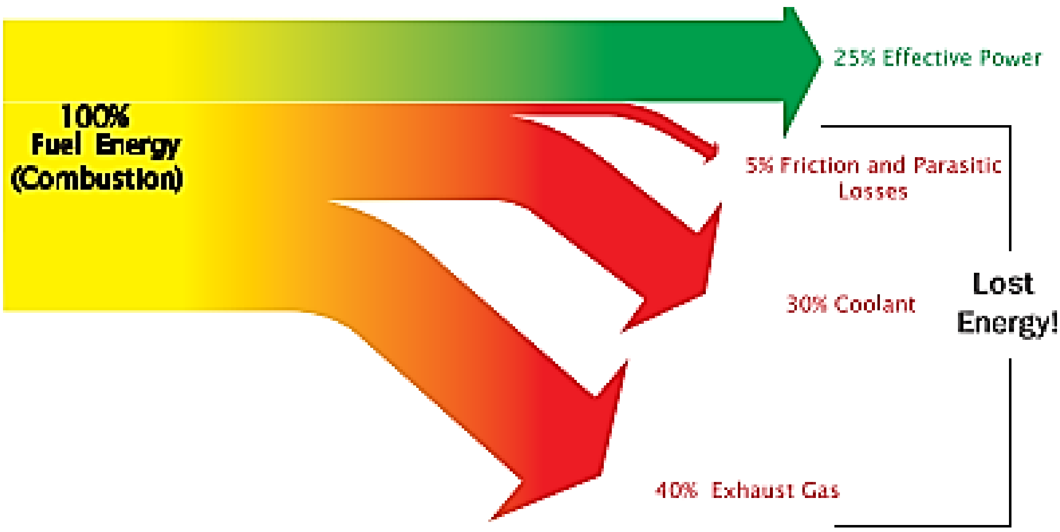


Figure 4.9: Sankey Diagram for an Internal Combustion Engine

Example 4.13:

An evaporator is to be fed with 10,000 kg/hr of a solution having 1 % solids. The feed is at 38°C. It is to be concentrated to 2% solids. Steam is entering at a total enthalpy of640 kcal/kg and the condensate leaves at 100°C. Enthalpies of feed are 38.1 kcal/kg, product solution is 100.8 kcal/kg and that of the vapour is 640 kcal/kg. Find the mass of vapour formed per hour and the mass of steam used per hour.

Answer:
Mass of vapour

Feed = 10,000 kg/hr @ 1 % solids
Solids = 10,000 x l/100 = 100 kg/hr
$Mass_{out}$ x 2/100 = 100
$Mass_{out}$ = 10,000/2 = 5000 kg/hr
Vapour formed = 10,000 — 5000 = 5000 kg/hr
Thick liquor = 5000 kg/hr

Steam consumption:

Enthalpy of feed = 10,000 x 38.1 = 38.1 x 10^4kca1
Enthalpy of the thick liquor = 100.8 x 5000 = 5, 04,000 kcal
Enthalpy of the vapour = 640 x 5000 = 32, 00,000 kcal

Heat Balance:

Heat input by steam + Heat in feed = Heat out in vapour + Heat out in thick liquor
[M X (640-100) + 38.1 x 10,000] = (32, 00,000 + 5, 04,000)
M x 540 = 33, 23,000
Mass of steam required = 33, 23,000/540 = 6153.7 kg/hr

Chapter 5: Energy Management System (EnMS): ISO 50001: 2018

5.1 Introduction

Energy management makes good business sense as energy costs is a significant portion in an organisation's budget. Individual organization cannot control energy prices, government policies or the global economy, but they can very well improve the way they manage energy in their organizations.

A systematic focus on energy management, through optimum use of resources and reduction in wastes, is expected to reduce cost. It can also lead to increased production, improved energy performance, higher profits, and reduced impacts due to rising energy prices. A reduction in energy consumption will also lower CO2 emissions to the environment, and the organisation thereby contributes its part to addressing the climatic change objectives of the country.

Despite these opportunities for energy savings and efficiency improvements, organisations hesitate implementing measures and reaping the benefits of potential reduction in operation costs. Most companies do not understand how much energy they currently use and how much they potentially save by implementing an EnMS. Another barrier in achieving energy savings is the lack of commitment at all levels, especially top management in the organization, to make changes necessary to achieve these improvements.

In order to manage energy well, an organization requires an effective Energy Management System (EnMS) to be established, implemented, maintained and continually improved. There are two ways to doing it; they can develop and implement their own Energy Management System or they can implement Energy Management System conforming to ISO 50001.

5.2 Why ISO 50001 to Manage Energy Effectively?

It is in the interest of the organizations to go for ISO 50001 since it is based on the management system model that is already understood and implemented by organizations worldwide. It can make a positive difference for organizations of all types immediately even without any investment, while supporting longer term efforts for capital intensive energy-efficient technologies.

In order to spur interest in energy efficiency and help organisation take appropriate actions to overcome barriers in implementing practical energy saving measures, International Organisation for Standardisation (ISO) had released the first version of 'ISO 50001 Energy Management Systems (EnMS)–Requirements with guidance for use' in June 2011 and revised version of ISO 50001:2018 in August, 2018.

5.2.1 Energy Performance Approach

The standard provides requirements for a systematic, data-driven and facts-based process, focused on continually improving energy performance. Energy performance is a key element integrated within the concepts introduced in the standard in order to ensure effective and measurable results over time. Energy performance is a concept which is related to energy efficiency, energy use and energy consumption.

ISO 50001has made a major leap in 'raising the bar' by requiring an organization to demonstrate improved energy performance. There are no quantitative targets specified; an organization can choose its own targets and create an action plan to meet the targets. With this structured approach, an organization is more likely to see tangible financial benefits. Energy Performance Indicators (EnPIs) and energy baselines (EnBs) are two interrelated elements addressed in this document to enable organizations to demonstrate energy performance improvement.

5.2.2 Relationship between Energy Performance and the EnMS

The ISO 50001 standard addresses both energy performance improvement and a management system approach to manage energy. The clause no. 4 of the standard on the context of organzation, requires continual improvement of EnMS as well as energy performance to achieve intended outcomes. Accordingly, the EnMS promotes, supports and sustains the Energy Perfomance Improvement; achievement of other intended outcomes; and its continual improvement as illustated in Figure 5.1.

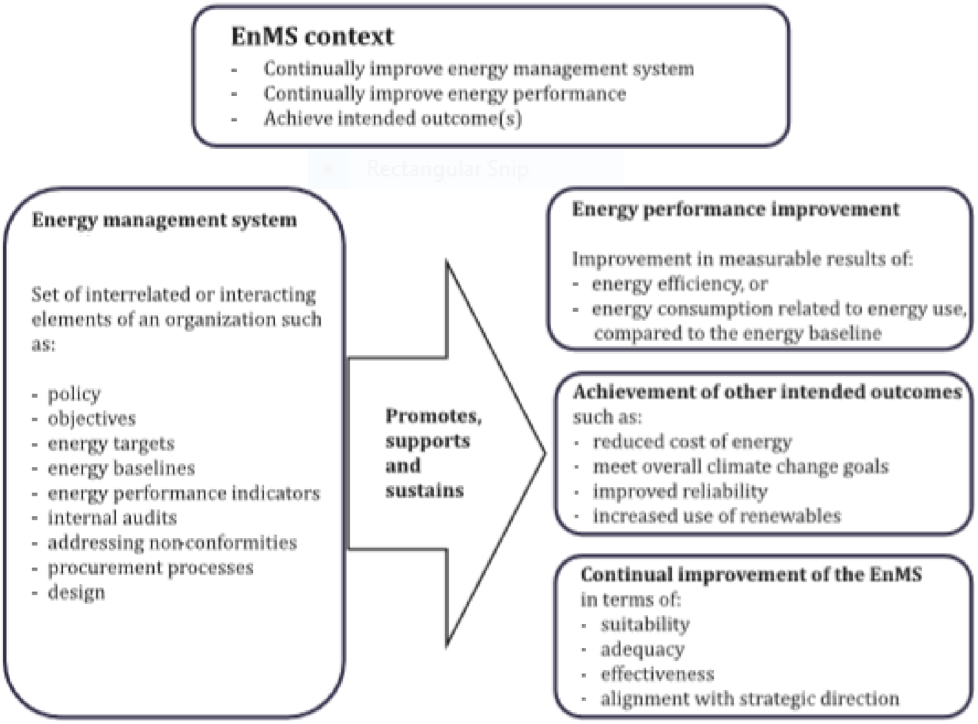


Figure 5.1: Relationship between EnMS and Energy Performance

5.2.3 Plan-Do-Check-Act (PDCA) cycle

The EnMS described in the standard is based on the Plan-Do-Check-Act (PDCA) continual improvement framework and incorporates energy management into existing organizational practices, as illustrated in Figure 5.2.

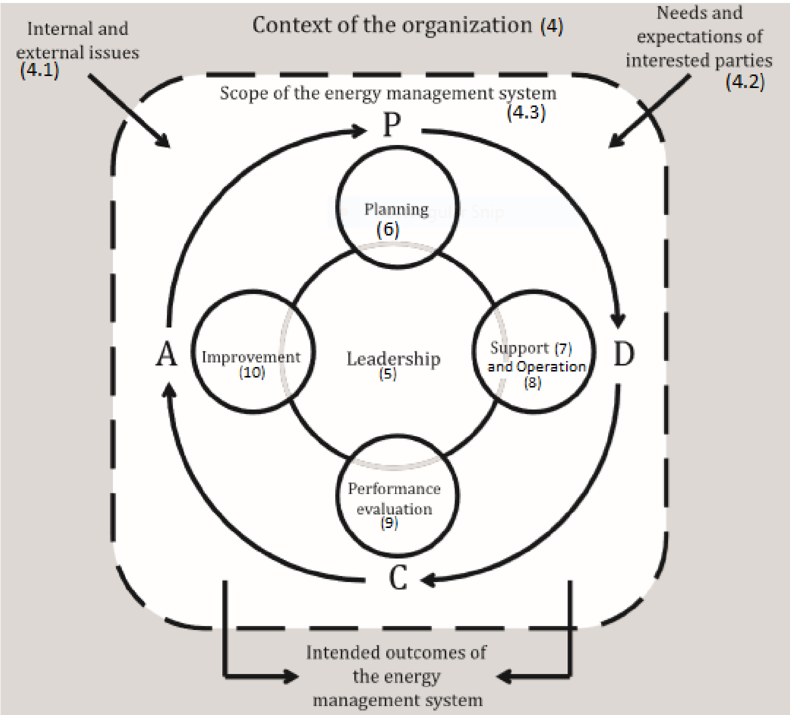


Figure 5.2: PDCA cycle

The PDCA Approach to EnMS **Plan:** understand the context of the organization, establish an energy policy and an energy management team, consider actions to address risks and opportunities, conduct an energy review, identify significant energy uses (SEUs) and establish energy performance indicators (EnPIs), energy baseline(s) (EnBs), objectives and energy targets, and action plans necessary to deliver results that will improve energy performance in accordance with the organization's energy policy. **Do:** implement the action plans, operational and maintenance controls, and communication, ensure competence and consider energy performance in design and procurement. **Check:** monitor, measure, analyse, evaluate, audit and conduct management review(s) of energy performance and the EnMS. **Act:** take actions to address nonconformities and continually improve energy performance and the EnMS.

5.3. Benefits of Implementing ISO 50001

The implementation of ISO 50001 will provide following benefits:

a) provide organizations with a well-recognized framework for integrating energy efficiency into their management/business practices,
b) provide a logical and consistent methodology for identifying and implementing

improvements that can contribute to a continual increase in energy efficiency across the facilities,

c) assist organizations to better utilize existing energy consuming assets, thus reducing costs and/or expanding capacity,
d) offer guidance on benchmarking, measuring, documenting, and reporting energy efficiency improvements
e) lead organizations to meet overall climate change mitigations goals by reducing their energy related greenhouse gas emissions,
f) assist facilities in evaluating and prioritizing implementation of state-of-the-art energy-efficient technologies,
g) provide an approach for organizations to encourage suppliers to better manage their energy, thus promoting energy efficiency throughout the supply chain.

5.4 Why a New ISO 50001 Version?

It is a part of continual improvement that every management standard is periodically reviewed. This version change is driven by high-level structure (HLS) implementation. The purpose of HLS is to make ISO 50001 comparable and compatible to other standards such as ISO 9001:2015 and ISO 14001:2015. This will help organization implementing or maintaining Integrated Management System (IMS).

The new version is targeted to build energy culture in an organization. Adoption of HLS is expected to make process owner more responsible for all systems rather than a single management system.

The new version also brings risk management approach—risk management, risk analysis— in energy management system.
Salient feature of HLS:

- A common structure for all Standards (ISO 9001, ISO 14001) etc.
- 10 clauses in all
- HLS structure + energy management specific clauses

All ISO Standards will now follow ten clauses recommended by HLS and few additional clauses which are specific to that particular standard.

The main changes compared to the previous version of ISO 50001:2011 are as follows:

i. adoption of ISO's requirements for management system standards, including a high-level structure, identical core text, and common terms and definitions, to ensure a high level of compatibility with other management system standards;
ii. better integration with strategic management processes;
iii. clarification of language and document structure;
iv. stronger emphasis on the role of top management;
v. adoption of context order for the terms and their definitions in Clause 3 and update of some definitions;
vi. inclusion of new definitions, including energy performance improvement;
vii. clarification on exclusions of energy types;
viii. clarification of "energy review";
ix. introduction of the concept of normalization of energy performance indicators [EnPI(s)] and associated energy baselines [(EnB(s)];

x. addition of details on the energy data collection plan and related requirements (previously energy management plan): and
xi. clarification of text related to energy performance indicators [EnPI(s)] and energy baselines [EnB(s)].
xii. clarification of text related to energy performance indicators [EnPI(s)] and energy baselines [EnB(s)] in order to provide a better understanding of these concepts.

The chapter numbers from here onwards are revised to match with Clause Numbers of ISO 50001:2018 standard to avoid any confusion. This chapter clarifies the requirements of the standard and how to meet those. To know the exact requirements under each clause, ISO 50001:2018 standard should be referred.

Interpretation of key words used in the standard

It may be noted that in the new standard, "shall" indicates a requirement; "should" indicates a recommendation; "can" indicates a possibility or a capability; and "may" indicates permission.

Besides, it should be remembered that

(i) the use of the word "any" implies selection or choice,
(ii) the words "appropriate" and "applicable" are not interchangeable. "Appropriate" means suitable (for, to) and implies some degree of freedom, while "applicable" means relevant or possible to apply and implies that if it can be done, it needs to be done,
(iii) the word "consider" means it is necessary to think about the topic but it can be excluded, whereas "take into account" means it is necessary to think about the topic but it cannot be excluded, and
(iv) the word "ensure" means the responsibility can be delegated, but not the accountability.

Requirements of ISO 50001:2018

1. Scope – Gives scope of the standard.

2. Normative references – There are no normative references in this document.

3. Terms and definitions – Gives definitions of various terms used. In new version, definitions have been divided into five categories and in place of 28 definitions in old version, there are 41 definitions in new version.

5.5 Context of organization

5.5.1 Understanding the organization and its context

The organization is required to determine external and internal issues that are relevant to its purpose and that affect its ability to achieve the intended outcome(s) of its EnMS and improve its energy performance. The analysis of organizational context will provide a high-level conceptual understanding of the external and internal issues that can affect, either positively or negatively, energy performance and the EnMS of the organization.

External issues could be related to interested parties such as existing national or sector objectives, requirements or standards; restrictions or limitations on energy supply, security and reliability; energy costs or the availability of types of energy; effects of weather; effects of climate change; effect on greenhouse gas (GHG) emissions etc.

Internal issues could include core business objectives and strategy; asset management plans; financial resource (labour, financial, etc.) affecting the organization; energy management maturity and culture; sustainability considerations; contingency plans for interruptions in energy supply; maturity of existing technology etc.

5.5.2 Understanding the needs and expectations of interested parties

Under this clause, the organization is supposed to identify the interested parties that are relevant to energy performance and the EnMS; the relevant requirements of these interested parties; and which of the identified needs and expectations need to be addressed by the organization through its EnMS.

Interested parties (stakeholders) can include Suppliers, Customers, Partners, Employees, Investors, Owners, Bankers/financial bodies, Regulatory bodies, Unions, Competitors, Society, Opposing pressure groups, government, shareholders etc.

Organization is also required to ensure that it has access to the applicable legal requirements and other requirements related to its energy efficiency, energy use and energy consumption; determine how these requirements apply to its energy efficiency, energy use and energy consumption; ensure that these requirements are taken into account and reviewed at defined intervals.

Legal requirements are laws and acts that apply to an organisation's energy use, consumption, and efficiency. These may include Energy Conservation Act, Boiler Act, Water Pollution Act, Air Pollution Act, Electricity Act, Factory Act etc. as applicable to the organization. Besides these, there may be some regional, national, or international laws that may apply to an organisation.

Other requirements that may apply to the organization include voluntary agreements, corporate agreements/targets, agreements with customers and suppliers, requirements of trade associations, agreements with community groups or NGOs etc.

A list of all applicable legal and other requirements relevant to energy should be developed, and the organisation needs to decide how these requirements apply to its activities and how compliance can be effectively ensured as shown in Figure 5.3. The entry process of identification and evaluation should be clear and include a description of how compliance is assessed. Best method would be to establish the responsibility for identification, compliance and monitoring and reviewing compliance.

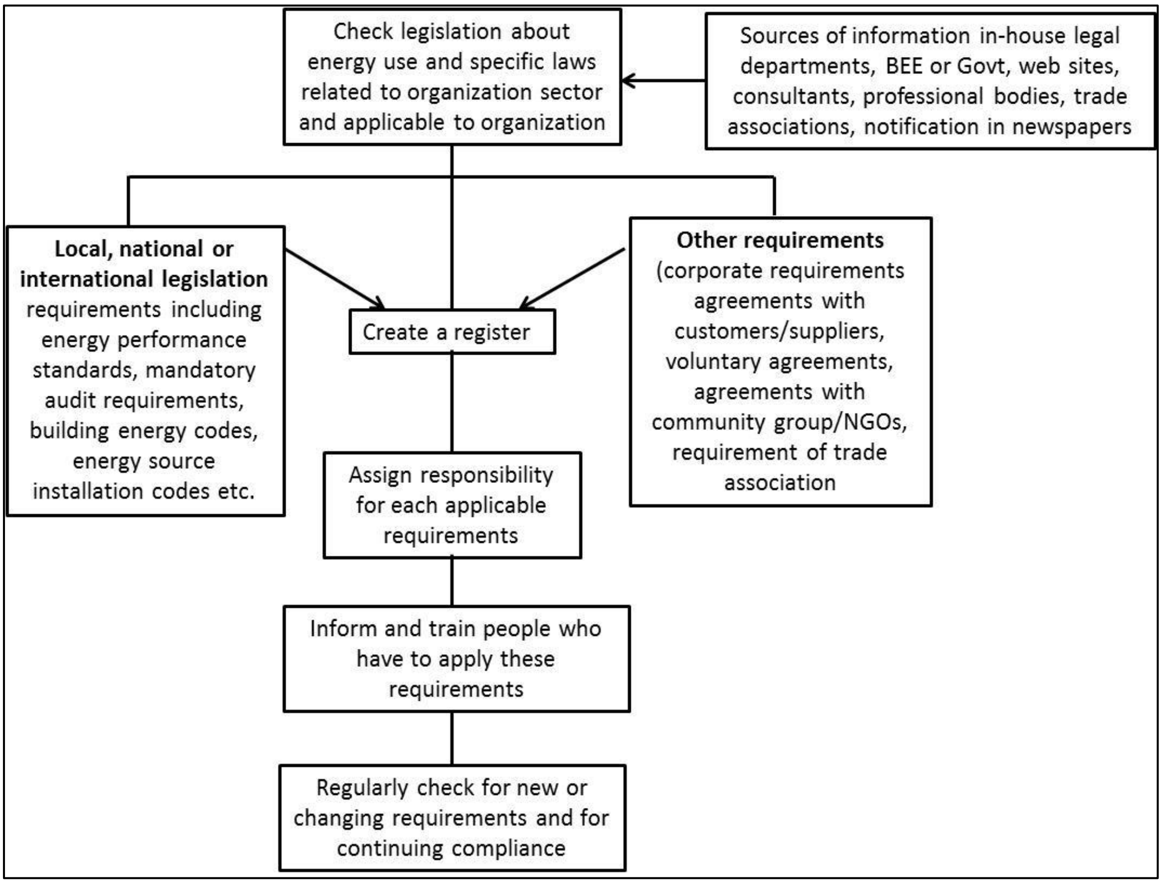


Figure 5.3: Addressing Legal and Other Requirements

The ISO 50001 standard requires organization to review legal requirements and other requirements at defined intervals. However, in addition to this interval, there might be some occasions when organization needs to review these requirements and such occasions could be changes to applicable legal and other requirements as well as changes in organization's operations that might affect applicability of these requirements.

5.5.3 Determining the scope of energy management system

The organization is required to determine and document the scope and boundaries to be covered in its EnMS to establish its scope. While determining the EnMS scope, the organization is required to consider the external and internal issues referred to in 5.5.1 as well as the requirements referred to in 5.5.2.

Scope covers facilities, operations, products and activities whereas boundaries cover parts of the site on which it has the authority to control its energy efficiency, energy use and energy consumption. In the new version, the organization cannot exclude an energy type within the scope and boundaries of EnMS.

5.5.4 Energy management system

The organization is required to establish, implement, maintain and continually improve an EnMS, including the processes needed and their interactions, and continually improve energy performance in accordance with the requirements of this document. The processes needed will depend on the size of organization and its type of activities, processes, products and services; the complexity of processes and their interactions; and competence of personnel.

5.6 Leadership

5.6.1 Leadership and commitment

New version of the standard has put stronger emphasis on the role of top management wherein it is required to demonstrate its leadership and commitment with respect to continual improvement of its energy performance and effectiveness of the EnMS by way of fulfilling a number of responsibilities mentioned therein. Top management can delegate some of those responsibilities but the overall accountability will still lie with top management.

Top management support is a prerequisite to the successful implementation of an energy management system. Top management should provide the necessary resources such as time, manpower, money, materials for effective implementation of the EnMS. Energy-saving opportunities are to be given same priority as part of normal daily activities and decision-making of the organisation. Top management commitment must be communicated and made visible to the entire organisation through employee involvement activities such as empowerment, motivation, recognition, training, rewards and participation.

5.6.2 Energy Policy

Energy policy is a high-level statement conveying the overall intentions and directions of the organisation aligned with its long-term goals. It is established and documented by the top management. It shows top management commitment and support to energy performance improvement and serves as a guideline for setting targets, making decisions, and providing framework for actions.

The energy policy should clearly state organisation's energy priorities. ISO 50001 requires that the energy policy must demonstrate the commitments at least for (i) continual improvement of energy performance and the EnMS, (ii) availability of information and necessary resources to achieve its objectives and energy targets, and (iii) satisfy applicable legal and other requirements related to energy efficiency, energy use and energy consumption.

An energy policy is the foundation for developing an organization's EnMS through all phases of planning, implementation, operation, performance evaluation and improvement. It provides a framework for setting and reviewing objectives and targets. Policy document should be a brief statement so that members of the organization can readily understand and apply to their work activities. The energy policy dissemination can be used as a means to manage organizational behaviour. The policy is required to well communicated within the organization, be available to interested parties and be periodically reviewed and updated as necessary. Every word used in energy policy is important and therefore, organization should avoid over committing and inclusion of those points in the energy policy which it cannot meet. A model energy policy is shown in Figure 5.4.

Model Energy Policy

As an energy intense manufacturer of specialty glass, ABC Company strives to reduce its energy consumption and costs and promote the long-term environmental and economic sustainability of its operations. We are committed to:

- ***Reduce energy use per unit of production in our manufacturing operations.***
- ***Ensure continual improvement in plant energy performance.***
- ***Deploy information and resources to achieve energy objectives and targets.***
- ***Uphold legal and other requirements regarding energy.***
- ***Consider energy performance improvements in design and modification of facilities, equipment, system, and processes***
- ***Effectively procure and utilize energy-efficient products and services.***

Managing Director: _____________ *Date:* _________

Figure 5.4: Model Energy Policy

5.6.3 Organizational roles, responsibilities and authorities

Top management is required to form an Energy Management Team which will have the responsibility and authority mentioned under this clause to ensure effective implementation of the EnMS and for delivering energy performance improvement in accordance with ISO 50001 International Standard. It is also required to ensure that the responsibilities and authorities for relevant roles are assigned and communicated within the organization.

The team approach takes advantage of the diversity of skills and knowledge of individuals. Good practice is to have a cross-functional team from all sections of the organizations that can affect energy performance. This approach provides an effective mechanism to engage different parts of the organization in the planning, implementation, maintenance and improvement of the EnMS as well as of energy performance. Members of the team may change from time to time and should be based on defined roles (designations) rather than named individuals.

For smaller organizations, a single person might be enough, whereas large organizations will require this cross-functional team for effective planning and implementation of EnMS in different parts of the organization. Size of this team will depend on size and nature of the organization and available resources.

5.7 Planning

5.7.1 Actions to address risks and responsibilities

5.7.1.1 This clause covers the strategic part of planning where the organization considers the issues referred to in 4.1 and the requirements referred to in 4.2 and reviews the organization’s activities and processes that can affect energy performance. While doing so, the organization is required to determine the risks and opportunities that need to be addressed to give assurance that the EnMS can achieve its intended outcome(s), including energy performance improvement; prevent or reduce undesired effects; and achieve continual improvement of the EnMS and energy performance.

By identifying risks and opportunities when planning the EnMS, an organization can anticipate potential scenarios and consequences so that undesired effects can be addressed before they occur. Similarly, favourable considerations and circumstances that can offer potential advantages or beneficial outcomes can be identified and pursued.

5.7.1.2 Under this clause, the organization is required to plan actions to address these risks and opportunities and how to integrate and implement the actions into its EnMS and energy performance processes as well as evaluate the effectiveness of these actions.

A concept diagram illustrating the strategic planning is shown in Figure 5.5.

Figure 5.5 Strategic Planning to address risk and responsibilities

5.7.2 Objectives, energy targets and planning to achieve them

5.7.2.1 The data analysis and other information outputs from Energy Review are used in developing Energy Objectives and Targets. Setting objectives and targets provides the means for transforming policy into action. These are to be established for all relevant functions and levels of the organization.

5.7.2.2 Objectives are broader and normally covers whole of the organization / department / section and directly relevant to organization's energy policy. They could be quantifiable as well as qualitative.

Quantifiable objectives have targets for performance improvement (e.g. reduce electricity consumption by 3 % by the end of the year). Qualitative objectives relate to energy behaviour, cultural change etc. It is often possible to provide some quantitative values for qualitative objectives, through surveys or other similar mechanisms.

Similarly, energy targets are consistent with energy objective as they emerge from them and have more details. Targets should be SMART (specific, measurable if practical, achievable, relevant and time-based). It can be expressed in terms of the percentage improvement in energy performance or improvement in energy consumption or the EnPI with appropriate baseline period reference.

Factors which need to be considered while establishing and reviewing objectives and targets include legal requirements and other requirements, significant energy uses, opportunities to improve energy performance, financial, operational and business conditions, technological options and the views of interested parties.

5.7.2.3 Actions which are required to be taken to achieve the targets are known as Energy Management Action Plans. The energy management action plans are the road map to what is needed to achieve the energy objectives and targets. These typically arise from the energy performance improvement opportunities that were identified and prioritised as part of the energy review.

Top management is supposed to provide required resources for successful implementation of action plans. All action plans are required to show allocation of responsibility, resources required, time frame for completion, how to verify the improvement in energy performance (measurement method and other relevant details) and how to verify the result etc. An example showing consistency relationship between Energy Policy, Objective, Target and Action plan is shown in Table 5.1.

Table 5.1: Consistency Relationship between Policy, Objective, Target and Action Plan

Relevant portion in Energy Policy	Energy Objective	Energy Target	Action Plan					
			Details of action plan on what is to be done	By whom	Method of verification for energy performance improvement	Resources required	Time frame for completion	Method of verifying results
We shall improve our energy performance continually	***Reduction in specific electrical Energy Consumption by end of July, 2019***	***Reduction of 10% in units consumed per MT of production as compared to 2017-18 by end of July, 2019***	*(i)* ***All remaining inefficient lighting to be replaced with LED lighting***	***A.M. (Purchase) to procure and Maintenance Inch. to install***	***Power drawn by each type of existing lighting and of corresponding replacement***	***Finance for procuring all remaining inefficient lighting and manpower for doing it***	***Dec, 2018***	***Electrical submeter readings installed on lighting feeder & compressed air section and electricity bill stating total energy consumption for the month***
			(ii) Replace pneumatic packing machines with mechanical packing machines	***A.M. (Purchase) to procure and Maintenance In-charge to install and commission***	***No compressed air is required by packaging machines***	***Finance and manpower for Tendering, procuring, installation and commissioning of mechanical machines***	***July, 2019***	
			(iii) Set screw air compressor pressure settings at optimum level to save power	***Maintenance In-charge***	***Power drawn by each compressor during load before and after resetting of pressures***	***Manpower and skill for resetting the pressures for load and unload on all air compressors***	***Dec, 2018***	
			(iv) Install VFDs at identified equipment having variable loads	***A.M. (Purchase) to procure and Maintenance In-charge to install***	***Air compressor does not run in unload mode***	***Finance and manpower for Tendering, procuring, installation and commissioning of VFDs***	***April, 2019***	

5.7.3 Energy review

To improve energy performance, it is necessary to understand how, why, and where energy is being consumed and to identify where opportunities to improve exist.

The energy review is the analytical part of tactical energy planning process (refer Figure 5.6). The purpose of the energy review is to obtain an overall picture of an organisation's energy use, patterns of use of each energy source, consumption trends, energy performance, variables affecting energy consumption (say production), opportunities for savings, and the resources required in terms of manpower, time and investments.

One of the important activities of energy review is to identify significant energy uses (SEUs) so that areas using more energy and/or having more potential for energy saving and/or both can be focused and planned accordingly. SEUs can be defined depending on the needs of the organization, such as by facility (e.g. warehouse, factory, office), by process or system (e.g. lighting, steam, transport, electrolysis, motor-driven) or equipment (e.g. motor, boiler). Once identified, the management and control of SEUs are an integral part of the EnMS.

Energy review is required to be updated at defined interval (at least annually) or when there are major changes in the energy scenario of the organization. The various steps involved in carrying out energy review are illustrated in Figure 5.6.

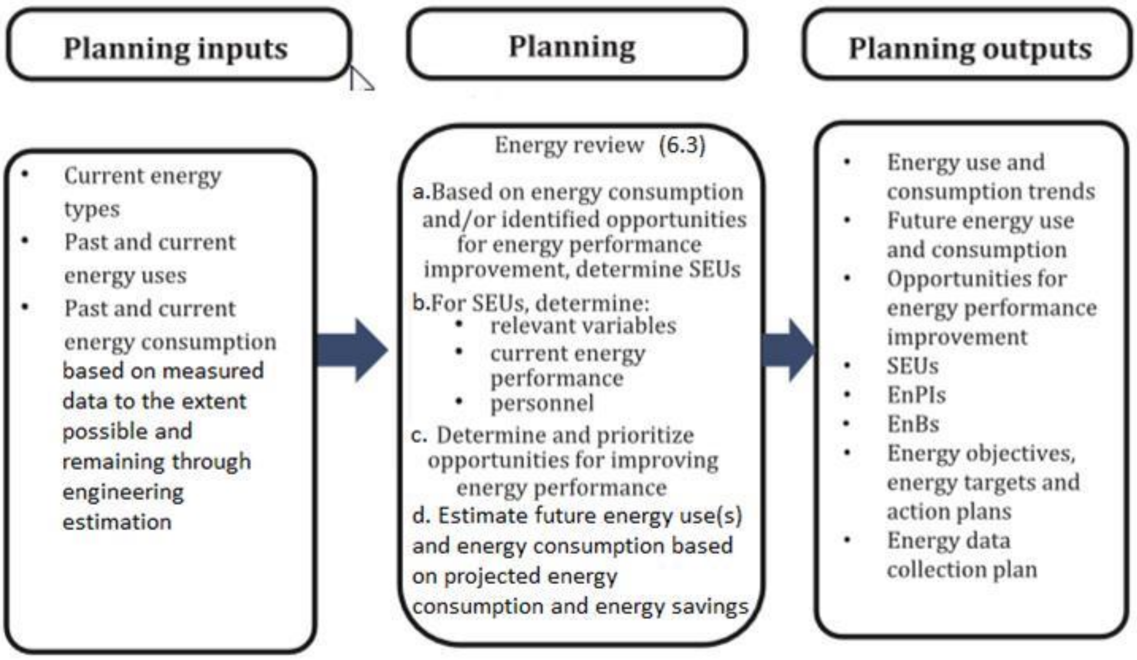


Figure 5.6: Energy Review

Steps in conducting Energy Review

1. Collect data on energy use for past 12/24 months
2. Analyse past and current energy use with relevant drivers (e.g. production)
3. Identify and challenge each SEUs (based on energy use and consumption)
   (If measured data on energy consumption are not available, then, estimate using actual power drawn and hours of operation)
4. Identify variables affecting energy consumption and effect on SEUs
5. Determine current performance and baseline of identified SEUs
6. Identify and prioritize opportunities for improvement
7. Estimate future energy used based on projected production and expected energy saving which may result from implementation of energy conservation measures.
8. Agree objectives, energy targets and action plans.

5.7.4 Energy Performance Indicators

Energy review provides the information and data needed to establish EnPIs. EnPI is a “ruler” that is used to compare energy performance before (reference EnPI value) and after (resultant or current EnPI value) the implementation of action plans and other actions. The difference between the reference value and the resultant value is a measure of a change in energy performance.

EnPI helps turn energy data into useful information for top management. Types and examples of EnPIs are as follows:

- Simple energy consumption in kWh or kcal (in total or breakdown by energy use or by facility or by equipment)
- Simple ratios like energy consumption per time, or per unit of floor area or per unit of production
- Statistical model including liner or non-linear regression

Where the organization has data indicating that relevant variables significantly affect energy performance, the organization shall consider such data to establish appropriate EnPI(s).The methodolgy the organization is going to adpot on this matter and updating of EnPIs needs to be maintained as documented information.EnPI value(s) shall be reviewed and compared to their respective baseline value(s) (EnB) to assess energy performance and improvements, and need to be retained as documented information. Comparing energy performance between the baseline period and the reporting period involves calculating the differrence in the value of EnPI between the two periods. The Figure 5.7 illustrates the simple case where direct measurement of energy consumption is used as EnPI and the energy performance is compared between the baseline period and the reporting period. It also shows whether target (in case it was set) has been achieved or not.

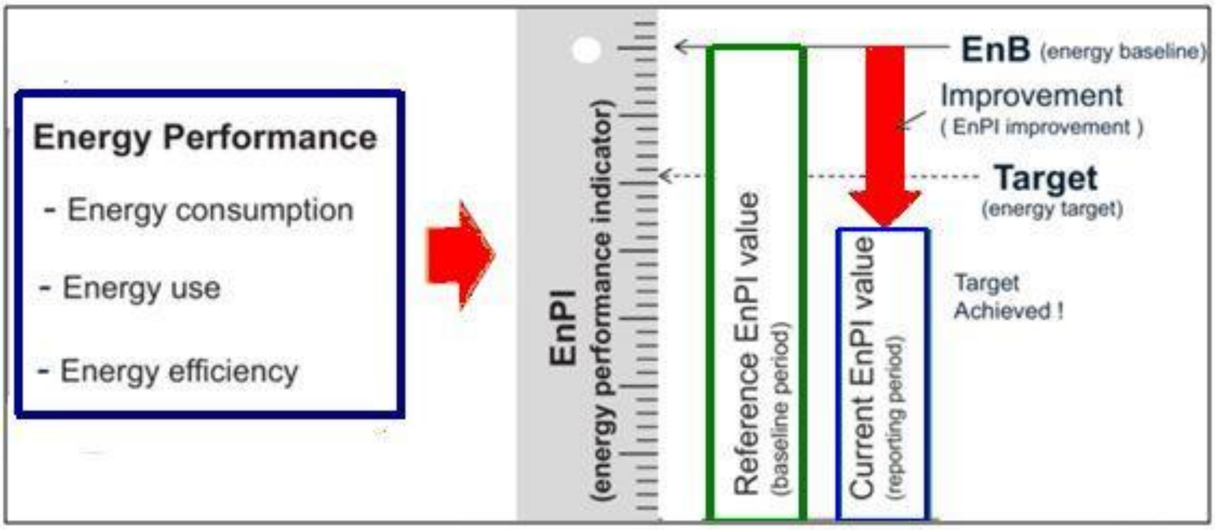


Figure 5.7: Energy Performance Indicator

With passage of time and maturity of EnMS, there should be increase in the number of EnPIs through indepth penetration (from whole organization level to facility to process/system-wise to individual equipment-wise).

5.7.5 Energy baseline

One of the main requirements of the ISO 50001 standard is to have continual improvement in energy performance of the organization, and to find out improvement, one has to have some base to compare with. This is what is known as "Energy Baseline" which is defined as the quantitative reference or references providing a basis of comparison of energy performance. Energy Review provides the information and data needed to establish the energy baseline.

The energy baseline is the reference for measuring energy performance over time. The type of energy baseline will depend on specific purpose of the Energy Performance Indicator (EnPI) and can be established at the facility, system, process, or equipment level. The energy baseline can be expressed as a mathematical relationship of energy performance as a function of relevant variables; an engineering model; a simple ratio; or simple consumption data (if there are no relevant variables).

Baseline is always pertaining to a period which is known as baseline period. This period should be representative of one complete cycle of the variations in the organizational operation like seasonal fluctuations in production in case of industries; occupancy in case of hotels; temperature& humidity in case of air conditioning in buildings etc. In all such cases, the baseline could be considered as one year. When determining energy performance improvement, the data needs to represent the same period as the baseline.

In almost all the cases, energy consumption is affected by relevant variables and these variables will be different in baseline period and the reporting period for which improvement is to be determined. Where the organization has data indicating that relevant variables significantly affect energy performance, the organization shall carry out normalization of the EnPI value(s) and corresponding EnB(s). Depending on the nature of the activities, normalization can be a simple adjustment, or a more complex procedure.

In order to do “apple to apple comparison” and to correctly assess the improvement made in energy performance, some adjustments in baseline may be required in certain cases. These cases could be one or more of the followings:

a) where current EnPIs, the organizational boundaries and the energy baselines are no longer appropriate and effective to reflect organizations energy use and consumption, or

b) there have been major changes to the process, operational patterns, or energy systems, (for example steam turbine is installed to generate electricity between baseline period and reporting period which will change the entire energy including fuel scenario of the organization) or

c) according to a predetermined method like ‘normalization’ in PAT, where adjustment is made in the reporting period energy consumption due to changes in relevant variables or Static factors.

5.7.6 Planning for collection of energy data

Data are critically important in monitoring and analyzing key characteristics as identified under clause 9.1.1. Planning for which data to collect (minimum is given in the standard), how to collect them and how often to collect them form the Energy Data Collection Plan which will depend upon the size and complexity of organization, its resources and its monitoring and measurement equipment. This Plan needs to be reviewed at defined intervals and updated as appropriate. The measuring equipment used for monitoring energy consumption and performance for operational decisions should be accurate, consistent and periodically calibrated.

5.8 Support

5.8.1 Resources

Under this clause, the organization is required to determine and provide the resources needed for the establishment, implementation which can include human resources, financial resources, specialized skills, technology, data collection infrastructure etc.

5.8.2 Competence

This is the responsibility of organization to ensure that all people working under its control and which can affect its energy performance are competent on the basis of appropriate education, training, skills and experience and takes necessary action like the provision of training to, the mentoring of, or the reassignment of currently employed persons; or the hiring or contracting of competent persons etc., to acquire the necessary competence and evaluate the effectiveness of action taken as well as retain appropriate documented information as evidence of competence.

Training is one of the many methods for achieving competency. EnMS team members should be encouraged to continually develop, maintain and improve their knowledge, skills and expertise. Organization can also consider certification course like SREDA’s course for

Certified Energy Auditor/Manager or Lead Auditor course for ISO 50001 etc., to improve their competence level.

Competence requirements need be appropriate to the function, level and role of persons (including top management) doing work, which affects energy performance and the EnMS. Competence requirements are determined by the organization.

5.8.3 Awareness

Organization needs to ensure that every one working for it (regular employees, contract workers, security staff, helpers etc.) is aware of importance of conformity to energy policy and EnMS requirements; his/her roles, responsibilities and authorities in achieving the requirements of EnMS; benefits of improved energy performance as well as impact of their activities in achieving the same etc. Table 5.2 shows a sample training plan.

Table 5.2: Sample Training Plan

Type of Training	*Participants*
EnMS Awareness	*All who are working under the control of organization*
EnMS Implementation Training	*Middle Management /Energy Management Team*
EnMS Internal Auditor (IA) Training	*Energy Management Team/Anyone interested in conducting Internal Audit (However, their competency needs to be ensured before they are allowed to conduct IA)*
Training related to control of SEU	*All personnel related to SEUs*

5.8.4 Communication

Good internal and external communication is essential to managing change. It keeps personnel informed of energy management activities, incentives, and successes, which strengthens commitment and participation. Multiple channels of communication, whether verbal or nonverbal can be used such as meetings, videos, briefings, e-mails, posters, memos, circulars etc. The organization is required to determine the internal and external communications relevant to the EnMS, including on what it will communicate; when to communicate; with whom to communicate, how to communicate and who communicates. However, when establishing its communication process (es), the organization shall ensure that information communicated is consistence with information generated with the EnMS and is dependable.

Organization is required to implement a suggestion scheme with incentives and rewards for good suggestions that can be implemented to stimulate interest and participation of all those who are working under the control of the organization.

5.8.5 Documented information

5.8.5.1 General

Documented information is defined as the information required be controlling and maintaining by an organization and the medium on which it is contained. It can be in any format and media, and from any source. Also, it can refer to the management system, including related processes; information created in order for the organization to operate (documentation): and evidence of results achieved. Thus, in this new ISO version, the documented information has included document(s), documentation as well as records of previous version in single phrase.

Documentation enables communication of intent and consistency of action. Its use contributes to achievement of conformity to requirements of the standard and provides objective evidence thereof. However, generation of documentation should not be an end in itself, but it should be a value-adding activity. The extent of documented information for an EnMS can differ from one organization to another due to the size of organization and its type of activities, processes, products and services; the complexity of processes and their interactions; and the competence of persons working therein.

A certain amount of documented information is required in the EnMS. Minimum (mandatory) documented information) as required by the standard under various clauses (clause numbers are mentioned in the bracket) are: Scope and Boundaries of the EnMS (4.3); Energy Policy (5.2); Energy Objective and Targets (6.2.2); Action Plans for achieving energy objectives and targets (6.2.3); Methodology and criteria used to develop the energy review (6.3); energy review results (6.3);method for determining and updating EnPIs (6.4); EnPIs Values (6.4); EnB(s), relevant variable data and modifications to EnB(s) (6.5); data to be collected and retained (6.6); details on measurement, monitoring and other means of establishing accuracy and repeatability (6.6); evidence of competence (7.2); external origin (7.5.3); operational planning and control (8.1); design activities (8.2); results of the investigation and response to significant deviation (9.1.1); results from monitoring and measurements (9.1.1); results of the evaluation of compliance and any action taken (9.1.2); evidence of the implementation of the audit programs and the audit results (9.2.2); evidence of the results of management reviews (9.3.4); and nature of nonconformities and subsequent action taken as well as on results of any corrective action (10.1).

Documented information for whom the word “consider” has been used in the standard means it is necessary to think about the topic but it can be excluded. There is only one such documented information and it is on comments and suggestions received for improvement (7.4). Here, the organization is required to implement the suggestion scheme but can decide whether to include the comments and suggestions received as documented information in its EnMS or not.

5.8.5.2 Creating and Updating

This clause required organizations to take appropriate action while creating and updating documented information with respect to their identification and description (e.g. a title, date, author or reference number); format (e.g. language, software version, graphics) and media (e.g. paper, electronic) as well as review and approval for suitability and adequacy.

5.8.5.3 Control of documented information

There is no mandatory procedure that needs to be developed as documented information as per the standard. However, organization can still develop certain procedures as documented information for the convenience of all, especially if ISO management systems are new to the organization. Procedures which can be developed by organization in such a situation can include procedure on Documented Information Control, Internal Audit, Management Review, Nonconformity and Corrective Action, Communication, Identification of Competency, Skill &Training, and Significant Deviation.

Correct identification of the EnMS documents is crucial to ensure that the most up-to-date documents are in use, that they can be easily located, and that obsolete documents are removed from the points of use. Documented information required by the EnMS and by this document shall be controlled to ensure that it is available and suitable for use, where and when it is needed; is adequately protected (e.g. from loss of confidentiality, improper use, loss of integrity). For the control of documented information, the organization is required to address certain activities, as applicable like distribution, access, retrieval and use; storage and preservation, including preservation of legibility; control of changes (e.g. version control): and retention and disposition.

Any documented information, once developed for the EnMS (including technical documents wherever appropriate) as well as external documents which have been generated outside of the organization, need to be controlled. For this purpose, organization is required to implement a procedure where the complete process mentioned under this clause of the standard will be followed. Some examples of documents of external origin are laws/acts like The Sustainable and Renewable Energy Development Authority Act-2012, Energy Efficiency & Conservation Rules-2016, Energy Audit Regulation-2018, important technical documents including equipment manuals prepared by OEMs etc.

5.9 Operation

5.9.1 Operational planning & control

This involves examination of how significant energy uses are operated and maintained in comparison with energy-efficient practices. Best practices or criteria for operation and maintenance are developed, ensured that these practices are routinely followed, people responsible for following these practices are well communicated about these, and keeping documented information to the extent necessary to have confidence that the processes have been carried out as planned.

Under this clause, the organization is required to control planned changes and review the consequences of unintended changes, taking actions to mitigate any adverse effects, as necessary. The organization is also required to ensure that outsourced SEUs or processes related to SEUs are controlled.

Although not mandatory, it is a good practice to have documented information on operation and maintenance practices related to energy. These include work instructions, standard operating procedures (SOPs), work flow diagrams etc.

5.9.2 Design

The design activity associated with energy-saving and operation control presents one of the best opportunities to improve energy performance of new facilities, extensions to existing facilities, new or modified production process, upgrades, refurbishment, change of use and design. While doing so, organization should consider improved technologies, alternative energy such as renewable or less polluting types of energy options, best available energy efficient techniques, practices and emerging trends.

It is much better to design and implement these projects properly the first time round rather than to carry out upgrades or retrofits later. The costs of incorporating energy efficiency measures during the design stages are much lower and the benefits of doing so are greater than implementing as changes later during the operation stage. This approach can avoid frequent barriers to appropriate energy performances such as oversized equipment, over specified systems, and the use of inefficient technologies. Where applicable, the results of the energy performance consideration shall be incorporated into specification, design and procurement activities.

It is possible that equipment and systems may operate at partial or variable load for significant periods of time and therefore, it should be considered during the design, procurement and commissioning phases of the project.

5.9.3 Procurement

Procurement is an opportunity to improve energy performance through the use of more efficient products and services. It is also an opportunity to work with the supply chain and influence its energy behaviour.

Procurement policy of the organization should always consider energy implications while purchasing energy services, products, equipment and even purchase of energy itself. Also, while purchasing these, one should consider all costs for their expected life cycle. These costs include capital cost including taxes and duties, installation and commissioning cost, energy cost, maintenance cost, lubricant cost, operating manpower cost, disposal cost etc.

This clause of the standard calls organization to establish and implement the criteria for assessing energy use, consumption and efficiency over planned or expected operating lifetime when procuring energy using products, equipment and services which are expected to have a significant impact on the organization's energy performance. This can include life cycle costs as mentioned above; expected impact on the overall system energy performance (e.g. the energy efficiency of a pumping system at the planned system operating conditions); performance at part load and under fluctuating loads; certification from reputed agencies or from other third parties.

Even while purchasing energy, organization should consider the opportunities for reducing cost in purchasing electricity and fuels. Factors which can be considered while evaluating purchase of energy should include quantity (to check for bulk discounts for more quantity or penalty for less quantity), quality (voltage fluctuation, harmonic quality etc), price or rates, contract period, reliability, flexibility etc.

Examples of Energy Service providers are energy consultants, energy service companies (ESCOs), energy service providers, energy auditors, energy related trainers etc. Energy services can include annual maintenance services (AMC) and contracts; equipment and technology advice; project design, construction and commissioning; vehicle and transport services and energy or utility suppliers.

Many times, energy performance of an equipment or system is adversely affected due to fact that the organization had not defined and documented energy purchasing specifications while placing the purchase order and hence, wherever applicable, the organization shall define and communicate specifications for ensuring the energy performance of procured equipment and services as well as for the purchase of energy.

5.10 Performance evaluation

5.10.1 Monitoring, measurement, analysis and evaluation of energy performance and the EnMS

5.10.1.1 General

There are a number of key characteristics that an organisation should monitor, measure and analyse to be aware of its energy performance at regular intervals. To know whether performance is improving as planned, organisation needs to monitor minimum of the key characteristics mentioned in the standard. Organization is also required to determine the methods for monitoring, measurement, analysis and evaluation, as applicable, to ensure valid results; when the monitoring and measurement shall be performed; and when the results from monitoring and measurement shall be analysed and evaluated.

The organization is supposed to evaluate its energy performance and the effectiveness of the EnMS as well as improvement in energy performance by comparing EnPI value(s) against the corresponding energy baselines.

The organization is also required to investigate and take appropriate actions to significant deviations in energy performance which could be on negative side i.e. adverse, or positive side. It is important to investigate deviations on the positive side also so as to ensure their repetition every time.

5.10.1.2 Evaluation of Compliance with legal requirements and other requirements

The organization should determine if processes for evaluating compliance with legal and other requirements (which have already been identified and planned under clause 4.2 of the standard) are in place and whether they can be adapted to address the needs of the EnMS. This process is supposed to be carried out at planned frequency and documented information is to be retained.

5.10.2 Internal audit

5.10.2.1 An internal audit of an EnMS is an objective, systematic review of all or part of an organization’s EnMS which is carried out at planned intervals. It must be remembered that internal audit of EnMS is a ‘fact finding’ exercise and not a ‘fault finding’ exercise and therefore, auditor should not look out for only finding faults. The facts which need to be found out through Internal Audit are whether the EnMS improves energy performance; conforms to the organization's own requirements for its EnMS as well as to its energy policy, objectives and energy targets established by the organization, the requirements of the ISO 50001 standard and is effectively implemented and maintained. Of course, during this fact-finding exercise, auditor may come across certain non-conformities which are required to be highlighted in the internal audit reporting.

During an internal audit, the auditors' interview relevant personnel, observe operational activities, review documents, and examine records and data.

5.10.2.2 Under this clause, organization is required to plan, establish, implement and maintain (an) audit programme(s) as per the details mentioned in the standard.

Internal audit can be carried out more frequently for areas (i) that influence energy performance substantially, (ii) where important nonconformities (NCs) have been identified in previous audits, (iii) that have experienced important changes and (iv) areas where important changes are being planned. Similarly, EnMS internal audits can be conducted less frequently for those areas that do not significantly impact energy performance or for processes that have fewer Nonconformities from previous audits. However, it is suggested that all areas and processes should undergo internal audits annually for at least first two years of EnMS implementation.

5.10.3 Management review

5.10.3.1 This is the key responsibility of top management focused on ensuring the on-going suitability, adequacy, effectiveness and alignment with the strategic direction of the organization. Management review highlights the top management on the positive outcomes as well as the weaknesses, in order to provide effective recommendations for improvements.

Management review is conducted at planned frequency, which should be at least once a year, within which corrective action can be taken and appropriate systems adjustments can be made. All records pertaining to management review meetings are required to be maintained.

5.10.3.2 Minimum Agenda for the management review meeting is a status regarding action from previous management review, changes in internal and external issues and associated risks opportunities relevant to EnMS, Internal as well as external audit results, existing energy policy appropriateness in the present circumstances, review of the compliance of legal and other requirements, opportunities for continual improvement and competence, monitoring and measurement results, status of nonconformities and corrective actions etc.

5.10.3.3 Management review is also supposed to review in depth analysis of the extent to which objectives and energy targets have been met; energy performance and energy performance improvement based on monitoring and measurement results including the EnPI (s) and status of the action plans.

5.10.3.4 It is subsequently the task of top management to take decision related to continual improvement opportunities and need to changes in the EnMS which will indicate the organization's energy performance in complete and best possible manner, how improvement in energy performance is progressing, any changes in the energy policy, EnPIs, EnB(s), objectives, targets and action plans, allocation of resources, the improvement of competence, awareness and communication etc.

5.11 Improvement

5.11.1 Nonconformity and corrective action

Non fulfilment of a requirement is Nonconformity. This requirement could be of ISO 50001 standard, of the EnMS which organization has prepared, or of its operation control etc. In simple words any deviation from specified norms is Nonconformity.

When a nonconformity is detected, the first step is to take appropriate action to resolve the immediate situation and it is known as correction, e.g. reduction in air pressure to a level affecting the plant operation due to dirty filter in an air compressor is a nonconformity and to clean or replace the filter is the correction which will restore the correct air pressure, i.e. nonconformity will get eliminated.

However, taking correction may not be enough and nonconformity may reoccur until and unless, investigation is carried out to find out its root cause and then, action is taken to eliminate the root cause of the problem. This is known as the corrective action. In other words, action taken to prevent reoccurrence of a detected nonconformity is corrective action. In the above example of compressed air, corrective action would be to determine why filter got dirty and to address the root cause to prevent its reoccurrence. For example, filter might be dirty due to its location in a dusty room and relocating it in a cleaner room or outside the room will be the corrective action.

Taking correction and corrective action should not be confined to internal or external audits only as normally perceived and carried out. Several other sources like results of evaluations of compliance reviews, failure to reach specified targets in monitoring and measurement processes, failure to comply with operational control procedures, repeated significant deviations, routine inspection of the plant etc should also be considered for raising non-conformities. In other words, any activity not happening as per norms in day today activity of the organization is also nonconformity and hence, Nonconformity can be raised on it calling for correction and corrective action to take place.

Addressing NCs should be seen as a part of continual improvement process and these give the opportunities to an organization for making improvement. Corrective actions are so important for the organization that their status is reviewed by top management in every Management Review Meeting.

5.11.2 Continual improvement

As committed in the energy policy, the organization is required to continually improve the suitability, adequacy and effectiveness of the EnMS and also continually improve its energy performance. Demonstrating continual energy performance improvement across the scope and within the boundaries of the EnMS does not mean all EnPI values improve. Some EnPI values improve, and others do not; but across the scope of the EnMS, the organization demonstrates energy performance improvement.

Summary

From time to time, organization needs to review its entire EnMS journey as to where it wanted to be, what was the situation, what was planned, what needed to be done, whether it has reached there and ultimately what next to improve continually as shown in Figure 5.8.

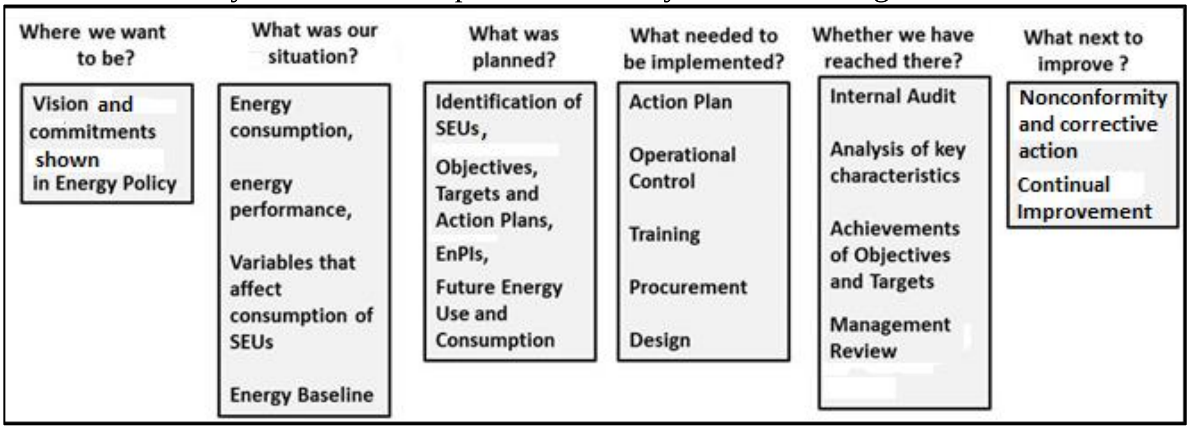


Figure 5.8: EnMS Journey Review

Chapter 6: Project Management

6.1 What is a Project?

A project is a "temporary endeavour undertaken to create a unique product or service".

Projects are temporary because they have a definite beginning and a definite end. They are unique because the product or service they create is different in some distinguishing way from similar products or services.

Designing, installation and commissioning of a cogeneration system in an industry is an example of a project. The unique work is defined by the cogeneration system and has a specific beginning and end. A project manager is responsible for the project, overseeing the contractors and managing the schedule and budget.

Projects are means for change. Such change can be sought or it can be resisted. Changing practices or investing money for energy efficiency is an occurrence of change. Fortunately, energy related projects generally have low risk attached to both the means of achieving change and result of that change. The energy manager should seek opportunities to save energy and aim to influence all projects in which energy is a significant factor. It may be that, in the early stages, an energy benefit will add to the arguments in favour of the project. Investment in energy efficiency is also good publicity news that can be given to customers and media.

Project management is a set of principles, methods, and techniques that people use to effectively plan and control project work. Project management principles and techniques help complete projects on schedule, within budget, and in full conformance to project specifications. At the same time, they help achieve the other goals of the organization, such as productivity, quality, and cost effectiveness. The objective of project management is to optimize project cost, time, and quality.

6.2 Project Development Cycle (PDC)

The various steps in the PDC are:

1. Project Identification and Screening
2. Technical Design
3. Financing
4. Contracting
5. Implementation
6. Performance Monitoring

Project Identification and Screening

The first step in the project development cycle is to identify components of the project. Projects may be identified both internally and externally:

- ✓ Internal identification takes place when the facility manger identifies a package of energy saving opportunities during the day-to-day energy management activities, or from detailed energy audits.

- ✓ External identification of energy savings can occur through systematic energy audits undertaken by a reputable energy management consultant, energy service company or industry organization.

In screening projects, the following criteria should be used to rank project opportunities:

- ✓ Economic feasibility of energy savings measures (Internal rate of return, net present value, cash flow, average payback)
- ✓ Sustainability of the savings over the life of the equipment.
- ✓ Ease of quantifying, monitoring, and verifying energy savings.
- ✓ Availability of technology, and ease of adaptability of the technology to Bangladeshi conditions.
- ✓ Other environmental and social cost benefits (such as reduction in GHG emissions and local pollutants such as SOx emissions)

Technical Design

For a project to be considered a viable investment, the project proponent must present a sound technical feasibility study that identifies the following elements in detail:

- ✓ The proposed new technologies, process modifications, equipment replacements and other measures included in the project.
- ✓ Product/technology/material supply chain (e.g., locally available, imported, reliability of supply)
- ✓ Any special technical difficulties (installation, maintenance, repair), associated skills required.
- ✓ Preliminary designs, including schematics, for all major equipment needed, along with design requirements, manufacturer's name and contact details, and capital cost estimate.
- ✓ Organizational and management plan for implementation, including timetable, personnel requirements, staff training, project engineering, and other logistical issues.

Financing

When considering a new project, it should be remembered that other departments in the organization would be competing for capital for their projects. However, it is also important to realize that energy efficiency is a major consideration in all types of projects, whether they are:

- ✓ Projects designed to improve energy efficiency
- ✓ Projects where energy efficiency is not the main objective, but still plays a vital role.

Most organization reaches the point when all the obvious measures to save energy have been taken and capital investment is needed to make further savings. Low cost measures for saving energy, which can be treated as mini projects in their own rights, should be given top priority. It is necessary to ensure that the present system is operating efficiently before spending any money.

If all the projects in a portfolio of applications to top management are within the policy and the procedures of the organization, then the one chosen for approval is likely to be the one, which gives the best return on the investment, and which is best presented. Many organizations have a priority list which gives preference to capital expenditure on projects offering certain advantages or removing particular disadvantages.

Project funds can be obtained from either internal or external sources.

Internal sources include:

- ✓ Direct cash provision from company reserves
- ✓ Revenue budget (if payback is less than one year)
- ✓ New share capital

External sources of funds include:

- ✓ Bank loans
- ✓ Leasing arrangement
- ✓ Payment by savings i.e. a deal arranged with equipment supplier
- ✓ Energy services contract
- ✓ Private finance initiative

Before applying for project fund, all the options for funding the project are discussed with finance managers. Often, energy savings improve Viability of non-energy projects.

The availability of external funds depends on the nature of your organization. The finance charges on the money borrowed will have an impact on the validity of the project.

If outside financing is sought for an energy management project, it may be obtained from a private bank, or from one of the special financing programs offered by national development banks and other funding agencies. In addition to the usual information on company assets and lines of credit, financial agencies will require an assessment of the financial feasibility of the proposed project. This should include a fully specified proforma financial worksheet that presents project cash flows, net present value, and internal rate of return.

Contracting

Since a substantial portion of a project is typically executed through contracts, the proper management of contracts is critical to the successful implementation of the project. In this context, the following should be taken care.

- ✓ The competence and capability of all the contractors must be ensured-one weak link can affect the timely performance of the contract.
- ✓ Proper discipline must be inculcated among contractors and suppliers by insisting that they should develop realistic and detailed resource and time plans that are matching with the project plan.
- ✓ Penalties-which may be graduated-must be imposed for failure to meet contractual obligations. Likewise, incentives may be offered for good performance.
- ✓ Help should be extended to contractors and suppliers when they have genuine problems-they should be regarded as partners in a common pursuit.
- ✓ Project authorities must retain independence to off-load contracts (partially or wholly)

to other parties well in time where delays are anticipated.

If the project is to be implemented by an outside contractor, several types of contract may be used to undertake the installation and commissioning:

- ✓ Traditional Contract: All project specifications are provided to a contractor who buys and installs equipment at fixed price or cost plus a mark-up. Also called as fixed-price or lump sum contract, the contractor takes the risk of unforeseen problems in exchange for a larger profit. This type of contract is appropriate when dealing with unknown vendors or when project manager anticipates the work is risky.
- ✓ Extended Technical Guarantee/Service: The contract offers extended guarantees on the performance of selected equipment, and/or offers service/maintenance agreements.
- ✓ Extended Financing Terms: The contractor provides the option of an extended lease or other financing vehicle in which the payment schedule can be based on the expected savings.
- ✓ Guaranteed Saving Performance Contract: All or part of savings is guaranteed by the contractor, and all or part of the costs of equipment and/or services is paid down out of savings as they are achieved.
- ✓ Shared Savings Performance Contract: The contractor provides the financing and is paid an agreed fraction of actual savings as they are achieved. This payment is used to pay down the debt costs of equipment and/or services.

Implementation

A great deal of the emphasis in the planning stage of any project is on understanding where and when problems may occur. Many projects introduced by energy managers end up as some other manager's responsibility, 6.g. a production manager or a works engineer. The following needs to be thought ahead and anticipated.

- ✓ Type and extent of measurements needed to control and measure the success of the project
- ✓ Winning the confidence and cooperation of key personnel involved.
- ✓ Timely and frequent communication between participants.

With proper techniques, changes and modifications in project can be understood and incorporated without loss of control.

Before considering the components of a plan, its purpose must be defined. A plan turns a proposed project into reality. As reality often differs from theory, the plan should consider as many technical, financial and other 'what ifs' as possible.

Performance Monitoring

In order to keep a tab on the progress of the project, a system of monitoring must be established. This helps in:

- ✓ Anticipating deviations from the implementation plan
- ✓ Analyzing emerging problems

- ✓ Taking corrective action

In developing a system of monitoring, the following points must be borne in mind:

- ✓ It should focus sharply on the critical aspects of project implementation.
- ✓ It must lay more emphasis on physical milestones and not on financial targets.
- ✓ Monitoring must be kept simple.

Project Review

Once the project is commissioned the review phase has to be set in motion. Performance review should be done periodically to compare actual performance with projected performance. A feedback device, it is useful in several ways:

a) It throws light on how realistic were the assumptions underlying the project
b) It provides a documented log of experience that is highly valuable in future decision making
c) It suggests corrective action to be taken in the light of actual performance
d) It helps in uncovering judgmental biases

6.3 Project Planning Techniques

To achieve control of a project, it is necessary to plan. For more complex projects, the more advanced planning methods are needed. Many project management software packages are available with detailed operational manuals.

Work Breakdown Structure (WBS)

Work Breakdown Structure (WBS) is the process of dividing complex projects to simpler and manageable tasks. The project managers use this method for simplifying the project execution. In WBS, much larger tasks are broken down to manageable chunks of work. These chunks can be easily supervised and estimated.

First main deliverable of a project is identified and then the higher levels tasks are broken into smaller chunks of work. In the process of breaking down the tasks, one can break them down into different levels of detail. The level of breakdown detail depends upon project type and the management style followed for the project. WBS can be displayed using tree structure or list or tables.

WBS is developed before dependencies are identified and activity durations are estimated. The WBS can be used to identify the tasks before constructing Gantt chart and networks such as Critical Path Method -CPM and Program Evaluation and Review Technique— PERT.

Gantt chart

During the era of scientific management, Henry Gantt developed a tool for displaying the progress of a project in the form of a specialized chart. An early application was the tracking of the progress of ship building projects. Today, Gantt's scheduling tool takes the form of a horizontal bar graph and is known as a Gantt chart.

Gantt chart is now commonly used for scheduling the tasks and tracking the progress of energy management projects. Gantt charts are developed using bars to represent each task. The length of the bar shows how long the task is expected to take to complete. The duration is easily shown on Gantt charts.

A basic sample for a pumping station is shown in Figure 6.1. The horizontal axis of the Gantt chart is a time scale, expressed either in absolute time or in relative time referenced to the beginning of the project. The time resolution depends on the project - the time unit typically is in weeks or months. Rows of bars in the chart show the beginning and ending dates of the individual tasks in the project.

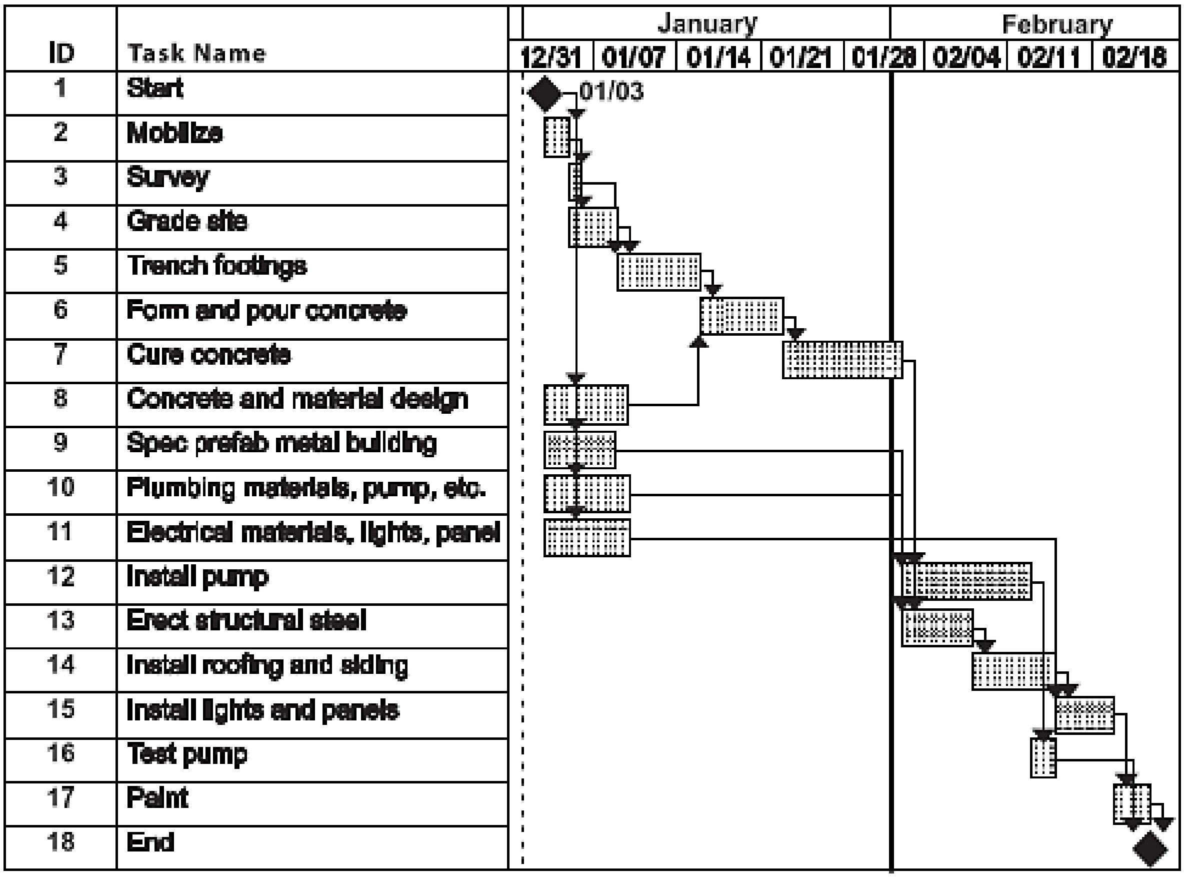


Figure 6.1: Gantt chart for a Pumping Station

In the example in Figure 6.1, each task is shown to begin when the task preceding it completes. However, the bars may overlap in cases where a task can begin before the completion of another, and there may be several tasks performed in parallel. For such cases, the Gantt chart is quite useful for communicating the timing of the various tasks.

Limitation of Gantt chart

The Gantt chart does not normally show the logical interdependencies between the predecessor and successor activities very well. Such requirements are best served by the network diagram, which shows logic clearly but does not have a time scale axis like the Gantt chart.

Gantt Chart Enhancement

This basic version of the Gantt chart is often enhanced to communicate more information.

- ✓ A vertical marker can used to mark the present point in time (If a vertical line is drawn through a given day, the activities that are scheduled to be taking place simultaneously will have the line pass through them. In this way the need for simultaneous resources can clearly be seen).
- ✓ The progression of each activity may be shown by shading the bar as progress is made, allowing the status of each activity to be known with just a glance.
- ✓ Dependencies can be depicted using link lines or color codes.
- ✓ Resource allocation can be specified for each task.
- ✓ Milestones can be shown.

Project Networking Techniques

Project network shows dependency relationships between tasks/activities in a project in a graphical View. It shows clearly tasks that must precede or succeed other tasks in a logical manner. It is a powerful tool for planning and controlling project

Network Definitions

Activity: Any portions of project (tasks) which required by project, uses up resource and consumes time.

Event: Beginning or ending points of one or more activities are called 'nodes'

Network: Combination of all project activities and the events

Two ways of representing activities are activity-on-arrow (AOA) and activity-on-node (AON).

Activity-on-arrow (AOA) is represented by the activities on arrows which are connected at events (nodes shown as circles) to show the dependencies (preceding or succeeding) as shown in Figure 6.2.

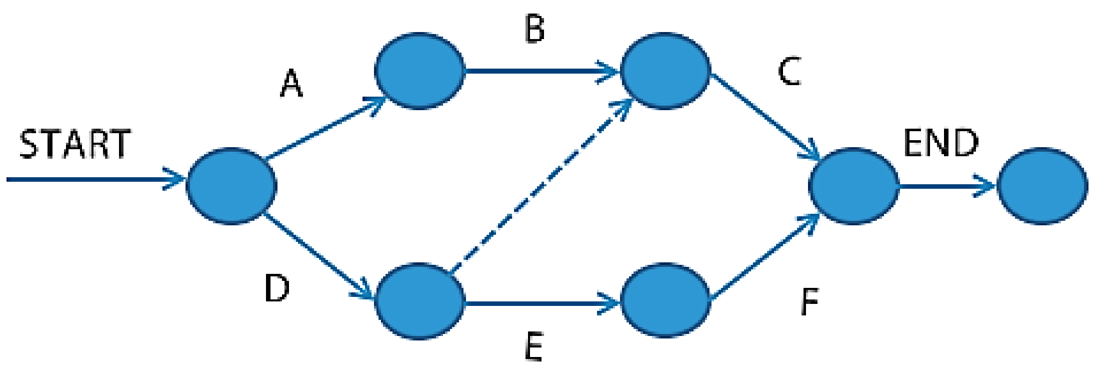


Figure 6.2: Activity-On-Arrow Method

Activity-on-node (AON) is represented as nodes on the network and events that signify the beginning or ending of activities are depicted as arcs or lines between the nodes as shown in

Figure 6.3. This method is used in project management software packages.

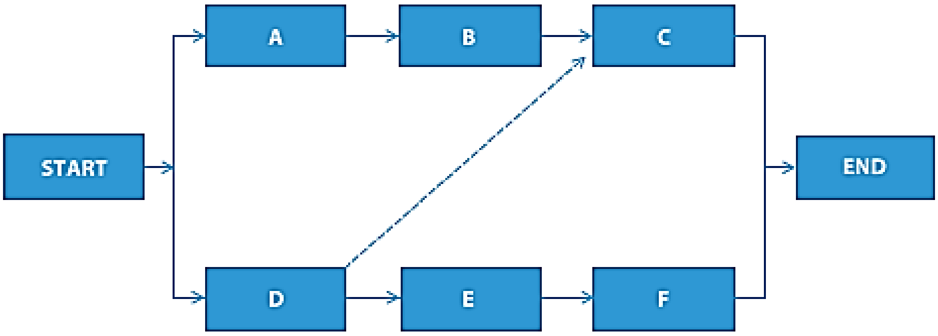


Figure 6.3: Activity-On-Node Method

Dummy activity is required if two or more activities having identical starting and ending events. In above Figures, it is shown as dotted line to ensure that activity C starts only after activity B and activity D are completed.

Critical Path Method (CPM)

In 1957, DuPont developed a project management method designed to address the challenge of shutting down chemical plants for maintenance and then restarting the plants once the maintenance had been completed. Given the complexity of the process, they developed the Critical Path Method (CPM) for managing such projects.

CPM provides the following benefits:

- ✓ Provides a graphical View of the project.
- ✓ Predicts the time required to complete the project.
- ✓ Shows which activities are critical to maintaining the schedule and which are not.

Steps in CPM Project Planning

1. Specify the individual activities
2. Determine the sequence of those activities.
3. Draw a network diagram.
4. Estimate the completion time for each activity.
5. Identify the critical path (longest path through the network)
6. Update the CPM diagram as the project progresses.

1. Specify the Individual Activities

From the work breakdown structure, list the activities in the project. The project (made up of several tasks) should have only a single start activity and a single finish activity.

2. Determine the Sequence of the Activities

Develop the relationship among the activities. Decide which activities must precede and which must follow others.

3. Draw the Network Diagram

Draw the "Network" once all the activities and their sequencing have been defined. Network diagram originally was developed as an activity on node (AON) network, but some project planners prefer to specify the activities on the arrow.

4. Estimate Activity Completion Time

Assign time and/or cost estimates to each activity using past experience or the estimates of knowledgeable persons.

CPM is a deterministic model that does not take into account variation in the completion time, so one fixed time is used for an activity.

5. Identify the Critical Path

The critical path is the longest-duration path through the network. The significance of the critical path is that the activities that lie on it cannot be delayed without delaying the project. Because of its impact on the entire project, critical path analysis is an important aspect of project planning.

The critical path can be identified by determining the following four parameters for each activity:

- ✓ ES - Earliest start time: the earliest time at which the activity can start given that its precedent activities must be completed first.
- ✓ EF - Earliest finish time: equal to the earliest start time for the activity plus the time required to complete the activity.
- ✓ LF - Latest finish time: the latest time at which the activity can be completed Without delaying the project.
- ✓ LS - Latest start time, equal to the latest finish time minus the time required to complete the activity.

The total float (slack time) for an activity is the time between its earliest and latest start time, or between its earliest and latest finish time. Slack is the amount of time that an activity can be delayed past its earliest start or earliest finish without delaying the project.

The critical path is the path through the project network in which none of the activities have slack, that is, the path for which ES=LS and EF=LF for all activities in the path. A delay in the critical path delays the project. Similarly, to accelerate the project it is necessary to reduce the total time required for the activities in the critical path.

6. Update CPM Diagram

As the project progresses, the actual task completion times will be known and the network diagram can be updated to include this information. A new critical path may emerge, and structural changes may be made in the network if project requirements change.

Example 6.1 Illustration of CPM

WBS of a project is given in Table 6.2.

Table 6.2: WBS for a Project

Activity	Immediate Predecessor	Completion Time (weeks)
A	-	5
B	-	6
C	A	4
D	A	3
E	A	1
F	E	4
G	D,F	14
H	B,C	12
I	G,H	2

The information in WBS indicates that the total time required to complete activities is 51 weeks. However, it can be seen from the network that several of the activities can be conducted simultaneously (A and B, for example). It is necessary to calculate critical path of the network.

Earliest Start Time and Earliest Finish Time

We can do a forward pass calculations. Starting at the network's origin (node 1) and using a starting time of 0, we compute an earliest start (ES) and earliest finish (EF) time for each activity in the network. The expression EF = ES + t can be used to find the earliest finish time for a given activity. The completion time or the duration of an activity is represented as t.

For example, for activity A, ES = 0 and t = 5; thus the earliest finish time for activity A is EF = 0 + 5 = 5. Refer Figure 6.4.

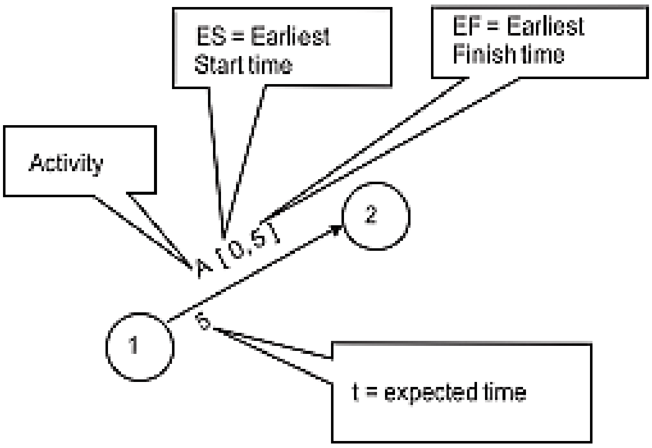


Figure 6.4: Early Start Time and Early Finish Time

Completing the network from start based on above (Forward pass), we can calculate all ES and

EF time as shown in Figure 6.5.

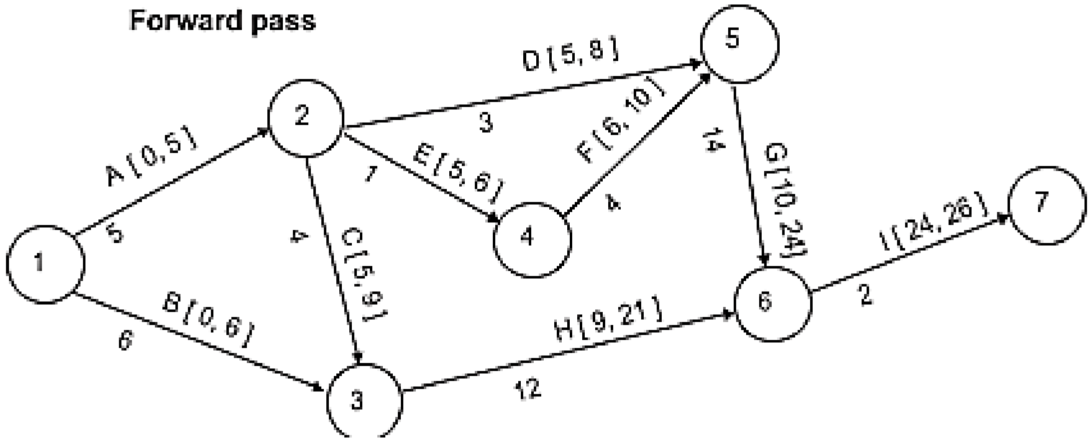


Figure 6.5: Network with ES and EF time in Forward Pass

[Earliest start time rule:

The earliest start time for an activity leaving a particular node is equal to the largest of the earliest finish times for all activities entering the node]

Similarly, we can do a backward pass calculation. Starting at the completion point (node 7) and using a latest finish time (LP) of26 for activity I, we trace back through the network computing a latest start (LS) and latest finish time for each activity.

The expression LS = LF — t can be used to calculate latest start time for each activity. For example, for activity I, LF = 26 and t = 2, thus the latest start time for activity I is LS = 26 -2 = 24.

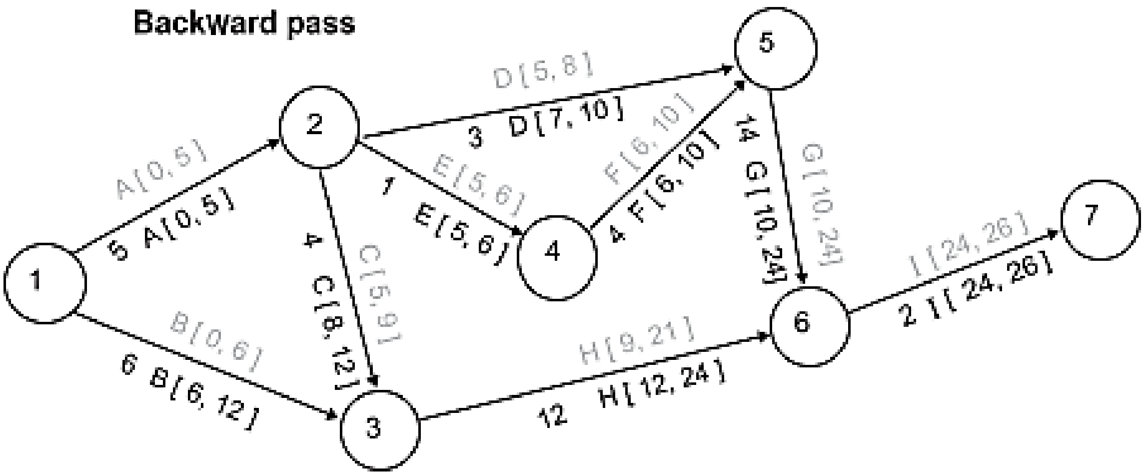


Figure 6.6: Network with LS and LF time in Backward Pass

[Latest finish time rule:

The latest finish time for an activity entering a particular node is equal to the smallest of the latest start times for all activities leaving the node.]

Float or Slack or Free Time

Slack is the length of time an activity can be delayed without affecting the completion date for the entire project. For example, slack for C = 3 weeks, i.e Activity C can be delayed up to 3 weeks {LS (8 weeks) — ES (5 weeks) or LF (12 weeks) — EF (9 weeks) = 3 weeks} as given in Figure 6.6.

Float or slack shows how much allowance each activity has i.e. how long it can be delayed without affecting the completion date of the project. Critical path is a sequence of activities from start to finish with zero slack. Critical activities are activities on the critical path.

Critical path identifies the minimum time to complete project. If any activity on the critical path is shortened or extended, project time will be shortened or extended accordingly. If resources have to be spent to speed up some activities, it should be only for critical activities. Such shortening or project in critical path by adding resources is called project crashing. If resources have to be saved by lengthening some activities, it should be only for non-critical activities, up to the limit of float.

Table 6.3: Summary of Project Calculations

Activity	Duration (weeks)	Earliest Start ES	Earliest Finish EF	Latest Start LS	Latest Finish LF	Float or Slack LS-ES or LF-EF	Critical Path
A	5	0	5	0	5	0	Yes
B	6	0	6	6	12	6	
C	4	5	9	8	12	3	
D	3	5	8	7	10	2	
E	1	5	6	5	6	0	Yes
F	4	6	10	6	10	0	Yes
G	14	10	24	10	24	0	Yes
H	12	9	21	12	24	3	
I	2	24	26	24	26	0	Yes

The total time to complete the activities is 26 weeks. The activities which are critical and must be completed to keep the project within schedule are A, E, F, G, and I. Non-critical activities can be delayed before they cause delay in project completion time as per float or slack shown against each activity shown in Table 6.3.

Program Evaluation and Review Technique (PERT)

The Program Evaluation and Review Technique (PERT) is a probabilistic network model that allows for randomness in activity completion times. PERT was developed in the late 1950’s for the US. Navy’s Polaris project having thousands of contractors. It has the potential to reduce both the time and cost required to complete a project.

PERT steps are similar to CPM with only difference as to the estimation of time. Unlike CPM where times can be estimated with relative certainty, confidence, PERT uses 3 time estimates.

T_m= most likely time estimate
T_0 = optimistic time estimate
T_p = pessimistic time estimate

PERT assumes a normal bell-shaped distribution (beta probability distribution) for the time estimates. For a beta distribution, the expected time for each activity can be approximated using the following weighted average:

Expected time = (Optimistic + 4 x Most likely + Pessimistic) / 6

Expected Time $(T_e) = \frac{(T_0 + 4T_m + T_P)}{6}$

Standard Deviation $(\sigma) = \frac{(T_p - T_o)}{6}$

Variance $(V) = \left\{\frac{T_p - T_0}{6}\right\}^2$

The variance in the project completion time can be calculated by summing the variances in the completion times of the activities in the critical path. Given this variance, one can calculate the probability that the project will be completed by a certain date assuming a normal probability distribution for the critical path. The normal distribution assumption holds if the number of activities in the path is large enough.

The calculation procedure is similar to CPM. The expected times may be displayed on the network diagram. The various times are calculated using the expected time for the relevant activities. The earliest start and finish times of each activity are determined by working forward through the network and determining the earliest time at which an activity can start and finish considering its predecessor activities.

The latest start and finish times are the latest times that an activity can start and finish without delaying the project. LS and LF are found by working backward through the network. The difference in the latest and earliest finish or latest and earliest start of each activity is that activity's slack. The critical path then is the path through the network in which none of the activities have slack.

Example 6.2 Illustration of PERT

For the following project details (Table 6.4), PERT chart has to be prepared.

Table 6.4 Project Details

Activity	Immediate Predecessor	Optimistic Time *To*	Most Likely Time *Tm*	Pessimistic Time *Tp*	Expected Time *Te*	σ	V
ⓐ	-	10	22	22	20	2	④
b	-	20	20	20	20	0	0
c	-	4	10	16	10	2	4
ⓓ	a	2	14	32	15	5	㉕
e	b,c	8	8	20	10	2	4
f	b,c	8	14	20	14	2	4
g	b,c	4	4	4	4	0	0
h	c	2	12	16	11	2.32	5.4
i	g,h	6	16	38	18	5.33	28.4
ⓙ	d,e	2	8	14	8	2	④

PERT Network diagram showing activities, ES, EF in forward pass is shown in Figure 6.7.

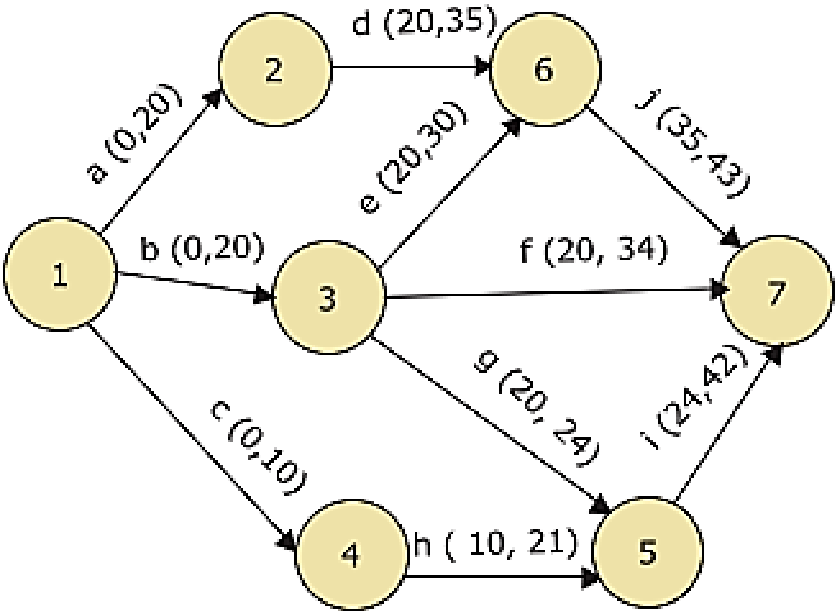


Figure 6.7: ES and EF for Network in Forward Pass

PERT Network diagram showing LS, LF in backward pass is shown in the Figure 6.8.

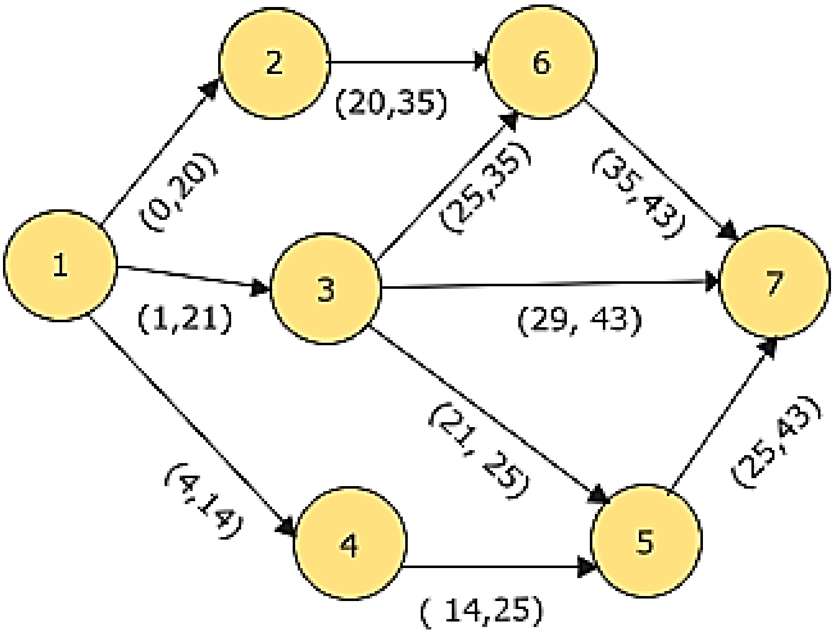


Figure 6.8: LS and LF for Network in Backward Pass

The details of network calculations from forward and backward pass are summarized in Table 6.5

Table 6.5 Summary of Project Calculations

Activity	Expected Time	Earliest Start ES	Earliest Finish EF	Latest Start LS	Latest Finish LF	Float or Slack LS-ES or LF-EF	Critical Path
a	**20**	**0**	**20**	**0**	**20**	**0**	**Yes**
b	20	0	20	1	21	1	
c	10	0	10	4	14	4	
d	**15**	**20**	**25**	**20**	**35**	**0**	**Yes**
e	10	20	30	25	35	5	
f	14	20	34	29	43	9	
g	4	20	24	21	25	1	
h	11	10	21	14	25	4	
i	18	24	42	25	43	1	
j	**8**	**35**	**43**	**35**	**43**	**0**	**Yes**

Critical path: a, d, j = 43 days

Such PERT chart is not final. It may be necessary to make adjustment in PERT chart as project progresses. As the project unfolds, the estimated times can be replaced with actual times. In cases where there are delays, additional resources may be needed to stay on schedule and the PERT chart may be modified to reflect the new situation.

Benefits of PERT

PERT is useful because it provides the following information:

- ✓ Expected project completion time.
- ✓ Probability of completion before a specified date.
- ✓ The critical path activities that directly impact the completion time
- ✓ The activities that have slack time and that can lend resources to critical path activities.
- ✓ Activities start and end dates.

Limitations of PERT

- ✓ The activity time estimates are somewhat subjective and depend on judgment.
- ✓ Even if the activity times are well-estimated, PERT assumes a beta distribution for these time estimates, but the actual distribution may be different.
- ✓ Even if the beta distribution assumption holds, PERT assumes that the probability distribution of the project completion time is the same as that of the critical path. Because other paths can become the critical path if their associated activities are delayed, PERT consistently underestimates the expected project completion time.

6.4 Implementation Plan for Top Management

Implementation is the stage where all the planned activities are put into action. Before the implementation of a project, the top management should identify their strength and weaknesses (internal forces), opportunities and threats (external forces).

The strength and opportunities are positive forces that should be exploited to efficiently implement a project. The weaknesses and threats are hindrances that can hamper project implementation. The implementers should ensure that they devise means of overcoming them.

Monitoring is important at this implementation phase to ensure that the project is implemented as per the schedule. This is a continuous process that should be put in place before project implementation starts.

As such, the monitoring activities should appear on the work plan and should involve all stake holders. If activities are not going on well, arrangements should be made to identify the problem so that they can be corrected. When implementation of the project is not on target, there is a need for the project managers to ask themselves and answer the question, “How best do we get there?”

The implementation plan should include a project schedule or timeline. The level of detail included in a schedule depends upon the role of individual on the project. The Table 6.6 shows an example of high-level schedule that was developed by boiler engineer.

Table 6.6: Sample of Project Schedule

Date of Completion	Milestone
June 1	Delivery of boiler components
July 25	Completion of erecting
August 10	Completion of auxiliaries
August 15	Boiler testing and commissioning

6.5 Planning Budget

The project budget will be used throughout the remainder of the project to track project, expenses and measure the money actually spent on project activities against the estimates given for those activities. The final budget figures are based on estimates provided by the project team, key stakeholders, vendors, and others after careful review of the Planning documents.

Most of the costs expended on the project, known as project costs, are fairly obvious and apply to most projects. For example, salaries, office supplies, and telephone charges will apply to almost all projects.

These project costs and most others fall into one of three categories: human resource costs, administrative costs, or resource costs
.
Human Resource Costs are the costs associated with the personnel on the project. They include salaries and the cost of benefits (such as vacation rime and health insurance).

Administrative costs are the everyday costs that support the work of the project but are not necessarily directly related to a specific task on the project. Local telephone expense, copier paper, heating expenses, and support personnel are examples of administrative costs.

Resource costs include things such as materials needed for specific tasks, equipment leases, long- distance telephone expense, travel expenses, and so on. These expenses are specific to the project.

Direct Costs versus Indirect Costs

In addition to the three categories of project costs, there are also two types of costs: direct and indirect costs. Direct costs include costs such as salaries, equipment rentals, and training for team members. Any cost that can be directly attributed to project work is a direct cost.

Indirect costs are not specific to the project. For example, project team may work with other members of the organization (who are not working on the project) in the same building. The lease cost for the building is an example of an indirect cost because it is not specifically related to the project since all the company employees work there.

Another example of an indirect cost is administrative staff, managers, or other functional members who will be assisting the project team with project activities (such as someone from the procurement department) but are not assigned tasks themselves. Each organisation has its own procedures for accounting for indirect costs. Finance or Accounting Department can provide guidance on how indirect cost should be accounted for in the project budget.

Budget Estimation

If the project ends up as an unsuccessful project, one of the reasons could be inadequate budget. The responsibility for determining project cost lies mostly with finance manager and he gets approval from senior management. The project manager is told about the final budget and is expected to work with the allocated budget. If this is the case, project manager can contribute to budgeting process by using his communication and negotiation skills with finance manager. The first step in creating the project budget is to gather all the Planning documents for reference. The project goals and deliverables for obvious budget expenses have to be reviewed. The WBS, network diagram also has to be reviewed to identify costs associated with them.

The WBS is used to identify, estimate, and assign costs to each element of the project. The work package level is where individual costs and estimates for each task (provided the work package level shows tasks) are shown, whereas the higher levels in the WBS will show rolled-up total costs.

Analogous Estimating establishes an estimate for the current project based on the actual costs of previous projects that are similar in size and scope to the ongoing project. Bottom-up Estimating establishes individual estimates for each tasks and adds them all together to determine the total estimate for the project.

6.6 Procurement Procedures

Many organizations have a procurement department that will help you purchase the items needed for your protect. They may also help you create the budget. Always check with the procurement department to determine whether there are procedures you should follow when preparing your budget. Also be certain to work with the procurement department when purchasing services from vendors or contractors.

6.7 Construction

Project construction is the process of assuring that all systems and components of an industrial equipment are designed, installed, tested, operated, and maintained according to the operational requirements of the user. A commissioning process may be applied not only to new projects but also to existing units and systems subject to expansion, renovation or revamping.

In practice, the commissioning process comprises the integrated application of a set of engineering techniques and procedures to check, inspect and test every operational component of the project, from individual functions, such as instruments and equipment, up to complex amalgamations such as modules, subsystems and systems.

Commissioning activities, in the broader sense, are applicable to all phases of the project, from the basic and detailed design, procurement, construction and assembly, until the final handover of the unit to the owner, including sometimes an assisted operation phase.

6.8 Measurement and Verification

Measurement and Verification (M&V), sometimes also referred to as monitoring and verification, is a process, which is used to determine energy and demand savings. The primary application of M&V is in those energy efficiency projects where the return on the capital investment is tied to the projected energy savings that will be achieved. M&V becomes a central part of a contract if the contract payments or performance guarantee in a project are dictated by the magnitude of the energy savings that will result from the implementation of a set of energy efficiency measures. M&V is primarily focused on risks that affect the measurement or determination of savings from energy or water efficiency programs. These risks are defined in the terms of the contracts between the participants.

Energy or demand savings are determined by comparing measured energy use or demand before and after implementation of an energy savings program. In general:

$$\begin{aligned}\textbf{\textit{Energy Savings}} \\ &= \textbf{\textit{Base year Energy Use}} - \textbf{\textit{Post}} - \textbf{\textit{Retrofit Energy Use}} \\ &\pm \textbf{\textit{Adjustments}}\end{aligned}$$

The "Adjustments" term in this general equation brings energy use in the two time periods to the same set of conditions. Conditions commonly affecting energy use are weather, occupancy, plant throughput, and equipment operations required by these conditions. Adjustments may be positive or negative.

Adjustments are derived from identifiable physical facts. The adjustments are made either routinely such as for weather changes, or as necessary such as when a second shift is added, occupants are added
to the space, or increased usage of electrical equipment in the building. Adjustments are commonly made to restate base year energy use under post-retrofit conditions.

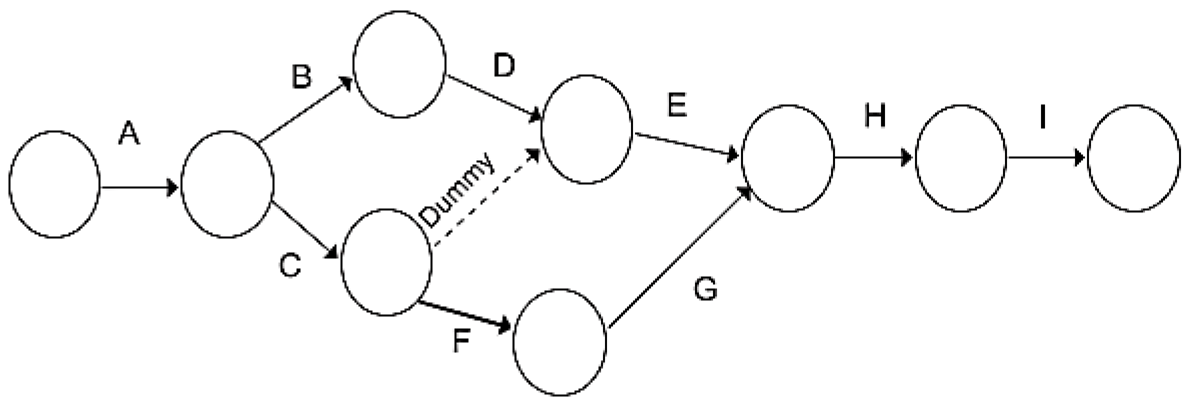
Example 6.3

For the following tasks, durations, and predecessor relationships in the following activity table,

Activity Description	Immediate Predecessor(s)	Optimistic (Weeks)	Most Likely (Weeks)	Pessimistic (Weeks)
A	---	4	7	10
B	A	2	8	20
C	A	8	12	16
D	B	1	2	3
E	D, C	6	8	22
F	C	2	3	4
G	F	2	2	2
H	E, G	4	8	12
I	H	1	2	3

a) Draw the network
b) Calculate expected time for all tasks
c) Calculate variance for all tasks

(d) Determine all possible paths and their estimated durations
e) Identify the critical path
Solution:
a) Network diagram is shown below:



(b) & (c) Expected Time & Variance:

$$T_e = \frac{T_O + 4\,T_m + T_p}{6}$$

$$\sigma = \frac{T_p - T_o}{6}$$

$$V = \left(\frac{T_p - T_o}{6}\right)^2$$

Activity Description	Immediate Predecessor(s)	Optimistic (Weeks)	Most Likely (Weeks)	Pessimistic (Weeks)	Expected Time T_e	Variance (V)
A	---	4	7	10	7	1.00
B	A	2	8	20	9	9.00
C	A	8	12	16	12	1.78
D	B	1	2	3	2	0.11
E	D, C	6	8	22	10	7.11
F	C	2	3	4	3	0.11
G	F	2	2	2	2	0.00
H	E, G	4	8	12	8	1.78
I	H	1	2	3	2	0.11

d)

A - B – D – E – H –I	7+9+2+10+8+2 = 38
A – C – E – H – I	**7+12+10+8+2 = 39**
A – C – F – G – H – I	7+12+3+2+8+2 = 34

The critical path is A— C — E — H — I

e) Duration of critical path is 39 weeks.

Chapter 7: Energy Monitoring, Targeting and Reporting

7.1 Introduction

Energy monitoring and targeting is primarily a management technique that uses energy information as a basis to eliminate waste, reduce and control current level of energy use and improve the existing operating procedures. It builds on the principle "you can't manage what you don't measure". It essentially combines the principles of energy use and statistics.

Energy monitoring, target setting, and reporting (MT&R) is the activity which uses information on energy consumption as a basis for control and managing consumption. The three component activities are distinct yet inter-related:

7.2 What is Monitoring and Targeting?

Monitoring is the regular collection of information on energy use. Its purpose is to establish a basis of management control, to determine when and why energy consumption is deviating from an established pattern, and as a basis for taking management action where necessary. Monitoring is essentially aimed at sustaining an established pattern.

Effective monitoring involves regular collection of energy and related variable for example production, analysis of data and investigation of deviation from expected performance using some performance model.

Targeting or Target setting is the identification of desirable energy consumption level and working towards achieving them. Targets are based on the historical (average or best) data acquired during the monitoring as well as benchmarking with energy performance of similar organisations.

Reporting involves “closing the loop” by putting the management information generated from the monitoring process in a form that enables ongoing control of energy use, the achievement of reduction targets, and the verification of savings.

It is putting information in a form that drives action to control energy use and achieve targets.

Monitoring and target setting have elements in common and they share much of the same information. As a general rule, however, monitoring comes before target setting because without monitoring you cannot know precisely where you are starting from, or decide if a target has been achieved. The reporting phase not only supports management control, but also provides for accountability in the relationship between performance and targets.

Monitoring and Targeting is a management technique in which all utilities such as fuel, steam, refrigeration, compressed air, water, effluent, and electricity are managed as controllable resources in the same way that raw materials, finished product inventory are managed.

It involves a systematic, disciplined division of the facility into Energy Cost Centres. The utilities used in each centre are closely monitored, and the energy used is compared with production volume or any other suitable measure of operation. Once this information is available on a regular basis, targets can be set, variances can be spotted and interpreted, and remedial actions can be taken and implemented.

The Monitoring and Targeting programs have been so effective that they show typical reductions in annual energy costs in various industrial sectors between 5 and 20%.

7.2.1 Need for Monitoring & Targeting

The energy used by any industry or facility varies as production processes, volumes, and inputs vary. Determining the relationship of energy use to key performance indicators will allow management to determine:

- Whether current energy use is better or worse than before;
- Trends in energy consumption that reflect seasonal, weekly, and other operating patterns;
- How much future energy use is likely to vary if some aspects of business change;
- Specific areas of wasted energy;
- Comparisons with other businesses with similar characteristics. This "benchmarking" process will provide valuable information of the effectiveness of operations as well as energy use;
- How business reacted to changes in the past;
- How to develop performance targets for an energy management program.

7.3 Elements of Monitoring &Targeting System

The essential elements of M&T system are:

Recording - Measuring and recording energy consumption

Analyzing & Comparing- Rating energy consumption to a measured output, such as production quantity for 12-24 months of historical data to obtain standard energy performance. Standard energy performance is established through regression analysis of past data. If these data do not exist, then it will be necessary to conduct an energy audit to establish standard energy performance. Standard Energy Performance provides a base line for the assessment of future performance. It can also be used as an initial target.

Setting Targets -Setting targets to reduce or control energy consumption.

Monitoring -Comparing energy consumption to the set target on a regular basis.

Reporting- Reporting the results to management including any variances from the targets which have been set and related performance problems in equipment and systems. Energy management reports should be produced on regular basis. These reports provide the stimulus for improved energy performance and should also quantify any improvements that are achieved.

Controlling -Implementing management measures to correct any deviations, which may have occurred.

Particularly M&T system will involve the following:

- **Checking** the accuracy of energy invoices
- **Allocating** energy costs to specific departments (Energy Accounting Centers)

- **Determining** energy performance/efficiency
- **Recording** energy use, so that projects intended to improve energy efficiency can be checked
- **Highlighting** performance problems in equipment or systems

7.4 Structuring of a Monitoring System

The first and the most important step is the development of a measurement concept. Measuring points are defined for energy data acquisition. For accumulation of data, sensors are needed. The next step is the data processing and saving. This step contains the visualization and analyzing of the data. With the data processing, controlling system comes into action.

Figure 7.1 shows typical basic design of a standardized monitoring system. Inputs to the monitoring system are energy data and operational data. The outputs from the monitoring system are key figures, alarming for deviation system, reporting structure and the documentation.

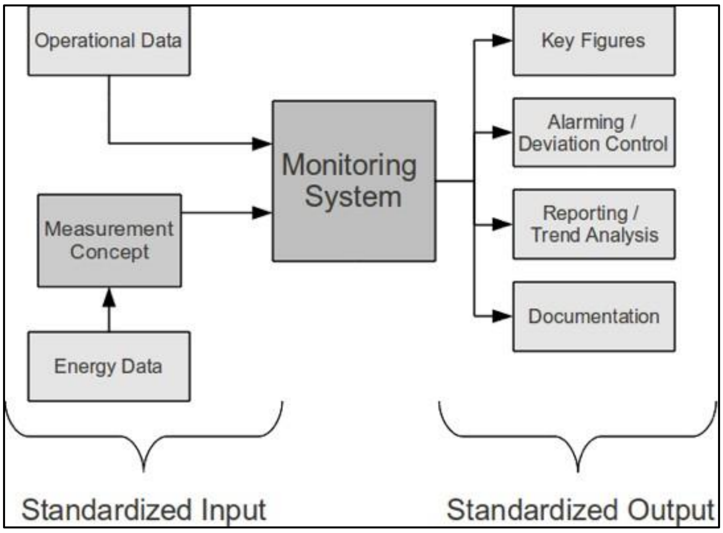


Figure 7.1: Work Flow for a Standardized Monitoring System

The design of the monitoring system will differ between companies. The basic elements must be later improved according to the individual needs of the companies as part of continual improvement.

7.5 Requirements for System Configuration

Before system design, requirements should be defined. It must be decided what kind of data should be included in the monitoring system. Data such as energy flow by type and quantity, material flows describing input and output of the analyzed process as well as monetary flows are needed as reference parameters. Other information may include heated area, time, and number of employees or ambient temperature. The information includes raw data which requires interpretation or re-assessed information as the result of an analysis or calculation.

Consistency and reliability of the identified energy data flow should be ensured through appropriate measuring technology. The location of the sensors and periodicity of the data collection should be decided. A key point here is the measuring accuracy and sensor sensitivity. The possibility of reading errors because of manual readouts must be minimized. The metering precision should be ensured.

Information should be provided to the concerned person appropriately either in form of onsite display or centrally through data acquisition station. It must be also decided whether reports are sent to the receiver because of deviation (alarm) or at preset intervals (standard report) or both.

Another aspect to be considered is where and how fast the information has to be made available. The process owner is able to assess, interpret the data and act immediately. The person-in-charge must have information in time so that he or she can intervene where necessary. In some cases it might be advisable to inform the top management as well.

The elapsed time before an error in the run of process is detected or indicated as unusual behavior depends on process dynamics. Each process has arrange of normal behavior. Deviations out of this range can be temporary and self-regulating or they also might indicate need for immediate intervention.

The other influencing factors are measuring points. Some measured process-related parameters influence only the surrounding process. Other measurement points may require the measurement of additional parameters, for example, correlation of parameters like between pressure and temperature. These correlations can be uni- or bi directional. Intensity of connections can differ and a various amount of parameters can be affected.

Similar to this challenge is the inclusion of external influencing factors. Instead of resulting from a process itself they influence the system from the outside. Relevant impacts are all parameters that influence the course or the result of the considered process. This means that each system can have its own influencing factors. External influences are parameters like climate conditions such as ambient temperature or air humidity.

7.6 Scope and Information for Monitoring, Targeting and Reporting

Information related to energy use may be obtained from following sources:

- Plant level information can be derived from financial accounting systems-utilities cost centre
- Plant department level information can be found in comparative energy consumption data for a group of similar facilities, service entrance meter readings etc.
- System level (for example, boiler plant) performance data can be determined from sub-metering data
- Equipment level information can be obtained from name plate data, run-time and schedule information, sub-metered data on specific energy consuming equipment.

All of these data are useful and can be processed to yield information about facility performance.

7.7 Data and Information Analysis

Within the activity of M &T, data and information are distinct entities. The activity of monitoring a facility, system or process involves both measurement and analysis. Data are raw numbers such as would be the result of a measurement. Information is the result of some type of analysis upon data.

Figure 7.2 illustrates the distinction between data and information for a production situation. In this case, energy consumption and production of a melting furnace are routinely measured and recorded.

What refines performance data into management information is the analysis. The Management information seeks questions about performance that would not be evident in the raw data, and can lead to actions for correction of problems or optimization of performance. The distinction between data and information is illustrated in the Figure 7.2.

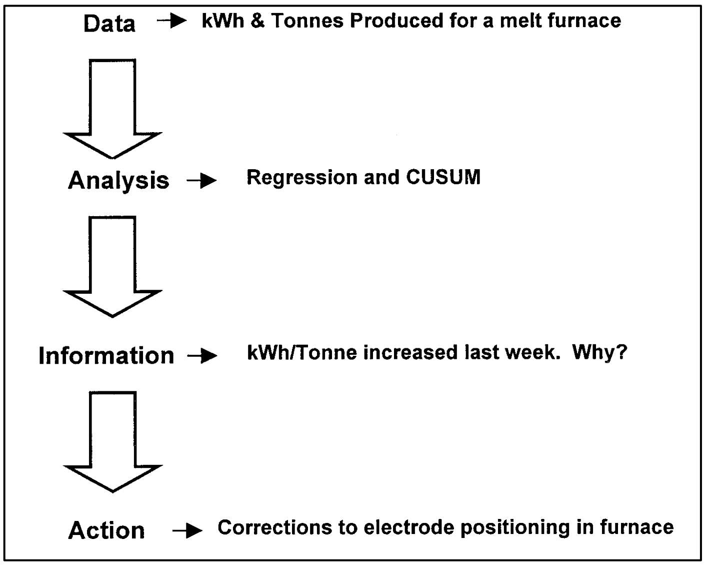


Figure 7.2: Example of Data and Information in Production System

The process illustrated in the Figure 7.1 is not linear. Corrections to electrode positioning in the furnace has to result in another cycle of monitoring and analysis to ensure that the change has been effective and is being sustained. New optimisation actions typically result, and so the cycle-measure-analyse-action-continues indefinitely, true to the intent of continuous improvement as shown in Figure 7.3.

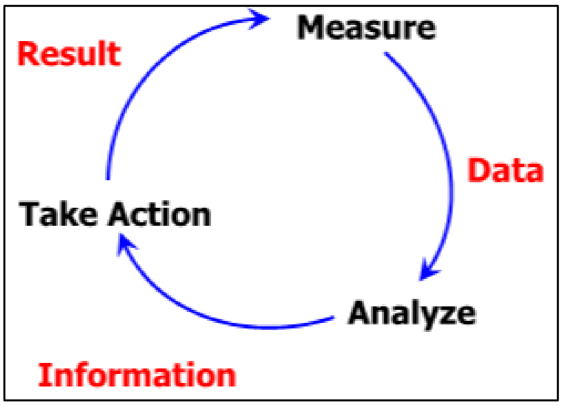


Figure 7.3: The Measure-Analyze-Action Cycle

Annual Energy Consumption

The simplest analysis is to produce percentage breakdown of annual energy consumption and cost data. This is a useful technique which enables to assess overall energy performance of a plant or building quickly and easily. The analysis of annual energy consumption should be carried out as follows:

1. Convert all the energy consumption data into standard units (usually the kcal) using the standard energy conversion shown in Table 7.1.
2. Compile the data as shown in the Table 7.2 showing the annual energy consumption and cost for various fuel and energy types.
3. Compline the above information to produce percentage breakdown of the total energy consumption and cost of each energy types (Table 7.3).
4. Produce pie-chart similar to those shown in Figure 7.4 and Figure 7.5 to show graphically the energy and cost contribution of each energy type.
5. Similar procedure can be followed for previous years to identify trends.

Table 7.1: Standard Energy Conversion

Energy source	*Supply Unit*	*Conversion Factor to kcal*
Electricity	kWh	860
HSD	Kg	10,500
Furnace Oil	***Kg***	10,200
LPG	***Kg***	12,000

Table 7.2: Annual Energy Consumption and Cost for various Fuels and Energy Types

Month	*Thermal Energy*					*Electrical Energy*					***Total Energy Bill***
	Furnace oil	***LPG***	***HSD***	***Total Thermal Consump-tion***	***Total Thermal Bill***	***Day***	***Night***	***Total Electricity Consump-tion***	***Maximum Demand***	***Total Electricity Bill***	
	kcal	***kcal***	***kcal***	***kcal***	***Tk. Lakh***	***kWh***	***kWh***	***kWh***	***kVA***	***Tk. Lakh***	***Tk. Lakh***
1											
2											
3											
….											
….											
11											
12											
Sub-Total											
%											

Table 7.3: Example of % Breakdown of Energy Consumption & Costs

Energy Type	*Purchased Units*	*Consumption*		*Cost*	
		kcal	*%*	*Tk.*	*%*
Electricity	***1570***	***1350200***	***18***	***6280***	***20***
HSD	***36***	***378000***	***5***	***1620***	***5***
Furnace Oil	***456***	***4651200***	***62***	***20520***	***66***
	110	***1320000***	***15***	***2750***	***9***

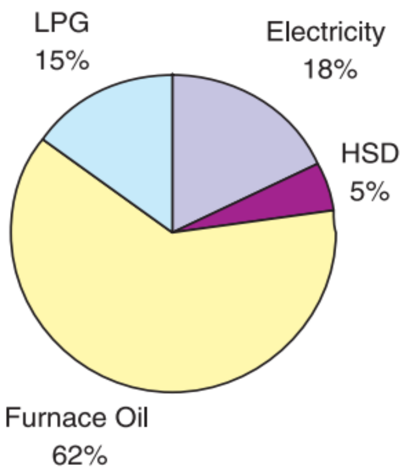


Figure 7.4: % Share of Energy

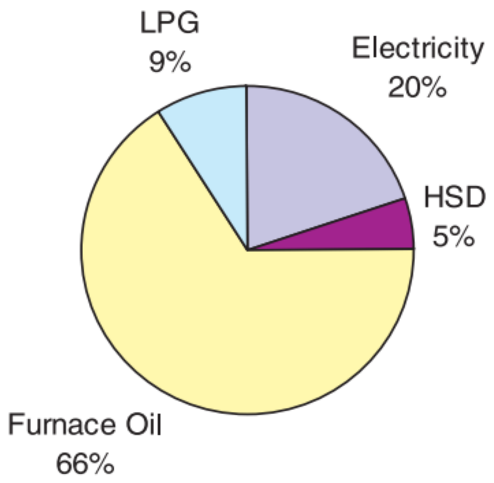


Figure 7.5: % Share of Cost

It may be noted that this simple analysis identifies energy consumption and cost breakdown and trends and does not make any allowance for variable factors which may influence energy consumption e.g. climatic zones or occupancy for buildings. Hence, this analysis cannot be used as a comparison tools between different organizations.

7.8 Annual Energy consumption using Bar Chart

The energy data normally entered and made available in a spreadsheet. Since, it is hard to envisage what is happening from the plain data in the spreadsheet, the data is presented using a bar chart. The starting point is to collect and collate 24 months of energy bills and present the monthly energy consumption for current year and the previous year side-by-side (Figure 7.6). However, this method is not useful; hence production data is also needed for the same 24 month period.

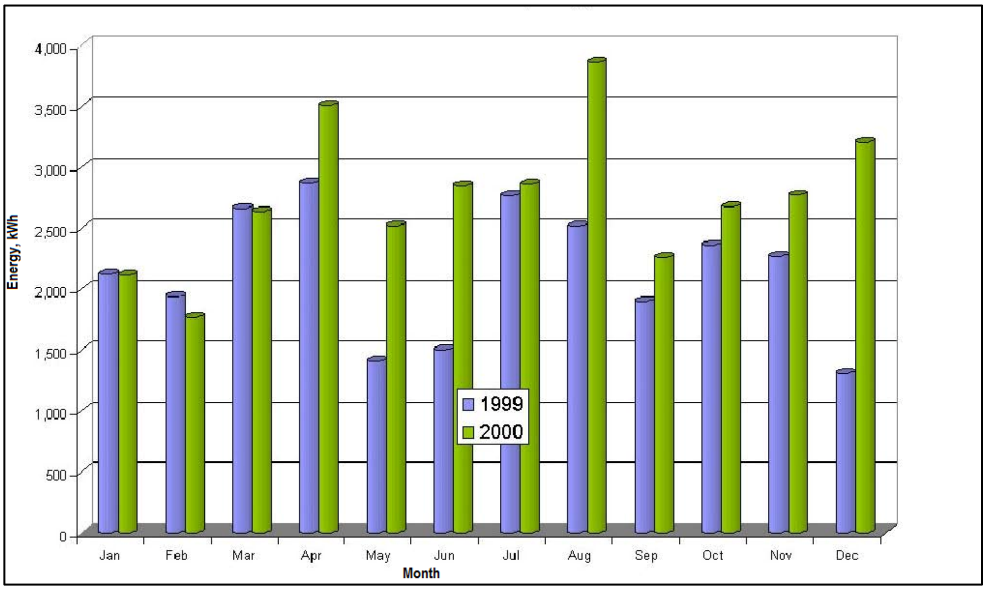


Figure 7.6: Bar Chart—Production for Current and Previous Years

Time-dependent Energy Analysis

If monthly energy consumption data is available, it is possible to produce a simple graph in which energy consumption is plotted against time (Figure 7.7). Time-dependent analysis enables us to identify general trends and seasonal patterns in energy consumption. Any exception to the norm is also identified immediately.

The limitations of this analysis are that it is difficult to find out why certain trends occur or if a particular trend is there or not. Although, this tool is useful, it can be used only as a comparative tool and not an absolute one.

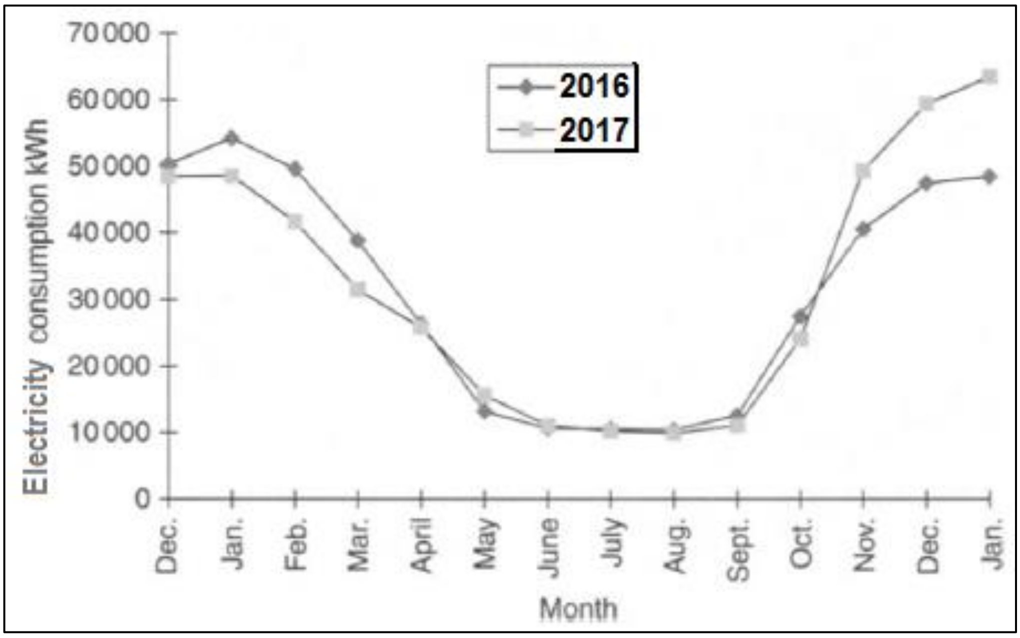


Figure 7.7: Monthly Electricity Consumption

From the time dependent graph shows monthly electricity consumption for the years 2016 and

2017 is shown, the following can be inferred:

- Electricity consumption during the months of January to March of 2017 is consistently lower than that of corresponding period of 2016.
- The base load electricity consumption is approximately10, 500 kWh/month.
- Energy consumption during the months of November and December 2016 and January 2017had increased significantly compared with the corresponding 2016 figures indicating possible loss of control over electricity consumption.

However, it is not possible to identify why the energy consumption for January, February and March 2017 is lower than for the same period in 2016. For this, further analysis is needed.

It is also possible to plot more than one variable using this chart, for example, oil consumption along with electricity consumption data.

Norm Chart

The norm chart is a sequential plot of actual energy consumption overlaid on a plot of target consumption (Figure 7.8). It highlights exceptions which senior and operational manager can easily understand

.

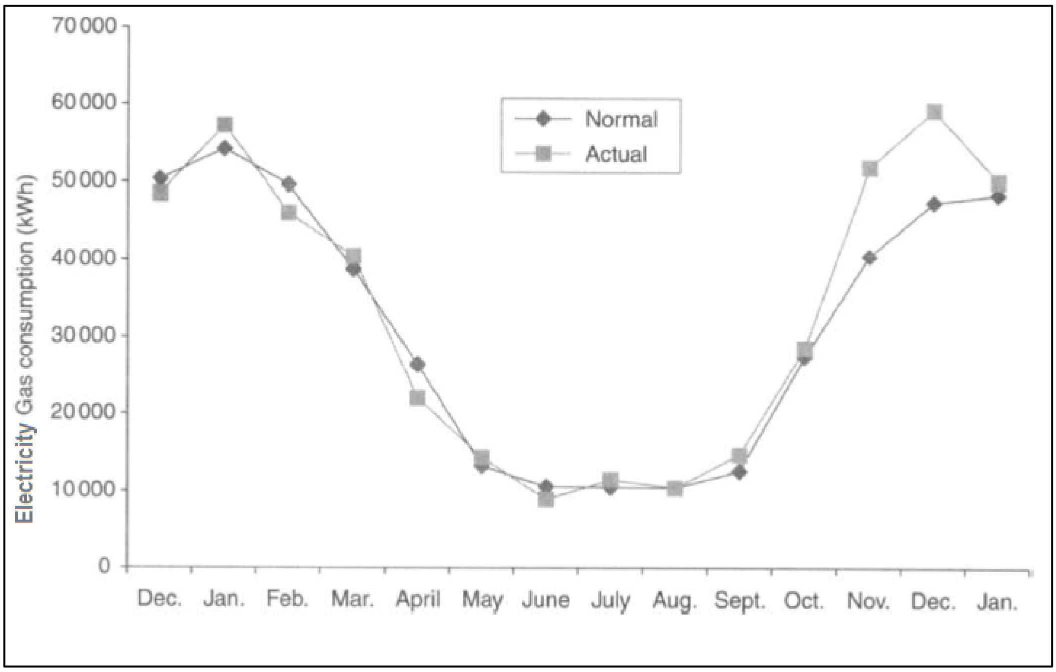


Figure 7.8: Norms Chart for Gas Consumption

Deviance Chart

The difference between target and actual energy consumption is plotted month wise (Figure 7.9). If for any month, energy consumption is above the target or predicted value, the consumption is plotted as a positive value; by contrast a negative value is returned if actual energy consumption is lower than predicted.

When producing a deviance chart it is useful to show on the graph limits of normal operation, since this helps to distinguish between normal limits and serious deviations from the norm. Deviance charts are most suited at highlighting problems so that remedial action can be taken. They can also be used to initiate detailed exception reports.

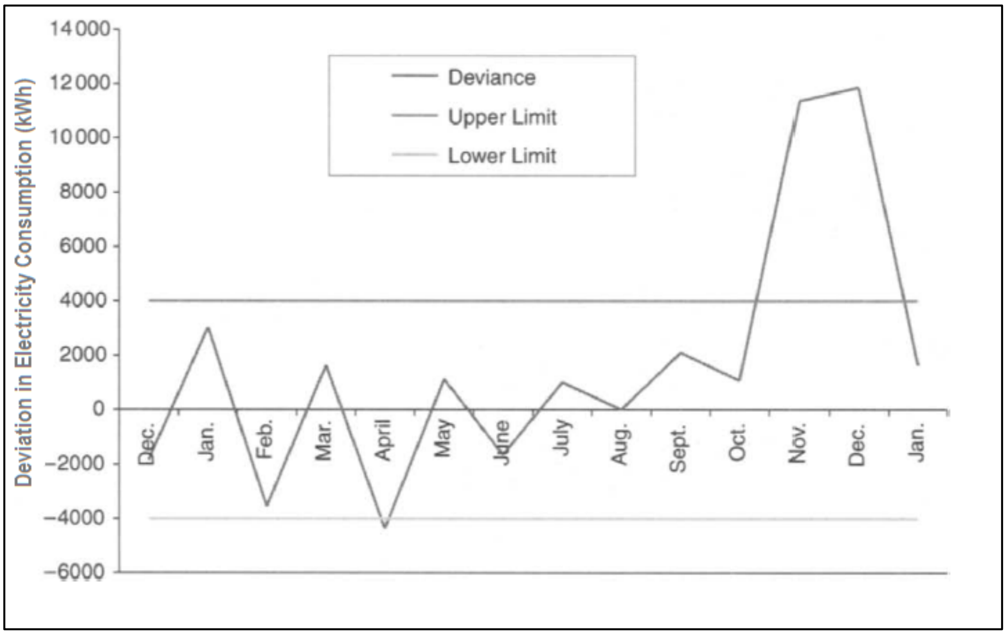


Figure 7.9: Deviance Chart for Gas Consumption

Moving Annual Total

If more than twelve months of production and energy data are available, moving annual total can be plotted. Each point in the chart represents the sum of the previous twelve months of data as shown in Figure 7.10.Each point covers a full range of the seasons, holidays, etc. In this way, this technique smoothen errors in the timings of meter readings.

If just energy reading is plotted, only a part of the story is conveyed. By plotting energy and production on the same chart-using two y-axes, both energy and productions normally track each other. This suggests no cause for alarm.

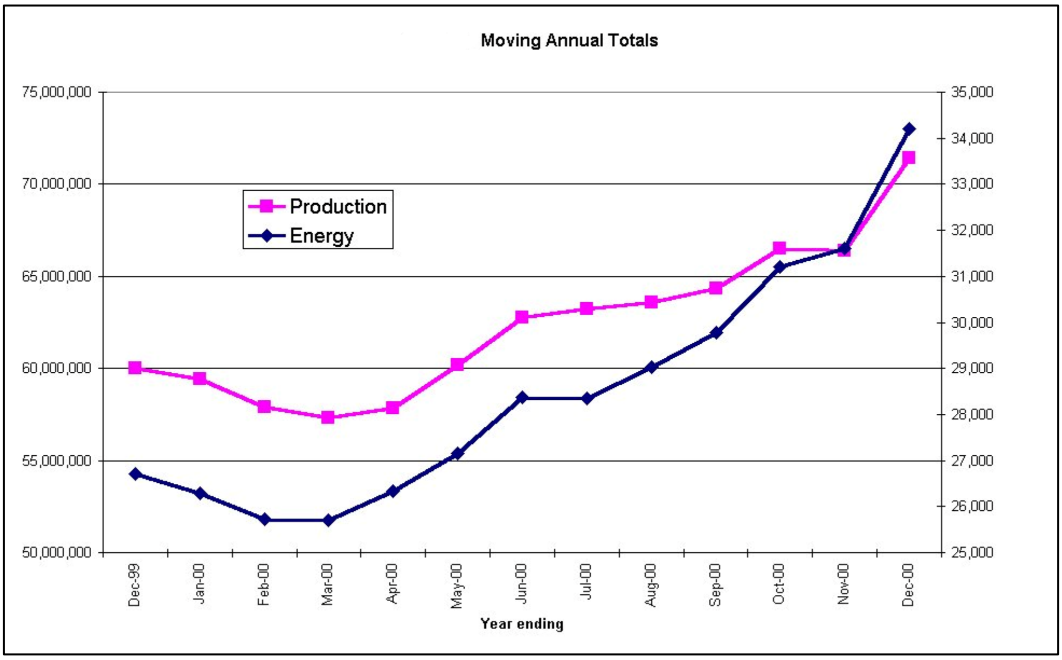


Figure 7.10: Moving Annual Total - Energy and Production

Any deviation in energy line has to be watched so that early warning of energy waste can be detected or alternatively to verify whether energy efficiency measures are making a positive impact.

7.9 Relating Annual Energy and Production using Bar Chart

For any company, energy should directly relate to production. If energy and related production data are available for the 24 months period, it is possible to find the impact of production on energy consumption. For this specific energy consumption (SEC) which is energy consumption per unit of production can be calculated for each month and plotted as shown in Figure 7.11. The chart shows trends very low SEC in December followed by rising trend in SEC.

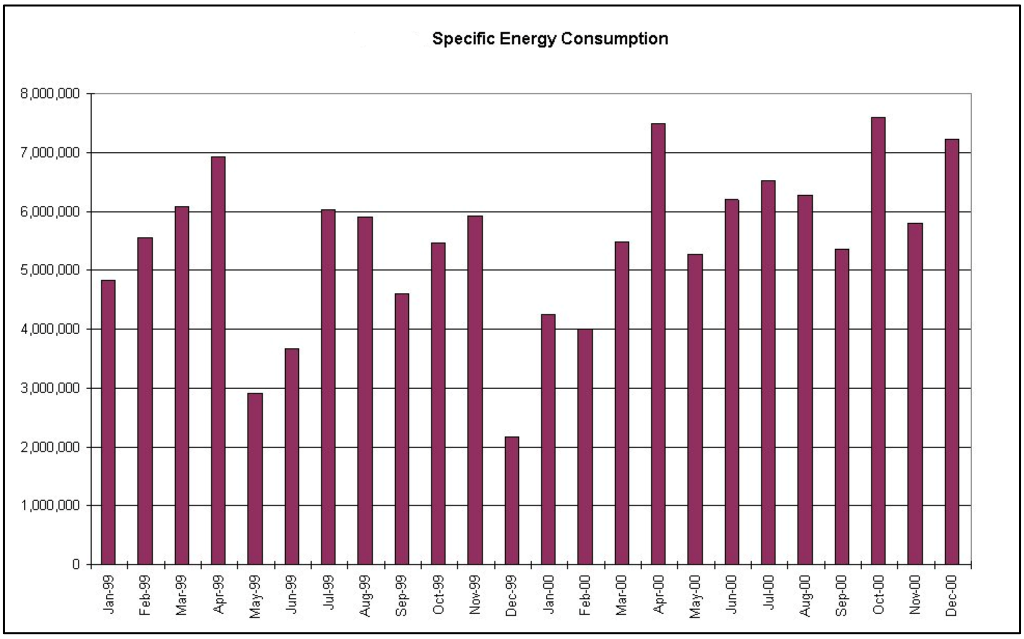


Figure 7.11: Monthly Specific Energy Consumption

The level of production may have an effect on the specific consumption. If production data are included in the SEC chart, understanding becomes even better (Figure 7.12). It can be seen that the low SEC resulted when the production reached a peak. This indicates that there might be fixed energy consumption i.e. consumption that occurs regardless of production levels.

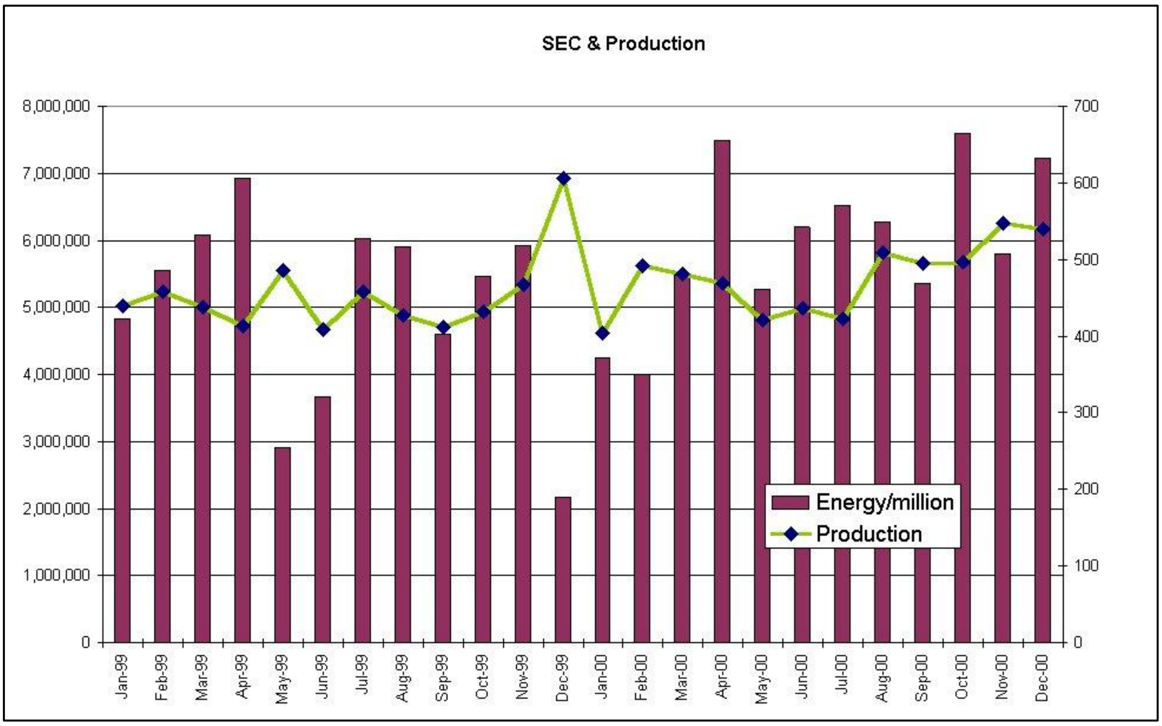


Figure 7.12: SEC and Production

7.10 Linear Regression Analysis

Linear regression analysis is a statistical technique which determines and quantifies the relationship between variables. It is a widely used energy management tool which enables standard equations to be established for energy consumption, often from data which would otherwise be meaningless.

Regression analysis overcomes the limitation of time-dependent analysis by removing the 'time' element from the analysis and focusing instead on the variables which influence energy consumption. It is a versatile technique which can be used to analyse a wide variety of applications. When used as an energy management tool, the variables commonly compared are:

- Natural gas/Furnace Oil consumption versus the number of units of production.
- Electricity consumption versus the number of units of production.
- Water consumption versus the number of units of production.
- Electricity consumed by lighting versus hours of occupancy.

Regression analysis is very much dependent on the quality of the data used. If an analysis indicates the absence of a significant relationship between two variables, it does not necessarily mean that no relationship exists. The significance of results depends on the quantity and quality of the data used, and on the variables used in the analysis. The Table 7.3 shows influencing factors which can impact energy consumption.

Table 7.3: Factors which influence Energy Consumption

Energy	*Purpose*	*Influencing Factors*
Electricity	***Air compressors***	***Air volume delivered***
Furnace oil	***Steam raising in boilers***	***Amount of steam generated***
Steam	***Production process***	***Production volume***

a) Single Independent Variable

XY Scatter Diagram

XY Scatter Diagram provides better understanding of relationship between energy and production. For example if energy consumption in tonnes of oil (TOE) equivalent (i.e. a dependent variable) and production in Metric tonnes (MT) (i.e. an independent variable) in a foundry furnace are plotted against each other on a graph a relationship between the two can be obtained as shown in Figure 7.13.

This chart shows a low degree of scatter which is indicative of a good fit. If data fit is poor, it indicates poor level of control and hence a scope for energy savings; for a poor data fit, where relationship is expected, it indicates poor control and hence a potential for energy savings.

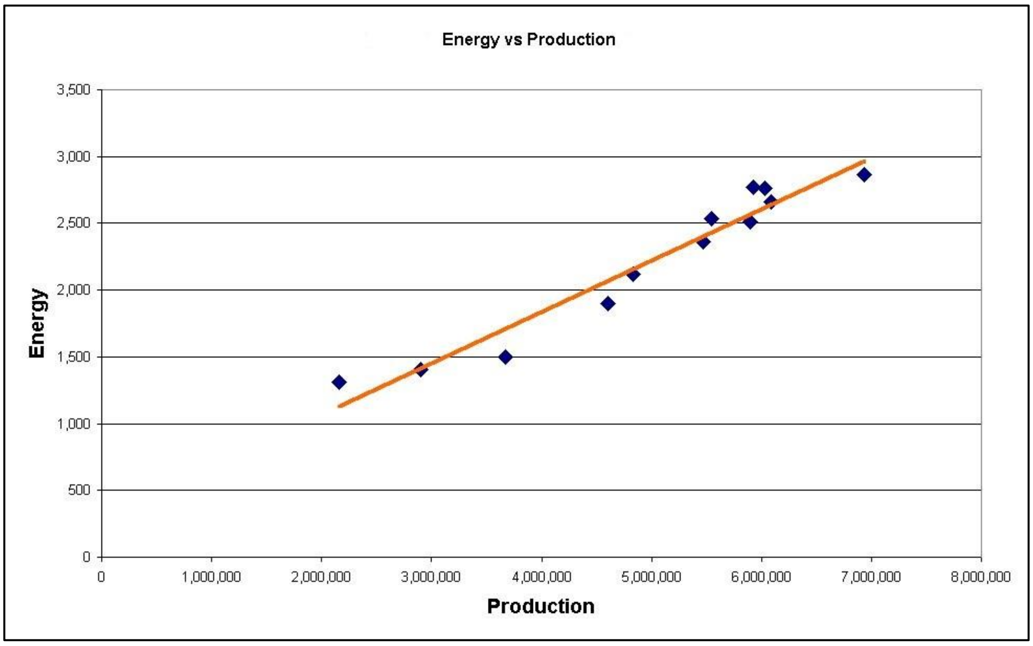


Figure 7.13 XY Chart for Energy-Production Relationship

This relationship is in fact linear and it is possible to derive an equation for the *best-fit* straight-line curve through the points plotted on the graph. The *best-fit* straight-line curve is determined by summing the squares of the distances from the straight line of the various data points. Once established, this linear equation can be used to predict future energy consumption. In addition, it can be used as a *standard performance* equation for energy *monitoring and targeting* purposes.

The relationship between energy and production, provide basis for performance measurement. Charting energy against production can be carried out easily using XY chart option. Best-fit straight line is obtained if trend line is added to the data set on the chart.

The trend chart can be used to derive "standard" for the up-coming year energy consumption.

In producing the production/energy relationship chart a relationship relating production and energy consumption is obtained as follows:

Energy consumed for the period = c + mx Production for same period

Where M is the energy consumption directly related to production (variable) and C is the "fixed" energy consumption (i.e. energy consumed for lighting, heating/cooling and general ancillary services that are not affected by production levels). Using this, the expected or "standard" energy consumption for any level of production can be calculated within the range of the data set.

The basis for implementing a factory level M&T system has now been established. The standard energy consumption can be predicted and appropriate targets can be set —for example, standard energy consumption less 5%. A better approach might be applying different reductions to the fixed and variable energy consumption. Although, the above approach is at factory level, the same can be extended to individual processes if sub metering is installed. At a simple level, the chart can be used to plot upcoming month energy consumption based on planned production.

The generic equation for a straight line graph can be represented as follows:
$y = c + mx$

Where
y is the dependent variable (e.g. energy consumption),
x is the independent variable (e.g. production),
c is the value at which the straight-line curve intersects the 'y' axis, and
m is the gradient of the straight-line curve.

Energy consumed for the period = C + m x Production for the same period

If the straight line $y = c + mx$ is best fitted to a set of data sample points;it can be shown that
$(x_1, y_1) \cdot (x_2, y_2) \cdots (x_n, y_n)$

$cn + m\Sigma x = \Sigma y$

$c\Sigma x + m\Sigma x^2 = \Sigma xy$

Where n is the number of data points. These equations are known as the normal equations.

An Example establishing the values of c and m is illustrated as follows:

Consider a foundry which during a monitoring programme produces the following sample data:

Month	1	2	3	4	5	6	7	8	9
Production, Tonnes /month, x	380	440	460	520	320	520	240	620	600
Energy use, Toe / month, y	340	340	380	380	300	400	280	424	420

Therefore:

n	x	y	x^2	xy
1	380	340	144400	129200
2	440	340	193600	149600
3	460	380	211600	174800
4	520	380	270400	197600
5	320	300	102400	96000
6	520	400	270400	208000
7	240	280	57600	67200
8	620	424	384400	262880
9	600	420	360000	252000
	4100	3264	1994800	1537280

Therefore, the normal equations become

$9c + 4100m = 3264$

$4100c + 1994800m = 1537280$

Therefore

$$c = \frac{3264 - 4100m}{9}$$

Therefore

$$4100\,(3264-4100m)/9 + 1994800m = 1537280$$

$$1486933 - 1867778m + 1994800m = 1537280$$

$$127022m = 50347$$

$$m = 0.4 \text{ and } \quad c = 180$$

The best fit straight line equation is therefore: $y = 180 + 0.4\,x$

From this equation, it can be seen that the theoretical base load for furnace is 180 TOE.

The same relationship can be obtained by plotting in a graph as shown in Figure 7.14.

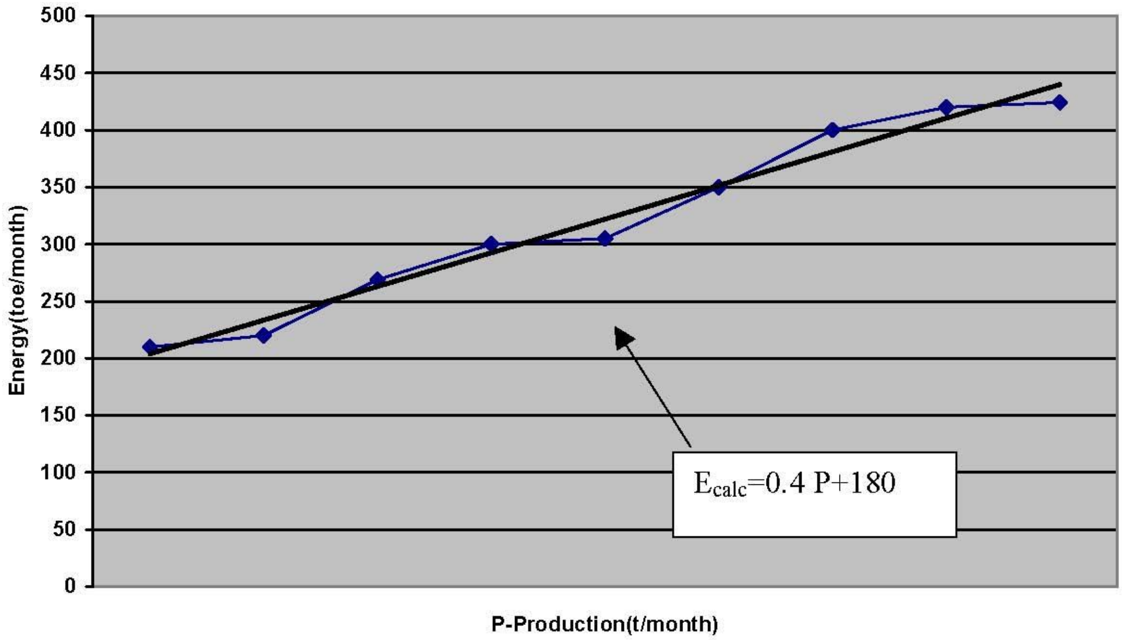


Figure 7.14: Energy-Production Relationships for Foundry

Correlation Coefficients

The regression analysis method enables a *best-fit* straight line to be determined for a sample data set. However, in some circumstances the sample data points maybe very scattered with the result that the derived equation may be meaningless. It is therefore important to determine how well the *best-fit* line correlates to the sample data. This can be done by calculating the *Pearson correlation* coefficient, which gives an indication of the reliability of the line drawn. The Pearson correlation coefficient is a value between 1 and 0, with a value of 1 representing 100% correlation. The Pearson correlation coefficient (r) can be determined using the following equation:

$$r = \frac{\Sigma(x - \bar{x})(y - \bar{y})}{\sqrt{[\Sigma(x - \bar{x})^2 \Sigma(y - \bar{y})^2]}}$$

Where x, y are the x and y values, and $\bar{x}, \bar{y}$ are the average of x and y values. Example 4.3 illustrates how the correlation coefficient may be calculated.

x	y	$(x - \bar{x})$	$(y - \bar{y})$	$(x - \bar{x})(y - \bar{y})$	$(x - \bar{x})^2$	$(y - \bar{y})^2$
380	340	-75.56	-22.67	1712.59	5708.64	513.7778
440	340	-15.56	-22.67	352.59	241.98	513.7778
460	380	4.44	17.33	77.04	19.75	300.4444
520	380	64.44	17.33	1117.04	4153.09	300.4444
320	300	-135.56	-62.67	8494.81	18375.31	3927.111
520	400	64.44	37.33	2405.93	4153.09	1393.778
240	280	-215.56	-82.67	17819.26	46464.20	6833.778
620	424	164.44	61.33	10085.93	27041.98	3761.778
600	420	144.44	57.33	8281.48	20864.20	3287.111
4100	**3264**	**0**	**0**	**50346.67**	**127022.22**	**20832.00**

Therefore,

$$r = \frac{50346}{(127022.22 \text{ x } 20832)^{0.5}} = 0.98$$

Table 7.4 shows minimum acceptable correlation coefficients for given numbers of data samples.

It can be seen from the Table that the correlation coefficient is very good.

Table 7.4: Minimum Correlation Coefficients (r)

Number of data samples	Minimum correlation coefficient (r)
10	**0.767**
15	**0.641**
20	**0.561**
25	**0.506**
30	**0.464**
35	**0.425**
40	**0.402**
45	**0.380**
50	**0.362**

b) Multi-variable analysis

Often energy consumption can be influenced by several different variables. When this is the case the relationship can be described by the equation:

$y = c + m_1 x_1 + m_2x_2 + \ldots\ldots + m_nx_n$

Where, $x_1, x_2 \ldots\ldots x_n$ are the variables that influence y.

It is difficult to solve multivariable analysis by hand calculation. It is therefore advisable to use specialist computer software which can be employed to determine the statistical relationship between the variables.

7.11 CUSUM

Cumulative Sum (CUSUM) represents the difference between the baseline (expected or standard consumption) and the actual consumption points over the baseline period of time. This technique not only provides a trend line, but also calculates savings/ losses and alerts when the energy performance changes.

A typical CUSUM graph follows a trend and showing random fluctuation of energy consumption and should oscillate around standard (or expected) consumption. This trend will continue until something happens which alters the pattern of consumption such as the effect of an energy saving measure or, conversely, a deterioration in energy efficiency (poor control, house-keeping or maintenance).

CUSUM chart (Figure 7.15) for a generic company is shown. The CUSUM chart shows what is really happening to the energy performance. The formula derived from the 1999 data was used to calculate the expected or standard energy consumption.

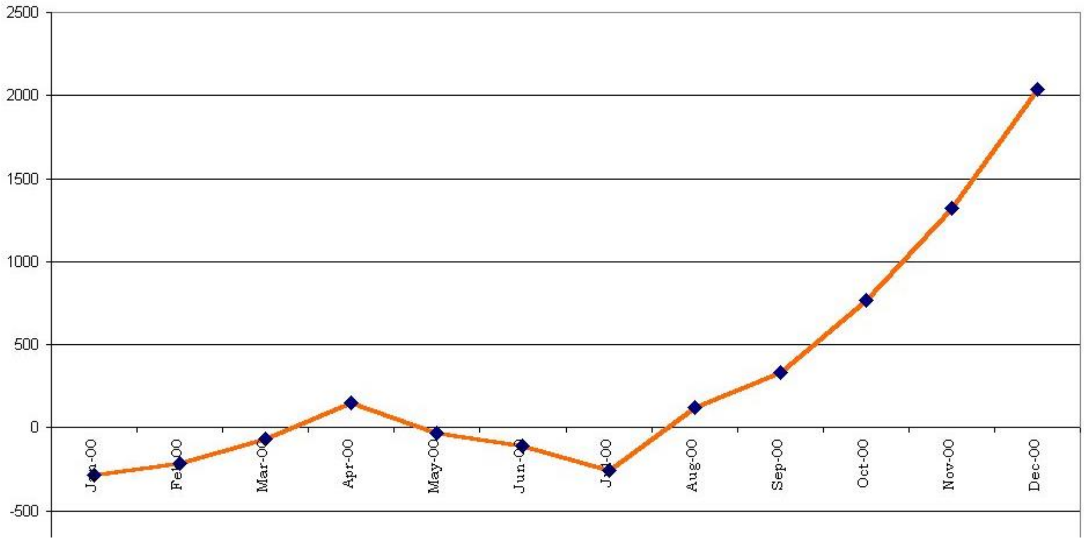


Figure 7.15: CUSUM Chart

From the chart, it can be seen that starting from year 2000, performance is better than standard. Performance then decreased (indicated by upward trend in line) until April, and then it started to improve until July (indicated by downward trend in line).

However, from July onwards, there is a marked, decline in energy performance indicated by upward trend line. When looking at CUSUM chart, the changes indirection of the line (upwards or downwards) indicate events that have relevance to the energy consumption pattern.

However, site information is needed to interpret the reasons. For this sample company since there have been no planned changes in the energy system, the change in energy performance can be attributed to poor control, housekeeping or maintenance.

Example Illustrating: CUSUM Technique

Energy consumption and production data were collected for furnace in a foundry over a period of 18 months. During month 9, a heat recovery system was installed. Using the plant monthly data, estimate the savings made with the heat recovery system. The plant data is given in Table 7.5:

Table: 7.5: Month Wise Production with Energy Consumption		
Month	E_{act} - Monthly Energy Use (toe * / month)	P - Monthly Production (tonnes / month)
1	340	380
2	340	440
3	380	460
4	380	520
5	300	320
6	400	520
7	280	240
8	424	620
9	420	600
10	400	560
11	360	440
12	320	360
13	340	420
14	372	480
15	380	540
16	280	280
17	280	260
18	380	500

*toe = tonnes of oil equivalent.

Steps for CUSUM analysis

1. Plot the Energy –Production graph for the first 9 months
2. Draw the best fit straight line
3. Derive the equation of the line (Equation derived is E = 0.4 P + 180)
4. Calculate the standard energy consumption based on various production using the equation
5. Calculate the difference between actual and standard energy consumption
6. Compute CUSUM as shown in the following Table
7. Plot the CUSUM graph
8. Estimate the savings accumulated from use of the heat recovery system.

These steps are shown in the Table 7.6.

Table 7.6: CUSUM Calculations					
Month	E_{Act}	P	E_{Std}= (0.4 P + 180)	$E_{act} - E_{Std}$	CUSUM (Cumulative Sum)
1	340	380	332	+8	+8
2	340	440	356	-16	-8
3	380	460	364	+16	+8

4	380	520	388	-8	0
5	300	320	308	-8	-8
6	400	520	388	+12	-6
7	280	240	276	+4	-2
8	424	620	428	-4	-6
9	420	600	420	0	-6
10	400	560	404	-4	-10
11	360	440	356	+4	-6
12	320	360	324	-4	-10
13	340	420	348	-8	-18
14	372	480	372	0	-18
15	380	540	396	-16	-34
16	280	280	292	-12	-46
17	280	260	284	-4	-50
18	380	500	380	0	-50

E_{act} - Actual Energy consumption

E_{Std} - Standard energy consumption

From the **Figure 7.16,** it can be seen that the CUSUM graph oscillates around the zero line for first 10 months and then drops sharply after 11thmonth. This suggests that the heat recovery system took almost two months to commission and reach proper operating conditions, after which steady savings have been achieved. Based on the graph savings of 44 TOE (50-6) have been achieved in the last 7 months. This represents savings of almost 2% of energy consumption.

CUSUM chart for last 18 months is shown in Figure 7.16 below.

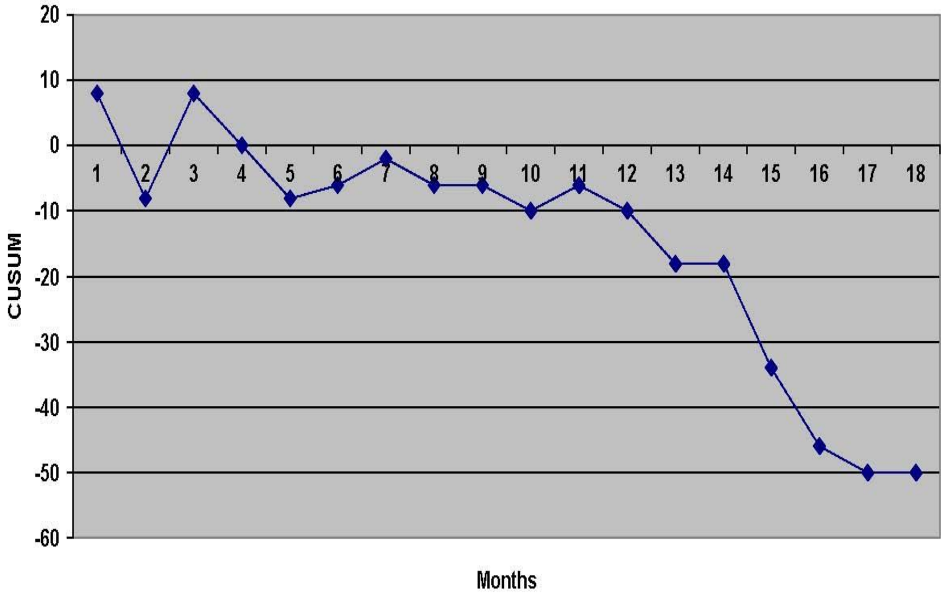


Figure 7.16: Example CUSUM Graph

7.12 Energy Management Information System (EMIS)

The use of specially designed information system software is advisable when operating an M&T programme. However, software should not be seen as a replacement for the energy manager, but simply as tools which enable large amounts of data to be stored and analysed quickly. A number of energy management software packages are commercially available, with varying degrees of complexity and costs. However, they all tend to share the following generic features:

- ✓ A database facility, which is capable of storing and organizing large quantities of data collected over a long period of time.
- ✓ The ability to record energy data for all utility types, including data taken from both meters and invoices.
- ✓ The ability to handle complex utility tariffs. Tariffs vary from place to place, and are becoming increasingly complex as competition is introduced into the utilities sector.
- ✓ The ability to handle other related variables such as degree days and production data.
- ✓ A data analysis facility. This is achieved by incorporating statistical analysis software into the energy management software.
- ✓ A reporting facility, which is capable of quickly producing energy management reports.
- ✓ With the more sophisticated energy management packages it is possible to interface the software with Building Management Systems (BMS), so that energy data can be automatically recorded on a regular basis (e.g. hourly).

One of the great advantages of computer-based systems is their database facility, which enables historical data and data from many sources to be instantly compared. This facility is particularly useful when comparing site energy costs on a utility basis and enables energy managers quickly to assess the relative performance of various Energy Accounting Centres (EACs). In this way EACs which are under-performing can be quickly identified and remedial action taken.

Designing Information Reporting Systems

One of the major outputs of any M&T programme is the production of energy management reports. These reports perform the vital role of communicating key information to senior and operational managers, and are therefore the means by which action is initiated within an organization. In order to ensure that prompt action is taken to minimize wasteful practices, reports should be as simple as possible and should highlight those areas in which energy wastage is occurring. Reports should be published regularly so that energy wasteful practices are identified quickly and not allowed to persist too long. Reports should be brief and relevant, and conform to a standard format which should be generated automatically by a computer. This minimizes preparation time, and also familiarizes managers with the information being communicated.

Most M&T programmes require reports to be published weekly or monthly. Monthly reports are usually applicable to large organizations with many sites, with weekly reports being more suitable to complex high energy consuming facilities. In applications where energy consumption is particularly high, reports may be produced daily. If the reporting period is too long, energy may well be needlessly wasted before managers are notified of the problem and remedial action is taken. Yet, if the reporting period is too short this will lead to an over-complex M&T system in which too much irrelevant information requires consideration.

The primary purpose of energy management reports is to communicate effectively with senior and operational managers. They should therefore be tailored to suit the needs of their readers, with different managers within organizations requiring different levels of report. Operational managers may need weekly reports, whereas senior management may only require a quarterly review. Figure 7.17 illustrates the relationship between reporting frequency and managerial status.

One big disadvantage of producing a large number of regular reports is that they can swamp operational managers with what may appear to be irrelevant information. One good way to get around this problem is to adopt a reporting by exception system, in which reports are only generated when energy performance falls outside certain predetermined limits. This system has the great advantage that managers only receive reports when energy performance is either poor or very good. In addition, everyone involved in the reporting process benefits from a reduced workload.

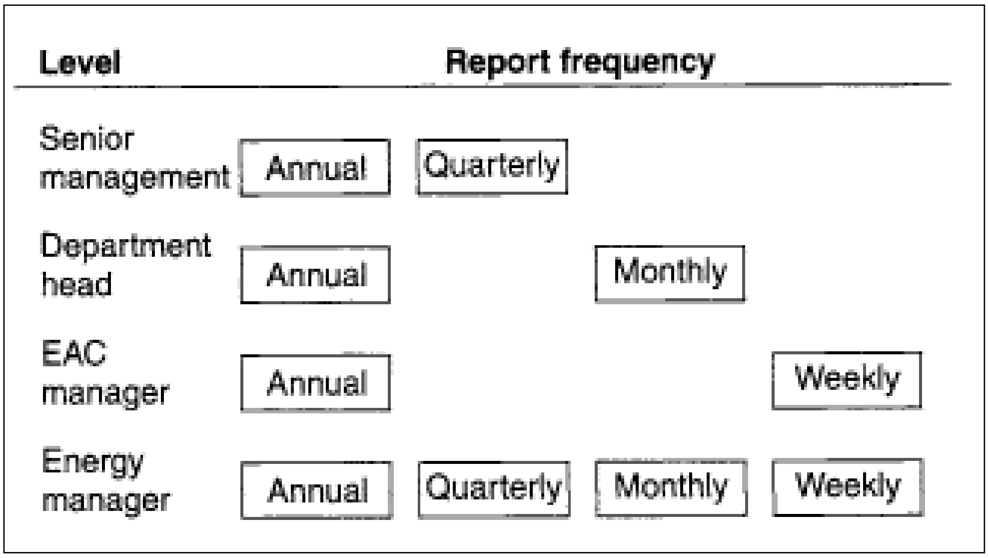


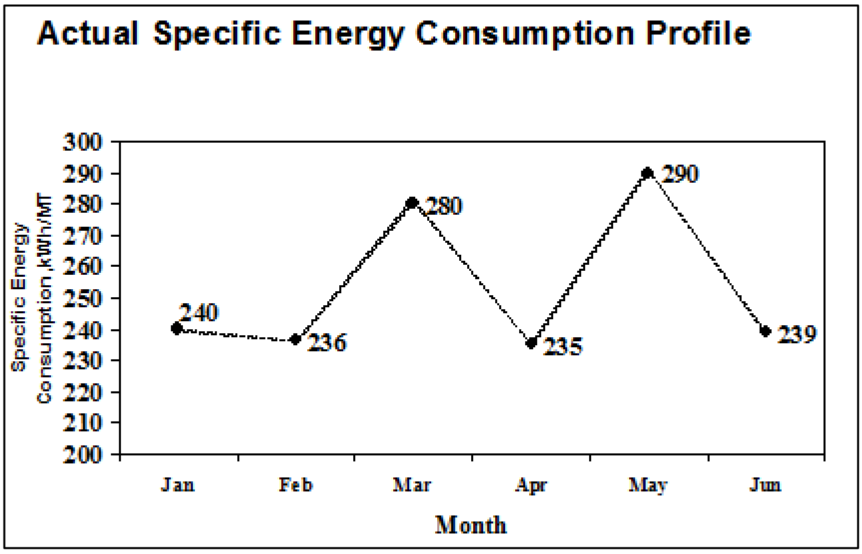
Figure 7.17: Relationships between Managerial Status and Report Frequency

Example 7.1

Energy saving (retrofit) measures was implemented in a process plant prior to Jan-2017. Use CUSUM technique and calculate energy savings for 6 months period of 2017.

The company produced consistently 3000 T/month in each of the first six months.

Refer the graph given in table below.



The predicted (expected or standard) specific energy consumption for 3000 MT production is 260 kWh/MT.
It may be noted that retrofits were not functioning during March & May 2017.

2017-Month	*Actual - SEC, kWh/MT*	*Predicted SEC-kWh/MT*	*Difference= Actual-Predicted*	*CUSUM*
Jan	***240***	***260***	***- 20***	***-20***
Feb	***236***	***260***	***- 24***	***-44***
Mar	***280***	***260***	***+ 20***	***-24***
Apr	***235***	***260***	***- 25***	***-49***
May	***290***	***260***	***+ 30***	***-19***
Jun	***239***	***260***	***- 21***	***-40***

Energy Savings for six months = 40 kWh/MT x 3000 MT
= 1.20 lakh kWh

Example 7.2

Use CUSUM technique to develop a table and to calculate energy savings for 8 months period. For calculating total energy saving, average production can be taken as 6,000 MT per month. Refer to field data given in the table below.

Month	Actual SEC, kWh/MT	Predicted SEC, kWh/MT
May	1311	1335
June	1308	1335

July	1368	1335
Aug	1334	1335
Sept	1338	1335
Oct	1351	1335
Nov	1322	1335
Dec	1320	1335

Month	Actual SEC, kWh/MT	Predicted SEC, kWh/MT	Diff = (Act - Pred) (- = Saving)	CUSUM (- = Saving)
May	1311	1335	-24	-24
June	1308	1335	-27	-51
July	1368	1335	33	-18
Aug	1334	1335	-1	-19
Sept	1338	1335	3	-16
Oct	1351	1335	16	0
Nov	1322	1335	-13	-13
Dec	1320	1335	-15	-28

Savings in energy consumption over a period of eight months are 28 x 6000 =1, 68,000 kWh

Example 7.3

The Energy- production data (for Jan-June, 2011) of an industry follows a relationship: Calculated energy consumption = 0.5 P +220.

A Waste heat recovery system was installed at end of June 2011 and further data was gathered up to December 2011.

Using CUSUM technique, calculate energy savings in terms of ton of oil equivalent (toe) and the reduction in specific energy consumption achieved with the installation of waste heat recovery system.

The plant data is given in the table below.

2017-Month	Actual Energy Consumption, toe/month	Actual production, ton/month
Jan	620	760
Feb	690	960
Mar	635	790
Apr	628	830

May	545	610
Jun	540	670
July	590	760
Aug	605	820
Sep	670	940
Oct	582	750
Nov	512	610
Dec	540	670

The table below gives values of actual energy consumption vs. calculated (predicted) energy consumption from July – Dec. 2017.

Specific energy consumption monitored vs. predicted for each month. The variations are calculated and the Cumulative sum of differences is calculated from Jan-June-2017.

2017-Month	E_{act}.	Ecal= 0.5P+220	E_{act}- E_{cal}	CUSUM
July	590	600	-10	-10
Aug	605	630	-25	-35
Sept	670	690	-20	-55
Oct.	582	595	-13	-68
Nov.	512	525	-13	-81
Dec.	540	555	-15	-96

Energy savings achieved = **96 toe**

Reduction in specific energy consumption = 96/4550 = 0.021 toe/tonne of production (Production for 6 months = 760+820+940+750+610+670 = **4550 tonnes**)

Example 7.4

Use CUSUM technique and calculate energy savings for first 6 months of 2011 for those energy saving measures implemented by a plant prior to January, 2011.

The average production for the period Jan-Jun 2011 is 1000 MT/Month

The plant data is given in the following table:

2011-Month	*Actual Specific Energy Consumption, kWh/MT*	*Predicted Specific Energy Consumption, kWh/MT*
Jan	1203	1121
Feb	1187	1278

Mar	1401	1571
Apr	1450	1550
May	1324	1284
Jun	1233	1233

2011-Month	*Actual - SEC, kWh/MT*	*Predicted SEC- kWh/MT*	*Difference= Actual-Predicted*	*CUSUM*
Jan	1203	1121	82	82
Feb	1187	1278	-91	-9
Mar	1401	1571	-170	-179
Apr	1450	1550	-100	-279
May	1324	1284	40	-239
Jun	1233	1233	0	-239

Energy Savings for six months = 239 kWh/MT x 1000 MT x 6 months
= -1,43,400 kWh