Manual on Energy Management and Conservation Practices

Prepared by The Energy and Resources Institute
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

Introduction

1.1 Energy

Energy is vital in providing us comfort, entertainment, and productivity throughout all our daily experiences. It is one of the essential elements for human development. Various sources of energy can be used to power human activities and often this energy must be transferred from source to a useful form. The quality of life of individuals and societies is affected by energy choices. Today, energy decisions are influenced by economic, political, environmental, and social factors in all countries.

Guyana's forests cover 87 percent of the country's land (around 45.7 million acres). The balance of the land is the coastal plain where 80% of the population live with their main occupation in agriculture. The country's economy has been hinged on agriculture and extractive Industries as its pillars and contribute significantly as a major share in GDP. Energy is vital to a country's economic growth and development, as it supports such diverse economic activities as agriculture, transportation, manufacturing, and services.

From its inception, the energy policy of Guyana adopted an implementation strategy that includes the promotion of increased utilization of indigenous energy resources (bagasse, wood waste, rice husk, hydropower) wherever feasible, more efficient utilization of energy alongside, continued oil exploration activities. In 2015 actual discovery of commercial oil deposits in Guyana's deep waters changed its landscape. The first crude oil consignment from extraction in 2020 paved the path for significant downstream business, which has impacted all sectors of the economy.

With a small population and enormous land mass, Guyana attracts major worldwide interest in exploring investment opportunities after discovering oil reserves. The need for increasing amounts of energy is placing a heavy burden on energy–supply systems. The migration of workers especially from the Caribbean region creates a demand for housing and transport which in turn results in increased fuel consumption – especially petroleum–based fuels. Hence, there is an urgent need for maximum conservation of existing energy supplies and maximum efficiency in their use. Energy conservation is a means by which the energy demand can be significantly reduced without causing discomfort or diminishing the quality of life.

Guyana is committed to eliminating complete dependence on fossil fuels and opted toward the rapid expansion of a renewable energy supply as its energy transition. Projects like energy transition (solar, wind and hydropower) require more modifications and a significant investment. Prudent decisions are required as it is critical to evaluate energy conservation measures for investments and realizable energy cost savings. There are currently several advanced clean and more cost-effective energy technologies that can help minimise environmental impacts (e.g., mitigation of carbon emissions).

1.2 Purpose of the Manual

The Energy Management Manual aims to provide the information needed to develop energy efficiency in the commercial, industrial, and residential sectors and create awareness amongst the stakeholders to improve energy efficiency. The purpose is to promote improvement in energy efficiency in these sectors leading to a reduction in GHG (greenhouse gases) and a reduce the country's dependence on fossil fuels.

A first step of any energy−management program is to identify energy−consumption patterns:

- Where energy is used;
- How energy is used;
- What forms of energy are used;
- How much energy is used;
- When energy is used.

Information on the energy data recording and analysis is included in the last chapter to facilitate the end-user to assess the above considerations.

The second step is the performance assessment of the major energy-consuming equipment and systems. The manual covers chapter wise as Electrical Systems, Lighting Systems, Refrigeration and Air-Conditioning, Rotatory Equipment's (Pumps, Fans), Boiler and Steam systems, and Renewable energy applications. These are commonly used equipment/systems across end-users. These chapters provide suggestions and examples of possible savings. To make investment prudent, financial analysis is a critical task. The same is highlighted in the financial management chapter.

The manual brings together the recent information on energy management. It presents information in the form where ordinary residents, commercial shop/restaurant owners, industry technicians can easily understand and practice or assess their facilities without the support of engineers. Various examples are provided with many no−cost and low−cost methods for reducing energy consumption. The case studies section highlights the energy savings opportunities through technology interventions in Government procurement, which will serve to exemplify and drive other end users to follow similar techniques.

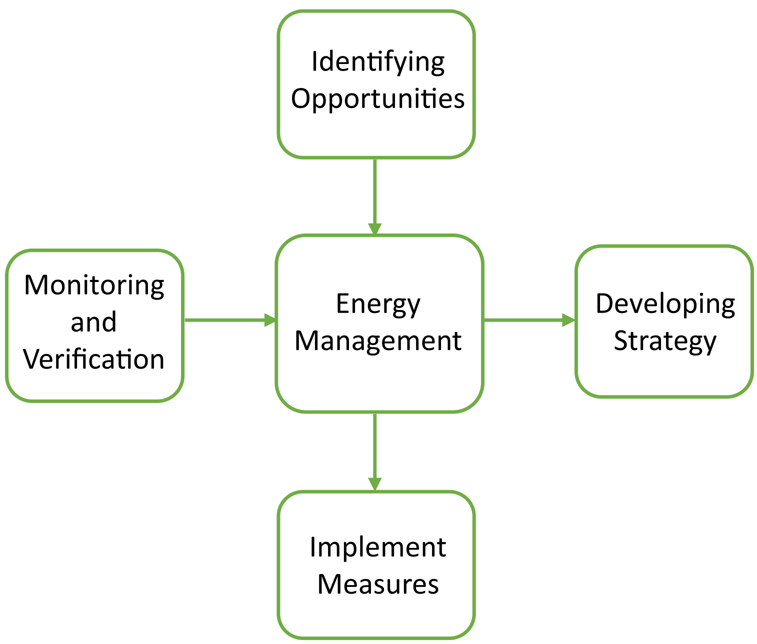
1.3 Energy Management

Through energy conservation and improved energy efficiency, energy management is considered to provide the most significant scope for reducing the requirements for energy and its impacts on the environment. Implementation of energy management in any facility (building or manufacturing unit) requires actions like service or retrofits of equipment or change of process demands for investment which can lead to energy cost savings.

Energy conservation is the concept of minimising energy consumption by reducing activities; sometimes, it is a certain degree of sacrifice. On the other hand, energy efficiency maintains the same quality and quantity of output while using less energy. Energy efficiency and conservation are integral parts of energy management. The Table below provides further elaboration to help distinguish the two.

Table 1.1: Energy efficiency v/s energy conservation

Energy Efficiency	Energy Conservation
Energy Efficiency is using technology that requires less energy to perform the same function (or) service.	Energy Conservation is using less energy by adjusting behaviour, habits, purchases etc. (in addition to using energy more efficiently)
Technology improvement / advancement	
Examples	**Examples**
Use of high-efficiency lighting bulbs (LED)	Use of Staircase
Use of high-efficiency ceiling fans (BLDC)	Use of bicycle
Use of inverter-based air conditioner	Use correctly sized burner based on cooking vessel
Use of induction technology – cook stove	Use of renewable energy resources.



1.4 Benefits of Energy Conservation

Technologically, energy is a vital infrastructure for economic development and so its demand is increasing day by day. The world's known stocks of fossil fuels are said to last not more than 100 years. It is a significant cause of concern as it may lead to an energy crisis. Another cause of concern is the emission of greenhouse gases from the manifold demand for energy and causing severe environmental damage. Renewable power is increasingly cheaper than any new electricity capacity based on fossil fuels. However, end-user efficient use of energy leads to lower capacity addition. The most effective strategy for meeting energy demands is efficient energy use and conservation.

Improving energy efficiency is central to reducing energy demand. Investment in energy efficiency is prioritized across all economic sectors, including residential / commercial buildings and industrial operations. Short-term measures create awareness and increase end-user energy savings with attractive payback periods. In contrast, long term measures entail large infrastructure improvements such as electricity grid upgrade and modernization to reduce losses. Adopting energy efficiency measures can also reduce carbon emissions, save money and generate substantial social and environmental co-benefits.

CHAPTER 2

Guyana Energy Overview

2.1 Energy Resources

Guyana is one of the fastest-growing countries in the world, with projected GDP growth of over 20% rise in recent years. According to the World Bank, the annual percentage growth rate of GDP was 43.48% in 2020 compared to 5.35% in 2019 and 4.44% in 2018. The country is classified as an upper-middle-income country with a population of 787,000. To meet the energy demand, the country primarily depends on imported oil products such as Heavy Fuel, Oil, Mogas, Diesel, Kero/aviation fuel, and Liquefied petroleum gas (LPG).

Due to continued economic development and an increase in Gross National Income (GNI) per capita, the country's energy consumption has also increased in the last few years. In 2016, the total primary energy consumption through fossil fuel was 33,541 TJ, and it increased to 39,611 TJ in 2020. Due to a continuous increase in energy consumption, the import of fossil fuels was also growing linearly.

During the starting of the Covid-19 pandemic in 2020, the energy consumption of the majority of the countries was reduced due to the nationwide lockdown imposed by the respective country's government. On the contrary, the energy consumption in Guyana increased, and to meet the increased energy requirement, 5% more fossil fuels were imported in 2020 compared with the import of fuel in 2019. Fuel import in thousand BBLS from 2016 to 2020 is shown in figure 2.1.

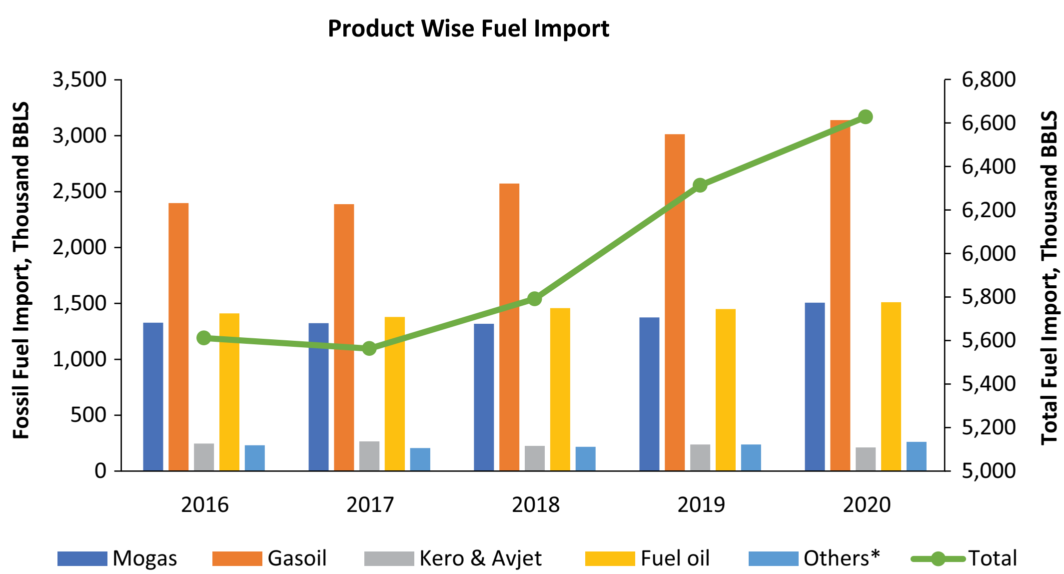


Figure 2.1: Product-wise fuel import

**Includes LPG, LNG and Avgas.*

Source: GEA energy statistics report.

A significant share of imported fossil fuel is used for generating electricity. A breakdown by fuel type indicates that HFO generator units account for 85% and LFO 15% of the total available capacity in the Demerara Berbice Interconnected System (DBIS). For the Isolated Systems, 25% capacity is HFO, and 75% is LFO. Due to the large dependency on imported fuel, the electricity price is significantly higher than in other Caribbean countries.

2.2 Electricity Generation

The Guyana Power and Light (GPL) is the largest electricity supplier and it plays a critical role in developing the country's economy. At present, the company does not have sufficient reliable generation capacity to meet the forecasted peak demand, and this is further exacerbated by the lack of redundant circuits in the transmission and distribution networks. The situation would worsen due to the ageing network infrastructure dependency. Forty-seven megawatts (47 MW) of Heavy Fuel Oil fired baseload generator units within the DBIS have surpassed the economic lifespan threshold of 20 years. Additionally, 11.53 MW of LFO fired units have exceeded the 20 years limit.

The total installed capacity of fuel oil generator sets is 270 MW. However, due to ageing, the actual capacity of most generator sets is derated and the actual available generation capacity in 2021 is 149 MW only. Region-wise, installed capacity and availability of reliable power are shown in table 2.1.

Table 2.1: Summary of region-wise installed power generation capacity

	Total Available Capacity (MW)	Reliable Capacity (MW)	Unreliable Capacity (MW)
DBIS			
Demerara	166.7	63.6	103.1
Berbice	37.4	9.7	27.7
Total	204.1	73.3	130.8
Isolated			
Anna Regina	12	4.8	7.2
Wakenaam	1.06	0.41	0.65
Leguan	0.82	0.82	
Bartica	5	3.4	1.6
Total	18.88	9.43	9.45
Total	**222.98**	**82.73**	**140.25**

To improve the reliability of electricity generation, the Government of Guyana has provided financial support to GPL to facilitate the construction of the first single and largest power generation facility of 46.5 MW. Apart from issues related to the ageing of generator sets, GPL is also facing issues related to high technical and non-technical losses. The primary reasons for high technical losses are:

- Aged and lengthy conductors (medium and low voltage);
- Inefficient transformers; and
- Insufficient reactive power compensation.

The main reason for high non-technical losses are:

- Unmetered supplies;
- Defective meters;
- Street lighting; and
- Electricity theft.

According to the GPL Development and Expansion Program report, the total system losses reduced from 37% in 2006 to 26.5% in 2020. Even though the total system losses reduced drastically it is still the priority of GPL to reduce it further through the Power Utility Upgrade Programme (PUUP). The electricity generation trend from non-renewable resources and % losses is shown in figure 2.2.

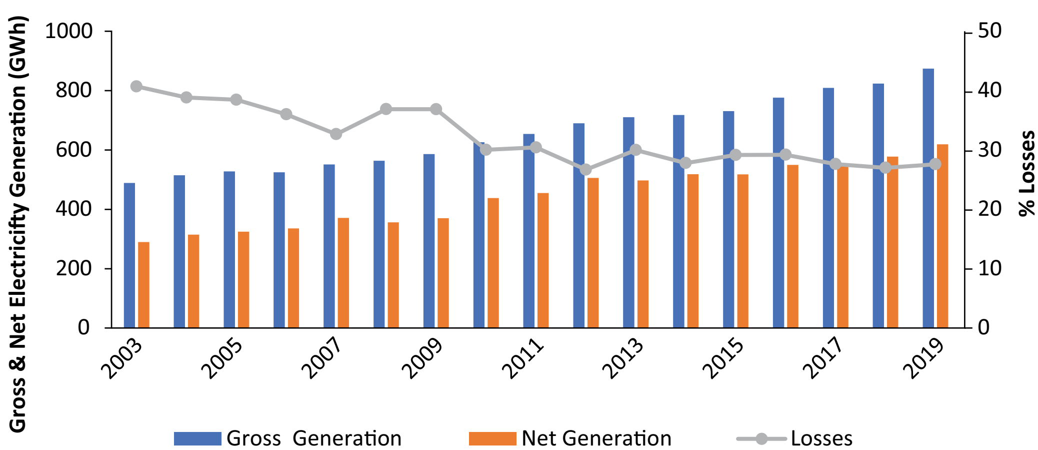


Figure 2.2: Electricity generation from non-renewable resources

Source: GEA energy statistics report

In 2018, the gross electricity generation from non-renewable energy resources was 823 GWh, and it increased to 874 GWh in 2019. The increase in annual electricity generation is supported by a growing population and increased energy consumption. The major share of electricity generated in 2019 was consumed in the industrial sector, followed by residential, commercial, and streetlights.

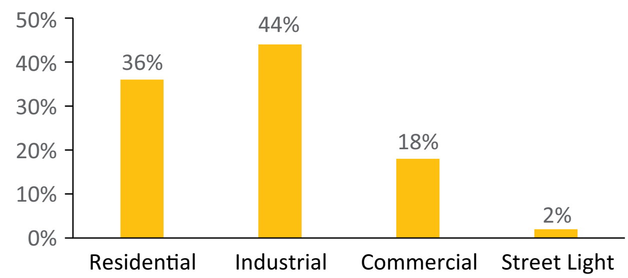


Figure 2.3: Electricity Consumption by Sector

GPL is also working continuously to increase the accessibility of electricity in the country. According to the World Bank, in 2010, only 82% of the population in Guyana had access to electricity, and in 2019 it increased to 92%. GPL projects an increase in its customer base from 205,814 in 2020 to potentially 265,667 by the end of 2025.

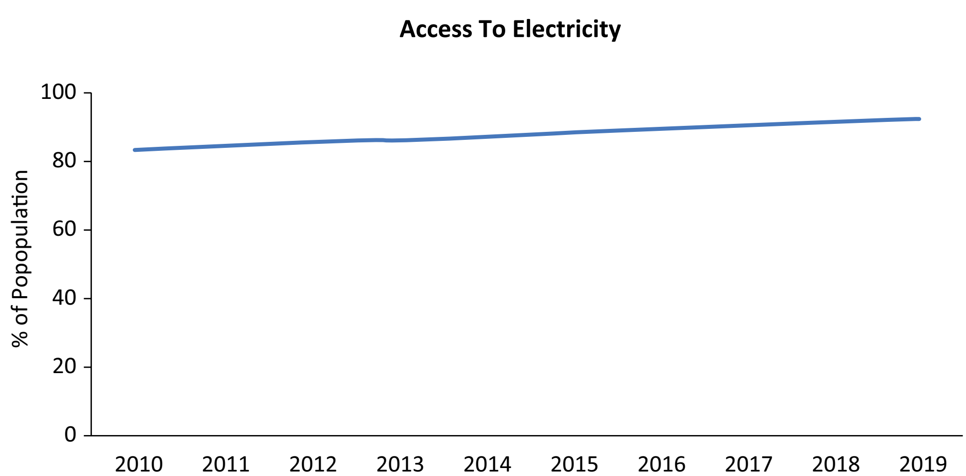


Figure 2.4: Access to electricity

Source: World Bank.

Due to the increase in industrialization and government endeavors to provide uninterrupted power supply to all, per capita electricity consumption increased by 46%, with a compound annual growth rate (CAGR) of 3.88% in a decade from 2009 to 2019. The electricity consumption per person in kWh is shown in figure 2.5.

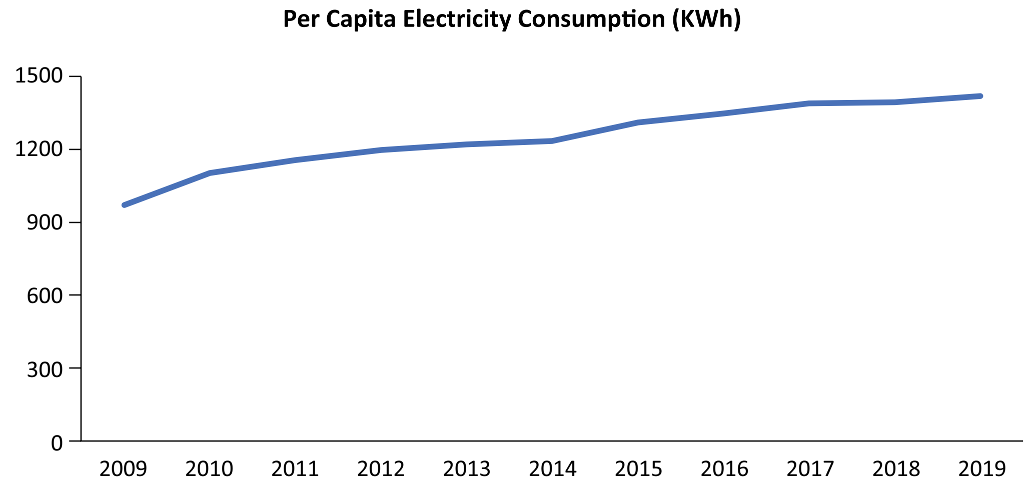


Figure 2.5: Per capita electricity consumption

2.3 Renewable Energy

In Guyana, solar energy, wind, and hydropower are good complementary resources. Solar energy is available during daylight hours, peaking at noon, while wind is stronger during evening hours and at nights. Wind is lower during the wet seasons, but hydropower is fully available. Natural gas provides a short to medium-term solution, over the medium and long term the most sustainable and resilient energy mix in Guyana would be formed by solar, wind, hydro and biomass power plants.

Utility Scale Hydropower Plant

Hydropower has the potential to provide both utility-scale and small-scale capacity. Within the renewable energy resources available in Guyana, hydro will be important to provide firm capacity and short-term energy storage to compensate daily and weekly fluctuations form solar and wind. Hydro will provide, in the long-term, a cheaper solution than any other technology, due to its long lifespan. Guyana has a potential for 8.5 Gigawatt (GW) of hydropower on 33 hydropower plants (including storage capacity and run-of-river). It is anticipated that Guyana will build two hydro plants over the next 20 years: Amaila Falls and another which is still to be identified. Out of the total 33 potential sites, many were assessed in the 70s and 80s, when environmental and social standards were lower. It is anticipated that the new site will be identified by 2025, with the goal of providing 370MW of capacity by 2035 and a further 150MW of capacity by 2040.

Small Hydro – Isolated Grids

Guyana is currently implementing three small hydropower projects: a 150kW in Kato, the rehabilitation of Moco-Moco hydropower site, which would increase the capacity up to 0.7MW and a new 1.5MW hydropower plant in Kumu. Moco-Moco and Kumu hydropower projects will provide energy to Lethem grid. It is expected those two projects, in combination with an ongoing solar PV project, will provide the Lethem grid with 100% renewable energy in 2023. Other small hydro projects will be pursued to provide energy to the regional grids as well as Hinterland villages

Solar Photovoltaic (PV)

Solar photovoltaic (PV) is close to being established as a mature technology in the country. Local prices are in-line with developed countries and local technology providers have the capacity to supply, install and operate on-grid and off-grid. Self-generation is allowed as per Guyana's legislation. Any consumer who wishes to interconnect their solar PV system into the public grids to eliminate the need for battery storage (solar PV on-grid) must submit an interconnection request and comply with the Interim Interconnection Requirements set by GPL. As part of the roof-top solar PV for Government buildings programme, about five megawatts was installed at 291 buildings across the ten Administrative Regions during the period 2012-2020. By 2023, GPL will have its first solar on-grid PV farm in Berbice with a total capacity of 10 megawatts-peak (MWp) financed by the Guyana-Norway Partnership. This solar PV farm will generate one percent of the total energy demand in DBIS.

Wind Energy

Guyana's coast is exposed to the steady Northeast trade winds. A private developer has installed a tower with a wind speed data logger to measure the potential to install large wind turbines. The project is expected to provide 25MW of power. Plans are in place to conduct wind measurements along the coast and at Leguan. The measures taken in the other locations together with the practical experience from the 25MW wind farm installation will design the future wind programme of the country.

Biomass

There is some practical experience on the use of biomass as an energy resource for self-consumption like rice husk on the rice mills, the use of the distillate waste to produce biomethane at Demerara Distillers Limited (DDL) or the use of bagasse for co-generation at the Skeldon Sugar Estate. The Skeldon co-generation plan—for 30MW of electricity generation using bagasse from the sugar process—was designed to produce excess power that would be exported to the grid. The plant is no longer working as a co-generation system due to the closure of the sugar factory. An assessment report on the co-generation possibilities at Albion and Uitvlugt Sugar Estates concluded that it is feasible to install at least a total power capacity of 23MW.

CHAPTER 3

Electrical System

3.1 Overview

GUYANA POWER & LIGHT INC. (GPL) is the main supplier of electricity in Guyana, South America with its franchise area encompassing all three counties of Demerara, Berbice and Essequibo. The power is mainly transmitted at 69 kV high voltages and stepped down to 13.8 kV (medium voltage) for main distribution. The domestic or non-domestic end users get the following low voltage system of supply.

- Standard Domestic : Single Phase, 2 Wire, 120/240V, 60 Hz
- Domestic/Non-domestic : Three Phase, 4 Wire, 415 V, 60 Hz

The electricity consumers are mainly categorised as residential, commercial, industrial and Street lights. The electrical power distribution system of a sample facility is shown in Figure 3.1. The facility receives electricity at the point of common coupling i.e. power transformer and from there the power is stepped down to the required voltage level and connected to a main power control centre (PCC) or main power board. From PCC, the power is distributed directly to different equipment and motor control centres to power different utilities and lighting. For emergency power back-up, Diesel Generators may be used and they are connected at PCC with proper control mechanism.

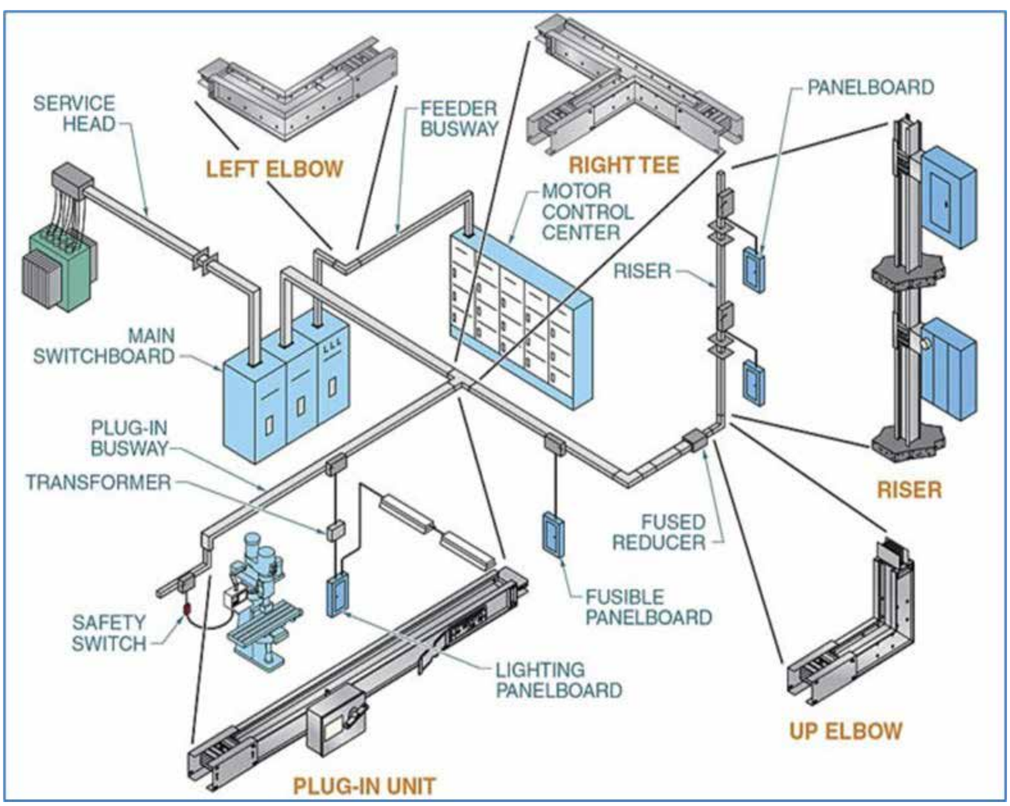


Figure 3.1: A sample electrical distribution system

3.2 Transformers

A transformer is a static device which transforms energy at one voltage level and delivers the same quantity of energy at a different voltage. This ability of the transformers enables electrical energy to be generated at relatively low voltages and transmitted at higher voltages to minimise transmission line losses and voltage drop. Transformers usually consist of two windings called Primary winding (High Voltage) and Secondary winding (Low voltage), which are physically separate and magnetically coupled together. In some cases, a third winding will also be present, called Tertiary winding to provide a different voltage output for additional auxiliary loads. The primary winding is connected to the power source and the secondary winding is connected to the load side. The primary and secondary winding has a different number of winding turns and the ratio of these turns is called the transformation ratio. There are some tappings provide on the primary or secondary of the transformer winding to adjust output voltage up to 5% as per the requirement. These taps can be adjusted in off-line mode (Off-Circuit tap changer) or on-line mode (On load tap changer - OLTC). There are two different types of transformers used in electrical systems. They are:

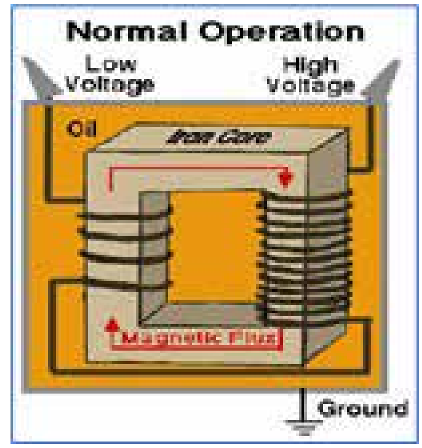


Figure 3.2: Transformer

- **Power transformers**: These are mainly used in power transmission, substations as well as in large industries. (*Example:* 69/13.8 kV substations where power is received at 69kV through 69kV transmission line. The received power is stepped down to 13.8 kV voltage level by means of suitable capacity power transformers and distributes to various industries and public.)
- **Distribution transformers**: These are mainly employed for distributing power for lower voltage distributing networks as a means of end user connectivity (distribution voltage levels include 13.8kV, 415 V, 240V, 120V)
- Apart from power and distribution transformers, there are some other types of transformers which are mainly used for different applications such as:
  - » **Auto transformers**: used for linear voltage variations
  - » **Instrument transformers**: used for measuring high voltages and high currents and also it is used of protection purpose.
  - » **Control transformers**: used in low power electronic applications.

Depending on the type of construction, the transformers are classified as Oil type and dry type transformers.

- **Oil type transformers** are generally of higher rating and oil is used as an insulating material as well as a means of cooling the system's winding.
- **Dry type transformers** are generally of small capacity and designed for indoor applications where safety is the concern.

Dry type transformers have higher losses when compared with Oil type transformers. However, due to recent improvements in materials technology, high efficient transformers are developed with amorphous core materials which offer significantly reduced no-load losses. Amorphous core transformers are dry type and offer 70 to 80% reduction in no-load losses when compared with the conventional ones.

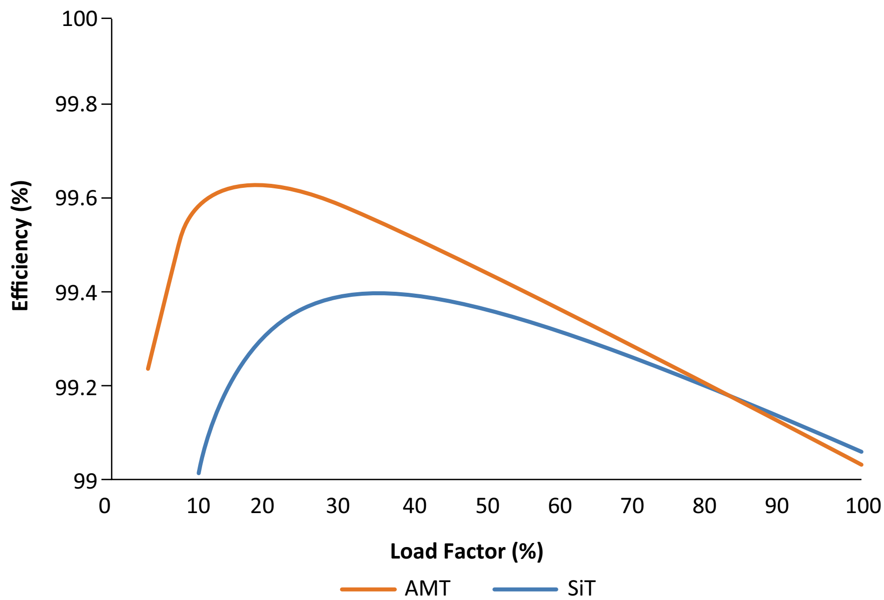


Figure 3.3: Comparison of conventional & amorphous core transformers

The location of the distribution transformer should be in such a place that it will be close to the load centre such that the low voltage level cables drawn to the loads shall be small and distribution losses will be on the lower side. The rating of transformers is calculated by multiplying the total connected load by the diversity factor.

Diversity factor is defined as the ratio of overall maximum demand of the facility to the sum of individual maximum demand of all equipment.

$$\text{Diversity factor} = \frac{\text{Maximum Demand (MD) of the facility, kVA}}{\sum(MD_1+MD_2+MD_3+\ldots+MD_n\ ),\ \text{kVA}}$$

Where, MD_1 : Maximum demand of equipment 1

MD_2 : Maximum demand of equipment 2

MD_3 : Maximum demand of equipment 3

MD_n : Maximum demand of equipment n

Diversity factor will always be less than 1. It varies from industry to industry on various factors such as individual loads, load factor and future expansion needs.

Transformer efficiency and losses:

Since the transformer is a static device and has no moving parts, its efficiency level is high, in the range of 96 to 99 percent. The inherent losses of transformers not only depend on the operating load but also on the type of the design and construction material. Transformers have two types of losses. 1) No-load losses; 2) Load losses

No-load losses or Core losses are the fixed losses of the transformer which is the power consumed to sustain the magnetic field in the transformer's core whenever the transformer is energised. Core losses are again sub-divided into hysteresis losses and eddy current losses. Hysteresis loss is the energy lost through reversing the magnetic field in the core as the magnetising AC rises and falls and reverses direction. An Eddy current loss is a result of induced current circulating in the transformer core.

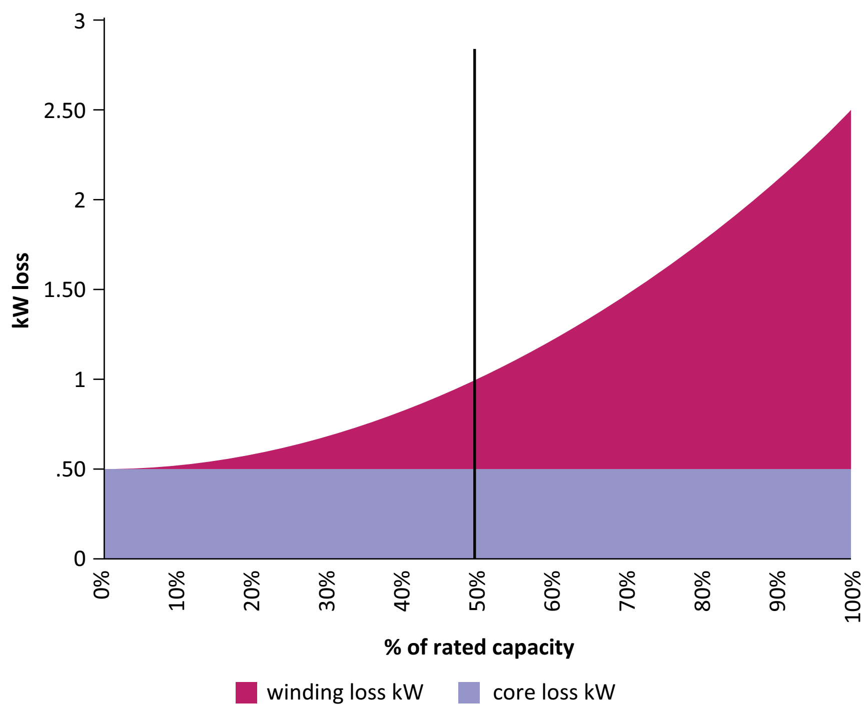


Figure 3.4: Transformer loss vs % load

Load losses or Copper losses are the variable losses which vary with respect to the transformer loading. Copper losses are the losses due to ohmic resistance and the load current flowing through the primary and secondary winding.

$$\textit{Copper losses, (Watts)} = P_C = I^2 * R$$

Where I is the load current flowing through the winding and R is the resistance of the winding. Typical values of transformer losses for some widely used distribution transformers are given in Table 3.1.

Table 3.1: Transformer losses of different transformer ratings

Rating, kVA	No load loss, Watts	Load losses, Watts
25	68	509
63	125	829
100	320	1950
160	455	2800
250	640	4450
500	900	6450

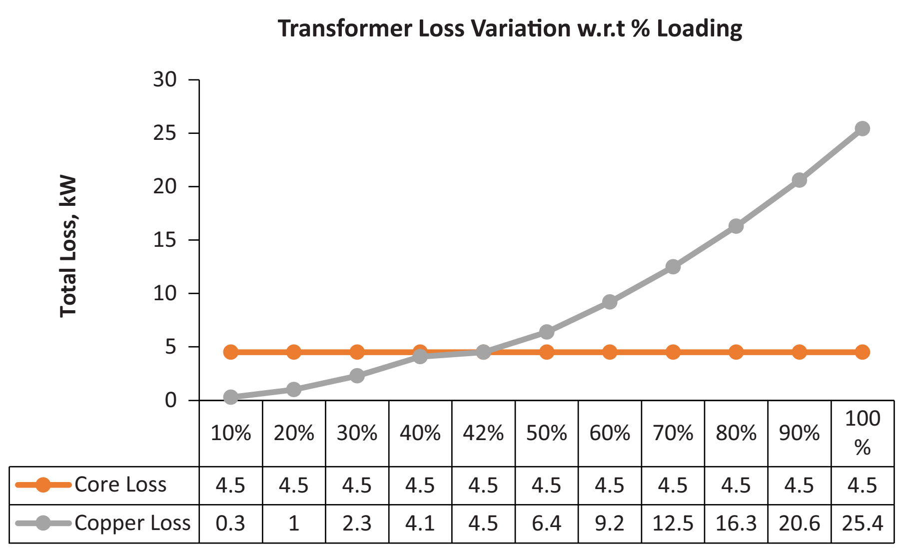
For a given transformer, the manufacturer will provide a test certificate which consists of no load and load test details. The total transformer losses can be calculated based on the following formula.

$$\textit{Total transformer losses } P_{Total} = (P_{No\ load\ loss} + (\%\textit{transformer loading})^2 * P_{load\ losses})$$

Where,

$$\%\ \textit{Transformer loading} = \frac{\textit{Actual load on transformer, kVA}}{\textit{Rated load of transformer, kVA}} * 100$$

The transformer should always be operated at the best efficiency point which is the % loading of the transformer when Core losses are equal to copper losses. Copper losses depend on percentage loading of the transformers. For example, the transformer loss scenario of 33/6.6 kV, 3 MVA power transformer is illustrated as an example below.



	10%	20%	30%	40%	42%	50%	60%	70%	80%	90%	100 %
Core Loss	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Copper Loss	0.3	1	2.3	4.1	4.5	6.4	9.2	12.5	16.3	20.6	25.4

Figure 3.5: Transformer loss scenario of 33/6.6 kV, 3 MVA power transformer

The above figure illustrates how the copper losses vary with respect to the percentage loading of the transformer. Above best efficiency point, copper losses increase drastically. Hence, Distribution transformers should be loaded optimally for better efficient operation. The following equation can be used to calculate the best efficiency point (BEP).

% Loading of transformer at BEP can be calculated when

Core losses= (% loading of transformer)^2 ** Copper losses*

$$\Rightarrow \text{\% Loading of Transformer (@BEP)} = \sqrt{\frac{\text{Core losses}}{\text{Copper losses}}} \times 100 = \sqrt{\frac{P_{no\ load\ losses}}{P_{load\ losses}}} \times 100$$

Example: A facility has 100 kVA transformer at its incomer. The operating load of the facility is 50 kVA. Calculate the total daily operational losses of the transformer. The facility operates for 10 hours a day. Consider no-load losses and load losses of the transformer as 320W and 1950W respectively based on the manufacturer test reports.

Solution: % Loading of the transformer = $\frac{50}{100} \times 100 = 50\%$

$$\text{\% Loading of Transformer (@BEP)} = \sqrt{\frac{320}{1950}} \times 100 = 40.5\%$$

The transformer is operating at 50% loading whereas; the BEP is at 40.5%.

$$\textit{Total transformer losses } P_{Total} = \frac{\left(320 + \left(\frac{50}{100}\right)^2 * 1950\right)}{1000} = 0.81\ kw$$

$$\textit{Daily transformer losses} = 0.81\ kW \times 10\textit{hours} = 8.1\ kWh$$

The transformer consumes a total energy of 8.1 kWh/day.

3.3 Demand Side Management

There has been significant growth in the electricity use that has led to strain on the installed power generation capacity to meet the demand. Since adding more capacity is a costly affair and its economical only in long time prospect, effective load management at user end can help to minimise the peak demand on the utility infrastructure as well as better utilisation of existing capacities. Load management is a powerful means of improving efficiency of utility performance and end use. This is popularly termed as "Demand Side Management (DSM)". The measures that are considered under DSM are time of use tariffs, penalties for exceeding the permissible maximum demand etc. The following strategies can be used as a part of DSM program:

- Actual accounting of Energy data – consumption and losses at various levels
- Following effective monitoring and control methods
- Good housekeeping measures
- Identification of loss occurring areas and taking measures to minimise
- Optimisation of end use equipment
- Use of technically advanced energy efficient equipment at consumer end.

Maximum demand refers to peak amount of energy that is consumed in a given period. Various steps to understand and control the maximum demand are explained below:

1. Load Curve:

'Load curve' is the consumer load demand plotted against time of the day. If the load curve is plotted for each hour of a single day (24 hours), it is called 'hourly load curve'. If the daily load demand is plotted over a month, it is called daily load curve. A daily load curve of a small manufacturing facility is shown as an example in Figure 3.6.

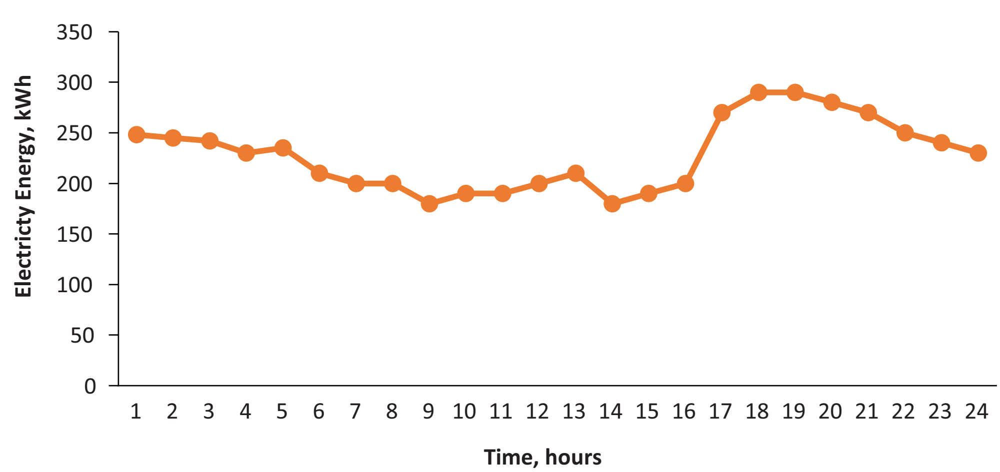


Figure 3.6: Daily load curve of small manufacturing facility

From the graph, it can be observed that in a typical load curve has an 'Ups and Downs' in the profile which can be technically called as 'peaks and valleys' respectively. Based on this, the "Load Factor" can be obtained with following formula:

$$\textit{Load factor} = \frac{\textit{Energy consumed in 24 hours (kWh)}}{\textit{Maximum load recorded, kW)} \times 24 \text{ hours}}$$

Load factor gives an indication of energy consumption characteristic of facility over a given period of time and its value ranges from a small fraction to 1. The value of load factor which is close to 1 is considered to be the best value. The load curve helps to predict the time of occurrence of the peak load and aid the facility's management to control the demand.

2. *Load re-scheduling:*

Any facility or process industry which operates throughout the day will have a number of operating loads as per the requirement. Some of the equipment operation is critical to the process and some may be non-critical such as load in utilities like water treatment plant, effluent and sewage treatment plant etc. From the load curve, the managers can understand when the peak load is occurring and schedule the operations in such a way to minimise the peak demand and improve the load factor.

3. *Load staggering:*

In large industries, there may be many equipment including large capacity motors. Switching ON multiple large sized motors simultaneously can increase the maximum demand. Hence, it is important to properly plan the switching ON of these motors one after the other as much as possible.

4. *Energy storage:*

Some of the food processing industries may need a lot of energy to meet hot or cold-water requirements. Hot water generators or chillers are installed to fulfil the requirement and they may switch ON or OFF automatically. There can be instances when these equipment may switch ON during peak hours which can lead to increase in energy demand and cost. In such cases, it is highly recommended to consider installing a hot or cold storage facility to avoid increasing the demand.

Example*: Ice bank system is used in dairy industry and some chemical industries. Ice is prepared in the facility during non-peak hours and same is used for meeting cold water requirement during the peak hours.*

5. *Captive power generation:*

Industries widely use electricity from grid and keep Diesel power generators (DG set) for emergency use. Based on the electricity bill analysis, the unit electricity cost in some areas may be higher than the captive power generation cost during the peak hours. If the maximum demand is occurring during the peak hours as specified by the electricity tariff, then it is a wise decision to shift the power consumption source to DG set from the grid to reduce energy use cost.

6. ***Reactive power compensation:***

Reactive power compensation is the method of controlling the maximum demand by means of adding capacitor banks at the incomer which can help to improve power factor by inducing capacitive currents to compensate inductive load currents.

3.4 Power factor improvement

Majority of the industrial loads are inductive in nature and only few of them are resistive in nature. It is very important to improve the power factor of the operating loads as well as at the incomer to reduce losses due to power flow in the cables which will eventually reduce the demand. For this purpose, capacitors are widely used in industrial as well as commercial facilities. To understand the benefits of installing capacitors, it is essential to understand 'the Power triangle' concept which is explained in Figure 3.7:

$$kW = kVA * \cos Ø$$

- Apparent Power is represented in KVA (Kilo Volt Ampere);
- Active or Real or True Power is represented in KW (Kilo Watts)
- Reactive Power is represented in KVAR (Kilo Volt Ampere reactive) - Reactive power is 'inductive' and 'capacitive' in nature.
- Active power is required to perform the 'work' and Reactive power is required to create and maintain 'electro-magnetic fields'.

$$\text{Active power (P)} = \text{Apparent Power (S)} * \text{Power factor (PF)}$$

$$\text{Power factor} = \cos Ø = \frac{kw}{kVA}$$

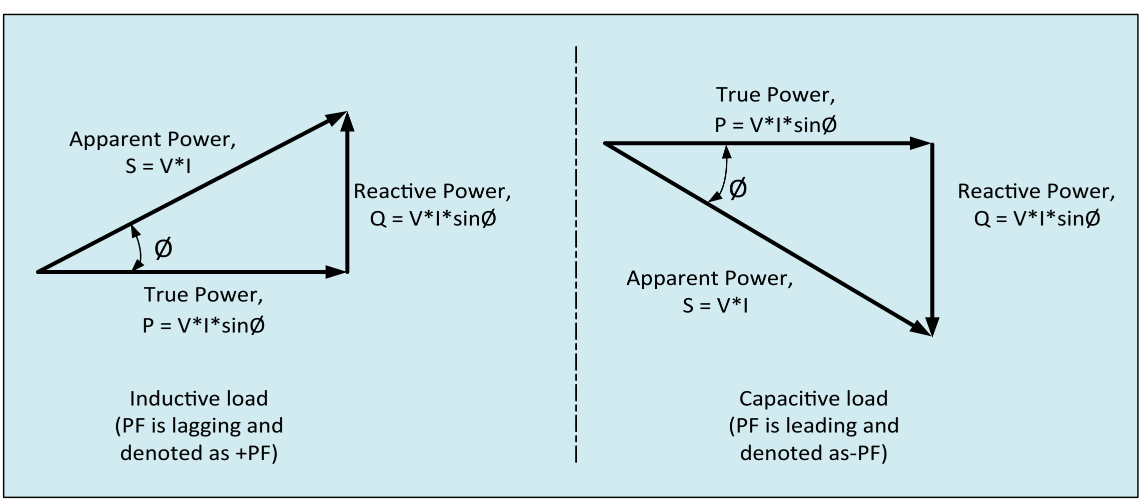


Figure 3.7: Power Triangle

Power factor is the ratio of real power used in a circuit to the apparent power delivered to the circuit. For a purely resistive load, PF is equal to Unity. For an inductive load, the PF is lagging i.e., reactive power is lagging the active power and it is denoted as (+) PF. For capacitive loads, the PF is for leading i.e., reactive power is leading the active power and it is denoted as (-) PF. Some of the examples of resistive, inductive and capacitive loads are given below:

- Resistive loads : Electric heaters, Arc furnace, Incandescent lamps, etc;
- Inductive loads : Electric motors, Fluorescent tube lights, etc;
- Capacitive loads : Capacitors, Synchronous condenser, etc;

Capacitors provide negative currents to compensate for the positive inductive load currents that can help in reducing the gap between the active power and apparent power. In industries and electrical utilities, Capacitors are connected at various locations to improve the power factor. Different ways of connecting capacitor in an industry are shown in Figure 3.8.

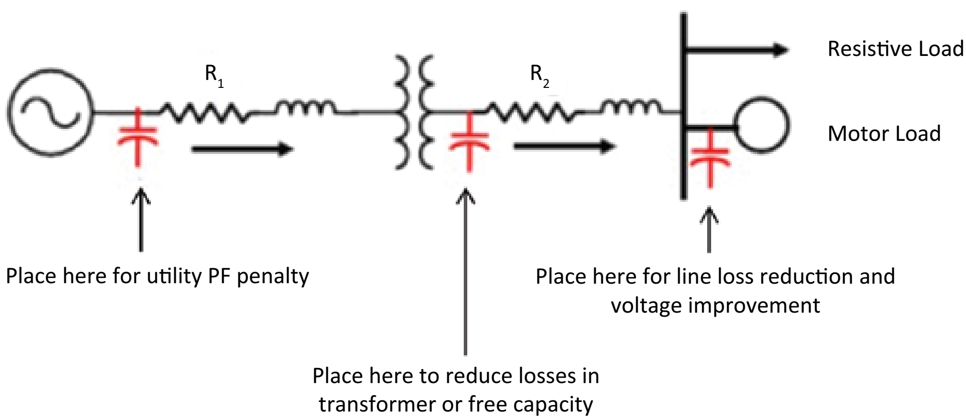


Figure 3.8: Capacitors connected in an electrical network

The capacitor banks connected at different locations have different uses which are explained below:

- Capacitor banks connected at the incomer of any facility or power distribution feeders can help in minimising the maximum electricity demand (kVA).
- Capacitors connected at the load end (or load centres like MCC) can help in minimising the cable losses i.e, I^2R losses (where I = Load current carried by the cable and R is the resistance of the cable).
- When capacitor banks are connected at the load end, the voltage level at the point of coupling will also improve.
- Capacitor bank connected at the load end, will also reduce KVA loading of the generators, transformers, and cables.
- Capacitors always improve the power factor from the point of coupling to the upstream network.

- A good power factor can help in utilising the full capacity of the electrical system without enhancing its capacity. Hence, power factor control is a widely used method for demand control.

Selection and sizing of capacitor banks: Capacitor bank for power factor improvement are of two types:

1) **Fixed Capacitor banks:** Fixed capacitor banks are connected across a base load or across the loads which are not varying in nature.

   Example: 1) Capacitor banks connected at the motor end where the load is fixed.

   2) Capacitor banks sized to suit the base load of a factory.

2) **Automatic Power factor controller (APFC):** A group of Capacitor banks are connected together to an automatic power factor controller which senses the load current and switches ON or OFF the capacitors as required to meet a set value of power factor.

   Example: APFC for loads which are variable in nature such as MCC board where a group of motors are connected, and they operate in switch ON and OFF mode as per the process needs.

The capacitors can be selected based on the following formula

*Size of capacitor bank in kVAR=input kW**[tan$\varnothing_1$ -tan$\varnothing_2$]

Where,	tan$\varnothing_1$	: Trigonometric ratio for existing PF
	$\varnothing_1$	: $\cos^{-1} PF_1$
	tan$\varnothing_2$	: Trigonometric ratio for new PF
	$\varnothing_2$	: $\cos^{-1} PF_2$

Example: A commercial building has a load of 50 kW with an operating PF of 0.75. The facility decides to install capacitors and improve the PF to 0.95. Calculate the size of capacitors required?

Solution:	Existing PF	= PF_1	= cos$\varnothing_1$	= 0.75
	New PF	= PF_2	= cos$\varnothing_2$	= 0.95
	tan$\varnothing_1$	= tan ($\cos^{-1}$0.75)		= 0.882
	tan$\varnothing_2$	= tan ($\cos^{-1}$ 0.95)		= 0.329

Size of capacitor bank in kVAR = 50 * [0.882-0.329] = 50 * 0.553 = 27.65 kVAR

In order to avoid the difficulty of using the above formula, a table was developed to ease the calculation and same result can be obtained with multiplying factors provided in the following table. Table 3.2 gives a set of multiplying factors through which the sizing of capacitors can be easily performed.

Table 3.2: Multiplying factors to estimate the size of the capacitor bank

Original PF	Desired PF				
	1.00	0.95	0.90	0.85	0.80
0.55	1.519	1.18	1.03	0.89	0.763
0.60	1.333	1.00	0.84	0.71	0.583
0.65	1.169	0.84	0.68	0.54	0.419
0.70	1.020	0.69	0.53	0.40	0.270
0.75	0.882	0.55	0.39	0.26	0.132
0.80	0.750	0.42	0.26	0.13	
0.85	0.484	0.29	0.13		
0.90	0.328	0.15			
0.95	0.620				

*Size of capacitor bank = Input kW * multiplying factor*

By knowing the existing power factor, the multiplication factor may be used to estimate the size of capacitor bank required for the present level of load (kW).

Example: Power factor of a 50 kW load is 0.75 which has to be improved to 0.95 to minimise the electricity bill. Calculate the size of capacitor bank required to be installed at the facility main incomer.

Solution:	New PF	= 0.95
	Old PF	= 0.75
	Load	= 50 kW

For old PF of 0.75 and new PF of 0.95; the multiplying factor taken from the above table is 0.55.

*Size of capacitor bank = 50 * 0.55 = 27.5 kVAR*

Therefore, the size of the capacitor bank required for installing at the facility main incomer is 27.5 kVAR 30 kVAR.

3.5 Electric motors

Electric motors are typically responsible for transferring electrical power to mechanical power, and they consume about 50 to 70% of total industrial energy consumption depending on the type of industry. Any motor has two main parts i.e., a stator (stationary part) and a rotor (rotating part). Electric motors can be of alternating current (AC) or Direct Current (DC) category and further sub divided into many types. The classification of electric motors is presented in Figure 3.9:

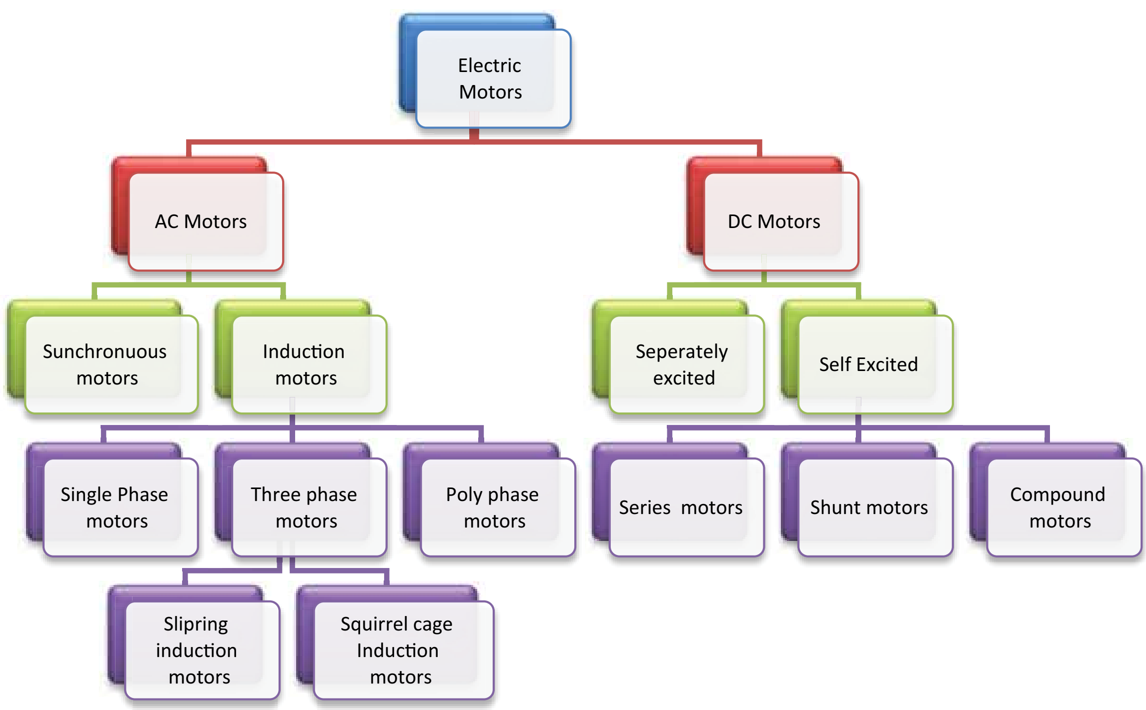


Figure 3.9: Classification of electric motors

From the Figure 3.9, it can be seen that there are several varieties of electric motors available for carrying different type of works. Among all types, induction motors (single and three phase induction motors) are widely used in performing industrial, commercial, residential and agricultural activities. Synchronous motors are also used in some industrial applications. The speed of electric motors is expressed in "revolution per minute (RPM)". And the speed of the motor is dependent on the frequency and number of poles. The formula to calculate synchronous speed of the motor is given below:

$$\text{Sychronous speed} = \frac{(120 \times \textit{Frequency (in Hz)})}{\textit{Number of poles}}$$

The electric motors operating with 50 Hz frequency have synchronous speeds like 3000 / 1500 / 1000 / 750 / 600 / 500 / 375 RPM corresponding to the number of poles 2, 4, 6, 8, 10, 12, 16 (always even number) respectively. Synchronous motors always operate at synchronous speeds and induction motors operate at a speed that is less than the synchronous speed. The difference between the synchronous speed and the full load speed is known as 'slip'.

$$\textit{Slip}\ (\%) = \frac{\textit{Sunchronous speed-Full load speed}}{\textit{Synchronous speed}} \times 100$$

The speed of the induction motors can be practically varied by adjusting the supply voltage and frequency keeping slip constant. This speed variation (either increase or decrease) can be achieved by using Variable Frequency Drives (VSD). The speed variation limits will be specified by manufacturer for each type of motor. Electric motors are inductive in nature and hence their operating power factor is on the lower side which is dependent on the motor operating load.

Motor Efficiency:

The input energy to the motor is electric power and the output power is termed as shaft power (mechanical energy). The ratio of output to the input is called Efficiency. The formula to calculate motor efficiency is given below:

$$\%\ \textit{Motor Efficiency}\ (\eta_M) = \frac{P_{OUT}}{P_{IN}} \times 100$$

Where;	P_{IN}	= Input Power, kW =
	V	= Supply Voltage
	I	= Load Current
	CosØ	= Power Factor
	P_{OUT}	= Output power = Shaft power

Shaft power is determined by measuring torque generated by the motor. It needs an additional torque meter connected to the motor shaft to measure the actual torque generated. The following formula can be used to calculate the shaft power through the torque method:

$$\textit{Shaft Power} = \frac{2\pi N\tau}{60}$$

Where; N = Motor speed, RPM

T = Torque generated by the motor

Motor efficiency can also be calculated by estimating the losses that take place during the motor's operation. Motor losses are of two types: 1) No-load losses 2) Load losses

No-load losses: also called fixed losses or rotational losses or iron losses. These losses occur due to magnetisation of core. These losses are independent of the motor operating load and dependent on core material, geometry and input voltage. No-load test is used to measure and estimate the fixed losses.

Load losses: also called as variable losses. These losses occur due to stator winding resistance and miscellaneous stray losses. Heat generation takes place in the stator and rotor due to the flow of current which is relational to resistance (R) of the material and the square of the load current (). As resistance (R) is temperature dependent, it is necessary to consider temperature correction factor while estimating the stator and rotor losses. Stray losses are very difficult to estimate or measure as they arise from a variety of sources, but is generally proportional to the square of the rotor current.

$$\textit{Total motor losses } (P_{Losses}), \textit{ Watts } 0\ P_{No\text{-}load} + P_{Load}$$

$$P_{OUT} = P_{IN} - P_{Loss}$$

$$\%\ \textit{Motor Efficiency } (\eta_M) = \frac{P_{IN} - P_{LOSS}}{P_{IN}} \times 100$$

In this way, motor efficiency can be estimated on a test bench in torque method (direct method) as well as loss estimation method (Indirect method) as specified by IEEE Standard 112. It is difficult to estimate motor efficiency on field as it needs to stop the motor from operation which can affect the activity being performed. However, with the help of slip and input measured power we can estimate the operating efficiency in crude manner.

Motor selection and operating load survey:

Selecting a suitably sized motor for meeting the torque required for intended application is an important technical consideration. The performance and efficiency of the motor depends on its loading percentage. This relation is illustrated in Figure 2.10. In industrial applications where motors are mainly used, it can be seen based on the measurements that motors operate at different loads.

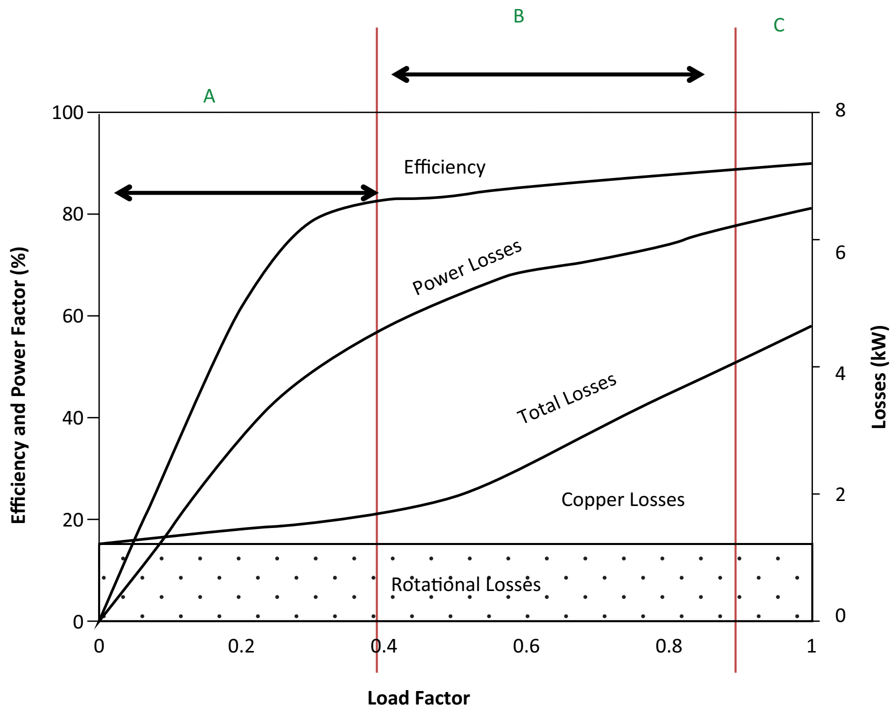


Figure 3.10: Motor efficiency variation with respect to operating load

The motor efficiency tends to fall drastically at loads below 40%. A 'Motor Load Survey' during an Industrial Energy audit helps the operating staff to quickly understand about the operational behaviour of different motors operating in various sections of the facility. Based on the survey results, the motors can be segregated into three categories:

- A: under loaded condition (<40% load)
- B: Optimum load condition (>40% and < 90%)
- C: Overload condition (>90% load)

To estimate the motor loading the following formula can be used:

$$\textit{\% motor load} = \frac{\textit{Rated kW}}{\textit{Input measured kW})/(\textit{Rated motor efficiency}} \times 100$$

Input power can be measured with the help of a digital energy meter. Rated kW and Efficiency details are available on the motor name plate or test certificate. In industries, significant number of motors will be operating in under loaded conditions which can contribute to low operating power factor and energy losses. Wherever possible, the identified under loaded motors can be replaced with downsized high efficiency motors which help in improving the reliability, power factor and minimising the motor operational and cable losses. The overloaded motors can be kept under observation and if the scenario continues, then the cause of the problem has to be investigated and rectified. Hence, selection of a suitable capacity motor for a given application is of highest priority to minimise losses and maintain good power factor. Some of the parameters to be considered during motor choice are:

- Areas of motor use – Corrosive or dusty or hazardous
- Ambient temperature and altitude
- Physical space available

Factors affecting the Motor performance:

Some of the factors that affect the motor efficiency and performance are listed below:

- Power quality - It shall meet IEEE 519 standards
- Voltage unbalance - Restricted to below 0.5%. With increased percentage of voltage unbalance can result in increase in unbalance currents among the three phases which can create additional energy losses.
- Re-winding of motors can cause drop in the efficiency up to a level of 2% (for every time rewound).

Energy Efficient motors:

Energy efficient motors (EEM) are the latest ones in which design improvements are incorporated specifically to increase operating efficiency by reducing inherent losses over the conventional standard motors. Improvements include:

- the use of lower-loss silicon steel,
- a longer core to increase resistance,
- thinner laminations and smaller air gap
- between stator and rotor,
- copper instead of aluminium bars in the rotor,
- Superior bearings and smaller fan etc.

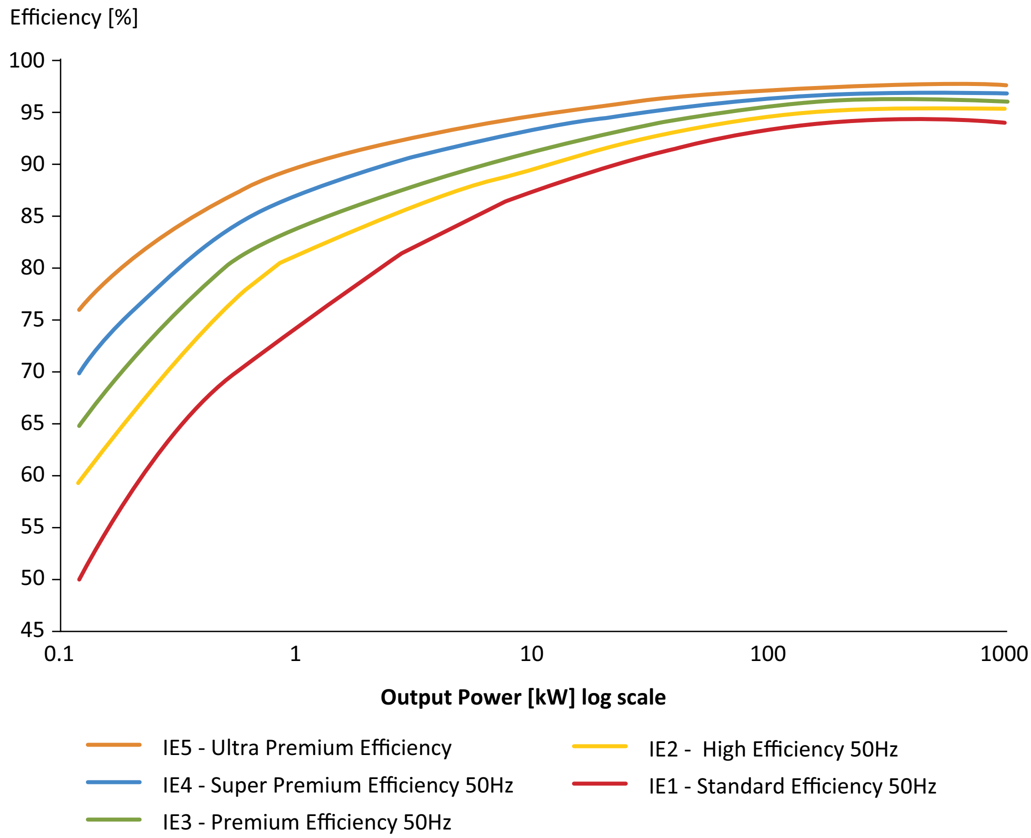


Figure 3.11: IEC efficiency standards for different class motors

NEMA and IEC 60034-2 are the main standards that are followed internationally to specify the motor efficiency standards. IE1, IE2, IE3, IE4 and IE5 are the sub classification of motors efficiency classes from Standard efficiency to Ultra-Premium Efficiency. EEMs are typically 3 to 4% higher efficient than the standards motors. While replacing an old standard motor with new energy efficient motor, the following formula can be used to estimate power savings:

$$\textit{Power savings, kW} = \textit{rating of old motor in kW} \times \left(\frac{100}{\eta_{standard}} - \frac{100}{\eta_{new}} \right)$$

Example: An old standard efficiency class 7.5 kW electric motor being operated in a production line which operates 24 x 7. The management has found that this motor is continuously creating problems and production is lost. Hence, they decided to change the existing motor with new energy efficient motor. The name plate efficiency of the old motor is 83% and the new motor is 87%. Calculate the annual energy savings if the motor is operated for 8000 hours per year and electricity cost is 0.78 EC$. Investment cost of new motor is 800 EC$.

Solution:	Old Motor capacity	= 7.5 kW with rated efficiency of 83%
	New Motor capacity	= 7.5 kW with rated efficiency of 87%
	Annual operating hours	= 8000 hours

$$\textit{Power savings, kW} = 7.5 \times \left(\frac{100}{83} - \frac{100}{87} \right) = 0.42\ kW$$

Annual energy saved = 0.42*8000 = 3360 kWh

Annual cost savings (@58 GY$/kWh) = 194,880 GY$.

3.6 Diesel Generator sets

A diesel generator (DG) set is a combination of a diesel engine with electric generator (alternator). The diesel engine is used as a prime mover to rotate the alternator for generating electricity. DG sets usually operate with diesel as fuel. Some special engines have the capability to operate with either diesel or natural gas and these are called dual fuel engines. DG sets are used as a main power generating units that are connected to the power grid and also used as power back-up units in emergency conditions. They are also used as isolated power generating units where grid facility is not available. While operating in parallel with the grid or any renewable energy source, proper control mechanisms such as AMF (Auto Mains Failure) relay and automatic load current sensing devises shall be employed to protect the DG set and damaging due to under loading. It is always not recommended to operate DG sets below 25% loading with respect to its full rated capacity.

Proper sizing of DG sets is critical to avoid low-load or a shortage of power. For single phase power users such as residential and small commercial sectors, DG set size ranges from 8 to 30 KVA. For three phase application such as large power applications and industrial applications, DG set sizes ranges up to 10,000 kVA. Depending on the size of the engine and availability of water resources, the cooling system can be air cooled or water cooled type. Water cooled DG sets require more maintenance as well as consumes high auxiliary power than air-cooled DG sets of similar capacity.

Fuel consumption is one of the main important things to be considered while choosing a DG set. The amount of electricity generated by a DG set for one litre of fuel is called 'Specific Fuel Consumption (SFC)' which is expressed in kWh/L.

$$\textit{Specific Fuel Consumption}\left(\frac{kWh}{L}\right) = \frac{\textit{Electricity generated per hour}}{\textit{Quantity of fuel consumed,Litres}}$$

SFC is a measure of efficiency of DG set and it varies with respect to the percentage loading of the DG set. A sample performance curve of 400 kVA DG set is shown in Figure 3.12 as an example. Hence, it is highly recommended to operate DG sets at optimum load conditions. The following Table 3.3 provides a sample data regarding average fuel consumption of different capacity DG sets per hour at different load conditions.

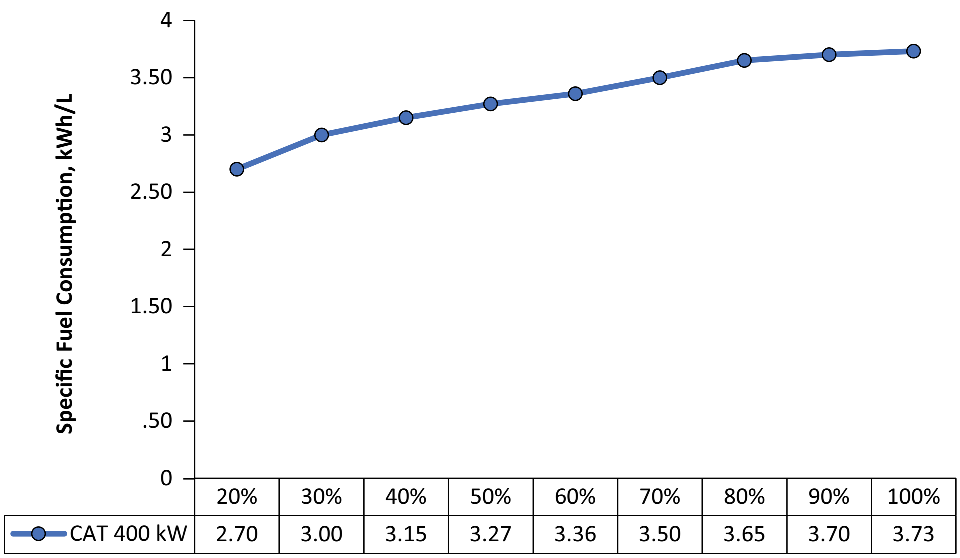


Figure 3.12: SFC Vs % loading

Table 3.3: Approximate fuel consumption details of different capacity DG sets

DG set size, kW/kVA	Approximate fuel consumption (Diesel), litres/hr			
	25% load	50% load	75% load	100% load
8/10	1	1	2	3
10/12	1	2	3	4
12/15	1	2	3	4
16/20	1	3	4	5
20/25	2	3	5	6
24/30	2	4	5	7
32/40	3	5	8	10
40/50	3	6	9	12
60/75	5	9	14	19
80/100	7	12	18	25
120/150	8	16	24	32
160/200	10	20	30	40

3.7 Electricity Billing

The electricity tariff structure for different types of consumers of the Government and Non-Government sector effective from April 11, 2021 is provided below:

Non-Government:

Rate Category	Tariffs	Fixed-Rate/Demand Charge, GY$	Energy Rate, GY$ after 15% fuel rebate
Residential: Lifeline	A < 75 kWh	341.54	39.10
Residential	A > 75 kWh	351.04	43.43
Commercial	B	2467.00	56.38
Industrial	C	1760.22	50.93
Industrial	D	1760.22	48.78
Street Lights	E		43.08

Government:

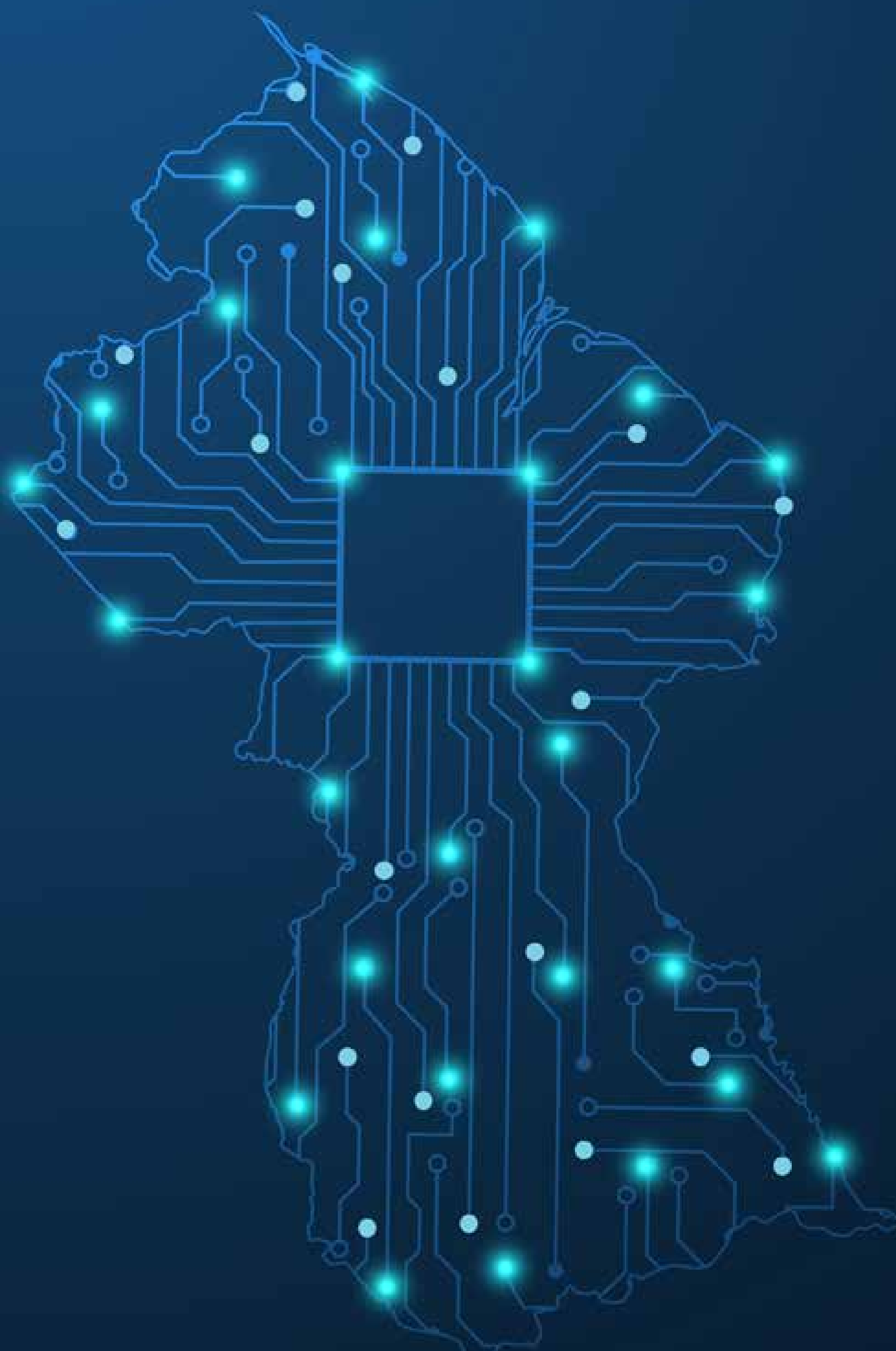
Rate Category	Tariffs	Fixed-Rate/Demand Charge, GY$	Energy Rate, GY$ after 15% fuel rebate
Residential: Lifeline	A < 75 kWh	386.47	47.18
Residential	A > 75 kWh	386.47	47.81
Commercial	GB	2574.25	58.83
Industrial	GC	1836.75	53.14
Industrial	GD	1836.75	50.90
Street Lights	GE		44.96

The electricity grid of Small Island Developing States (SIDS) is predominantly powered by fossil fuel mainly the expensive and highly polluting Diesel Generator sets. There is a conscious move to switch to renewable energy largely through solar PV and to a certain extent, wind power. The demand side load of the grid comprises mainly industries, residences and commercial buildings. The demand fluctuates with time. The supply-side consisting of DG sets have to match this fluctuating load.

The grid is evolving with the integration of further variable renewable power on the supply side with reduced firm power through DG sets and highly variable renewable power. This calls for electrical storage for balancing power generation on the supply side and varying load on the demand side. Hence, it becomes imperative that before the grid adopts electrical storage, proper demand-side management like energy efficiency measures, smart meters should be implemented across sectors. Implementation of energy management directly benefits the end-user with maximum economic returns with minimal environmental impact.

CHAPTER 4

Lighting Systems



Light is a phenomenon that makes seeing possible by the naked human eye. It is a part of the Electromagnetic Spectrum that has a different range of frequencies of electromagnetic radiation with specific wavelengths and photon energies. The visible light falls in between the Ultraviolet and Infrared spectrum. The Sun is the major source of energy that emits most of the power in the visible light and infrared region besides other electromagnetic spectrum frequencies. The wavelength of the visible light spectrum falls in the range of 380 to 760 nm (400-790 terahertz). Figure 4.1 represents the visible light in the electromagnetic spectrum.

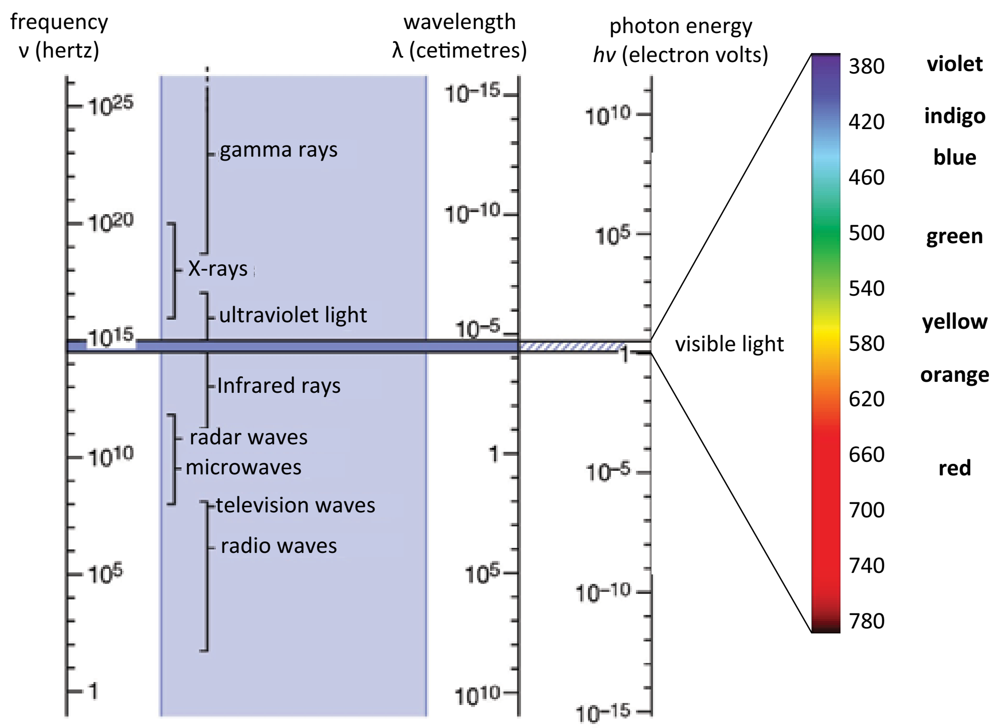


Figure 4.1: Frequency range of electromagnetic spectrum showing visible light

The visible light is measured in lumen (lm) which is the photometric equivalent of Watt, subjective to match the human eye response of the "standard observer". Yellowish-green light receives the greatest weight because it stimulates the eye more than blue or red light of equal radiometric power.

$$1 \textit{ Watt} = 683 \textit{ lumens at } 555 \textit{ nm wavelength}$$

The relative sensitivity of the human eye towards visible light spectrum wavelength variation is presented in Figure 4.2.

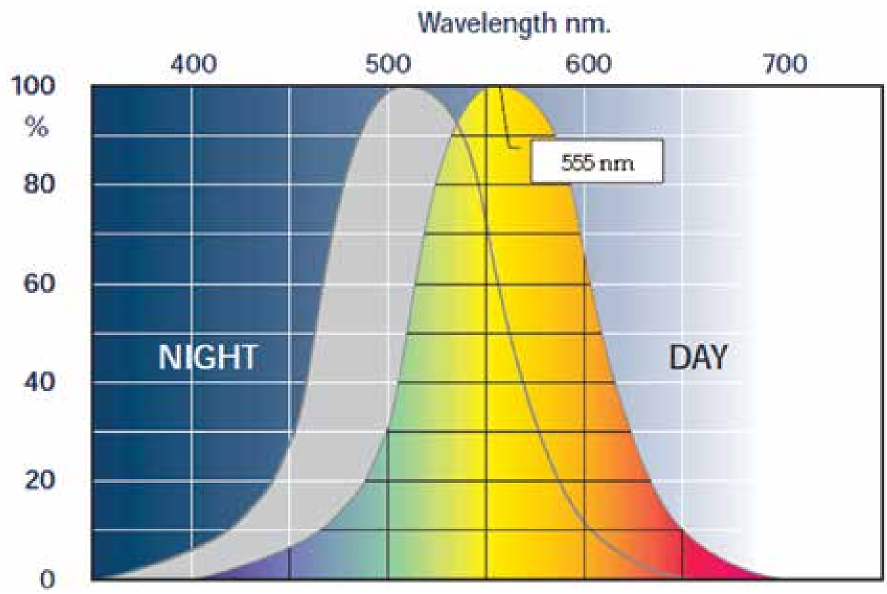


Figure 4.2: Relative sensitivity of human eye towards visible light spectrum

4.1 Understanding Lighting terminology

Natural light comes mostly from Sun. However, there are man-made sources that produce light energy by consuming external energy source such as fossil fuels. Artificial light sources constitute mainly flame sources (through the combustion of wood, gas and oil) and electric powered lighting lamps. Moreover, artificial lighting has visual, emotional and biological effects on human health.

Colour is a phenomenon of psycho physiologic interpretation of the visible electromagnetic spectrum incident on different object surfaces. Depending on the wavelength, the interaction of visible light with light-sensitive cells in the eye allows us to see different colours. All the objects are observed by contrasts of colour and luminance present on different parts of the surface. The following Figure 4.3 illustrates the phenomenon of light emitted by an artificial source and incident on an object and how it is perceived by the human eye.

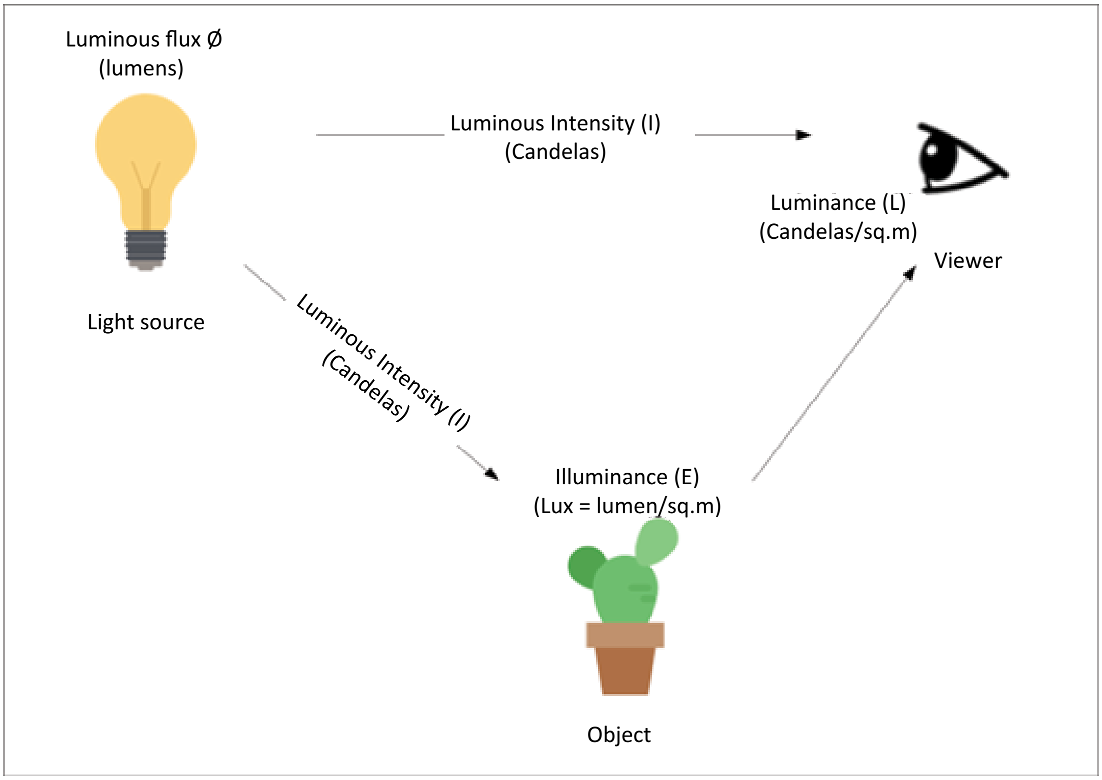


Figure 4.3: Interactions of artificial light with object surfaces and the human eye

Based on these interactions the lighting terminology can be demonstrated and major terms are explained below:

Luminous flux (Ø): is defined as the total quantity of light emitted by a light source (lamp) which is expressed as LUMEN (lm).

Luminous Efficiency is a measure of light source's economic efficiency, defined as the ratio of the luminous flux to the electrical power consumed (lm/W).

Luminous Intensity (I) is the quantity of light radiated by the lamp source in a specific direction. It is measured in CANDELA (cd).

Illuminance (E): is a photometric term defined as the quantity of light incident on a surface or a plane. Illuminance is commonly called a 'light level' measured in lumens incident on a plane of one square foot or one square meter area. This term is generally expressed as LUX (lx).

$$\textit{Illuminance (E)} = \frac{\textit{Luminious flux (lm)}}{\text{area } (m^2)}$$

Luminance (L): is a basic lighting parameter that is perceived by the human eye. Luminance is defined as the impression of the brightness of a light source which is majorly dependent on the colour and degree of reflection of the surface (cd/m^2).

4.1.1 Indoor lighting

The concepts discussed above provide a technical base to understand the quality features of appropriate indoor lighting. Some of the criteria are listed below:

- Proper design to match the interiors and activity performed
- Adequate illumination level
- Uniform brightness distribution
- Right light colour with appropriate colour rendering
- Minimum glare and avoiding reflections
- Daylight integration
- Energy Efficiency – Technology and Smart controls

Lux levels are specified for specific visual tasks and are designed for the area in which it takes place. The *Illuminance level* shall not fall below a minimum level as per standards in the visual task area and there shall not be any great difference in brightness so that uniformity shall not fall below a particular value. The room's brightness depends on the *reflectance factors* of the room and object surfaces that determine the perception of the room and reflected light. *Glare* is also an important factor to be considered which, if not properly controlled, shall affect the person sitting in the room through loss of concentration, fatigue and more frequent mistakes. The glare of the luminaires that are in the room can be evaluated with the help of the UGR (Unified Glare Rating) method, as specified in the standard EN12464-1 (Lighting of indoor workplaces). The colour of the light determines the room's basic appearance and atmosphere. Different light technologies produce different colour and it is expressed as the temperature at which a heated black body radiator matches the colour of the light source. *Colour temperature* is usually measured in Kelvin (K).

Description	Colour temperature	Appearance	Association
WW (Warm White)	Up to 3300 K	Yellow -Reddish	Warm
NW (Intermediate White)	3300 – 5300 K	White	Neutral
TW (Cool White)	From 5300 K	Green -Bluish	cool

The colour temperature chart is presented in Figure 4.4.

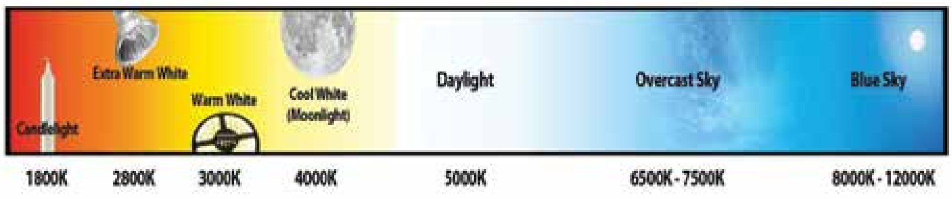


Figure 4.4: Colour Temperature Chart

Colour rendering is the ability of the light source to reproduce surface (8 test colours R_1 to R_8) colours as true as possible compared to a reference light source. It is identified by Colour Rendering Index (CRI). The ideal value of CRI = 100. Whereas artificial light sources are divided up into CRI levels: CRI > 90 – Very good and CRI > 80 – Good. CRI < 80 is considered to be bad and shall not be selected for workplaces. Figure 4.5 shows an illustration of CRI and the colour temperature of a light source.

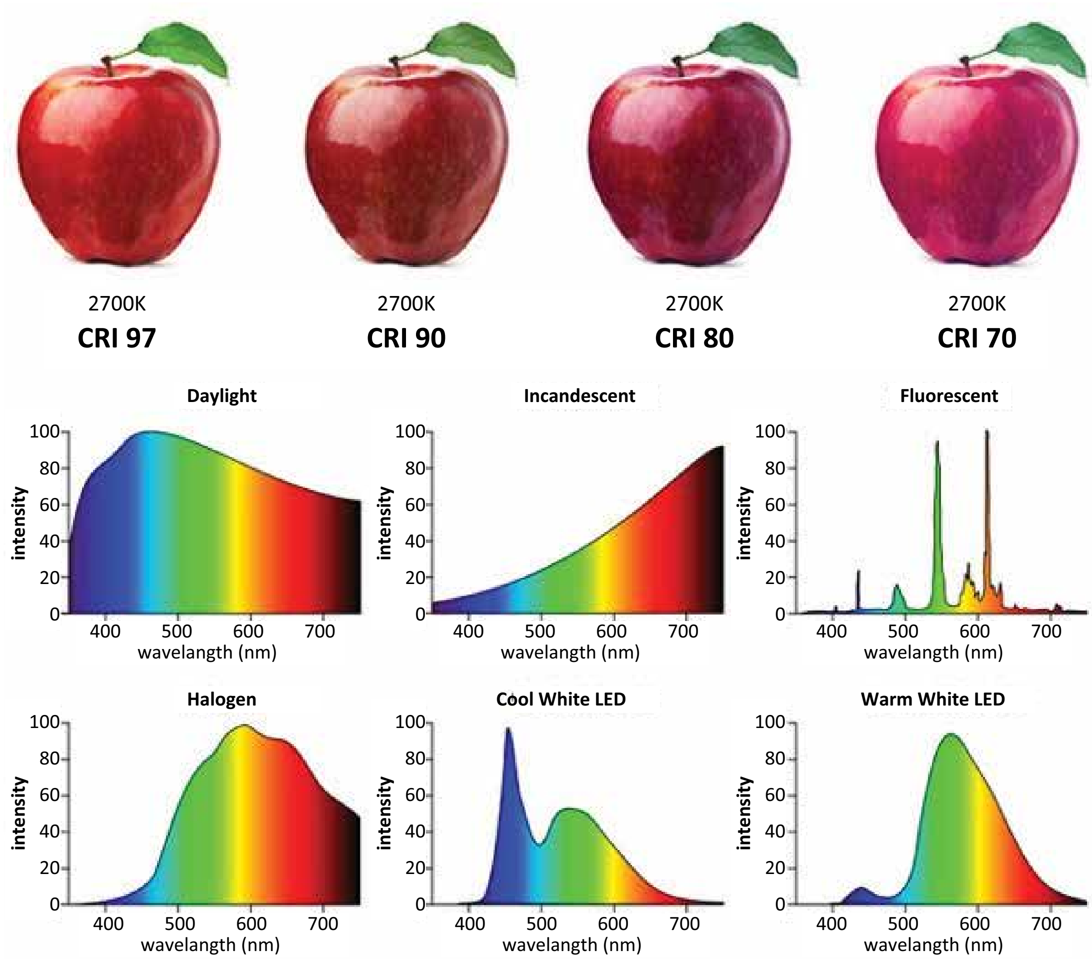


Figure 4.5: CRI and Colour temperature illustration of different light sources

Figure 4.5 depicts how variation in CRI and colour temperature of different light sources makes a difference in the visual perception of the human eye. Depending on the type of application and the need, lighting system in workplaces can be designed either directly or indirectly.

4.1.2 Outdoor lighting

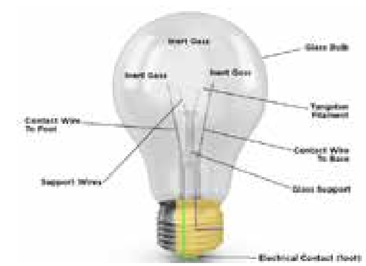
The following are the criteria that have to be considered for the illumination of outdoor areas such as parks, squares, building perimeters, streets and facades:

- The target area to be illuminated has to be visualized both horizontally and vertically during the design phase
- Balanced brightness distribution
- Avoiding dark patches
- Choosing the right light colour and CRI

4.2 Lamp types and comparison of various features

A lamp is a device that is used to produce artificial lighting using electricity or fuel. Artificial lighting does not have the exact characteristic of natural light emitted by the sun. Lamps are usually fitted in a casing called Luminaire that includes all necessary parts such as a control circuit for supporting the lamps to glow. Incandescent lamp is the first artificial light developed followed by other technologies such as fluorescent tube light (FTL) and high-intensity discharge lamps (HID). Light Emitting Diodes (LED) is the latest in technology that uses semiconductors. All light sources have their unique characteristics to their operating parameters such as colour, efficacy, lamp life etc.

Details of some of the most commonly used lamps are presented below:

Lamp Type	Description	Picture
Incandescent	• Also known as GLS (General Lighting Service) lamp • It consists of a tungsten filament enclosed by an evacuated glass cover filled with inert gas. • The lamp emits around 10% visible light and 70% infrared light. • The remaining 20% is lost in the form of heat as electric current passes through the filament and heats it directly. • CRI > 90; Very good. • Operating hours: 750 to 2000 hrs • Luminous Efficacy: 12 lm/W • Environmental friendly as it contains no mercury	 Incandescent Lamp
Halogen Lamp	• It is another type of incandescent bulb having a tungsten filament enclosed by an evacuated glass cover filled with halogen gas. • The use of halogen gas increases the efficiency and life of the lamp when compared with the incandescent bulb. • More heat is generated as electric current directly passes through the filament. • CRI > 90; Very good. • Operating hours: 2000 to 4000 hrs • Luminous Efficacy: 20 lm/W • Environmental friendly as it contains no mercury	 Halogen Lamp

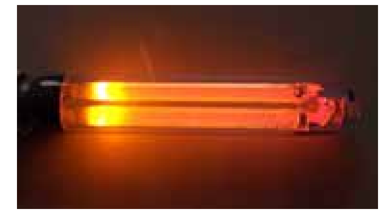
Details of some of the most commonly used lamps are presented below:

Lamp Type	Description	Picture
Fluorescent Lamp – **Fluorescent Tube Light (FTL) and Compact Fluorescent Light (CFL)**	• It contains a glass tube with a small quantity of mercury vapour (for white light) with a special fluorescence coating on the interior surface. • To obtain other light colours, different gases are used. For example, Carbon dioxide is used for green light and neon gas to get red colour. • FTL has two filaments at each end. When electricity is supplied, high voltage is applied to the filaments using starter and choke. • An invisible UV radiation is generated which is high enough to ionise the heated gas inside the tube. The hot ionised gas is called 'plasma' which excites the fluorescent coating on the tube's inner surface to produce visible light. • FTL's are 3 to 5 times more efficient than incandescent lamps. • Different type of FTL's available depending on size & shape are » T12: 38mm (1.5" diameter; 2 & 4 feet length) » T8: 25mm (1" diameter; 2 & 4 feet length) » T5: 16mm(5/8" diameter; 2 & 4 feet length) » T2: 6mm(1/4" diameter) » U-bent or Circular tubes » Compact fluorescent tubes (CFL) • T5, T8 and CFLs are the most efficient among all FTLs • FTLs generally produce 25% of the light in visible radiation and 30% in Infrared radiation. • CRI – ranges from 65 to 85 • Operating hours: 15, 000 to 30,000 hrs • Luminous Efficacy: 50 to 68 lm/W • Lumen depreciation: 20% after 50% of life • FTLs are generally used for indoor applications. • Less environmental friendly as it contains a small quantity of mercury	 Fluorescent Tube Light  Compact Fluorescent Lamp

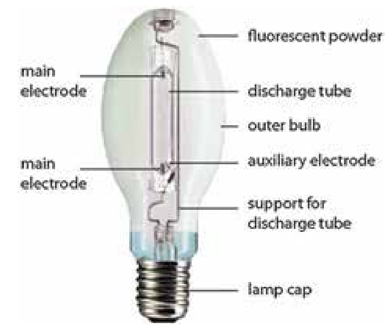
Details of some of the most commonly used lamps are presented below:

Lamp Type	Description	Picture
Induction lamps	• Induction lamps are a type of fluorescent lamp that works on the principle of electromagnetic induction and does not use any electrodes in the tube. • Light is created using an electromagnetic field to excite mercury particles mixed in an inert gas like argon or krypton. • The mercury creates a UV light and a phosphor on the inner side of the bulb or tube, filters the energy into visible light. • The lamp has three components: frequency generator (Ballast), discharge tube and electromagnetic coils. • CRI > 80 • Operating life: 60, 000 to 100,000 hrs • Luminous Efficacy: 80 to 100 lm/W • Lumen depreciation: 10% after 50% of life • These are generally used for general purpose, industrial, warehouse, street lighting and floodlighting etc. • Induction lamps use mercury amalgams, a chemically stable material that consists of mercury combined with other metals. Unlike mercury vapour, this is environmentally friendly.	 Induction Lamp

Details of some of the most commonly used lamps are presented below:

Lamp Type	Description	Picture
HID lamps – **Low-pressure sodium vapour lamp (LPSV)**	• LPSV technology is similar to FTL technology as they work on low pressure. However, they are considered under HID category. • These lamps are most efficient but the quality of light is very poor among all lamp types. • LPSV is a monochromatic light source and under this light, all colours appear black, white or shades of grey to the human eye. • The usage of these lamps is very limited and due to poor CRI, they are used for outdoor applications where colour quality is not important. • Efficacy: 150 to 200 Lm/W • Operating life: 18,000 hours	 Low Pressure Sodium Vapour Lamp
HID lamps – **High-pressure sodium vapour lamp (HPSV)**	• HPSV lamps use a discharge tube in which excess sodium is present and produces saturated sodium vapour conditions during lamp operation. Also, it has mercury to produce a trimmer gas to ease ignition and limit heat conduction from the discharge area to the tube well. The discharge tube is housed in an empty glass cover. • HPSV lamps emit light in a good portion of the visible light spectrum. • CRI <30 Very poor • Efficacy: 80 to 120 lm/W • Operating life: 24,000hours • Lumen depreciation: 30% after 50% of life • These lamps are widely used for outdoor and industrial applications as the light is yellow. • Less environmental friendly as it contains a small quantity of mercury.	 High Pressure Sodium Vapour Lamp

Details of some of the most commonly used lamps are presented below:

<table>
<tr><th>Lamp Type</th><th>Description</th><th>Picture</th></tr>
<tr><td>HID lamps –
High-Pressure Mercury Vapour lamp (HPMV)</td><td>• The discharge in HPMV lamps takes place in a quartz discharge tube containing a small amount of mercury and argon gas filling to help ignition.
• Some part of the discharge radiation occurs in visible light and some part is emitted in ultraviolet radiation.
• CRI <50
• Efficacy: 45 to 60 lm/W
• Operating life: 24,000 hours
• Lumen depreciation: 40% after 50% of life
• These lamps are widely used for outdoor and industrial applications as the light is yellow.
• Less environmental friendly as it contains a small quantity of mercury.</td><td>
High Pressure Mercury Vapour Lamp</td></tr>
<tr><td>HID lamps –
Metal Halide lamp (MH)</td><td>• MH lamps consist of a mixture of rare-earth halides in addition to mercury and argon to augment the lamp properties.
• The lamp needs a starter to switch on and a highly compact electric arc is produced in a discharge tube similar to the tungsten-halogen cycle.
• MH lamps have significantly better CRI than HPMV lamps
• CRI < 70 fairly good
• Efficacy: 75 to 100 lm/W
• Operating life: 15,000 hours
• Lumen depreciation: 50% after 50% of life
• Application: Industrial and floodlighting.
• Less environmental friendly as it contains a small quantity of mercury.</td><td>
Metal Halide Lamp</td></tr>
</table>

Details of some of the most commonly used lamps are presented below:

Lamp Type	Description	Picture
LED	• Semi-conductor technology of producing light and this unique technology is stated as Electro-Luminescence. • LEDs are made of inorganic semiconductor materials that can produce different colours of light. • LED is quite small (< 1mm2). Additional optical components are added to shape the light output • The efficacy of LED ranges from 80 to 130 lm/W. • CRI >85 which is very good. • Operating life: 50,000 hours • Lumen depreciation: up to 10% after 50% of life • Can be practically used in any kind of application • Emits no UV or IR radiation • Environmental friendly as no mercury is used. • LEDs are the most widely used and efficient lighting technology available at present.	 LED Lamp

4.3 Standards for Illuminance maintained in different applications

Illuminance (E) is measured using a Lux meter. As a minimum requirement, the lux meter should have an average precision range with a tolerance of 10%. Mean illuminance shall be measured in a defined grid under proper defined conditions as per the standards such as

- EN 12464-1: Lighting of indoor workplaces
- EN 12464-2: Lighting of outdoor workplaces
- EN 12193: Sports facility lighting

Illuminance maintenance value (E_m) is the level that shall not fall below the minimum required value as per the standards in the visual task area. E_m depends on the maintenance factor, which is determined by considering reduced luminous flux caused by the soiling and aging of lamps, luminaire, and room surface. Uniformity (U_O), Glare, and reflectance are the other factors that affect the illumination level.

As per the standards, the minimum illumination levels to be maintained for all non-working interiors should be around 20 Lux. For the working interior, depending on the surroundings and nature of work, an illumination range (minimum, average & maximum) is recommended. The middle value of the range is used for working interiors, and the higher value of the range shall be used for specific critical tasks. The lower value shall be used for non-critical areas.

The outdoor light level is approximately 10,000 lux on a clear sunny day. Inside the room, the light level may be reduced to 1000 lux near the windows due to daylight ingression, and in the middle rooms, it may be as low as 25 to 50 lux, which states that additional artificial lighting is needed in interiors. For routine activities, the light levels can be in the range of 100 – 300 lux. For areas such as inspection tasks, the light level can be 500 to 1000 lux. The light level may even reach 1500 to 2000 lux for more detailed and precise work. Table 4.1 provides a broad summary of lux levels to be maintained for common indoor areas.

Table 4.1: Summary of recommended illumination levels in common indoor areas

Activity	Illumination (lux, lumen/sq.m)
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Working areas where tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theatres, Archives	150
Easy office work, classrooms	250
Normal office work, PC work, study library, Groceries shop, showrooms, Laboratories	500
Supermarkets, Mechanical workshops, office landscapes	750

Contd...

Table 4.1: Summary of recommended illumination levels in common indoor areas

Activity	Illumination (lux, lumen/sq.m)
Normal drawing work, Detailed mechanical workshops, Operation theatres	1000
Detailed drawing work, very detailed mechanical works	1500 - 2000
Performance of visual tasks of low contrast and very small size for a prolonged period	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

The "Illuminating Engineers Society Recommendations Handbook" shall be reviewed for recommended illumination levels of other sectors.

4.4 Lighting system design methods

While designing a lighting system, the main challenge is to prioritize productivity improvement and minimize energy costs. There are several factors to be considered for designing a proper lighting system for any application. Concepts of minimum illumination level, uniformity, maintenance factor, glare effect, reflectance factors shall be well-thought-out in addition to the task performed, type and colour of the interior. The prime factors to be considered for determining the appropriate average light/illumination level are:

- Task being performed
- The age group of the occupants

Keeping in mind the above considerations; suitable type, technology, and quantity of lamps and luminaires shall be selected with the following aspects:

- Lumen output required to meet the minimum standard level
- Best suited technology which can give required light with minimum energy consumption.
- The reflectance of the surrounding surfaces
- Room size and availability of natural daylight

The motivation for designing an efficient lighting system should be
"The right *kind* of light,
The right *amount* of light,
Exactly *where* we need it,
And only *when* we need it,
At the lowest total lifecycle cost"

A lighting system can be designed manually or by 3D modeling and visualization methods. To design a luminaire layout in manual method, two types of information are mainly required:

A. *Average illuminance level*: The calculation method that can be used to obtain the average illuminance level are

   1. For indoor lighting application, the Zonal Cavity Method (ZCM) is used with data obtained from a coefficient of utilization table

   2. For outdoor lighting situations, the Standard lumen formula is used with the Coefficient of Utilization (CU) value obtained directly from the CU curve which is provided by the manufacturer.

B. Illumination level to be measured at a given point by using a lux meter.

Zonal Cavity Method is also called as Lumen Method, which is the currently accepted method for calculating average illuminance levels for indoor areas. This method is accurate as it considers the effect of the internal reflectance of room surfaces. Even though this method considers several variables, the basic principle that foot-candles are equal to luminous flux over an area remains unchanged.

Figure 4.6 shows a typical room space to illustrate the ZCM concept. The basis of the ZCM concept is that a room is made up of three spaces or cavities.

- The space between the ceiling and suspended lighting fixtures is called a "ceiling cavity".
- The space between the work plane and floor is called a "floor cavity".
- The space between the suspended fixtures and the work plane is called "room cavity".

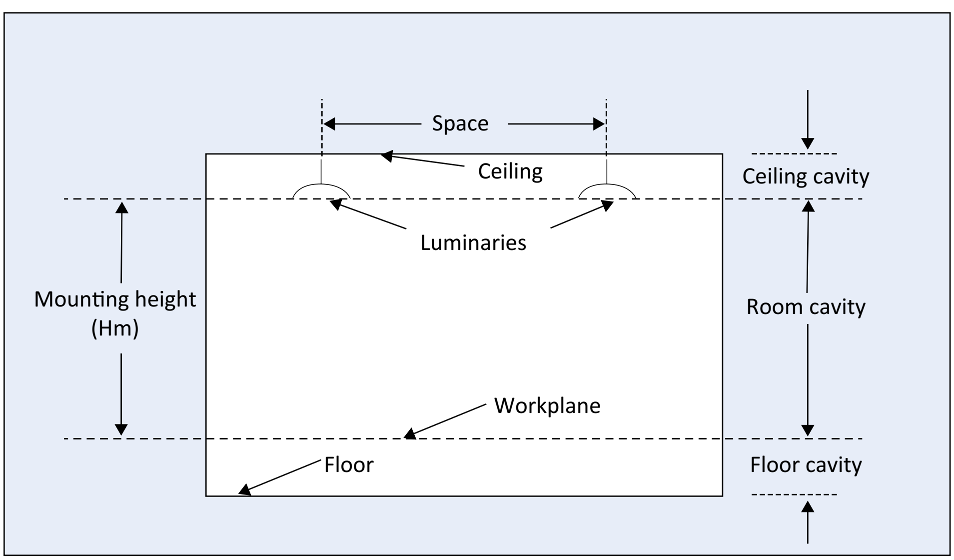


Figure 4.6: Typical room space illustrating the ZCM concept

Various steps involved in the Lumen method for calculating average illuminance levels for indoor areas are explained below:

Step 1: To decide the quantity of illuminance required in the work area and suitable type of lamp and luminaire

- Illumination standards shall be referred to obtain the quantity of illumination required depending on the type of room and nature of the task being performed.

  For example: As per the standard, office workspaces require an illuminance level of 200 lux. For this, we can choose either T8 FTLs or LED tube lights, considering the aesthetics and economics.

Step 2: Collect the dimensions and other details of the room space. An example is illustrated in the below table.

Room dimensions	Length	L1	15.0	m
	Width	L2	15.0	m
	Floor area	L3	225.0	m^2
	Ceiling height	L4	3.0	m
Surface reflectance	Ceiling	L5	0.7	p.u
	Wall	L6	0.5	p.u
	Floor	L7	0.2	p.u
Work Plane height from the floor		L8	1.0	m
Luminaire height from the floor		L9	2.8	m

Standard surface reflectance values for different applications are provided in the table below:

Description	**Ceiling**	**Walls**	**Floor**
Air conditioned office	0.7	0.5	0.2
Small Industry	0.5	0.3	0.1
Heavy industry	0.3	0.2	0.1

Step 3: Calculate room index value using the information collected above.

$$\text{Room Index} = \frac{\textit{Length x Width}}{\textit{Mounting height x (Length + Width)}} = \frac{\textit{L1 x L2}}{\textit{(L9-L8)x(L1+L2)}} = \frac{\textit{15x15}}{\textit{1.8 x (15+15)}} = 4.2$$

Step 4: Calculate the Utilization factor (UF), defined as the ratio of total lumen received on the working plane to the total lumen emitted by the light source.

$$UF = \frac{\textit{lumen received on the working plane}}{\textit{actual lumen emitted by the lamp}} \quad \text{or} \quad \frac{\textit{illumination under normal working condition}}{\textit{illumination when everything is clean or new}}$$

Manufacturers will provide "Coefficient of Utilisation (CU)" charts based on the photometric test reports. An example of CU chart is shown below:

Coefficients Of Utilization - Zonal Cavity Method
Effective Floor Cavity Reflectance 0.20

Ceiling reflectances

Wall reflectances

RC	80				70				50			30			10			0
RW	70	50	30	10	70	50	30	10	50	30	10	50	30	10	50	30	10	0
0	63	63	63	63	54	54	54	54	38	38	38	24	24	24	10	10	10	4
1	56	53	51	48	48	46	44	42	32	31	29	19	19	18	8	7	7	2
2	51	46	42	39	44	40	37	34	28	26	24	17	16	15	7	6	5	1
3	46	40	36	32	40	35	31	28	24	22	20	15	13	12	6	5	5	1
4	42	36	31	27	36	31	27	24	22	19	17	13	11	10	5	4	4	1
5	39	32	27	23	33	27	23	20	19	16	14	12	10	9	5	4	3	1
6	36	28	23	20	30	24	20	17	17	14	12	10	9	7	4	3	3	0
7	33	25	20	17	28	22	18	15	15	13	11	9	8	6	4	3	2	0
8	30	23	18	15	26	20	16	13	14	11	9	8	7	6	3	3	2	0
9	28	21	16	13	24	18	14	11	13	10	8	8	6	5	3	2	2	0
10	26	19	14	11	22	16	12	10	11	9	7	7	5	4	3	2	2	0

Room Cavity Ratios

(Source: https://docs.agi32.com/PhotometricToolbox/Content/Indoor_Report_Tool/ies_indoor_report_cu_table.htm)

Using these tables, it is possible to determine the UF for different light fittings if the following things are known

- reflectance value of floor, wall, and ceiling
- room index value
- type of luminaire

Considering twin-tube T8 fitting and room index value of 4.2, from the CU charts, the UF value is determined to be 0.41.

Step 5: Calculate the number of fittings required for the room, which can be estimated based on the following formula:

$$N = \frac{E \times A}{F \times UF \times LLF}$$

Where N = Number of fittings

E = Lux level required on the working plane

A = Area of the room

F = Total luminous flux of all the lamps in each fitting

UF = Utilisation Factor from the manufacturer's CU table data

LLF = Light loss factor (lamp lumen depreciation over a certain period for the new one)

LLF = Lamp lumen MF x Luminaire MF x Room surface MF

Where MF = Maintenance factor

Typical LLF values for different applications are provided in the table below:

Air-conditioned room	0.8
Clean Industry	0.7
Dirty Industry	0.6

Twin T8 FTL luminaire has two lamps, with each one having a luminous flux of 3000 lm.

Based on the above example data, number of fittings are calculated as follows:

$$N = \frac{200 \times 225}{2 \times 3000 \times 0.41 \times 0.8} = 22.9 \sim 23 \textit{ fittings}$$

So, 23 twin tube fixtures are required. The total number of T8 lamps required is 46.

Step 6: Assess the spacing between the luminaires for achieving desired uniformity.

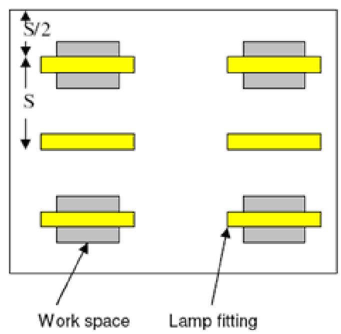
Each type of luminaire will have a recommended space-to-height ratio which the manufacturer will provide. In earlier design considerations, the uniformity ratio (which is the ratio of minimum illuminance to the average illuminance) was kept at 0.8 and a suitable space to height ratio is specified to achieve the uniformity. However, in modern designs, the uniformity ratio is considered between 1/3 to 1/10 depending on the task lighting and incorporating energy efficiency. The recommended space to height ratio for the above type of luminaire is 1.5. If the actual ratio is more than the recommended values, the uniformity of the lighting will be less. Care should be taken for the luminaire which is close to the wall that it shall be at least one half of the recommended spacing between the luminaires.

Actual luminaire spacing for the 23 twin T8 luminaire is calculated as follows:

Spacing between luminaires $= \dfrac{15}{5} = 3\ m$

Mounting height (L9-L8) = 1.8 m

Space to height ratio (SHR) = 3.0/1.8 = 1.67



Lamp Arrangement

The obtained value is close to the recommended value and hence 3 m spacing between the luminaire is accepted. It is better to choose luminaires with high SHR to reduce the number of fittings.

Based on recent technology advancements, several 3D modelling and visualisation techniques have been developed and they are widely used to design lighting systems in a better manner. Some of the software tools that are being used for designing the lighting systems are DIALux, Microlux light, Philips lighting tool, Visual-3D, LightCalc, AGI 32, Radiance etc.

4.5 Lighting system performance assessment or Lighting audit

Energy consumption for lighting purpose is one of the major components of total energy consumption in non-residential as well as commercial buildings. Recent studies proved that significant energy saving potential exists in lighting systems. Lighting audit is a reliable assessment tool for this purpose. Various lighting control concepts, approaches and technologies are available to achieve energy efficiency in lighting systems.

A lighting audit is a process of investigating the measures that present operational conditions against the standards to determine where the inefficiency lies and how cost-effectively changes can be made to improve the existing system.

Lamp Arrangement

Some of the steps involved in the process of lighting audit or lighting system performance assessment are listed below:

Step-1

- Prepare an inventory of lighting system elements (Number of lamps in each location along with lamp types) and lighting transformers, kind of work force and usage profile

Step-2

- Measure lux levels at various times of the day and document it along with the number of lamps kept ON
- Measure electrical power (V, I, kW, PF, kVA) at each location and record it

Step-3

- Compare the measured lux levels with the standard values as reference and identify areas of deviation
- Collect and analyse the failure rates of lamps, ballasts and the actual life expectancy levels from past data

Step-4

- Explore options for Energy efficiency improvement and make a road map of activities to be carried with timelines and cost economics

By following the above steps, the performance of the lighting system can be evaluated. Once the system's inventory data and the level of energy consumption are established, there are several options to follow best operating practices that can be considered for reducing lighting energy consumption and operation & maintenance costs are listed below:

I Use of natural day lighting

Industry and commercial spaces have warehouses to meet the storage requirements of raw materials or finished goods. In most cases, artificial lighting is being used 24 x 7 as an operational and safety requirement. In each warehouse, several 100s of lamps (either High-intensity Discharge lamps or LED lamps) are being used. Together they contribute to significant energy consumption. To minimize the lighting energy consumption during day time, modern plants make use of translucent sheets (Clear Polycarbonate sheet) or Solar tubes (daylight tubes).

By properly utilizing daylight wherever it is possible, around 30 to 50% of electricity consumption for artificial lighting can be reduced. The outdoor light lux level is approximately 10,000 lux on a clear day. Solar tubes are the best options for usage in the warehouse and office rooms.

Example: Depending on the size, one solar tube can be equivalent to replacing two 250 W HID lamps.

II. Reducing the number of lamps for minimising excess lighting

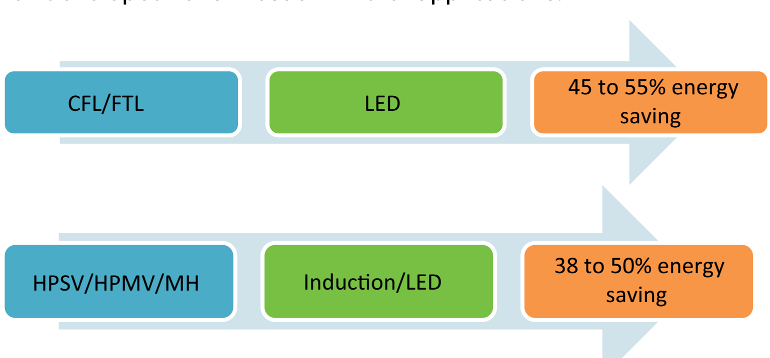
In Industry or any commercial location, there can be several instances where the lighting system is not designed efficiently. Measuring lux levels during the lighting audit will help to understand where light or illumination levels are high or low for the task being performed and compared with the standards. Thus, a decision can be taken if the number of lamps can be reduced if the lux level is high or increased if lux levels are found to be low. This measure improves employee performance, safety as well as the overall work environment.

III. Lighting Maintenance: Periodic cleaning of dusty bulbs and luminaires can improve illumination levels.

Periodically, dusty bulbs and luminaires are to be cleaned so that illumination reduced due to masking dust shall be revived and some hidden physical problems can be sorted out and rectified.

IV. Replacement of inefficient conventional lamps with the latest energy-efficient lamps.

Conventional lights such as incandescent, T12 and T8 FTL, HID lamps consume a lot of energy and also their life span is on the lower side which needs periodic maintenance. Currently, a lot of energy-efficient lighting technologies are available such as Induction and LED lamps with a long life span. Among both energy-efficient lighting technologies, LEDs are most prominent as they are commercially well developed for almost all kind of applications.



V. Lowering ceiling fixtures as much as possible closer towards the workspace (Task Lighting)

The measure suggests providing the required quantity of illuminance to the actual area where the main task is being performed and keeping the other areas of the room at a lower lux level. Machining section lighting and table lighting are good examples of task lighting. This measure will not only help in improving the working ambience but also helps reduce energy consumption by minimising the wattage of lamps being used in no-task areas or non-critical areas.

VI. Repainting the walls with more reflective colours

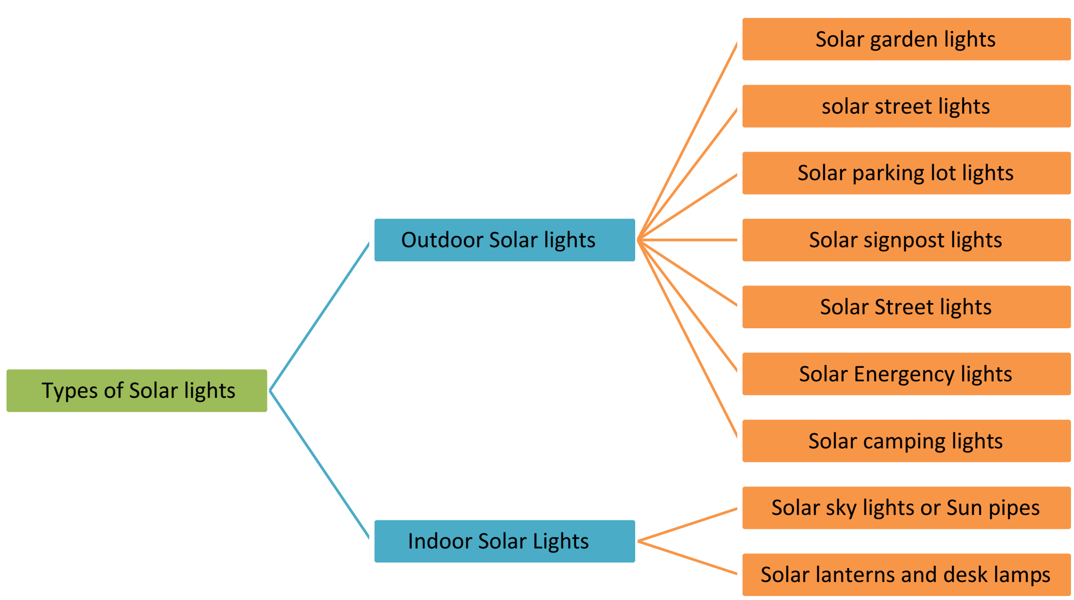
Overall lighting efficiency is directly affected by the colour of the ceilings, walls and other surfaces in the workspace. So repainting the wall with more reflective colours can improve the contrast and promote safety by increasing the amount of available light.

VII. Making use of Electronic Ballasts

Conventional electromagnetic ballasts (Chokes) are mainly used to provide higher voltage during the start of tube lights and parallel to limit the current during normal operation. They alone consumed about 10 to 15 Watts of energy consumption. However, electronic ballasts use oscillators that convert the supply frequency to about 20,000 to 30,000 Hz and consume very little energy (around 1 or 2 Watts). Also, the use of a starter is eliminated while using electronic ballasts and the flickering of lamps is reduced. One disadvantage of electronic ballasts is that they are very sensitive to power quality issues when compared with conventional electromagnetic ballasts.

VIII. Renewable energy integration for outdoor lighting needs

Nowadays Renewable energy technologies are predominantly used in almost all sectors and solar lights and offer cost-effective solutions for both indoor and outdoor lighting. Solar lighting uses components such as solar panels, control devices, LED lamps, batteries for energy storage and sensors for efficient operation. Various types of solar lights available for indoor and outdoor lighting are illustrated below:



Solar lights are highly environmentally friendly, cost-effective, low maintenance and easy to retrofit.

4.6 Energy efficiency with Lighting control devices

During the last few years, several advancements took place in lighting control systems that have significantly improved energy savings and visual comfort in rooms. However, proper selection of the control strategies needs to be made in a customised manner to suit the task being performed. Lighting control systems consists of manual and automatic control techniques. The details are presented in Figure 4.7.

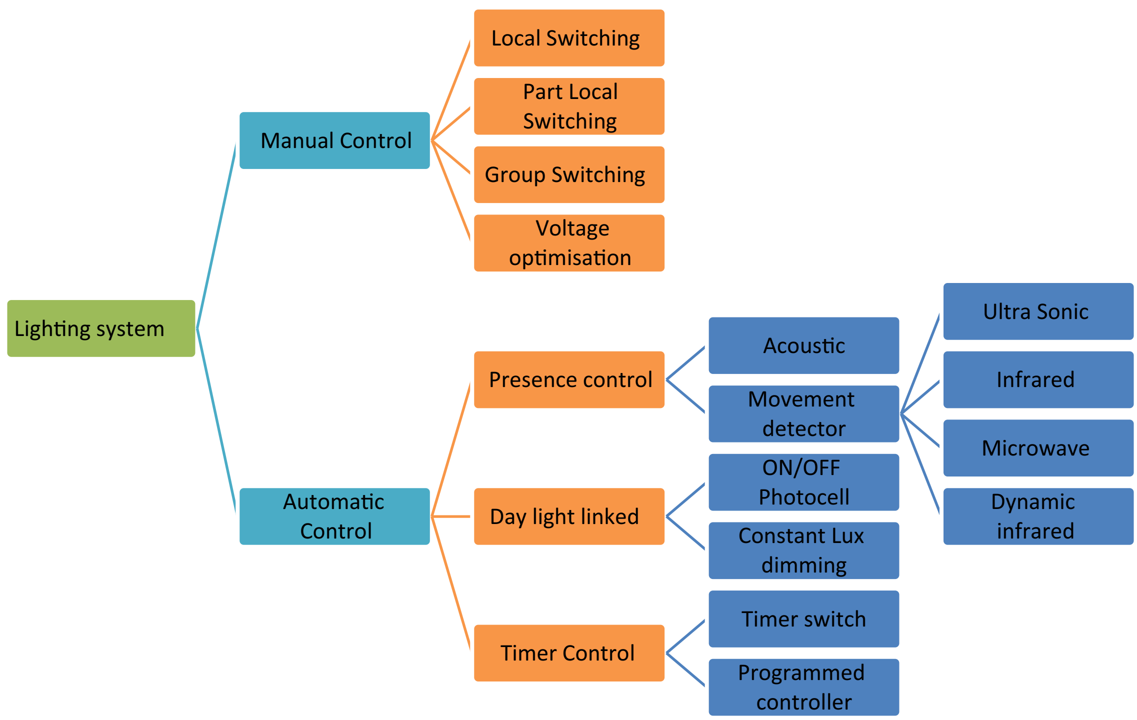


Figure 4.7: Different types of lighting control strategies

Manual Control techniques:

Manual lighting control techniques involve strategically switching ON/OFF lights as per the requirement and voltage optimisation.

- *Strategic light switching control*: Depending on the type of application, different types of switching method can be followed. For large spaces such as malls and warehouses, localised or group switching can be followed. For process industries, light switches which are required 24 hours and lights which are required only during night time should be segregated and operated on an as-needed basis instead of keeping switching ON. This kind of strategic light switching will help in minimising unnecessary operation of lights and minimise energy consumption.

- *Voltage control of lighting circuit*: The light output of Gas discharge lamps such as Fluorescent lamps and High-Intensity Discharge lamps (HID) such as HPSV, MH and HPMV lamps are affected due to variation of the input supply voltage. Reducing the input supply voltage shall reduce the lumen output of the lamps and lead to a reduction in energy consumption. Hence, wherever possible, lighting voltage reduction techniques shall be used as and when required, resulting in 5 to 15% of energy consumption. The following table illustrates the effect of voltage variation on the FTLs and HID lamps. The life of the lamps is increased and the failure rate is reduced by operating HID lamps at slightly lower voltage levels. Lighting Transformers having tap setting points can be used to minimise the overall lighting circuit voltage.

Description	10% lower voltage	10% Higher voltage
Gas discharge lamps – FTLs		
Light output	Decrease by 9%	Increase by 8%
Power output	Decrease by 15%	Increase by 8%
HID lamps		
Light output	Decrease by 20%	Increase by 20%
Power output	Decrease by 16%	Increase by 17%

Automatic Control techniques:

Automatic lighting control techniques involve switching ON/OFF lights utilizing sensors and timers controlled by the programmed microcontroller-based PLC or SCADA system. These systems can be either very simple or complex, depending on the type of application. Latest developments in automatic lighting control have reached the extent that the lighting system can be connected to the internet and operated from anywhere in the world.

- *Presence control*: This control method includes sensors that work based on sound (acoustic) or movement. These sensors can detect any movement or noise in the room spaces and operate lights accordingly. When no one is available in the room, the sensors disconnect the lighting circuit and reduce energy consumption.
- *Day light linked control*: This control method uses photocells or lux dimming devices. Photocells operate lights by sensing the availability of daylight. Lux dimming devices can be used to reduce or increase the illumination level as per the programming made to save energy. Daylight linked control techniques is mainly used for outdoor lighting in industries, streets etc.
- *Timer control*: this method of control work-based on-time control. Old mechanical timers are replaced by electronic timers,

Figure 4.8: Sensors based light controls

and these are the widely used cost-effective automatic control devices. Timers can be programmed either manually or remotely to switch ON and OFF lights in specific time slots according to the requirement in different seasons.

Street lighting control system:

A major share of energy is consumed by streetlights in municipal areas where a large number of street lights are illuminated within city limits. The type of lamps includes FTLs, HPSV, HPMV and MH lamps. The above-mentioned lighting system performance assessment and energy-saving measures incorporated with smart lighting controls will significantly impact Minimising energy consumption (up to 80%) with attractive payback.

Some suitable techniques include:

- Timer control
- Daylight control based on photocells and illumination control
- Switching control based on lux levels during midnight
- Voltage optimization
- Installation of PLC and microcontroller-based smart lighting controls and monitoring.

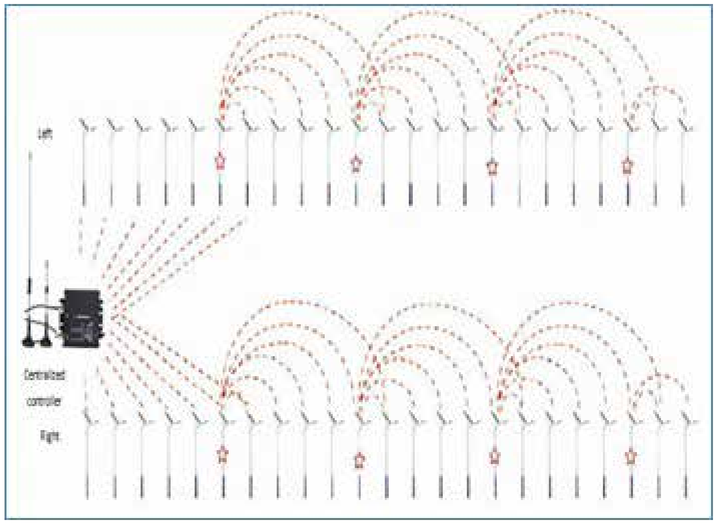


Figure 4.9: Centralised street light control system

Examples:

1. **Compare the techno-economics of replacing ten 400W HPMV lamps with suitable LED lamps. The lamps are operating for 10 hours/day and 365 days a year. The cost of electricity is GY$ 58/kWh?**

   Solution: The luminous Efficacy of HPMV lamps is ~60 lm/W

   The luminous Efficacy of LED lamps is ~ 120 lm/W

   Based on the luminous efficacy of the lamps that the supplier specifies, we can choose the capacity of the energy-efficient light to be retrofitted. In the present case, we can replace the existing 400W HPMV lamps with 200W LED lamps. The techno-economics are provided below:

Description	HPMV	LED
Rated capacity, W	400	200
Quantity	10	10
Operating hours/year	3650	3650
Annual Energy consumption, kWh	0.4*3650*10 =14600	0.2*3650*10 =7300
Annual Energy saved	7300 kWh	
Annual Energy cost saving @ GY$58/kWh	432,400 GY$	
Investment cost (cost of each 200W lamp = GY$ 46,680 inclusive of installation)	466,800 GY$	
Simple payback period	1.08 years	

In this way, we can estimate the energy cost savings and techno-economics of lighting system retrofits by considering the luminous efficacy and operating hours, energy cost and investment cost.

2. **A city municipality has conducted a pilot study on a street lighting feeder with 10 LED lamps of 150 W, with each being operated by a dimming control system. Estimate the annual savings due to the implementation of the dimming option when lights are operated between 6:00 pm to 6: 00 am for 365 days. Cost of electricity = 58 GY$/kWh**

   Solution: For this purpose, a lux meter is used to measure the actual illumination level (lux level) under the streetlights. Energy consumption is measured by using an energy meter.

Description	Nos.	Watts	Lux level	Hours/ day	kWh/day/ lamps	Total kWh/ day
LED (No dimming)	10	150	25	12	1.8	18
				Total	1.8	18
LED (Dimming)						
06:00 pm to 11:00 pm	10	150	25	5	0.75	7.5
11:00 pm to 12:30 am	10	99	16.5	1.5	0.1485	1.485
12:30 am to 04:30 am	10	60	10	4	0.24	2.4
04:30 am to 05:00 am	10	99	16.5	0.5	0.0495	0.495
05:00 am to 06:00 am	10	150	25	1	0.15	1.5
				Total	1.34	13.4

Annual operating hours = 12hr/day x 365days : 4380 hours

Annual energy consumption (No Dimming) : 18*365days/year = 6570 kWh

Annual energy consumption (With Dimming) : 13.4*365 = 4891 kWh

Annual energy saved (With Dimming) : 6570-4891 = 1679 kWh

Annual energy cost savings (with Dimming) : 1679*58 = GY$ 97,382

3. **An educational institute has planned to replace its classroom lighting with T12 fluorescent lamps (FTLs) by high-quality T8 LED tube lights (suitable for installing in reading areas). Calculate the techno economics of the investment.**

   Solution: Upon carrying a preliminary assessment, it is found that

   » The facility is making use of one hundred T12 FTLs for all its classrooms.

   » The lights operate for 10 hours during the day (8:00 am to 6:00 pm).

   » The existing lights are operating with electromagnetic ballast, and each ballast alone consumes around 12 to 14 Watts of electricity in addition to each lamp's power consumption of 40W. So, overall when a T12 FTL is operating, it consumed around 52 W (40+12) of electrical power.

   » Each T12 FTL emits around 2200 lumens at a rate of 55 lm/W efficacy.

Proposed LED Tube lights:

- High efficient and high-quality lights were chosen for the replacement.
- Each lamp consumes around 20 W of electrical power with a luminous efficacy of 110 lm/W and emits around 2200 lumen output.
- Investment for each LED lamp is GY$ 2750
- The average life of LED lamps is 50,000 hours

The techno-economic calculations are provided in the table below:

Description	T12 FTL	LED tube
	Existing	Proposed
No. of lights	100	100
Wattage of each lamp including choke losses	52	20
Annual operating hours	3000	3000
Annual energy consumption, kWh	15600	6000
Annual energy reduction, kWh	9600	
Annual energy cost-saving @ GY$ 58/kWh	556,800	
Investment cost (@ GY$ 2750 per lamp)	275,000	
Simple payback period	0.5 years	

Note: When retrofitting LED T8 to Fluorescent T12 fixture, the ballast must be bypassed as shown in the figure below. Eliminating the ballast saves additional maintenance, energy consumption, and performance costs. Additionally, by-passing the ballast will insure no RFI interference or audible buzz.

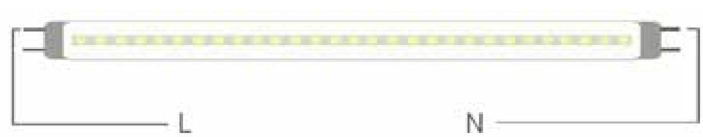


Figure 4.10: Connection diagram when retrofitted LED with FTL

4. **A food industry has a warehouse and during the walk-through energy assessment, it was found that all the lights in the facility are in ON condition throughout the daytime. A total of 40 lights that are being used are 400 W Metal Halide (MH) lamps. Propose a suitable energy-saving measure to minimise the lighting energy consumption of the warehouse.**

   Solution: For this purpose, a lux meter is used to measure the actual illumination level (lux level) inside the warehouse during the daytime which is around 30 to 40 lux. The overall power consumption is 16 kW. During the study, it was found there is no proper provision for daylight ingression into the warehouse, leading to switching ON all lights 24 x 7.

As an energy conservation measure, it is proposed to allow daylight as much as possible into the warehouse by installing either translucent sheets or Sun pipes/Solar tubes.

Translucent sheet

Solar Tube/Sun pipe

It is proposed to install suitable numbers of translucent sheets or Solar pipes so that artificial lights usage during the daytime can be minimized to a major extent, resulting in significant energy reduction. For example, it is proposed to install 20 solar tubes in this case.

Total Connected lighting load in warehouses	: 16 kW (day and night)
Operating hours during daytime	: 10 hours per day
Operating days	: 330 days.

Considering 80% of the lights can be switched OFF after installation of solar tubes

Proposed annual energy savings	: 42,240 kWh.
Proposed annual energy cost savings	: GY$ 2,449,920
(@ GY$ 58 /kWh)	
Cost of implementation of 20 solar tubes	: GY$ 1,870,000
(@ GY$ 93,500 for a Solar Tube)	
Payback period	: 0.76 Years

CHAPTER 5

Heating Ventilation and Air Conditioning (HVAC)

5.1 Introduction

In commercial buildings, space cooling, heating and ventilation are the significant energy consumers. The Heating, Ventilation and Air Conditioning (HVAC) system is vital for space conditioning of building envelopes like houses, hotels and restaurants. Also, it is useful in process industries such as fish and fruit storage.

The purpose of the HVAC system is to maintain good indoor air quality through adequate air ventilation and provide thermal comfort by controlling the desired air temperature (cooling/heating) and humidity.

This cooling effect of the air conditioning system is expressed in terms of Ton of Refrigeration (TR). One ton of refrigeration is defined as the amount of heat removed to convert one ton of water into ice at 0°C in 24 hours. The 1 TR equals 3024kCal/hr, 12000 Btu/hr, or 3.516 thermal kW.

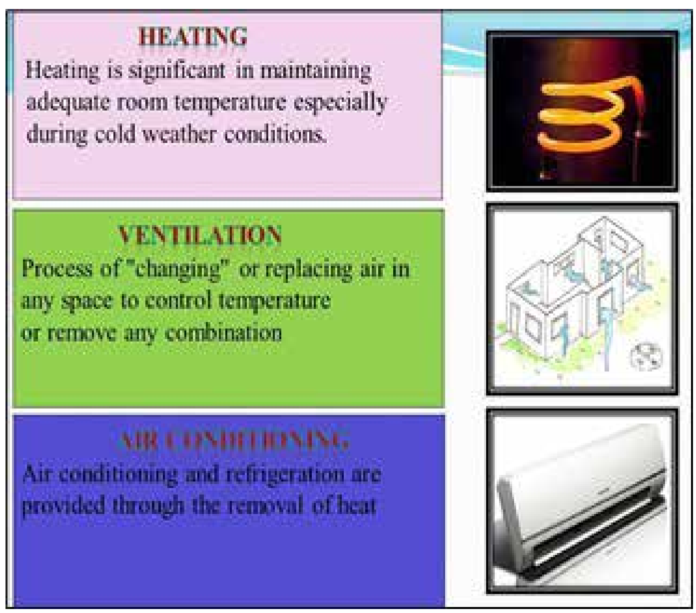


Figure 5.1: Heating, Ventilation and Air Conditioning system

In a tropical climate like Guyana and other coastal countries, an air conditioning system is commonly used for space and comfort cooling. This air conditioning system contributes significantly to energy consumption in buildings and industries. The energy consumption of the air conditioning system depends on various factors such as sensitive load changes, seasonal ambient conditions, operation, maintenance, etc.

This section explains the type of air conditioning systems, performance measurement and analysis as part of energy management, factors affecting the air conditioning system, and energy-saving opportunities.

5.2 Classification of HVAC system

The HVAC system is classified as a centralized system and decentralized or local system. The centralized system provides conditioning to the entire building facility, and the primary equipment is located in a centralized location such as a basement or separate room next to the main building. In a decentralized system, separate conditioning units are installed in specific building areas. Table 5.1 shows the comparison between centralized and decentralized systems.

Table 5.1: Comparison between centralized and decentralized systems

Criteria	Centralized system	Decentralized system
Schematic		
Example	Hotel, Malls, IT buildings, Hospitals, food processing industry, etc.	House, restaurant, small shops, etc.
Operating efficiency	For chilled water-based system- Specific energy is 065-0.85kW/TR For DX type system specific energy is 0.9-1.1 kW/TR	Individual air conditioning unit specific power is 1.1 to 1.5 kW/TR
Operating cost	Less operating cost as an energy efficient primary equipment	Less energy efficient primary equipment and hence operating cost is high
Maintenance cost	Maintenance cost is minimum as it is designed for long run operation (yearly once)	Periodically maintenance is required (4-6 month once)
Capital investment	Initial capital cost is high as it need additional equipment like pumps, air handling units, liquid transfer pipe, etc.to providing cooling to entire building	Initial investment is low compared to centralized air conditioning system
Capacity requirement	Due to diversity factor installed capacity is reduced	Maximum capacity is required as it caters to specific location

Contd...

Table 5.1: Comparison between centralized and decentralized systems

Criteria	Centralized system	Decentralized system
Redundancy	Standby equipment needs to be installed	No need of standby equipment
Reliability	Equipment of centralized system has long service life	Service life is less compared to centralized system
Flexibility	It has more flexibility due to standby equipment	Have to be installed in various locations to be more flexible
Life of equipment	Life of central air conditioning system is around 15-20 years	Life of air conditioning unit is around 10-12 years

5.3 Type of Refrigeration system available in market

A centralized and decentralized air conditioning system works on a principle of Vapour Compression Refrigeration (VCR), where mechanical energy is used as a driving force for cooling. Apart from VCR, Vapour Absorption Refrigeration (VAR) is also popular in a centralized system where thermal energy is used as the driving force.

5.3.1 Vapour Compression Refrigeration (VCR) System

The vapour compression refrigeration system is the most common system used for space cooling and industrial application. In this system, the refrigerant vapour is compressed to produce the cooling effect (refrigeration). The working fluid, i.e., refrigerant, changes phase from liquid to vapour and again vapour to liquid. In a VCR system, refrigerant evaporates at low temperatures, which provides a cooling effect. Figure 5.2 shows the refrigeration cycle components and the actual image.

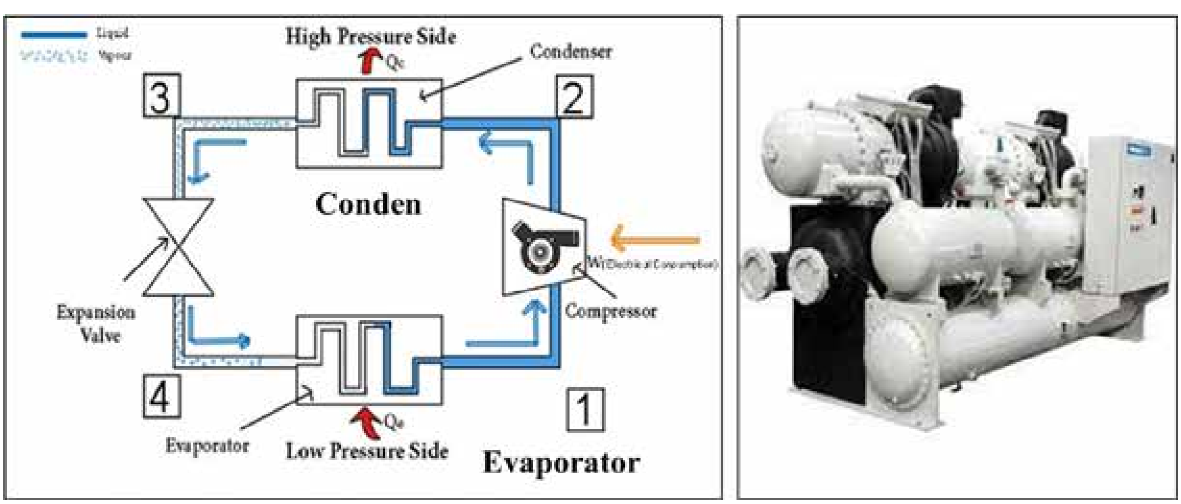


Figure 5.2: Refrigeration cycle components and actual image

Working of Vapour compression refrigeration system

There are four stages involved in the working of the vapour compression refrigeration system.

Stage1: Compression (Reversible adiabatic compression) In this stage, higher pressure, and the high-temperature superheated refrigerant vapour is created by the compressor, and this vapour refrigerant is sent to the condenser.

Stage 2: Condensation (constant pressure heat rejection) In this stage, the superheated refrigerant vapour will give its latent heat to the cooling fluid (water /air) in the condenser.

In the condenser, the refrigerant vapour will be converted into a liquid phase by heat extracted from the vapour. The saturated liquid then goes to the evaporator through an expansion valve.

Stage 3: Expansion (adiabatic expansion) At this stage, the pressure and temperature of the liquid will decrease, and after the expansion valve, the refrigerant phase changes from liquid to vapour

Stage 4: Evaporation (Constant pressure heat addition) In the evaporator, the refrigerant takes the heat from the evaporator to convert the liquid phase to the vapour phase. Hence, the medium (air/ water) will decrease the temperature inside the evaporator.

Direct expansion (DX) refrigerant system (package/split air conditioning system)

Direct refrigeration system works on vapor compression refrigeration (VCR) principle where the conditioning air is supplied to the space by the evaporator fan. In the fin coil (evaporator), the refrigerant changes phase from liquid to vapour, expands inside the tubes, and absorbs the heat energy from the ambient air; it is called the direct expansion (DX) refrigerant system.

The Refrigerant vapour is compressed by the compressor to higher pressure and then sent to the condenser, where it changes its phase from vapour to liquid and rejects heat through a coil and condenser fan. A temperature control senses the air temperature and starts or stops the compressor, thereby controlling its cooling and heating capacity. Images of different types of DX air conditioning system is shown in figure 5.3.

Variable refrigerant volume (VRV) system

The modern VRF technology uses multiple compressors with a master compressor and inverter-driven. It permits as many indoor units to be operated from a single outdoor unit (depending on the capacity). The inverter compressor is fitted with a microprocessor to change the speed and operation of other compressors based on the variation in the total cooling or heating load as determined by the suction gas pressure measured at the condenser unit. In a VRV system, the capacity can be controlled from 6% to 100%. A schematic diagram of the VRV system is shown in Figure 5.4.

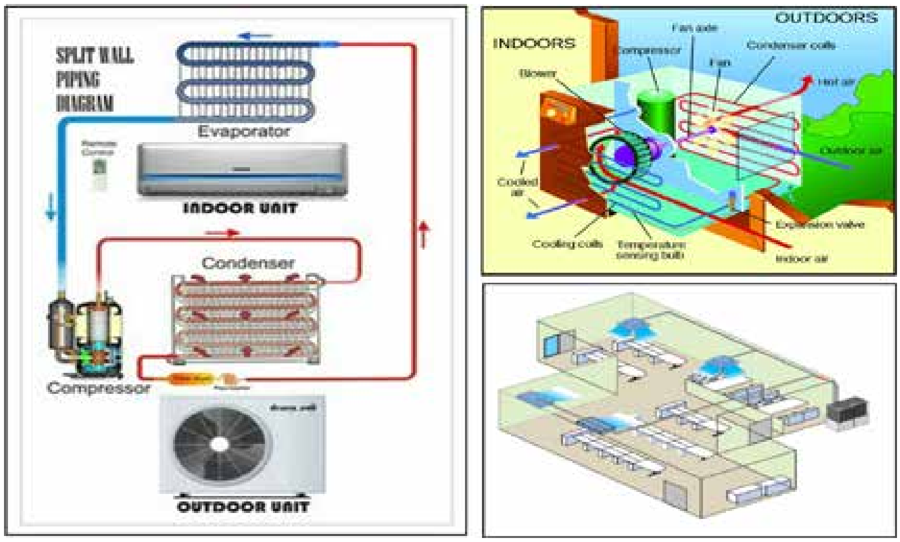


Figure 5.3: DX type air conditioning system

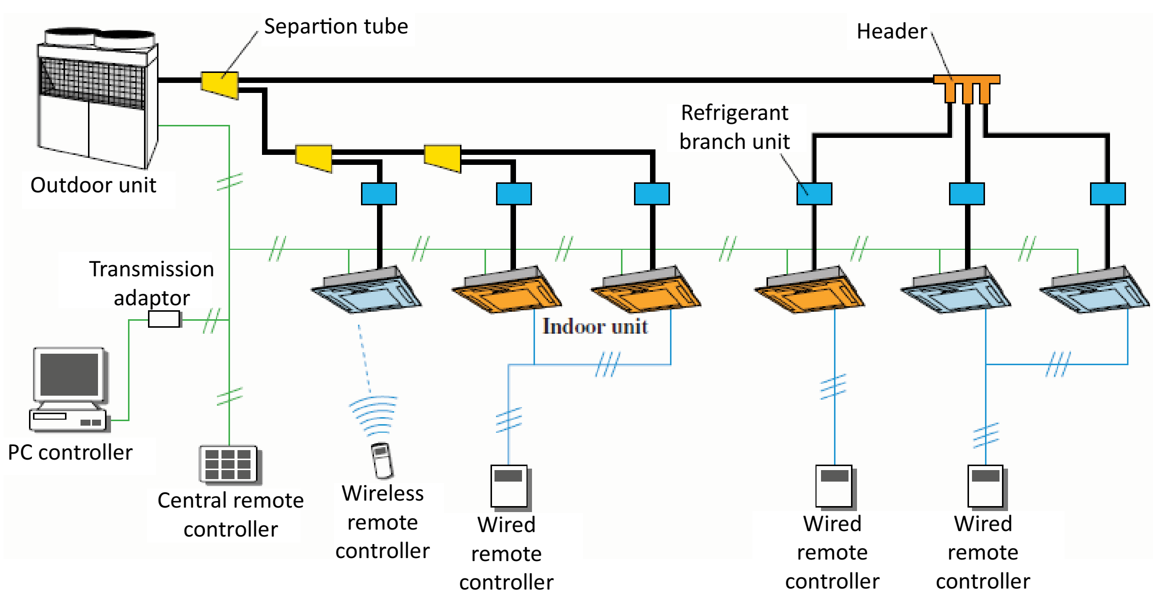


Figure 5.4: Variable refrigerant volume system

5.3.2 Vapour Absorption Refrigeration (VAR) system

The vapour absorption refrigeration system uses heat sources such as steam, hot water, flue gas, etc., to produce chilled water. This system is worked on the principle that refrigerant evaporates at low pressure and absorbs heat from its surroundings. In the VAR system, Lithium bromide (LiBr) solution is used as absorbent and pure water as a refrigerant to generate chilled water up to 5-6^{0}C.

Waste heat extracted from the process, diesel generator sets flue gas, etc., can be used as heat sources for the vapour absorption system. In this system, electricity is needed only for operating pumps and cooling tower fans. A schematic vapour absorption refrigeration system is shown in Figure 5.5.

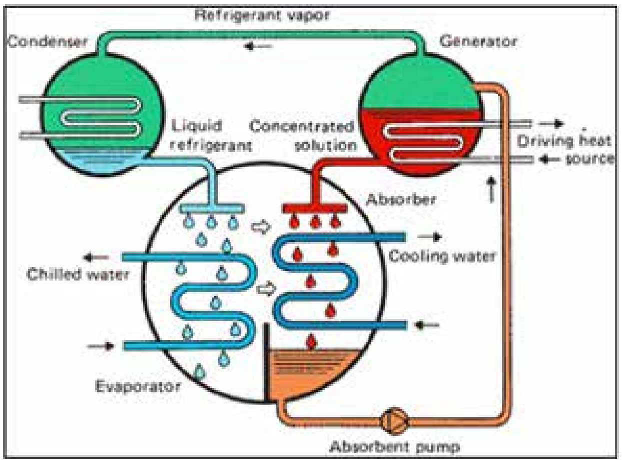


Figure 5.5: Schematic diagram of vapour absorption refrigeration system

A description of the absorption refrigeration concept is given below:

Stage 1- Evaporator

The refrigerant (water) evaporates in the evaporator under a high vacuum condition (754 mmHg) and at around 4^{0}C. The amount of energy required to change the phase of refrigerant from liquid to vapour is taken from chilled water circulated across the evaporator. The latent heat from this vaporization process cools the chilled water, and then this water is used for cooling purpose.

Stage 2- Absorber

For continuous operation of the evaporator, the vapour of refrigerant must be removed from the evaporator. In the absorber, the refrigerant vapour produced in the evaporator is absorbed into the LiBr solution. The heat is generated by absorbing water vapour to LiBr solution, which is removed by cooling water. The absorber helps to maintain the vacuum inside the evaporator.

Stage 3- Generator

The ability to absorb the refrigerant vapour reduces, as lithium bromide solution is diluted. In the generator, diluted LiBr solution is concentrated with the help of a heat source and re-circulated back to the absorber. Heating sources such as process heat, hot water, flue gas, steam, etc. are used for the concentration of LiBr solution by evaporating the refrigerant (water).

Stage 4- Condenser

In the condenser, cooling water is circulated to condense the refrigerant vapour, and then condensed refrigerant (water) is again supplied to the evaporator.

In general, a vapour absorption refrigeration system that uses LiBr as absorbent and water as a refrigerant has COP (Coefficient of Performance) in the range of 0.65 – 0.70, and it can provide chilled water 6~7^{0}C with a cooling water temperature of 30^{0}C. The ammonia-based system operates above atmospheric conditions and can operate below 0^{0}C. The capacity of Absorption machines is in the range of 10-1500 TR (Tonnes of Refrigeration). Absorption machine is more economical if waste heat sources such as process heat or Diesel generator flue gas are available.

5.3.3 Evaporative cooling system

Evaporative cooling is a heat and mass transfer process that uses water evaporation for air cooling. In evaporative cooling, a large amount of heat is transferred from air to water, and simultaneously the air temperature reduces. In the ancient era, this system was used to cool water in earthenware jars located in the passage of the air.

This is the oldest and the simplest type of system in which the outdoor air is directly brought into contact with water, cooling the air by converting sensible heat to latent heat. The evaporative cooling application is more effective in dry regions where the relative humidity is less than 40%. A schematic diagram of evaporating cooling is given in Figure 5.6.

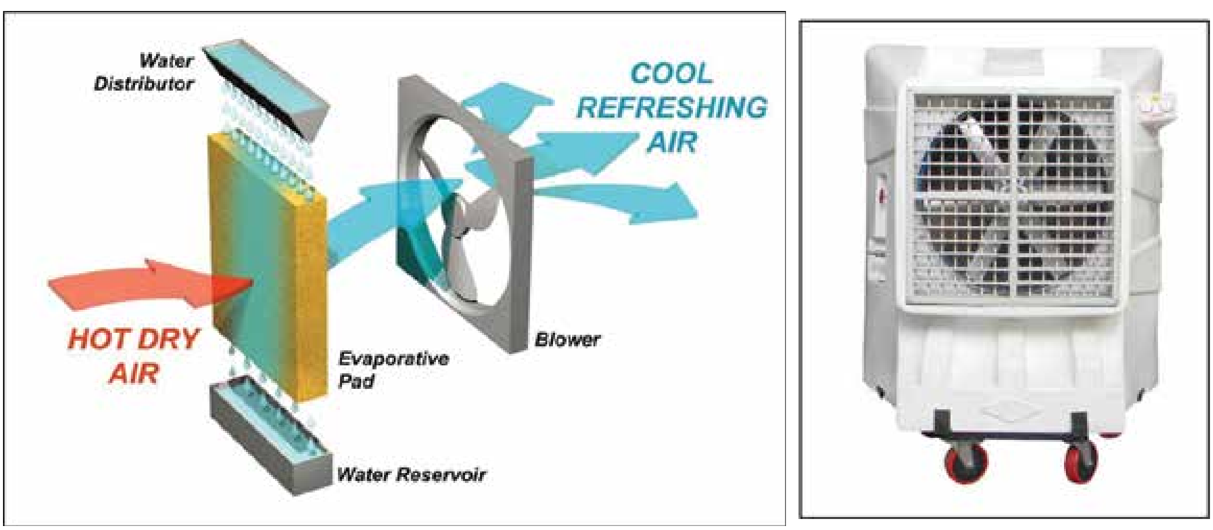


Figure 5.6: Schematic of evaporative cooling

The concept of evaporative cooling is very simple. Air is brought in close contact with water, and the amount of heat required for water evaporation is taken from the air, hence air cooled to a temperature close to the wet bulb temperature. This cool air can be used for comfort or process cooling where the humidity of more than 50% is acceptable such as in Textile industries.

Evaporating cooling systems are economical and effective as they reduce or eliminate chilled water-cooling requirements. It does not use any type of refrigerant; hence, it is environmentally friendly. Also, it is healthy and comfortable because it brings in outside air and removes stagnant air, smoke odours, and germs. It does not need an air-tight arrangement for effective utilization so that the building occupant can open doors and windows.

This system also has a few limitations, it does not operate well in a humid climate or during the rainy season. Temperature control is limited, and this system is not ideal for those with asthma or respiratory issues. Also, it needs make-up water for continuous operation.

5.4 Performance assessment of HVAC system

An air-conditioning and refrigeration plant is efficient when all the system components, that is, the compressor, the condenser, the evaporator, and the condenser cooling (heat rejection) system, are working in matched conditions. This means that under peak operating conditions they must perform to their optimum output.

To evaluate the performance, the testing engineer must have the parameters and duty requirements of each component. The engineer must also have the equipment capacity charts /tables to verify the effectiveness by using field measurement. This will evaluate cooling capacity (TR) and energy requirement at actual operating conditions. The basic test is to estimate the operating parameters and compare it with the design.

5.4.1 Components of HVAC system

The various components of refrigeration and air conditioning systems are:

- Chilling plant
  - Evaporator
  - Compressor (vapour compression refrigeration system)
  - Condenser unit (air-cooled/ water-cooled)
- Air handling unit
- Primary, secondary & condenser water pumps and cooling towers

5.4.2 Steps for performance measurement of vapour compression refrigeration (VCR) system

In measuring various parameters, the refrigeration system (chiller) equipment should be steady state. To reduce the efforts of short-term conditions, reading parameters should be taken simultaneously for all components of an HVAC system.

Measurement of various parameters in refrigeration system

To evaluate the performance of refrigeration system (chiller), various parameters such as chilled/ condenser water flow, chilled/ condenser water inlet and outlet temperature and compressor power consumption need to be measured. The schematic of the point of measurement is shown in figure 5.7.

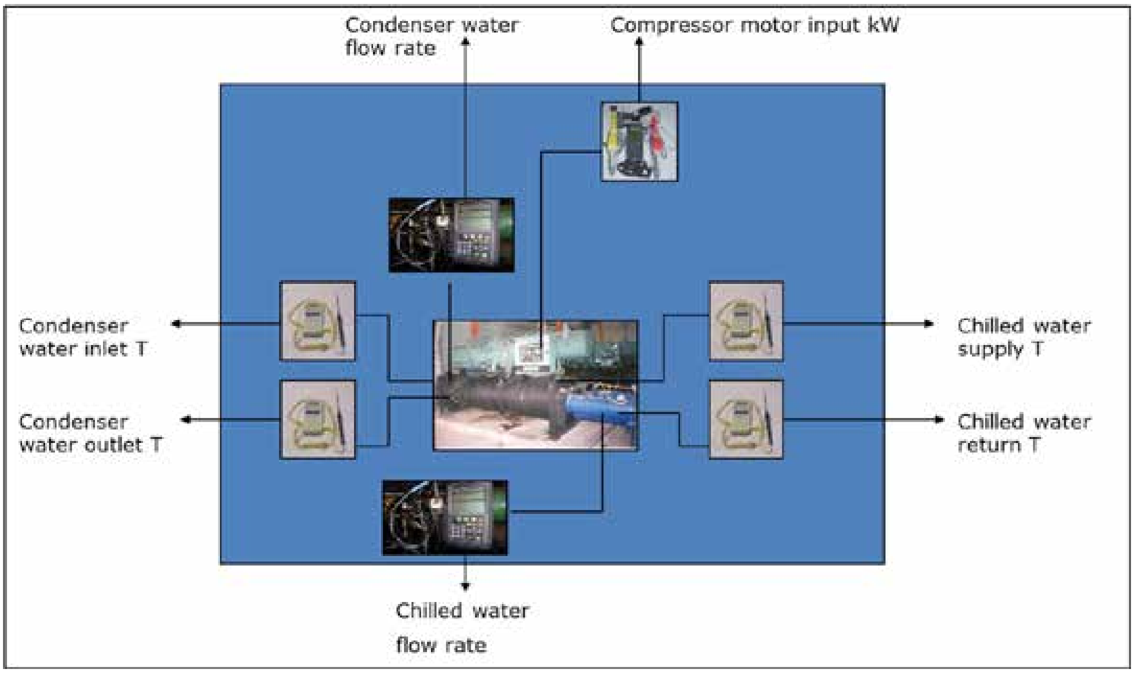


Figure 5.7: Measurement point in refrigeration system

For flow measurement

The flow can be measured by following ways in the absence of an online flow meter,

- In cold and hot well system conditions, the flow can be estimated by the tank level (dip or rise) by switching off cold well (secondary) pump;
- A Portable calibrated ultrasonic flow meter can be used to measure flow without disturbing the refrigeration system operational parameters;
- If the liquid circulation pump side pressure difference matches with pump design value then, consider the flow same as the design rated flow.

Note:

- During the performance measurement, accurate and calibrated instruments are required
- Generally, most refrigeration units are designed for 3 gpm/TR (0.68 m^3/ hr per TR) chilled water flow, and the Condenser side is designed for 4 gpm / TR (0.91m^3/hr per TR) cooling water flow

For measuring temperature

To measure the inlet and outlet temperature of the fluid, the chiller should be at steady-state condition. A measuring instruments should be used with a count of at least 0.10 ^{0}C.

Compressor power measurement

The compressor power can be measured by portable power analyser which would give direct reading of input power in kW. Otherwise, the current (amp) can be measured by the available tong tester. Consider power factor 0.9 and calculate power,

$$\text{Power} = \sqrt{3} \times \text{Voltage} \times \text{Current} \times \text{Power factor}$$

To estimate the net cooling at evaporator side

For analysis of cooling at evaporator side, need to measure the following,

- Chilled water flow
- Evaporator side water inlet and outlet temperature difference

The net cooling capacity in tons of refrigeration is obtained by the following equation:

$$\text{Cooling capacity, } TR = \frac{Q \times Cp \times (Ti - To)}{3024}$$

Where,

Q is mass flow rate of liquid circulation across evaporator in kg/hr

Cp is specific heat of circulating liquid across evaporator

Ti is inlet temperature of liquid

To is outlet temperature of liquid

Cooling effect 1 TR = 3024 kCal/hr

The commonly used figures of merit as performance assessment for comparison of refrigeration systems is through deriving energy efficiency ratios.

Energy efficiency ratios		
1	**Tons of refrigeration (TR)**	It is unit of measuring cooling effect of air conditioning system. 1TR (ton of refrigeration) is the amount of cooling obtained by one ton of ice melting in one day.
2	**Specific energy consumption (kW/TR)**	It is the ratio of actual power input (kW) to compressors to tons of refrigeration (TR) cooling produced. Lower specific energy consumption (kW/TR) indicates higher efficiency. Lower the specific power consumption means more efficient unit.
3	**Coefficient of Performance (COP)**	In other terms, air conditioning system efficiency is measured in W output (thermal) divided by W input (electrical power). The higher an air conditioner unit COP, the more efficient it is.
4	**Energy efficiency Ratio (EER)**	Performance of small air conditioning units and package units is frequently measured in EER rather than kW/TR. The EER is ratio of cooling capacity (in BTU/hr) to its power input (in watts) as full load condition. The higher the EER, the more efficient the unit.

Example 5.1: An IT building – call centre of four floors was installed with 350TR screw chiller. During energy audit measured chilled water flow is 200 m^3/hr and evaporator side, inlet and outlet temperature of chilled water is 12.0^{0}C and 7.5^{0}C respectively. What is cooling generation at evaporator side?

First to covert flow to kg/hr,

1 m^3/hr of water = 1000 kg / hr water

∴ 200m^3/ hr of water = 200 x 1000 kg /hr

Specific heat of water = 1 kCal/kg0C

$$\text{Cooling capacity, TR} = \frac{Q \times Cp \times (Ti\text{-}To)}{3024}$$

Cooling capacity, TR = {200 x 1000 (kg/hr) x 1 x (12 – 7.5)} / 3024

= 297.6 TR

Cooling generation at evaporator side is 297.6 TR.

Example 5.2: An International bank branch has installed 100TR capacity water cooled screw chiller for space cooling. Design specific power consumption of chiller is 0.68kW/TR. Measured chiller compressor input power consumption is 65 kW and evaporator side chilled water flow is 50m^3/hr and temperature difference is 5^{0}C across evaporator. Calculate operating specific power of chiller and compare with design? Also evaluate energy saving potential?

Cooling capacity, TR= $\dfrac{Q \text{ x } Cp \text{ x } (Ti\text{-}To)}{3024}$

Cooling effect, TR = { 50 x 1000 (kg/hr) x 1 x (5) } / 3024

= 82.67 TR.

Specific power consumption = Compressor input power (kW) / cooling effect (TR)

= 65 / 82.67

= **0.79 kW/ TR**

Operating specific power consumption is 0.79kW/TR which is high as compare to design (0.68kW/TR)

Difference in SPC = (Operating SPC) – (Design SPC)

= 0.79 - 0.68

= **0.11 kW/TR**

Potential for energy saving = Diff in SPC x operating cooling effect

= 0.11 (kW/TR) x 82.67 (TR)

= **9.0 kW**

Energy saving potential is 9.0 kW.

Example 5.3: A three-star hotel has a water cooled screw chiller of capacity 30TR to provide space cooling of the restaurant and lobby area. During field study, measured chilled water flow is 20m^3/hr and evaporator side water inlet and outlet temperature is 14^{0}C and 10^{0}C respectively. Power consumption of chiller compressor is 18.5kW. What is specific power consumption of chiller? Also measured auxiliary pump power such as chilled water pump consumed 2.7 kW, condenser water pump consumed 5.0 kW and power of cooling tower fan is 1.7 kW, what is overall kW/TR? And compare with design overall specific power consumption SPC (0.85kW/TR) and what is saving potential in chiller auxiliary?

Cooling capacity, TR= $\dfrac{Q \times Cp \times (Ti\text{-}To)}{3024}$

Cooling Capacity (TR) = Chilled water flow (m^3/hr) x Sp. Heat x Temp difference / 3024

= {20 x 1000 x 1 x (14-10)} /3024

= 26.45 TR

Specific power consumption of chiller = 18.5/26.5 = 0.70 kW/TR

Total power consumption = Comp. power + chilled water pump power + cond. pump power + cooling tower fan power

= 18.5 + 2.7 + 5.0 + 1.7

= 27.9 kW

Overall specific power = Total power (kW) / cooling load (TR)

= 27.9 / 26.45

= 1.05 kW/TR

Diff in overall SPC = Operating overall SPC – Design overall SPC

= 1.05 – 0.85

= 0.2 kW/ TR

Energy saving potential = Diff in overall SPC x cooling capacity

= 0.2 x 26.45

= 5.29 kW

Energy saving potential in auxiliary equipment is 5.29 kW.

Example 5.4: Office split air conditioning (ac) unit measured capacity is 2TR and power consumption of compressor is 2.4kW. What are the performance assessment values like Specific power, COP and EER?

Specific power consumption = Power consumption (kW) / Cooling capacity (TR)

= 2.4 / 2

= 1.2 kW/TR

Specific power consumption of ac unit is 1.2kW/TR.

$$\text{COP} = \frac{\text{Cooling effect (kW)}}{\text{Power input to compressor (kW)}}$$

COP =

$$\frac{\text{Cooling effect (TR) x 3024 /860}}{\text{Power input to compressor (kW)}}$$

COP = (2.0 x 3024/ 860) / 2.4

= 7.03 (kW)/ 2.4 (kW) = 2.93

COP of ac unit is 2.93.

$$\text{Energy efficiency ratio (EER)} = \frac{\text{Cooling effect (BTU/hr)}}{\text{Power input to compressor (W)}}$$

Energy efficiency ratio (EER) = Cooling effect (TR) x 12000/ power input (W)

= 2.0 x 12000 / (2.40 x 1000)

= 10.

Energy efficiency ratio (EER) of AC unit is 10.

5.4.3 Assessment of DX system

In DX system, the airflow at the fan coil units (FCU) or air handling unit (AHU) can be measured with an anemometer instrument. Dry bulb and relative humidity are measured at the inlet and outlet of the AHU or the FCU and converted into enthalpy by using a psychometric chart. The cooling load in TR is calculated as follows:

$$\textit{Cooling load, TR} = \frac{Q \times \rho \times (\text{hin-hout})}{3024}$$

Where,

Q: Air flow in m^3/hr

ρ: Air density in kg/m^3

hin: Inlet air enthalpy in kCal/kg

hour: Outlet air enthalpy in kCal/kg

Example 5.5: Near the Air Handling Unit (AHU) measured air velocity at suction side is 3.72 m/s and cross section air of suction side is 0.71 m^2. Return and supply air parameters as follows,

Return air temp: 25.1^{0}C and Relative humidity: 43.7%, Return air enthalpy: 11.72kCal/kg

Supply air temp: 14.8^{0}C and Relative humidity: 83.8%, Supply air enthalpy: 9.28 kCal/kg

Density of air: 1.13 kg/m^3

Calculate the AHU side cooling load?

Air flow rate (m^3/hr) = Air velocity (m/s) x cross section area (m^2) x 3600

= 3.72 x 0.71 x 3600

= 9508.32 m^3/hr

$$\text{Cooling load, TR} = \frac{Q \times \rho \times (\text{hin-hout})}{3024}$$

= 9508.32 x 1.13 x (11.72-9.28)/ 3024

= 8.66 TR

Cooling effect at AHU side is 8.66TR.

Example 5.6: Measured the performance of a home air conditioning unit where the connected indoor unit was not accessible for measurements. To evaluate the performance, measurements were carried at outdoor unit and measurement details are as follows,

Outdoor unit air flow: 1680m^3/hr

Supply ambient air temp: 33.3^{0}C, RH: 38.9% and enthalpy: 15.65kCal/kg

Return hot air temp: 41.9^{0}C, RH: 24.53% and enthalpy: 17.78kCal/ kg

Power consumption of air conditioning unit: 1.24 kW

Calculate specific power consumption, COP and EER?

Heap removed by condenser = Air flow x density x (enthalpy diff) / 3024

= 1680 x 1.18 x (17.78 – 15.65) / 3024

= 1.40 TR

Cooling effect at indoor unit = Heat removed by condenser – Comp power

= 1.41 – (1.24 kW x 860 / s3024)

= 1.41 -0.35

= 1.06 TR

Specific power consumption = power consumption/ cooling effect

= 1.24 / 1.06

= 1.16 kW/TR

Specific power consumption of AC is 1.16kW/TR

$$\text{COP} = \frac{\text{Cooling effect (kW)}}{\text{Power input to compressor (kW)}}$$

$$\text{COP} = \frac{\text{Cooling effect (TR)x3024 /860}}{\text{Power input to compressor (kW)}}$$

COP = (1.06 x 3024/ 860) / 1.24

= 3.727 (kW)/ 1.24 (kW)

= 3.00

COP of AC is 3.00.

$$\text{Energy efficiecny ratio (EER)} = \frac{\text{Cooling effect (BTU/hr)}}{\text{Power input to compressor (W)}}$$

Energy efficiency Ratio (EER) = Cooling effect (TR) x 12000 / power input (W)

= (1.06 x 12000) / (1.24 x 1000)

= 10.26

Energy efficiency Ratio (EER) of AC is 10.26.

Air conditioning cooling load can be estimated by back estimating different heat loads such as latent load, sensible load, internal equipment, people, type of building envelope and ambient air parameters.

A typical cooling load (TR) for air conditioning space (area in m^2) is presented as follows:

Small office cabin	= 0.1 TR/m^2
Medium size office (10-30 people occupancy)	= 0.06 TR/m^2
Large multi-storey office complex with centralized cooling system	= 0.04 TR/m^2

5.5 Factors affecting performance of HVAC system

5.5.1 Optimisation of heat exchangers

The refrigerant temperature is related to the refrigerant suction pressure, which indicates the compressor inlet duty condition. Hence, minimum/optimum compressor driving force can achieve the highest possible suction pressure and reduce energy consumption and would require proper sizing of heat transfer area of evaporators and rationalizing the temperature requirement to the highest possible value.

A 1^{0}C raise in evaporator temperature can reduce power consumption of compressors by 3%. Also, cooling capacity (TR) of the unit will also increase with the evaporator temperature and same is given in below Figure 5.8.

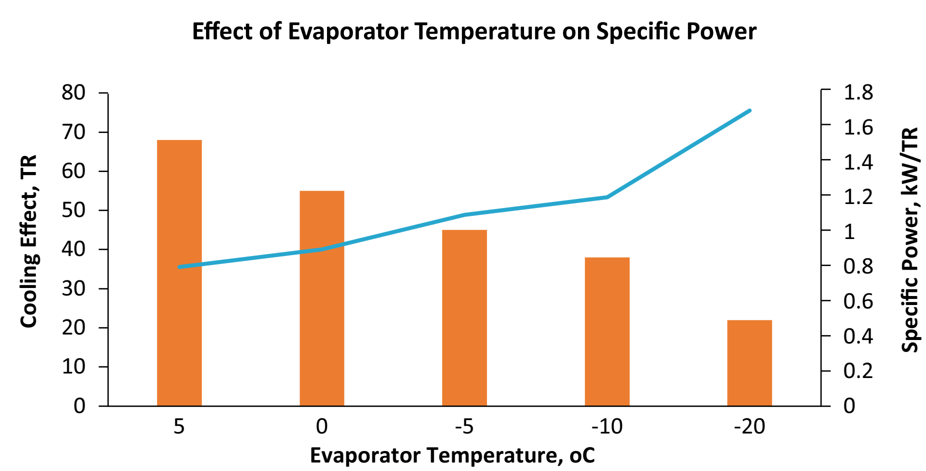


Figure 5.8: Effect of evaporator temp on specific power of air conditioning compressor

**Condenser temperature at 400C*

The condenser is a critical component in the refrigeration plant that directly affects the cooling capacity (TR) and compressor power consumption. The temperature and pressure of the condenser is dependent on the type of cooling (water /air) and the heat transfer area. A lower condensation temperature means that the compressor works at lower differential pressure and consumes less power.

Condensers are available as water-cooled and air-cooled type. Water-cooled with shell and tube heat exchanger that is associated with cooling tower operates the compressor at low discharge values and improves the TR capacity of the air conditioning plant. In an air-cooled condenser, the fan is used to force draft ambient air to pass over the tube-fin type heat exchanger to remove the condenser heat. Power consumption of air-cooled condensers is on the higher side compared to water-cooled.

5.5.2 Maintenance of Heat Exchanger Surfaces

Effective maintenance is the key to optimizing power consumption. Fouled condenser tubes force the compressor to work harder to attain the desired cooling requirement. For instance, 0.8 mm scale build –up in condenser tubes can increase energy consumption by as much as 35%.

A reduction of 0.55^{0}C in temperature of the cooling water that is supplied reduces the compressor power consumption by 3%.

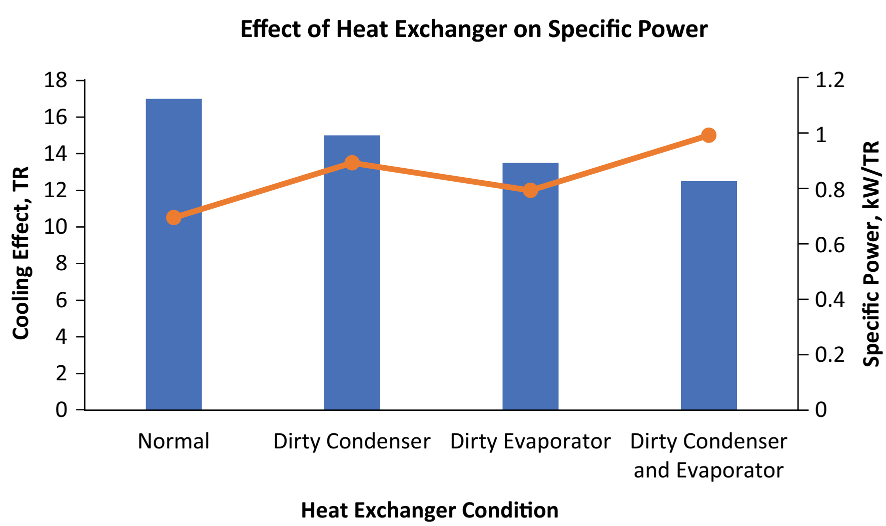


Figure 5.9: Effect of condenser performance on compressor power

**15 TR reciprocating compressor-based system.*

5.5.3 Capacity control of compressor

In various ways capacity of compressors can be controlled. In a reciprocating compressor, capacity control can be done through the cylinder thereby unloading results in incremental (step by step) modulation. In centrifugal compressor and screw compressor, modulation occurs through vane control and through sliding valves, respectively.

Normally, it is advisable to control the compressor based on the return water (return fluid) temperature rather than the supply temperature. This prevents unnecessary loading / unloading of the compressor. In case of constant load, the chilled water exit temperature should be monitored, especially in partial load conditions, to prevent operation at very low water temperature.

Capacity regulation through speed control is the most efficient option. In the centrifugal compressor, it is usually desirable to restrict the speed up to 50% of the capacity to prevent surging. In screw compressors, operating with speed control in part load condition is more effective than other type of compressors.

5.5.4 Chilled water storage

Depending on the load variation, it is economical to provide a chilled water storage facility with good insulation. This storage system can cater to the requirement so those chillers need not operate continuously. This system has the additional advantage of allowing the chiller to operate at the off-peak period to get lower tariff benefits offered by an electric utility company. Furthermore, the benefit is that at night ambient temperature is low, which helps to achieve lower condenser temperature and thereby reduce specific power consumption (kW/TR).

5.5.5 System design features

Good procurement practices improve the operating energy efficiency significantly. Some areas are as follows:

- Design cooling towers with FRP fans, PVC fills and drift eliminator.
- Use soft water as condenser water instead of raw water
- Optimum insulation thickness of cold lines, heat exchangers
- Adoption of roof coating, false ceilings whenever applicable to minimize cooling load
- Adopting of variable refrigerant volume system and sun film application for heat reflection
- As per requirement, proper number of air changes in the space cooled area
- Optimisation of lighting load in air conditioned area

5.6 Refrigerator and Freezers

The refrigerator and freezers are common and critical appliances in restaurants, houses, grocery stores, etc. They are operating around the clock to keep perishable products cold to increase shelf life, but contribute a good share in monthly energy bills. Typical commercial refrigerator consumes up to 17000kWh per annum while large commercial freezers consume up to 38000 kWh per annum[1]. To reduce this energy consumption of such appliances, US Energy department has launched new standard aimed to make refrigerator and freezers 30% more energy efficient compared to 2009 standards.

[1] https://www.energy.gov/eere/articles/6-energy-saving-tips-commercial-refrigerators-and-freezers

ENERGY STAR® is the US government backed symbol for energy efficiency. Providing simple, credible and unbiased information that consumers and businesses rely on to make well-informed decisions. Energy star certified refrigerators can maximize your energy and cost saving without sacrificing the features. This efficient refrigerator offers a high-efficiency compressor that creates less heat and use less energy, improves insulation that helps food stay cold and temperature and defrost mechanisms that help the refrigerator operate more efficiently.

Figure 5.10: ENERGY STAR® rating

In addition to the new standard, there are a few ways which can reduce the energy use of refrigerators and freezers are as follows:

- Check the door gasket and auto closers to make sure they are in good condition. Warm, humid air can enter into refrigeration compartment, if these gaskets are not working properly, resulting in energy waste and will impact stored food.
- Make sure the refrigerator system is clean and dust free, especially the coils. This can help improve heat transfer within the system
- Make sure the refrigeration system has enough space around it to ensure good airflow over the heat exchanger coils
- Install motion sensors for lighting in walk-in freezers. This will turn lights on and off only where needed.

5.7 Energy Saving opportunities

Energy efficiency options are provided as follows:

1. Process heat loads minimization

   Reduce process side (user side) cooling load:

   a. Flow optimization

   b. Minimize heat gains, loss of chilled water, and idle flow

c. Periodically clean / de-scale the heat exchangers (evaporator & condenser)

d. Increase heat transfer area to accept higher temperature coolant

2 At the air conditioning plant:

a. Ensure regular maintenance of all components as per manufacturer guidelines

b. Supply chilled and cooling water flows as per design specifications.

c. Regularly check the pressure drop across the evaporator and condenser side

d. Optimize the part-load chiller operation by installing a variable speed drive (VSD) for the compressor

3. Cold insulation

Choose the appropriate type of insulation and provide insulation to all cold pipes and equipment to minimize heat gains

4. Building envelope

Optimize volume of space cooling by providing appropriate false ceiling and segregation of condition area from non-condition area

5. Building Heat Load Minimization:

Reduce the cooling loads by roof painting, roof cooling, optimization of lighting, pre-cooling of fresh air by evaporative cooling, variable air volume, sun films applications, etc.

6. Ensure that the AC does not get overloaded and check the fuse or circuit breaker if the AC does not operate

7. Clean the filter and clean the evaporator and condenser coil periodically for efficient operation

8. Check and clean the thermostat regularly and replace it if required

9. Avoid frequent opening of door/ windows, which will increase the cooling load and result in higher AC unit power

10. Avoid direct sunlight enter in the air-conditioned space

11. Provide canopy over the outdoor unit to protect from direct sun rays, it will improve the performance of condenser as well increase service life

Some rules of thumb are:

- Refrigeration capacity reduces by 6% for every 3.50C increase in condensation temperature
- Reducing condensation temperature by 5.50C results in a 20-25% decrease in compressor power consumption
- A reduction of cooling water temperature by 0.550C results in decrease of compressor power by 3%.
- 1 mm scale build-up on condenser tubes can increase energy consumption by 40%
- Rise in evaporator temperature by 5.50C reduces power of compressor by 22-25%.

CHAPTER 6

Rotatory Equipment – Pumps & Fans

Rotating equipment is generally termed for the mechanical devices or components that use kinetic energy to move or transport the liquids, gases, and solids. Rotating equipment includes, but is not limited to, pumps, fans, blowers, compressors, turbines, engines, generators and gearboxes. Rotating equipment is widely utilized in various sectors and is mostly energy intensive.

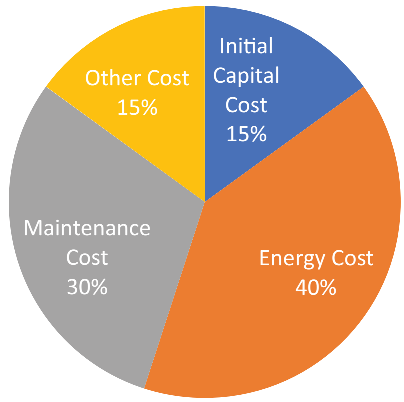


Figure 6.1: Life cycle costs of pumps & fans

Out of these, several devices such as the pumps and fans have their annual energy cost much more than the initial purchase cost as shown in figure 7.1. Since these rotating devices operate continuously in many sectors, even modest improvements in the system efficiency would lead to significant savings. Particularly, pumps and fans provide good opportunities for efficiency improvement, because system designs are often difficult to optimize before the installation mainly due to focus on minimizing the capital costs or chances of system failure. As a result, energy and maintenance costs may not be fully considered. Hence in this chapter, focus is on pumps and fans only.

6.1 Pumps

Pumps are devices that use input mechanical energy to increase the velocity, pressure, or the elevation of the incompressible fluid. Energy consumption for pumps is enormous and constitutes at least 25% of the World's electricity. In the present days across the world, numerous pumps are developed in many shapes and sizes to meet the different requirements of user.

6.1.1 Types of pumps

Based on the primary means of energy transfer to the fluid, pumps are classified into two main categories: dynamic (kinetic) and positive displacement. Apart from these, other energy transfer mechanisms comprise the electromagnetic force, momentum transfer, gravity, mechanical impulse and combination of these to differentiate the type of pumps. Based on the operating principle, some of the predominant pumps abundantly used worldwide are explained briefly in the following sections.

Positive displacement pumps: These pumps work by trapping a definite volume of a liquid in a chamber, which is alternatively filled from the suction and discharged at increased pressure using mechanical energy. Sub-classification majorly comprises of a reciprocating piston, rotary vane, diaphragm machines and gear type. These devices are adaptable for high-pressure operation at a constant flow rate (unless damping systems) of liquids pumping. However, they have limitations of mechanical considerations and efficient performance with high throughput.

Reciprocating pumps have an oscillating component such as piston, plunger or diaphragm that causes the liquids to flex back and forth in a chamber with check valves at inlet and discharge. The overall efficiency of these pumps varies from 50% to ~90% based on sizes. Diaphragm pumps are mainly used for handling hazardous or corrosive liquid. Gear, Lobe, screw, vane and cam pumps belong to rotary group preferred for handling viscous liquids.

Dynamic pumps: These pumps increase the velocity of liquid entering the pump by converting the kinetic energy of the fluid to potential energy in the form of increased pressure or elevation. The Centrifugal pump, axial flow pump, and mixed flow pump belong to the dynamic pump group.

Centrifugal pump: These pumps are the most widely used across various industrial applications and general utility services. These pumps offer multiple advantages: simple design, low initial cost, low maintenance, flexibility, and adaptability. The working of the centrifugal pump is explained below, along with schematic representation in figure 6.2

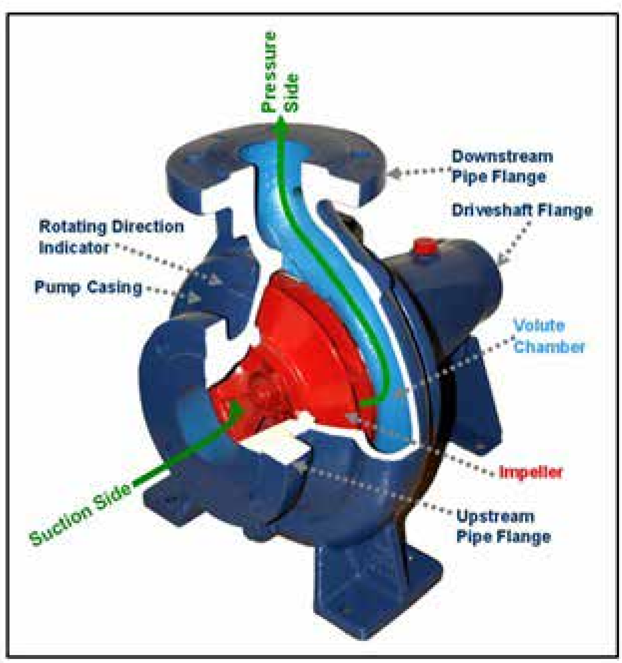


Figure 6.2: Centrifugal Pump

The two main parts of the pump are impeller and volute (or diffuser). The impeller, which is the only moving part, is attached to a shaft and driven by a motor. Impellers are generally made of bronze, cast iron, stainless steel and other materials. The volute houses the impeller and directs water to enter at the center and exits the impeller using centrifugal force. As water leaves the eye of the impeller, a low-pressure area is created and causes more liquid to flow into the impeller eye from the suction pipe. Atmospheric pressure and centrifugal force cause this to happen. This liquid is forced outward along the blades at increasing tangential velocity with the impeller spinning at high speed. The velocity head it has acquired when it leaves the blade tips is changed to pressure head as the liquid passes into the volute chamber and hence out the discharge of the pump.

Centrifugal pumps are sub-classified based on a number of stages, design of impeller, orientation of shaft and casing split, type of volute, miscellaneous applications and industrial standards.

Axial-flow pumps are designed for higher capacity and low-head applications, particularly in closed-loop circulation systems. Other pumps namely, electromagnetic pumps that use electromagnetic field as a driving force around the fluid conduit for causing to flow. The turbine or regenerative-type pump is another device that functions partially by mechanical impulse. Vertical pumps are used as pit pumps with tanks containing difficult-to-handle liquids.

Even though there are multiple options available for use, centrifugal pumps are regarded as the most economical followed by the positive displacement. Centrifugal pumps account for the major share of energy consumption among the most widely used pumps in the world. Hence, this manual chapter focuses on the centrifugal pump and its associated system.

6.1.2 Performance evaluation

A pump may raise the liquid through a pipe to a higher elevation, force to higher pressure, overcome the friction of the connected system, or perform any combination of these. It will be convenient to express this pressure in terms of the head (i.e., height of liquid column). Head developed by the pump will be same irrespective of density of the liquid being moved in system.

To cause the liquid to flow, work must be expended and required energy should be supplied. For attaining the higher efficiency of the pump, it is very important to consider the appropriate discharge requirements (Q) and total head (H), motor drive arrangements, power consumption (kW), actual contours of the hydraulic passages of the impeller and casing along with associated system configuration of network.

Performance curves, also known as pump characteristic curve, are typically plotted with test data of flow, head, and efficiency along with pump power consumption. A performance curve is a useful tool for indicating the operation regime for a given set of conditions. The typical performance curve is shown in the below figure 6.3.

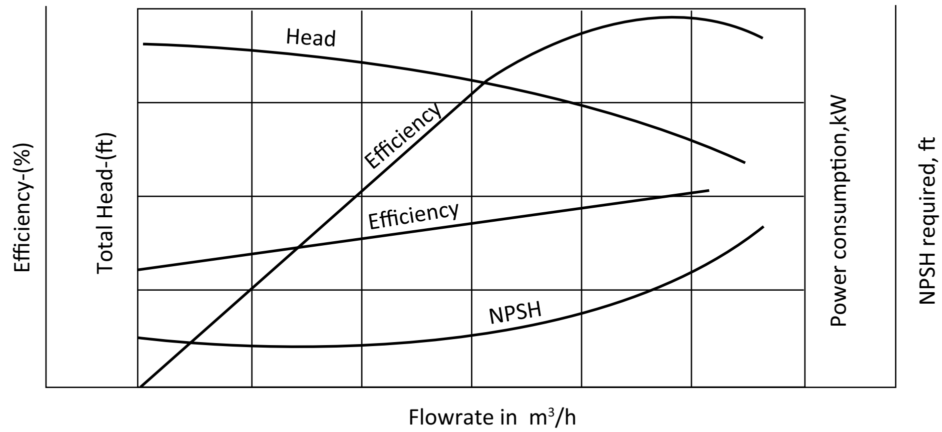


Figure 6.3: Typical performance curve of pump

From the above figure 6.3, it is observed that head or pressure decreases with increase in flow. Whereas efficiency increases with flow, reaches a maximum and then decreases for which 'family of curves' are to be made available by the pump manufacturers.

Pump Efficiency

Pump efficiency is defined as the ratio of hydraulic power delivered for the liquid to the input shaft power for the pump. The hydraulic power (kW) is the power utilized by the quantity of liquid to raise the water for an assigned head. The input power (kW) of the pump is mechanical power delivered by the motor drive to the pump shaft or coupling. Rated motor efficiency as indicated by the motor manufacturer on the nameplate of motor can be used to derive the shaft input power from the electrical input of motor or rated motor power.

Hydraulic power, pump shaft power, electrical input power, and pump efficiency formulas are explained below.

$$\text{Hydraulic power } (P_h) = \frac{\text{Flowrate (Q) x Total Head [H] x density of fluid (r) x gravity (g)}}{1000}$$

Where-

H – [h_d – h_s], in "m"

hd – discharge head, in "m"

hs – suction head, in "m"

ρ - kg/m^3,

g – 9.81 m/s^2

Flowrate in m^3/s = Q

Pump Shaft Power, kW = Ps

Motor efficiency, % = η_{motor}

Pump Efficiency, % = η_{pump}

Electrical Power, kW = PE

$$Now\ \eta_{pump} = \frac{\rho g Q H}{\eta_{motor} \times 1000} \qquad P_E = \frac{P_s}{\eta_{Motor}}$$

In case of water pump, a simple formula for hydraulic power (kW) could be written as $\frac{QH}{367.2}$

Example 6.1: Calculation of efficiency for water pump

For high-temperature circuit cooling of diesel engine sets, a centrifugal pump is delivering 94 m^3/h of water with discharge pressure of 32 m. The water is drawn from a storage tank that is 4 m below the pump's center line. The measured power of the motor is 14.7 kW with a motor efficiency 91%. Determine the pump's operating efficiency.

Hydraulic power (P_h) =

$$\frac{Q\left(\frac{m3}{s}\right) \text{ x Total Head [hd-hs],m x density of fluid (r)} \frac{kg}{m3} \text{ x g} \left(\frac{m}{s2}\right)}{1000}$$

Q = 94 m^3/h /3600 s = 0.0261 m^3/s, Total Head (H) = hd - hs = 32 – (-4) = 36 m

$$\text{Hydraulic power } (P_h) = \frac{0.0261\left(\frac{m3}{s}\right) \text{ x 36 m x 1000 } \frac{kg}{m3} \text{ x 9.81} \left(\frac{m}{s2}\right)}{1000} = 9.21\ kW$$

Pump shaft power (kW) = Motor power X motor efficiency factor = 14.7 kW X 0.91 = 13.37 kW

Pump efficiency (%) = hydraulic power / pump shaft power = 9.21 / 13.37 = 68.8 %

Pump's operating efficiency is estimated to be 68.8%

Performance evaluation methodology

For performance evaluation of pumps, it is essential to measure and monitor the operating parameters such as flowrate, pressure head and power consumption, along with design details of pumps and motors. The specialized instruments used during the energy audit include:

- Power analyzers to measure voltage, current, power factor, kW, kVA, kVAr, Hz, kWh.
- Ultrasonic water flow meters to measure the velocity & flow rate of pumps and pipelines
- Digital pressure sensor or pressure gauge to measure the delivery head of the pumps

Some of the photographs captured during the energy audit of pumps are given in figure 6.4:

Figure 6.4: Flow, pressure, and power measurement

Apart from the measurements, necessary data need to be collected like:

- Capacity controlling techniques - Throttling of valves or VSD
- Storage tank and distribution end details (with elevations) along piping network.
- Pressure drop and flow rate distribution for adequacy of pipelines.

Based on the data gathered from measurement and design details, pumping system efficiency will be evaluated and discussed with relevant personnel for further improvement options.

6.1.3 Design and selection criteria

In a water pumping system, the objective in most cases is to transfer the water from a source to a required destination, e.g. filling a high-level reservoir or a tank. A pressure (H) is needed to make the water flow at the required rate (Q), and this must overcome two types of 'head losses' in the system, namely 'Static Head' and 'Frictional Head'.

'**Static Head'** is simply the elevation difference in the height of the supply and destination reservoirs. **'Friction Head'** (sometimes called 'dynamic head loss') is the 'frictional loss', on the water being moved in pipes, valves and equipment in the system. Schematic representations of the system head for two different systems along with duty point curves are given in figure 6.5 and 6.6 respectively.

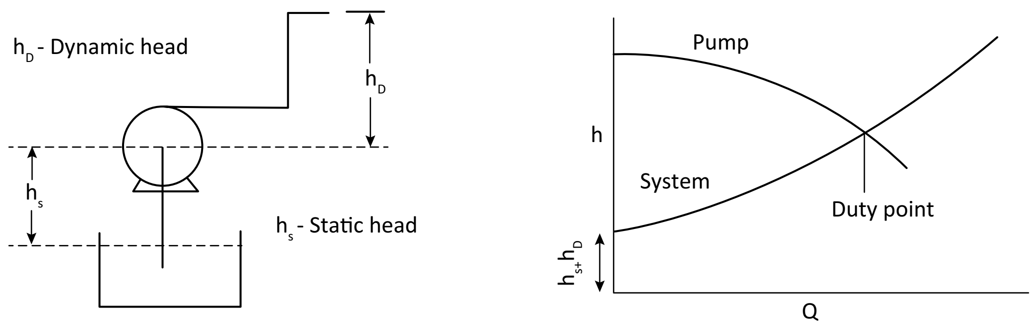


Figure 6.5: System head having both static and dynamic head

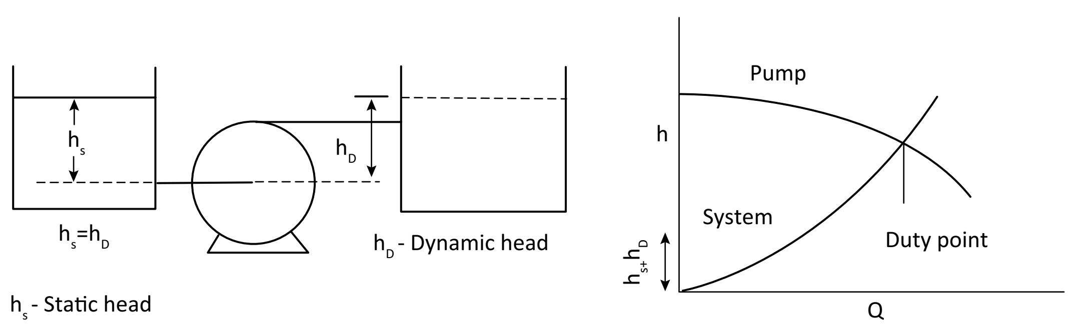


Figure 6.6: System head having only dynamic head

Ready made reference friction tables are universally available for various pipe fittings and valves, which are considered during initial design of the system. The friction losses are proportional to the square of the flow rate. 'Static Head' is a characteristic of the specific installation and reducing this head wherever possible generally helps both the initial cost of the installation and the cost of pumping water. 'Friction Head losses' must be 'minimized' to reduce the power consumption and pumping cost, but after ensuring adequate pipe size, fittings and length. However, further reduction in 'frictional head' requires larger diameter pipes which will increase the initial installation cost.

Pump Operating Point

For any water handling system, the 'operating point' is decided by the intersection of "pump characteristic" curve with "system characteristic" curve. When a pump is installed in a system, the effect can be illustrated graphically by superimposing the pump and system curves as shown in the adjacent **Figure 6.7**.

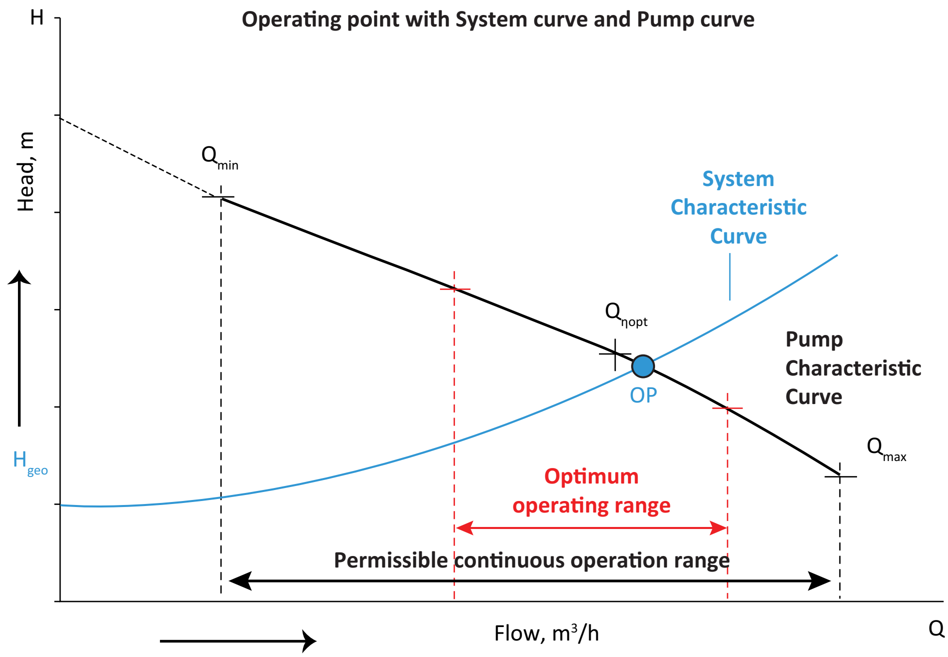


Figure 6.7: Pump operating point with pump curve & system curve

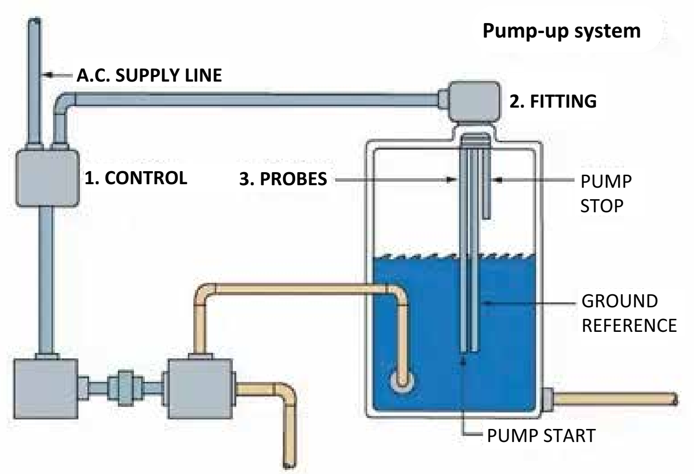
Normally the 'system characteristic' as explained earlier consists of two components, the 'Static Head' and the 'Friction Head'.

Ideally, this operating point would correspond to the flow rate as the pump's best efficiency point (BEP). While designing the pumping head including transient changes, it is imperative that '**head loss calculation'** has to be realistic with optimal safety margins not exceeding 15%.

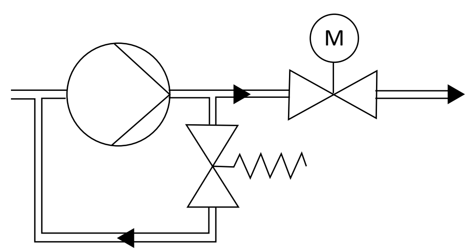
Factors affecting pump performance : When selecting pumps, it is essential to know the liquid to be handled, flow, head, fluid temperature, viscosity, vapor pressure, and density. Apart from that hydraulic aspects ensuring adequate pipe sizes and electrical parameters such as power, voltage and etc., also to be considered. With variety of pump types and number of factors which determine the selection of any one type for a specific installation, the designer must first eliminate all but those types of reasonable possibility.

6.1.4 Flow control strategy

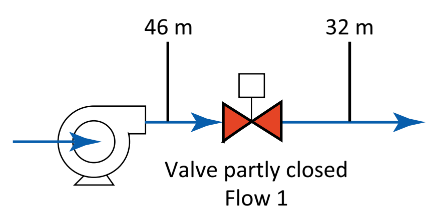
When flow rates vary with time, the control strategy to be employed for operational flexibility also enters into the pump selection decision. Some of the control methods are:



Start/stop control & Level controller: This technique involves the pump to start running for the designated tank or container, and once the desired levels in the tank are achieved pump will stop. Again it resumes operation once the levels are below the low level. Stress on the motors is higher, tendency to fail frequently over the long run.



Bypass valve: It comprises of two flows, one is flowing usefully into system and other part of flow returns to suction pressure side of pump. This technique is uneconomical as there is additional cost for construction of bypass circuit and no reduction in power consumption for energy cost savings.



Throttle output / Flow control valve : Traditional approach is to maintain the pump's running at rated speed at all times and throttle the pump delivery with a valve to achieve the desired lower flow. This corresponds to increasing the system pressure drop, which changes the locus of the head-flow curve and moves the operating point from the best efficiency levels.

Trimming impeller: It is the process of matching the diameter of the pump's impeller to reduce the energy added to the system fluid and deliver lower flow and pressure closer to the best efficiency point of the system curve. If the pump head required is lower than the design consideration or changes in system loads that are oversized for their application, then the best option is trimming or modifications of impeller up to 10 – 15% of its largest diameter.

Variable speed drive (VSDs) : It is the most efficient method of flow controlling for pumps. Power drawn varies as cube of speed. It is best suited for system of different flow rates without affecting efficiency. VSDs should be installed where static head component is less than the frictional loss component. If the static head contributes to a major percentage of the total head, it is better to replace the pump with a new pump.

Buy a new pump: Undersized pumps would be forced to work harder and oversized pumps would be throttled to regulate the discharge flow. Older pumps due to ageing, rotating elements and components lose their strength with deterioration factors of wear and tear. In all these cases, pumps draw more power and tend to operate away from the best efficiency point. The difference in the cost of running a mismatched pump against the appropriate pump may be so high that it might be more feasible to purchase new pumps of adequate size for the system.

Comparative analysis for the power consumption relationship with system (head-flow) curve for throttled operation and speed adjustment scenarios are explained in this section.

Two system characteristic curves corresponding to the same system, but for different 'throttle-valve' positions, i.e, partially closed valve and fully-open valve positions with reference to full load and partial load capacity control are shown in figure 6.8. At fixed speed, the operating point on the pump curve is pushed to the lower flow region. Thus, the pump develops higher head than required for the system. Excess head created by the pump is used to overcome the resistance of throttling valve and pressure drop created.

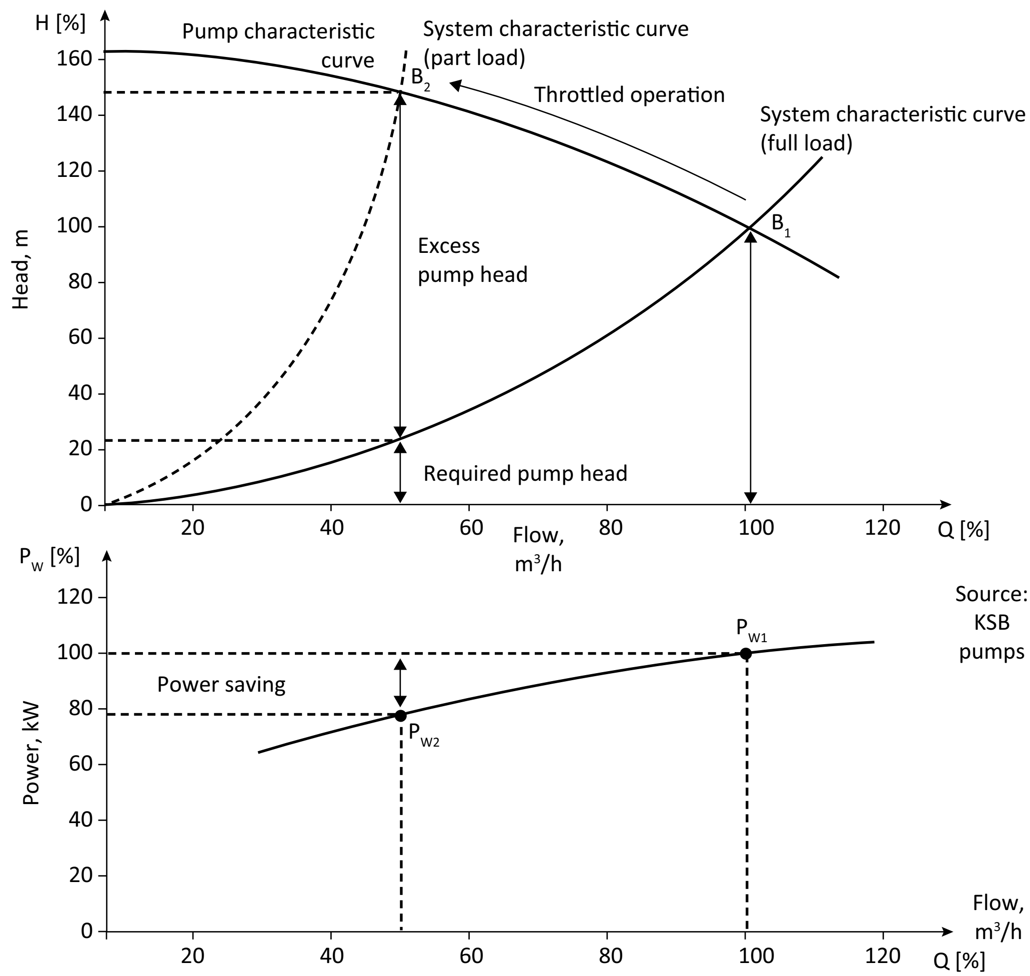


Figure 6.8: Pump power curves with throttling and speed adjustment

Affinity Laws:

If in case the supplier/vendor specified pump performance characteristic curves are not available for different sizes of the impeller or varying conditions of operating speeds of the pump, then the affinity laws or similarity relationship equation can be used. As per the affinity laws for pumps:

- Flow rate (Q) is proportional to impeller diameter (D) and impeller rotational speed (N).
- Head (H) varies as square of the impeller diameter (D) and impeller rotational speed (N).
- Break horsepower (BHP) varies as cube of impeller diameter (D) and rotational speed (N).

These empirical equations are expressed mathematically as per the table 6.1.

Table 6.1: Affinity laws for pumps at constant impeller diameter and constant impeller speed

	Constant impeller diameter	Constant impeller speed
Capacity	$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$	$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$
Head	$\frac{H_1}{H_2} = \frac{(N_1)^2}{(N_2)^2}$	$\frac{h_1}{h_2} = \frac{(D_1)^2}{(D_2)^2}$
Break horsepower	$\frac{\mathrm{BHP}_1}{\mathrm{BHP}_2} = \frac{(N_1)^3}{(N_2)^3}$	$\frac{\mathrm{BHP}_1}{\mathrm{BHP}_2} = \frac{(P_1)^3}{(P_2)^3}$

Affinity laws provide best estimate for the pump's performance through theoretical relationship between impeller sizes & pump output reference to speed. One such example is explained here.

Example 6.1: In one commercial building, water supply pumps have fixed speed motor with present water flowrate of 90 GPM leading to overflow and damaging the pipelines due to excessive pressure (>31 m). Instead of trimming the existing impeller, management of building decided to use v-belt drive with maximum impeller diameter and wanted to determine the pump flow and head at new operating speed (1235 RPM). Using the affinity laws for present operating characteristics of the pump (rated speed at 1480 RPM) at total head of 49 m, calculation details are given below.

Basis on data available: Flow (Q) = 90 GPM, Initial pump operating speed (N1) = 1480 RPM and proposed pump operating speed (N2) = 1235 RPM. Using the same (N2/N1) = (1235/1480) = 0.834.

From the affinity laws:

$\mathbf{Q_2 = Q_1 \times (N_2/N_1)}$	= 90 GPM x (1235/1480)	= 90 GPM x (0.834)	= 75 GPM
$\mathbf{H_2 = H_1 \times (N_2/N_1)^2}$	= 49 m x (1235/1480)2	= 96 x (0.834)2	= 34 m.

Based on the analysis, it can be seen that for 16.6% speed reduction, the flow has reduced by 16.6%, the total head has decreased by 30.6%, and the new operating point is closer to the system requirement.

Example 6.2: Throttled operation of oversized pump and retrofit of oversized pump

The chilled water pump operated at full speed to supply water to the compression chiller in a multi-story building. Performance evaluation of pump and design parameters revealed that the installed capacity of the pump was higher than required for the prevailing condition of the system, and hence capacity control was by discharge valve adjustment.

It was also known from the utility in charge that the required pressure head for supplying water to all floors ranges from 32 m to 36 m. Hence, it was suggested to install a variable speed drive (VSD) for the pump and operate at reduced speed with a wide open discharge valve and pressure feedback. Comparison of operating pump performance evaluation results with controlled valve and VSD at reduced speed of various scenarios is given in table 6.2.

Table 6.2: Comparative results of the controlled valve and VSD operation of the pump

Parameters	Units	Design	Operating with throttled valve	Operating with VSD – Various Scenarios			
Frequency of VSD	Hz		@ 60 Hz	@ 45Hz	@ 50 Hz	@ 57 Hz	@ 60 Hz
Flow	*m^3/h*	***250***	182	92	174	231	288
Head	*M*	***50***	38	34	38	36	33
Speed	RPM	1480	1480	1095	1273	1391	1480
Motor power	kW	55	44.9	19.8	27.7	33.7	42.9
Motor efficiency	%	92	92	92	92	92	92
Pump efficiency	*%*	***76***	***41.9***	**43**	**64.9**	**67.3**	**60.3**

Energy savings with techno economics and a picture of chilled water pumping are given below.

Energy savings calculation:

Power consumption with throttled valve	: 44.9 kW
Reduction in power consumption (avg.)	: 13 kW
Annual operating hours (12 h x 365 days)	: 4380
Annual energy savings	: 56940 kWh
Annual cost savings (@ GY$ 60 / kWh)	: GY$3.4 million
Investment cost for VFD (55 kW)	: GY$ 1.6 million
Simple payback period	: 0.45 year

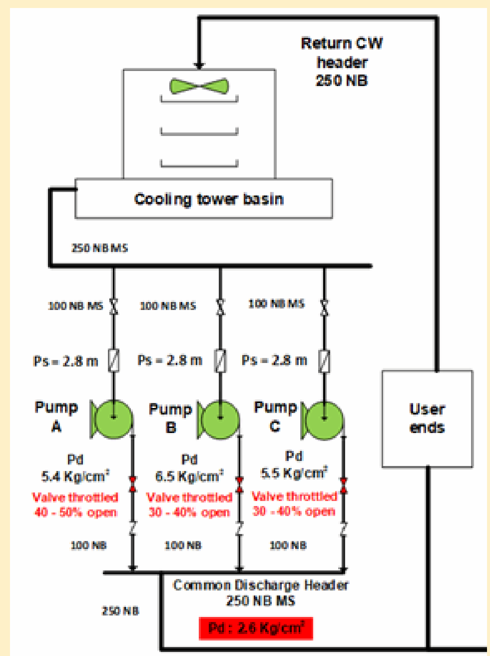
From this example, it is clear that the implementation of VSD to avoid throttling valves for flow control has realized significant energy and cost savings with an attractive payback period.

Example 6.3: Parallel operation of pumps and higher system resistance:

In Diesel generation (DG) sets power plant, management has installed three pumps for water supply to high-temperature circuit water cooling of the engine room and other utility areas. Normally two pumps were operating continuously in parallel combination, and the third one was based on the additional user end needs. Performance evaluation results of the pumps at different combinations are given in the below table and figure.

Table 6.3: Parallel operation of pumps

Particulars	Flow	Head	Power	Efficiency
Units	*m³/h*	*M*	*kW*	*%*
Design			-	-
Pump A	150	50	30	72
Pump B	150	45	30	72
Pump C	100	45	22	70
Operating				
Case 1: A, B & C	**255**	**52**	**70**	**55.4**
Pump A	86	54	24	57.9
Pump B	96	59	27	62.8
Pump C	73	49	19	56.4
Case 2: A & B	**210**	**50**	**59**	**53.3**
Pump A	101	50	29	52.1
Pump B	109	49	30	53.3
Case 3: A & C	**211**	**48**	**54**	**56.3**
Pump A	117	51	31	57.6
Pump C	94	45	23	55.1



Estimated operating efficiencies of pumps were found to be on the lower side, mainly due to improper sizing resulting in higher restriction for the flow. Though the pump's discharge pressure is in the range of ~5.4 –5.5 Kg/cm^2, after the discharge valve (with the opening of 30 – 40%), the header pressure maintained is 2.6 kg/cm^2 only. All the three pumps pipelines are of the same size (100NB), irrespective of the pump capacities, and all are connected to a common header (250 NB). Velocity in the pipelines is found to be higher (>3 m/s) than optimal limits (<2.0 m/s). Out of the three pumps, two are 15 years old, and one is energy efficient pump installed 2 years ago. Based on the same, it was suggested to replace existing pumps with adequate size pumps and pipelines (150NB). Proposed pump parameters with techno economics of energy savings are given below.

Proposed pump parameters: 2 no

Flow rate – 135 m3/h,

Total head – 30 m,

Pump efficiency - 72%

Input power – 16.8 kW,

Motor efficiency – 91%

Motor rating – 18.5 kW

Energy savings calculation:

Reduction in power consumption (avg.)	: 27 kW
Annual energy savings (8000 h operation)	: 216000 kWh
Annual cost savings (@ GY$ 60 / kWh)	: GY$ 12.96
Investment cost for pumps & pipeline	: GY$ 6.5 million
Simple payback period	: 0.45 year

Example 6.4: Multistage impeller for pumps like boreholes / reverse osmosis/irrigation

For two high-rise buildings A and B, each at similar elevation but different locations, multistage pumps were installed to supply water. Installed multi-stage pumps were of different head and same flowrate with fixed speed motor, even though pumps were of same OEM supplier. Performance evaluation results of both the operating pumps and their design parameters are given in table 6.4 and photos of multistage pumps in figure 6.16 and 6.17.

Table 6.4: Comparison of Multistage pumps operation

Parameters	Unit	Building A		Building B	
		Design	*Operating*	*Design*	*Operating*
Impeller – stages	No	6	6	4	4
Flow rate	m3/h	7	6.1	7.5	5.5
Head	M	120	70	80	71
Power	kW	5.5	5.1	3.7	3.0
Pump efficiency	%	50	26.8	52	42

Based on the same, it was suggested to remove one or two stages of impeller for Building “A” and operate without throttling the discharge valve. The estimated power consumption for a retrofit 4 stage impeller is 3.7 kW. Techno-economic calculations of energy savings are given below.

Energy savings calculation:

Reduction in power consumption (avg.)	: 1.4 kW
Annual operating hours (6 h x 365 days)	: 2190
Annual energy savings	: 3066 kWh
Annual cost savings (@ GY$ 60 / kWh)	: GY$ 0.2 million
Investment cost for impeller retrofit	: GY$ 0.2 million
Simple payback period	: 1 year

6.1.5 Energy conservation opportunities

- Use of siphon effect for the systems with free-fall return (gravity) and avoid pumping head
- Installation of booster pumps for areas with smaller loads at the higher head.
- Increase fluid temperature differentials to reduce pumping rates in the case of heat exchangers.
- Conduct water balance to minimize flows and avoid water re-circulation.
- In multiple pump operations, judiciously mix the operation of pumps and avoid throttling
- Use variable speed drives for variations of flow due to process requirement.
- Mismatch in design, provide VSD, trim/replace impeller or replace with correct sized pump.
- Replace old pumps by energy efficient pumps.

6.2 Fans

Fans and blowers are devices that use input mechanical energy to increase the velocity, pressure or elevation of the air and gases. Fans are used for relatively low pressures and high volume of air or gases to be handled either for supply or removal from the system. Whereas blowers are used for higher pressure of gases / air at relatively lower volume of air. Fans and blowers are used in many sectors such as industrial, residential, municipal utilities, mining, agriculture and commercial building like, offices, hotels and restaurants, etc.

6.2.1 Types of fans

There are primarily two types of fans – centrifugal and axial. The Centrifugal fan converts the imparted kinetic energy into pressure energy for the air or gas handled using a rotating element such as an impeller. A pictorial representation of the centrifugal fan is given in figure 6.9.

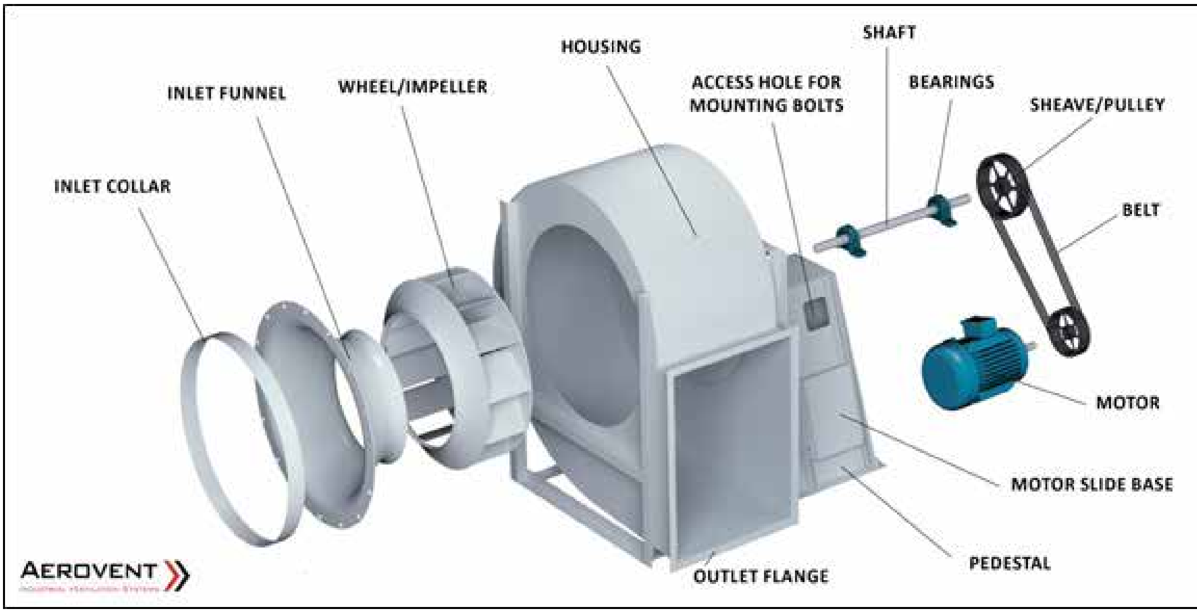


Figure 6.9: Centrifugal fan and its components

Source: Fan Pedia by Aerovent

In axial fans, air or gas is positively displaced along the axis of the fan and increases the pressure by using the mechanical energy of the propeller blades.

Centrifugal fans are usually less expensive than axial fans. In choosing the right type of fan, operational requirements of the system along with knowledge of the fan for most cost effective option is very essential and some of such scenarios will be discussed in the next sections.

Both centrifugal fans and axial fans are further classified based on the various shapes of blades and details of the same are given in below table 6.5.

Table 6.5: Classification of centrifugal fans and axial fans along with their applications

Centrifugal fans - classification			Axial fans - classification		
Type	Characteristics	Applications	Type	Characteristics	Applications
Forward curved blades 	Relatively low speeds; Low to medium air pressure; High air flow; Dip in pressure curve; Efficiency ranges from 55 to 65%; Power increases steadily with airflow.	Low temperature, HVAC, packaged units, suitable for high particulate air-streams, clean and dust-laden air/gases	Tube axial 	Medium pressure (250 - 400 mmWC); High airflow; Higher efficiency than propeller type; Dip in a pressure-flow curve before peak pressure point.	Ducted HVAC, drying ovens, exhaust systems
Radial 	High pressure (1400 mmWC); Low to medium air flow; Efficiency up to 75%; Power increases continuously	Various industrial applications suitable for high temperature, small particulates, moist, solids contaminated air/gases	Propeller 	High air flow at low pressures; Large change in airflow with small changes in static pressure; power decrease with increased airflow; Efficiency is low.	Air-cooled condensers and cooling towers. Moderate temperature, Air circulation, rooftop ventilation, exhaust

Contd...

Table 6.5: Classification of centrifugal fans and axial fans along with their applications

Centrifugal fans - classification			Axial fans - classification		
Type	Characteristics	Applications	Type	Characteristics	Applications
Backward curved blades 	3 different shapes: Flat blades are more robust; curved blades are more efficient; and Airfoil blades are most efficient (85%). Suitable for High pressure and high flow, power reduces as flow beyond increases point of highest efficiency	Relatively clean air/gases, HVAC, various industrial applications forced draft fans, etc.	Vane axial 	Medium to Higher static pressure (up to 500 mmWC); medium flow; dip in pressure-flow curve; use of guide vanes; most energy-efficient fans.	High-pressure applications including HVAC and Exhaust systems.

6.2.2 Performance evaluation and efficient system operation

A typical fan system comprises of a fan, motor drive, accessories and associated ducting system. Whenever a fan operates to move the volume of air or gas across the system there is resistance, which has to be overcome by additional energy to compensate the loss of static pressure. It is also known as system resistance.

System Characteristics

System resistance arises mainly due to two factors, namely friction losses and dynamic losses. Frictional losses are nothing but pressure losses that occur at the duct or piping system walls. Dynamic losses also known as velocity pressure losses, occur due to changes of direction in air or gas flow and at sudden duct expansion and contractions. System resistance varies as square of the volume (function of velocity) of air or gas handled by the system. Schematic representation of the typical system resistance curve is given in the figure 6.10

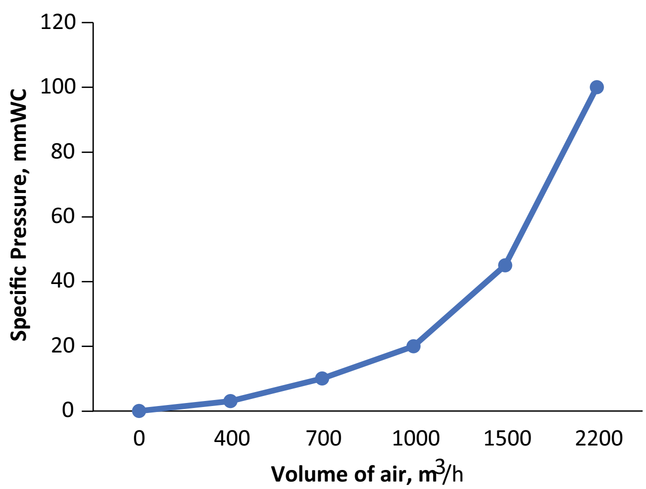


Figure 6.10: System resistance of fan/blower

For example, a fan operating with a specified volume of air in a narrow piping and multiple bends to the end user, requires more energy to overcome additional system resistance than in the larger ducts and minimum bends. If not, the volume supplied will be lower than desired. Hence, to determine the volume of air/gas that the fan will handle, it is essential to understand the system resistance characteristics.

The system resistance effect with various operating scenarios with restriction to smooth airflow into or out of a fan can be illustrated in the performance curve. Probable scenarios that lead to restriction are mainly due to poor configuration of ductwork and placing an elbow and damper control for flow. Illustration of system resistance scenarios on total pressure and power consumption of the fan based on performance curve are given in the figure 6.11.

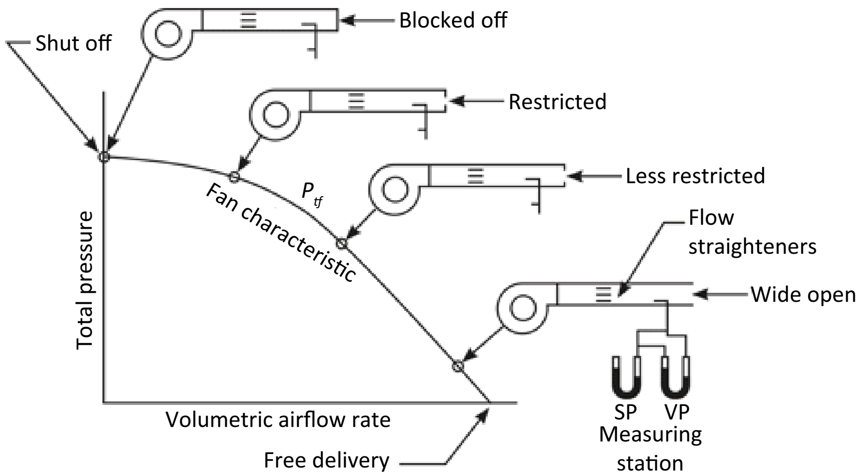


Figure 6.11: System resistance scenarios on fan curve

It can be seen from the above figure, that system resistance decreases the air flow handled by the fan. This may need to increased fan speed, leading to increased power consumption and a decrease in overall system efficiency.

Fan Characteristics Curve

Fan characteristics can be represented in the form of a fan performance curve, typically plotted with static pressure and power over a range of volume that a fan can handle for a given set of conditions. Performance characteristics curves are developed from the test data that will also include the efficiency range of the fan operating under the chosen conditions. When the system resistance curve and fan characteristic curves are superimposed graphically, the intersection point is the system operating point. Schematic representations of the fan operating point with other characteristic curves are given in the figure 6.12.

Another important aspect of a fan that can be derived from the fan performance curve is the best efficiency point (BEP), which indicates that the fan operates most cost-effectively in terms of energy efficiency and maintenance considerations.

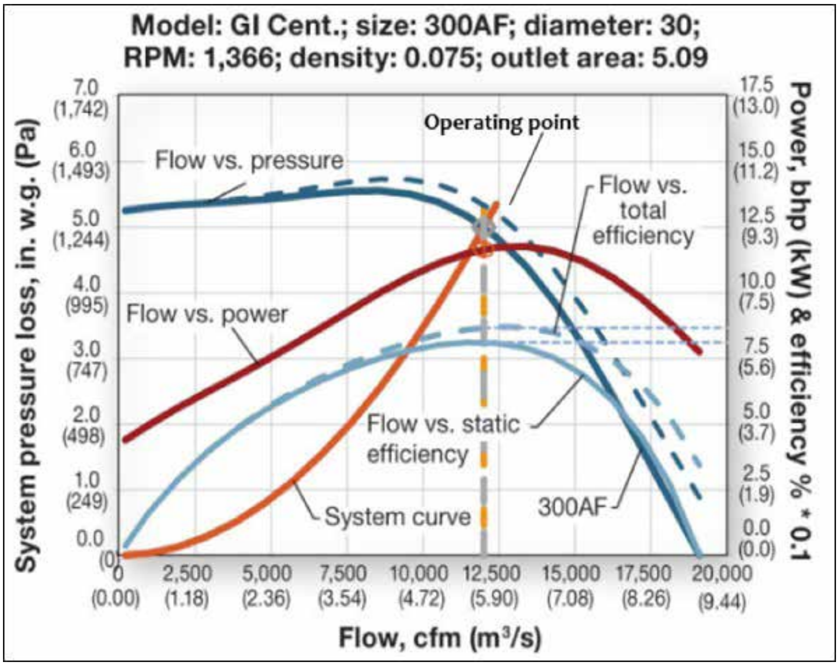


Figure 6.12: System resistance of fan/blower

Source: Axair

Affinity Laws for Fans

Like centrifugal pumps, fans also follow affinity laws to provide the best estimate for the fan's performance through a theoretical relationship between impeller sizes and fan output with reference to speed. The empirical equations for fans are given in table 6.6.

Table 6.6: Affinity laws for fans at constant impeller diameter and constant impeller speed

Fan parameters	Constant impeller diameter	Constant impeller speed
Flow (Q)	$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$	$\frac{Q_1}{Q_2} = \left(\frac{D_1}{D_2}\right)$
Total Pressure (P)	$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^2$	$\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^2$
Power consumption (kW)	$\frac{kW_1}{kW_2} = \left(\frac{N_1}{N_2}\right)^3$	$\frac{kW_1}{kW_2} = \left(\frac{D_1}{D_2}\right)^3$

Example 7.6: A Fan was operating with initial impeller diameter (D1) of 220 mm at flow (Q1) of 30 CFM and pressure (P1) of 96 mmWG at power consumption of 9 kW. Determine the flow, pressure and power for a new impeller diameter (D2) to 195 mm.

From the affinity laws:

$Q_2 = Q_1 \times (D_2/D_1)$ = 30 CFM x (195/220) = 30 x (0.886) = 26.58 CFM

Similarly head and power can be determined with operating point data from the pump's curve.

$P_2 = P_1 \times (D_2/D_1)^2$ = 96 mmWG x $(195/220)^2$ = 96 x $(195/220)^2$ = **75.3 mmWG**

$kW_2 = kW_1 \times (D_2/D_1)^3$ = 9 kW x $(195/220)^3$ = 9 x $(195/220)^3$ = **6.25 kW**

Based on the above scenario, for 11.36% diameter reduction, flow has reduced by 11.36%, pressure has decreased by 21.5%, and power consumption has reduced by 30.5%.

6.2.3 Design and selection criteria

For an efficient fan design system, it is essential to understand the operating requirements to precisely determine parameters such as airflow quantity, total pressure (inlet & outlet), temperature, airstream properties, and ducting layout. A detailed analysis should be carried out to estimate the pressure drop across the ducting system along with accessories such as lengths, bends, dampers, filters, etc. Optimal safety margins should be carefully considered rather than a conservative approach, if not the result would be over-sized fans that require high investment cost and also operate inefficiently with higher power consumption due to performance problems. Apart from that, the fan type and rotating part (impeller/ propeller) selection also plays a vital role with other factors such as lifecycle cost, efficiency, space limitations and drive arrangements.

Performance evaluation methodology

For performance evaluation of fans, it is very important to measure and monitor the operating parameters such as flow rate, static pressure, power consumption, and design details of fans and motors. The specialized instruments used for measuring the major parameters during the energy audit include:

- Power analyzers to measure the motor electrical parameters such as voltage, current, power, power factor.
- Stroboscope and tachometer to measure the speed of the fan and motor drive.
- Anemometer to measure the suction velocity directly.
- Digital manometer and pitot tubes to measure the static pressure – dynamic & velocity.
- Sling hygrometer and temperature to determine the properties of air and gases.

Some of the photographs captured during the energy audit of fans are given in figure 6.13

Figure 6.13: Flow, pressure & power measurement

Apart from the measurements, other necessary data that needs to be collected are:

- Power supply & other electrical data along with capacitor bank details
- Operating parameters of the system
- Capacity controlling techniques - Throttling of damper or VSD
- Schematic network of the ducting or piping system
- Performance characteristics curve
- Pressure drop, temperature drop and flowrate distribution.

Methodology adopted for fans operating static efficiency evaluation are explained below:

The fans are tested for field performance by measuring flow, pressure, temperature on the fan side, and electrical power consumption by the fan motor.

Static pressure is the fan's potential energy to overcome friction in the ducts, and it is converted to velocity pressure.

Velocity pressure is the pressure along the line of the flow that results from the air flowing through the duct, and it is used to calculate air velocity.

Total pressure is the sum of the static and velocity pressure. Velocity pressure and static pressure can change as the air flows through the different size ducts. However, the total pressure remains constant, changing only with friction losses. Total pressure change in the fan system is shown in the adjacent figure 6.14.

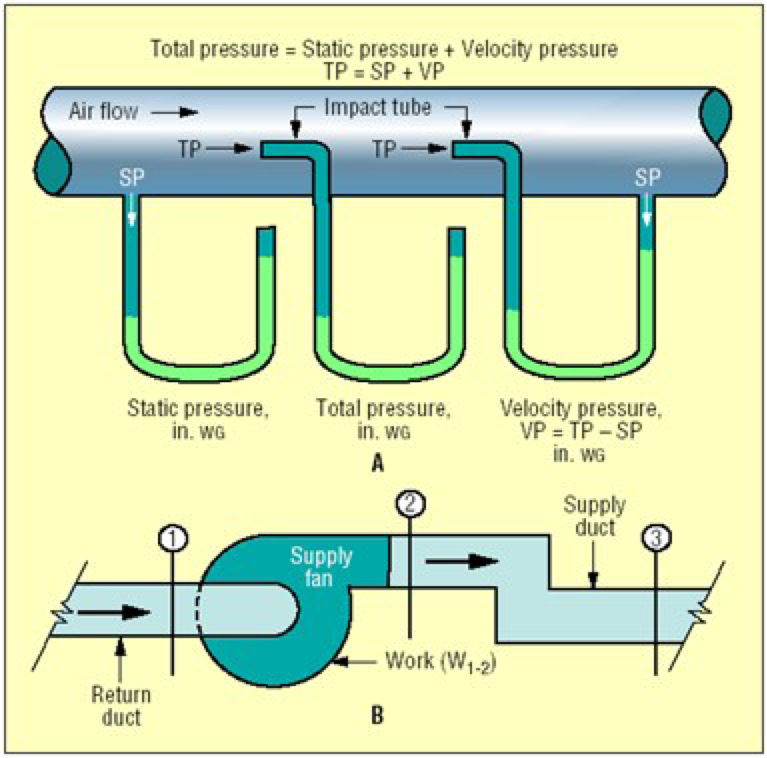


Figure 6.14: Pressure measurements in fan duct

As explained earlier, the fan flow is measured using a pitot tube and manometer combination, Velocity measurements by pitot tube and manometer combination can be taken at either inlet or outlet, sometimes both side of the fan as shown in the below figure 6.15.

Total pressure is measured using the inner tube of pitot tube and static pressure is measured using the outer tube of pitot tube. We get the velocity pressure when the inner and outer tube ends are connected to a manometer. To measure low velocities, it is preferable to use an inclined tube manometer instead of a U tube manometer.

However, care needs to be taken regarding number of traverse points, straight length section (to avoid turbulent flow regimes of measurement).

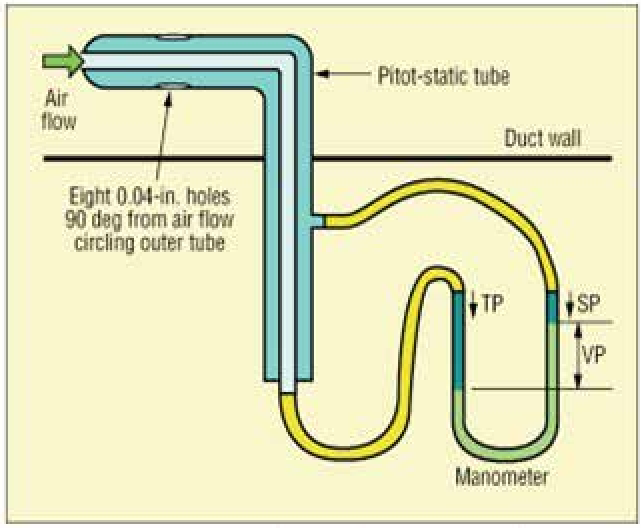


Figure 6.15: Pitot tube measurement configuration

Measurements and Calculations

Velocity pressure/velocity calculation: When velocity pressure is measured, the duct diameter area should be measured as well. This will allow us to calculate the velocity and the volume of air or gas flowing in the duct.

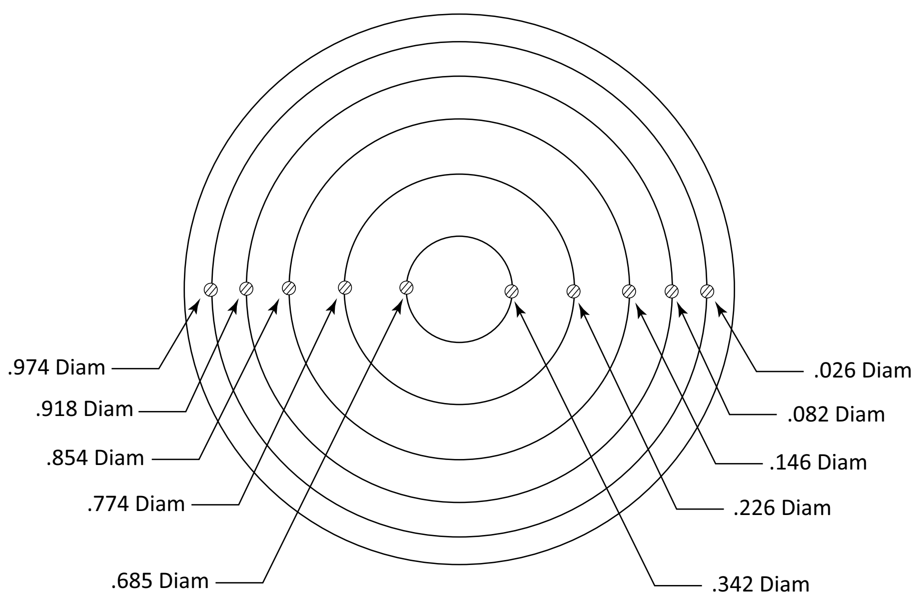


Figure 6.16: Traverse points for circular duct

The velocity pressure varies with friction across the duct (velocity is zero at wall and maximum at center) and the best place to take measurements is straight section for at least 3–5 diameters without any bends and curves or sudden changes of area.

To determine the average velocity, it important to take multiple sets of velocity pressure readings across the cross-sectional area of the duct. Normally for round ducts over 6 inches diameter, the multiple locations as illustrated in adjacent figure 6.16 will give areas of equal concentric area.

For each velocity pressure reading, the velocity should be calculated and the average of all the velocities should be used. Do not average the velocity pressure; average the velocities.

For best results, one set of readings should be taken in one direction and another set at a 90° angle to the first. For square ducts, the readings can be taken in 16 equally spaced areas. If it is impossible to traverse the duct, an approximate average velocity can be calculated by measuring the velocity pressure in the center of the duct and calculating the velocity. This value is reduced to an approximate average by multiplying by 0.9.

The density of air and gas is dependent on temperature and altitude. For calculating the velocity and volume from the velocity pressure measurements, density of air / gas is required. Hence, it is necessary to consider the density correction factor of air/gas at the particular place of measurement.

Formulae used for fan efficiency evaluation & other parameters calculations

Based on the data gathered from measurement and design details, the fan system efficiency will be evaluated and discussed with relevant personnel for further improvement options.

Fan efficiency is defined as the ratio of air power delivered for the air/gas to the input shaft power for the fan. The air power (kW) is the power utilized by the quantity of air/gas to reach the assigned pressure. The fan's input power (kW) is mechanical power delivered by the motor drive to the fan shaft or coupling. The rated motor efficiency as indicated by the motor manufacturer on the motor's nameplate can be used to derive the shaft input power from the electrical input of the motor or rated motor power.

Formulae used for fan efficiency evaluation & other parameters calculations of the fan system operation are explained below:

$$\textbf{\textit{Air density, Kg/m}}^3 = \frac{273 \times 1.293}{273 + t^{\circ}\,C}$$

t °C – temperature of gas/air at site condition

Velocity, m/s = $\dfrac{C \times \sqrt{(2 \times g \times h)}}{\rho}$

Where, C = Pitot constant

g = Acceleration due to gravity, 9.81 m/s^2

h = dynamic pressure, mmWG

ρ = Density at sample point, kg/m^3

By knowing the area of sample point and velocity, volumetric flowrate (Q) can be derived by:

Volume (Q), m^3/sec = Area (A), m^2 x Velocity (V), m/s

Air Power, kW = $\dfrac{\text{Volume (Q), } m^3/s \times \text{total pressure } [\Delta Pt]\text{, mmWc} \times \text{Gravity (g), } m/s^2}{1000}$

Fan efficiency (%) = $\dfrac{\text{Air power, kW}}{\text{Fan shaft power, kW}} \times 100$

If the Air Power is calculated from fan static pressure, ΔPs alone, then the efficiency calculated is called as Static efficiency of fan and same is defined as follows.

Static Efficiency (hstatic)%

$$= \frac{\text{Volume (Q), } m^3/s \times \text{static pressure } [\Delta Ps]\text{, mmWc}}{102 \times \text{power input to the fan shaft (E),kW)}} \times 100$$

Example of fan efficiency evaluation

Example 7.7: A fan operating in an air conditioning duct of 0.3 m x 0.4 m, the average dynamic pressure of air measured by pitot tube is 18 mmWG. The static pressure at the inlet of the fan is -15 mmWC and delivery side is 42 mmWC. Average temperature of the circulating air is 28°C. The measured motor power at motor input is 3.2 kW and the motor efficiency = 86%. Determine the total fan efficiency and also only static efficiency. Consider Pitot tube constant – 0.87.

Using the given available data:

Temperature of air (t °C) – 18 °C	Dynamic pressure (h) – 18 mmWG
Acceleration due to gravity (g) – 9.81 m/s^2	Pitot constant (Cp) – 0.87
Suction pressure (Ps) – 15 mmWC	Delivery pressure (Pd) – 42 mmWC
Motor power consumption – 4.7 kW	Motor Efficiency – 86 %
Duct dimensions – 0.4 m X 0.6 m	Calculated area – 0.4 x 0.6 = 0.24 m^2

Air density, Kg/m³ $= \dfrac{273 \times 1.293}{273 + t^{o}\,C} = \dfrac{273 \times 1.293}{273 + 18} = 1.213$

Velocity, m/s $= \dfrac{Cp \times \sqrt{2 \times g \times h}}{\rho} = \dfrac{0.87 \times \sqrt{2 \times 9.81 \times 18}}{1.293} = 12.6$ m/s

Volume (Q), m^3/sec = Area (A), m^2 x Velocity (V), m/s

= 0.24 m^2 x 12.6 m/s = 3.02 m^3/s.

Static pressure (ΔPs), mmWC = Delivery pressure (Pd) - Suction pressure (Ps), mmWC

(ΔPs) = 42 - (-15) = 57 mmWC.

Total pressure (ΔPt), mmWC = Static pressure (ΔPs) – Dynamic pressure (h), mmWC

(ΔPt) = 57 + 18 = 75 mmWC.

$$\textbf{Air Power, kW} = \frac{\text{Volume (Q), } m^3/\text{s x total pressure [}\Delta\text{Pt],mmWc x Gravity (g), m/ } s^2}{1000}$$

$$\text{Air Power} = \frac{3.02\ m^3/\text{s x 75 mmWc x 9.81 m/s}^2}{1000} = 1.69\ kW$$

Fan shaft power, kW = Motor input power, kW x Motor efficiency, %

= 4.7 kW x 0.86 = 4.04 kW

$$\textbf{Fan efficiency } (\eta_{fan})\ \% = \frac{\text{Air power, kW}}{\text{Fan shaft power, kW}} \times 100$$

$$\textbf{Fan efficiency } (\eta_{fan})\ \% = \frac{1.69\text{ kW}}{4.04\text{ kW}} \text{ x } 100 = 41.8\%$$

$$\textbf{Static Efficiency (hstatic)\%} = \frac{\text{Volume (Q), } m^3/\text{s x static pressure [}\Delta\text{Ps], mmWc}}{102 \text{ x power input to the fan shaft (E), } kW)} \times 100$$

$$\textbf{Static Efficiency (hstatic)\%} = \frac{3.02\ m^3/\text{s x 57 mmWc}}{102 \text{ x } 4.04\text{ kW}} \text{ x } 100 = 41.7\%$$

Estimated total fan efficiency is 41.8%, and static efficiency is 41.7%.

6.2.4 Flow Control Strategies:

Typically, after the fan design and installation, the fan will continue to operate at a fixed speed. Different methods for the flow or capacity control of the fans are generally carried out by the various options such as dampers, inlet guide vanes, pulley changes, and variable speed drives.

Dampers: Some fans are designed with the provision of dampers to control the airflow to the system either at the inlet or outlet of the fan. Dampers control the airflow by changing the amount of restriction in the system without changing the fan speed. Increased resistance often leads to higher pressure drop with additional power consumption for desired operating point.

Inlet Guide vanes (IGV): Guide vanes are curved sections that are mounted to the inlet or outlet of the fan and create a swirl or pre-rotate the air entering the fan. This design feature changes the angle at which the air is directed to the fan blades and varies the characteristics of the fan curve. Guide vanes are energy efficient for flow range from 80% up to 100%, below which the performance of fan drops significantly. Inlet guide vanes offer better control with marginal power savings compared to other dampers.

Figure 6.17: Damper Flap

Figure 6.18: Inlet guide vanes fan

Example 7.8: Damper control of oversized fan operation to replace with new fan and IGV

The forced draft fan supplied air to the hot air dryer, and capacity control was carried out by a damper adjustment, as shown in figure 7.29. Performance evaluation of the fan revealed that the installed capacity of the fan was higher than that required for the system. The estimated pressure drop across the suction damper at 50% opening was 150 mmWC, leading to increased power consumption & a drop in efficiency. Performance evaluation results are given in below table 6.7.

Table 6.7: Fan operating efficiency with damper

Parameters of fan	Units	Design	Operating
Flow rate	m^3/h	***7500***	3701
Suction pressure	mmWC	***-15***	*-140*
Delivery pressure	mmWC	***135***	*75*
Total Pressure	*mmWC*	**150**	215
Motor power	*kW*	***5.5***	5.4
Motor efficiency	*%*	**88**	88
Fan efficiency	***%***	***71***	**45.6**

Based on the field observation, as the fan was old (15 years) and inefficient, replacing a new energy-efficient lower capacity fan with inlet guide vanes for flow control was suggested. Proposed fan parameters along with energy savings are given below.

Proposed fan parameters:

Flow rate – 4200 m3/h,

Total pressure – 120 mmWC,

Fan efficiency - 70%

Input power – 2.4 kW,

Energy savings calculation:

Reduction in power consumption	: 3 kW
Annual energy savings (for 5000 h)	: 15000 kWh
Annual cost savings GYD 60 / kWh)	: GYD 3 million
Investment cost for new fan & IGV retrofit	: GYD 1 million
Simple payback period	: 0.34 years

Pulley Change: For the systems with belt-connected motor drive, which requires fan capacity decrease on a permanent basis, pulley change of the fan is the easiest method to handle the change in volume that can be achieved by speed change. Fan speed can be decreased or increased by adjusting the ratio of the pulley diameters for the motor and the fan. This requires a change in the drive pulley or the driven pulley, or in some cases, both pulleys.

Case study: Pulley change for capacity controlling of fan operation

In the diesel set power generation facility, an induced draft fan with belt coupled motor drive was used to de-dust operations and vent dust-free air into the atmosphere. The fan was operating at full speed and the estimated operating efficiency was found to be less (48%). This was mainly due to capacity control by a suction damper (opening around 75%), which is leading to higher pressure drop >126 mm WG and subsequent power loss. Based on the same, it was recommended to reduce the speed of the fan (by 15% of rated speed) with a higher size fan pulley, as shown in figure 7.30, and open the damper according to system pressure for energy savings.

Pulley change calculations are based on the affinity laws equation: $\mathbf{N_1D_1 = N_2D_2}$

- Initial speed (N_1) = 1480
- Proposed speed (N_2) = 85% of initial speed (N_1)
- Therefore $N_2 = 0.85N_1$
- Initial Diameter (D_1) = 272 mm
- Proposed diameter (D_2) = (N_1 D_1/N_2)
- D_2 = 272 x (N_1/0.85N_1) = 320 mm

Performance evaluation results of the operating fan before and after the pulley change and energy savings calculations are given in table 6.8.

Table 6.8: Fan efficiency before & after pulley change

Parameters of fan	Units	Before	After
Pulley diameter	*mm*	272	320
Operating speed	*RPM*	1480	1258
Flow rate	m^3/h	7453	7829
Total Pressure	*mmWC*	194	126
Power consumption	kW	9.1	4.6
Motor efficiency	%	90	90
Fan efficiency	%	48	65

Energy savings calculation:

Reduction in power consumption	: 3.6 kW
Annual operating hours (8 h x 365 days)	: 2920
Annual energy savings	: 10512
Annual cost savings (GY$ 60/ kWh)	: 0.63 million
Investment cost for pulley modification	: GY$ 0.25
Simple payback period	: 0.41 years

Variable Speed Drives (VSDs): Fans with systems that are operating over a wide range of their performance curves are often best efficient with VSDs or adjustable speed drives. VSDs use electronic controls to regulate motor speed which, in turn, adjusts the fan speed to deliver the output of flow and pressure more effectively. VSDs can be a good choice if the fan's loading is between 70 to 100% most of the time since power consumption by the fan varies as the cube of operating speed and the most efficient form of capacity control. However, fans systems with severe instability regions or infrequent flow variations should not be operated with VSD as it might lead to inefficient operating conditions and may not be economical.

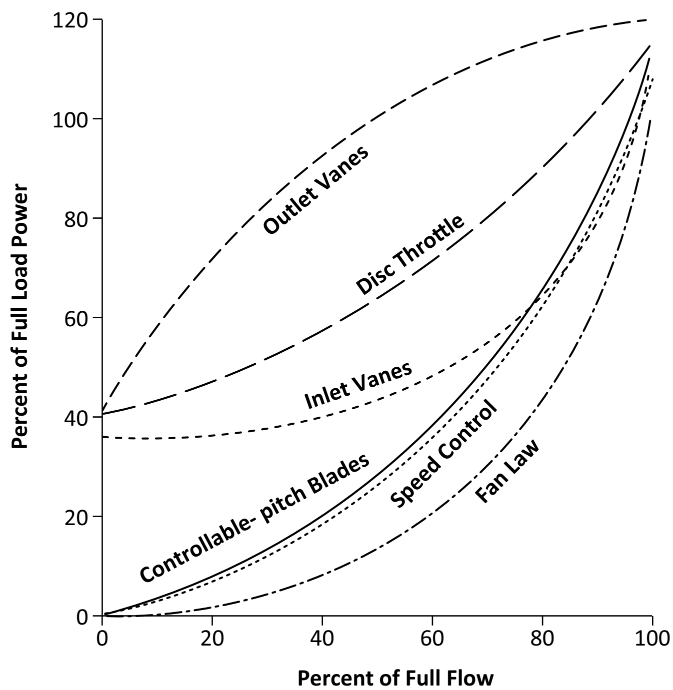
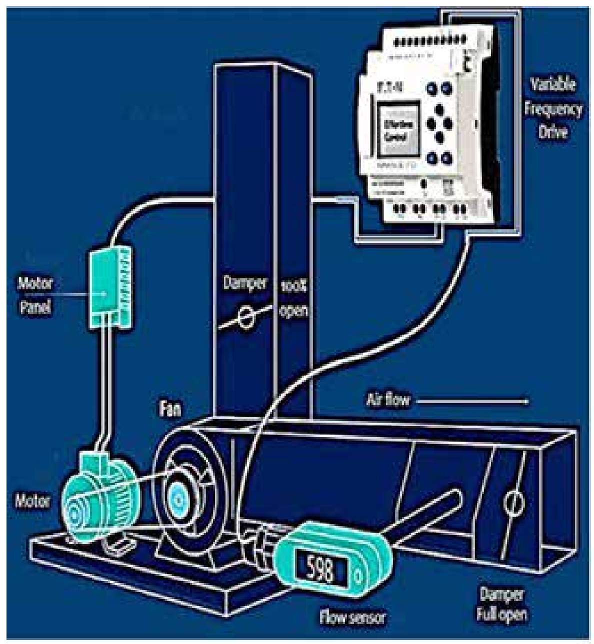


Figure 6.17: Power consumption by VSD & other fan control strategies

Case study: Variable speed drive for capacity controlling of fan operation

In one of the air handling units (AHU), the circulation air fan (Rated - 15 kW) was operating at full speed with suction damper in 35% open position for capacity control and measured power consumption at 50 Hz by the fan motor is 16 kW. It was proposed to install variable frequency drive (LT) for the fan and eliminate throttled damper operation as given in the adjacent figure.



Post implementation, previous operating point's flow and pressure was able to meet with the fan at reduced speed of 36 Hz with damper completely opened.

Comparison of performance evaluation results of operating fan with throttled damper and VSD at reduced speed along with energy savings calculations are given in table 6.9.

Table 6.9: Fan operating efficiency with VSD

Parameters of fan	Units	With Damper	With VSD
Frequency	*Hz*	50	36
Damper opening	*%*	35	100
Flow rate	*m^3/h*	10160	10098
Total pressure	*mmWC*	147	72
Motor power	kW	12.9	4.8
Fan efficiency	**%**	**35**	**46**
Pressure drop	%	90	15

Energy savings calculation:

Reduction in power consumption	: 8.1 kW
Annual operating hours (16 h x 365 days)	: 5840
Annual energy savings	: 47304
Annual cost savings GY$ 60 / kWh)	: 2.8 million
Investment cost for VSD (15 kW)	: 1.0 million
Simple payback period	: 0.3 years

Series and Parallel Operation: Multiple fans in series or parallel operation are another form of capacity control that can achieve the desired airflow without greatly increasing the system's package size or fan diameter. Parallel operation of fans will result in doubling the volume flow, but only at free delivery and system curve performance curves indicates that higher the system resistance, the less increase in flow. Series operation of multiple fans is a push-pull arrangement and best suitable for systems with high resistance. By staging two fans in series, the static pressure capability at a given airflow can be increased, but not exactly to double at every flow point. Multiple fans can be additionally equipped with inlet guide vanes, or VSDs to provide a high degree of flexibility and reliability in operation. However, for certain areas, the combined performance curve will be unstable and should be avoided.

CHAPTER 7

Boiler and Steam System

7.1 Introduction - Boilers

Boilers are used in various industrial units to convey heat for different applications. Steam is commonly used as the heating medium mainly for two reasons: (1) it is generated from water, which is usually available, and (2) it can store a large quantity of heat at a temperature, which can be conveniently used. Various types of fuels, namely coal, oil, gas, and biomass, are used for steam generation in boilers depending on the availability of fuel and cost economics prevailing in the plant. Some boilers even use waste (generally low-calorific value fuels) as fuel: for example, in distillery industries, biogas generation from distillery spent wash is used in boilers.

Boilers can be categorized into different types depending on water/flue gas passage in the boiler, fuel usage, and pressure generation. The types of boilers vary with respect to the requirement of the plant. Irrespective of the type of boiler used, the motive of the industry should be to generate the required quantity and quality of steam at minimum possible costs. This can only be achieved by reducing the various avoidable heat losses occurring within the boiler system, thus improving the efficiency of the same. Different boilers will have different efficiency levels depending on the fuel type (Table 7.1.).

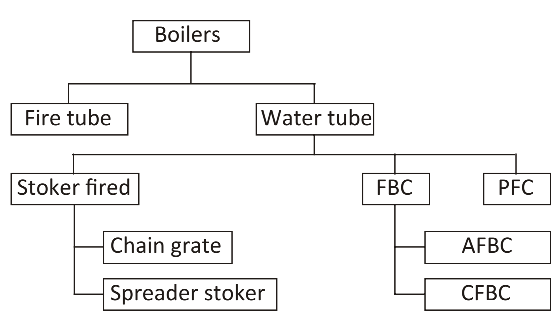
Table 7.1: Thermal efficiency levels

Boiler type	Thermal Efficiency (%)
Manually fired	40–60
Stoker-fired	
Coal	65–75
Bagasse	55–70
Oil and gas	
Up to 20 T/h (tonnes/hour)	70–80
Above 20 T/h	80–85
Fluidized-bed combustion (atmospheric)	75–80
Waste-heat	55–75
Pulverized-fuel-fired	80–90

7.2 Classification of boilers

Industrial boiler designs are predominantly influenced by fuel characteristics, firing methods, steam demand, and pressure requirements. Boilers can be broadly classified as:

a) Fire-tube boiler b) Water-tube boilers



7.3 Efficiency evaluation of boilers

There are two methods of evaluating the efficiency of boilers: the direct and the indirect methods.

7.3.1 Direct method

This is also known as the input-output method because it requires only the useful output and the heat input to evaluate the efficiency. The formula used is

Boiler efficiency = (Heat output/Heat input) × 100

= {Steam flow rate × (steam enthalpy–feed water enthalpy) × 100} / (Fuel firing rate × gross calorific value)

The direct method offers the following advantages.

- The plant personnel can evaluate the efficiency of boilers in lesser time
- Only few parameters are required for computation
- Monitoring through less instrumentation

However, this method suffers from the disadvantage of not being able to calculate losses under different heads to indicate why the efficiency is low.

7.3.2 Indirect method

The disadvantages inherent in the direct method can be overcome by the indirect method, which calculates various heat losses associated with the boiler. The efficiency can be arrived at by subtracting the heat loss percentages from 100. This method is known as the indirect method or the heat loss method.

There are many reference standards for boiler testing at site using indirect method, for example: British Standard, BS 2885: 1987 and USA Standard, ASME PTC-4.1 Power Test Code for Steam Generating Units. The standards do not include blowdown loss in the efficiency determination process. *(The sample calculation of Stoichiometric Air for natural gas combustion is given in end of chapter)*

A detailed procedure and the data for calculating boiler efficiency by the indirect method are given below.

- Ultimate analysis of fuel (H, O, S, C, moisture content [M], and ash content)
- Percentage (by volume) of O_2 (oxygen) in the flue gas
- Percentage (by volume) of CO (carbon monoxide) in flue gas
- Flue gas temperature in °C (Tg)
- Ambient temperature in °C (Ta) and humidity of air in kg/kg of dry air
- GCV (gross calorific value) of fuel in kcal/kg, as fired
- Percentage combustible (unburnt) in ash (solid fuels – Bagasse /rice husk)

Following are the different heat losses occurring in a boiler.

7.3.2.1 Dry flue gas loss (Lfg)

Generally, in a boiler, the major energy loss occurs through the flue gases, which escape at a high temperature. Dry flue gas loss depends on two factors: (1) flue gas temperature and (2) quantity of flue gas generated (depends on the excess air level). The excess air is related to the fuel being used in the boiler. Typically, the levels of excess air, as given in Table 7.2 are being practiced for different fuels to minimize the flue gas loss. Based on the theoretical air required, the actual combustion air quantity per kilogram of fuel can be calculated using the following formulae.

Ma = (1 + EA/100) @At

Where,

Ma = Actual quantity of air supplied for combustion/1 kg of fuel

EA = excess air (%) = O_2% @ 100/(21 – O_2%)

O2% = Percentage of oxygen in flue gas (by volume) and

A_t = 11.51 C + 34.30 (H – O/7.937) + 4.335 S

where,

A_t = theoretical dry air (in kg) required to completely burn 1 kg of fuel

C = carbon content obtained from ultimate analysis (kg/kg of fuel)

H = hydrogen content obtained from ultimate analysis (kg/kg of fuel)

O = oxygen content obtained from ultimate analysis (kg/kg of fuel)

S = sulphur content obtained from ultimate analysis (kg/kg of fuel)

Lfg = Mfg × Cpg × (Tg – Ta) × 100 / GCV

where,

Lfg = heat loss due to heat in dry flue gas (%)

Cpg = mean specific heat of dry flue gas over the range between gas temperature leaving the unit and the ambient temperature (~ 0.25 kcal/ kg °C)

Tg = flue gas temperature (°C)

Ta = inlet air temperature (°C)

GCV = gross calorific value (kcal/kg)

Mfg = quantity of dry flue gas (kg/kg of fuel)

M_{fg} = {(44.01 × CO_2 + 28.01 × CO + 32 × O_2 + 28.02 × N_2)} × {C + 12.01 × S/32.07} / {12.01 × (CO_2 + CO)}

where,

CO	=	% CO in flue gas by volume
N_2	=	% N_2 in flue gas by volume = 100 – (O_2 + CO_2 + CO)
C	=	carbon content of the fuel (kg/kg of fuel)
S	=	sulphur content of the fuel (kg/kg of fuel)
CO_2	=	% CO_2 in flue gas by volume

Percentage of CO_2 in flue gas by volume can be calculated from the following formulae

CO_2 (%) = {(max. CO_2/100) × (100 – 4.78 × O_2 + 1.89 × CO)–CO}

Max. CO_2 = maximum possible CO_2 (%) in the flue gas, by volume

It can be calculated by using following formula.

Max. CO_2 (%) = (31.3 × C + 11.5 × S) (1.504 × C + 3.55 × H + 0.56 × S +0.13 × N – 0.45 × O)

7.3.2.2 Heat loss due to moisture in fuel % (Lmf)

$$L_{mf} = \frac{M \text{ x } \{540 + C_{pw} \ (T_g - 100) + (100 - T_a\}}{GCV} \text{ x } 100$$

where,

M = moisture (kg) in 1 kg of fuel

C_{pw} = specific heat of water vapour (0.45 kcal/kg/°C)

T_g = flue gas temperature (°C)

T_a = inlet air temperature (°C)

7.3.2.3 Heat loss due to moisture from burning hydrogen in fuel % (Lhf)

$$Lhf = \frac{9 \text{ x } H \text{ x } \{540 + C_{pw} \ (T_g - 100) + (100 - T_a\}}{GCV} \text{ x } 100$$

Where,

H = Hydrogen (kg) in 1 kg of fuel

Cpw = specific heat of water vapours (0.45 kcal/kg °C)

Tg = flue gas temperature (°C)

Ta = inlet air temperature (°C)

Loss due to moisture and hydrogen in the fuel is dependent on the final flue gas temperature besides fuel composition (hydrogen and moisture content). The moisture content of fuel oils and gas is generally insignificant, whereas the hydrogen content is significant. The final flue gas temperature is, therefore, the only operating factor for a given fuel, which directly contributes to this loss (other than for moisture in solid fuel).

7.3.2.4 Heat loss due to moisture in air % (Lma)

Heat is absorbed by water vapour accompanying the air into the combustion chamber. Water vapour present in the air depends on the dry and wet bulb temperatures prevailing at the time, and are beyond the control of an operator. The other controllable factors, on which this loss depends, are excess air level and flue gas temperature.

$$L_{ma} = \frac{M_a \times SH \times C_{PW} \times (T_g - T_a)}{GCV} \times 100$$

where,

M_a = actual quantity of air supplied for combustion/ kg of fuel

C_{pw} = specific heat of water vapour (0.45 kcal/kg)

SH = specific humidity (kg/kg of dry air)

T_g = flue gas temperature (°C)

T_a = inlet air temperature (°C)

7.3.2.5 Heat loss due to CO (carbon monoxide) in flue gas % (LCO)

This loss is due to CO formation due to either improper air/fuel mixing or insufficient combustion air in the burning chamber. These conditions lead to the partial oxidation of carbon in the fuel and, thus, reduce the heat-release rate.

$$L_{co} = \frac{CO \times 5644 \times C}{(CO + CO_2) \times GCV} \times 100$$

7.3.2.6 Heat loss due to unburnt carbon in bottom ash % (Lubb)

$$L_{ubb} = \frac{(M_{ubb}/100) \times (M_{ash}/100) \times M_{fb} \times 8064}{GCV} \times 100$$

where,

M_{ubb} = % unburnt in bottom ash

M_{ash} = % ash content in fuel

M_{fb} = 0.25 for FBC boilers, 0.75 for stoker-fired boilers, and 0.1 for pulverized coal-fired boilers

7.3.2.7 Heat loss due to unburnt carbon in fly ash % (Lubf)

$$L_{ubf} = \frac{(M_{ubf} / 100) \text{ x } (M_{ash} / 100) \text{ x } M_{ff} \text{ x } 8064}{GCV} \text{ x } 100$$

where,

M_{ubf} = % unburnt in fly ash

M_{ash} = % ash content in fuel

M_{ff} = 0.75 for FBC boilers, 0.25 for stoker-fired boilers and 0.9 for pulverized coal-fired boilers

The above two losses apply only to solid fuel-fired boilers where unburnt carbon could be present in bottom ash or fly ash. A very small loss due to unburnt carbon would also occur while burning fuel oils, but this is generally ignored.

7.3.2.8 Heat loss due to sensible heat in bottom ash % (Lsb)

$$L_{sb} = \frac{(M_{ash} / 100) \text{ x } M_{fb} \text{ x } C_{pa} \text{ x } (T_{ba} - T_a)}{GCV} \text{ x } 100$$

where,

M_{ash} = % ash content in fuel

M_{fb} = 0.25 for FBC boilers, 0.75 for stoker-fired boilers and 0.1 for pulverized coal- fired boilers

C_{pa} = specific heat of ash (about 0.25 kcal/kg °C)

T_{ba} = bottom ash temperature (°C)

T_a = ambient temperature (°C)

7.3.2.9 Heat loss due to sensible heat in fly ash% (Lsf)

$$L_{sf} = \frac{(M_{ash} / 100) \ x \ M_{ff} \ x \ C_{pa} \ x \ (T_{fa} - T_a)}{GCV} \ x \ 100$$

where,

M_{ash} = % ash content in fuel

M_{ff} = 0.75 for FBC boilers, 0.25 for stoker-fired boilers and 0.9 for pulverized coal-fired boilers

C_{pa} = specific heat of ash (about 0.25 kcal/kg °C)

T_{fa} = fly ash temperature (°C)

T_a = ambient temperature (°C)

In solid fuel-fired boilers, ash is removed from the furnace bottom (bottom ash) and from the cyclones, bag filters, and ESP (fly ash) at higher temperatures. These losses are only a small percentage of the total heat loss but unavoidable.

7.3.2.10 Loss due to surface radiation and convection % (Lrc)

Radiation and convection loss occurs from the exterior surface of the boiler. This loss depends on the boiler surface temperature and the wind velocity. The loss in actual heat units is generally constant so that as a proportion of heat input the percentage loss is low when on 'full fire', and high on 'low fire'.

L_{rc} (%) = {(h × A × (T_s – T_a)) × 100}/(Fhr × GCV)

where,

h = heat transfer coefficient (kcal/m²/°C/h)

A = boiler surface area (m²)

Ts = average boiler surface temperature (°C)

Ta = ambient temperature (°C)

Fhr = fuel consumption (kg/h)

GCV = gross calorific value of fuel (kcal/kg)

Heat transfer coefficient (h) includes radiative and convective components and can be calculated as mentioned below.

h = 4.87 × 10-8 × ε × {(Ts + 273)4 – (Ta + 273)4}/(Ts – Ta) + 1.683 × (Ts – Ta)0.25 × (2.857 × V + 1)0.5

where,

ε = emissivity of boiler surface (0.15 for smooth and shining aluminum claddings, 0.6 for dull and rough surfaces)

V = wind velocity (m/s)

Total heat loss % (Thl) = L_{fg} + L_{mf} + L_{hf} + L_{ma} + L_{co} + L_{ubb} L_{ubf} + L_{sb} + L_{sf} + L_{rc}

Thermal efficiency of boiler (%) = (100 – Thl)

Example: Boiler details for calculateing efficiency

- Type of boiler : Dumping Grate
- Fuel fired : Bagasse
- Design capacity : 17.2 TPH
- Feed water flow rate : 21.0 TPH
- Steam pressure : 14.6 kg/cm²
- Water pre-heat temp. : 65 °C
- Boiler surface area : 380 m²
- Coal consumption : 35000 kg/h

Fuel analysis (as received basis)

- Carbon : 22.73%
- Hydrogen : 3.03%
- Sulphur : 0.00%
- Nitrogen : 0.00%
- Oxygen : 23.24%
- Ash : 1.50%
- Moisture : 49.50%
- Gross calorific value : 2300 kcal/kg

Bottom ash analysis

- Unburnt carbon : 15.00%
- Bottom ash temperature : 320 °C

Flue gas analysis

- Oxygen : 10%
- Carbon monoxide : 1000 PPM (parts per million)
- Temperature : 225 °C

Ambient temperature

- Dry bulb temperature : 28 °C
- Wet bulb temperature : 23 °C

Solution

Dry flue gas loss (L_{fg})

- Stoichiometric air requirement : 2.65 kg of air/kg of fuel
- Excess air : 90.91%
- Dry flue gas quantity : 5.56 kg/kg of fuel
- Specific heat of flue gas : 0.245 kcal/kg °C
- Dry flue gas loss : 11.91%

Heat loss due to moisture in fuel (L_{mf})

- Heat loss due to moisture in fuel : 14.38 %

Heat loss due to moisture from burning hydrogen (L_{hf})

- Heat loss due to H2 in fuel : 7.92%

Heat loss due to moisture in air (L_{ma})

- Absolute humidity : 0.0156 kg water vapour/kg dry air
- Heat loss due to moisture in air : 0.30%

Heat loss due to formation of carbon monoxide (L_{co})

- Heat loss due to formation of CO : 0.04%

Heat loss due to unburnt carbon in bottom ash (L_{ubb})

- Mfb = 0.75
- Heat loss due to unburnt carbon in bottom ash: 0.00%

Heat loss due to unburnt carbon in fly ash (L_{ubf})

- Mff = 0.25
- Heat loss due to unburnt carbon in fly ash: 0.00%

Heat loss due to sensible heat in bottom ash (L_{sb})

- Mfb = 0.75
- Heat loss due to sensible heat in bottom ash: 0.00%

Heat losses due to sensible heat in fly ash (L_{sf})

- Mff = 0.25
- Heat loss due to sensible heat in bottom ash: 0.00%

Loss due to surface radiation and convection (L_{rc})

- e = 0.6
- V = 1.2 m/s
- Ts = 60 °C
- h = 12.16 kcal/m2/°C/h
- Loss due to surface radiation and convection: 0.18%

Thermal efficiency of the boiler =

$100 - (L_{fg} + L_{mf} + L_{hf} + L_{ma} + L_{co} + L_{ubb} + L_{ubf} + L_{sb} + L_{sf}+L_{rc})$ = 65.2%

7.4 Energy conservation opportunities

After calculating the thermal efficiency of a boiler, it is easier to pinpoint the areas of energy loss and suggest ECOs (energy conservation opportunities) minimize them.

7.4.1 Maintaining optimum excess air

Excess air is one of the important parameters in determining boiler performance. Every fuel needs a specified quantity of stoichiometric air for its combustion. Since, in actual practice, the mixing of fuel with air is never perfect, a certain amount of excess air is always needed to complete the combustion and ensure the release of the entire heat contained in the fuel. Too much air results in excessive heat loss as the superfluous air does not take part in combustion but carries away heat to the atmosphere from the boiler furnace. Besides, surplus air lowers the boiler furnace temperature and thereby the heat transfer rate, resulting in lower combustion efficiency.

Likewise, if excess air is lesser than the optimum quantity, combustion would be incomplete, resulting in the formation of gases like CO in the flue gas. The maximum permissible limit for CO is 0.1%. Above this, the loss due to CO formation is much higher than the benefit availed of on account of lower excess air level. The excess air levels for boilers depend on the combustion technologies and the type of fuel. The recommended levels of excess air are given in Table 7.2.

Table 7.2: Recommended excess level

Fuel	Excess air (%)
Coal	
PFC	15-20
FBC	30-60
Stocker	30-60
Fuel oil	15-30
Bagasse	25-35
Wood	20-25
Black liquor (distillery, pulp & paper)	5-7
Natural, coke oven, and refinery gas	5-10
Blast furnace gas	15-18

7.5 Waste heat recovery from flue gas

The stack temperature should be as low as possible. However, it should not be so low that water vapour in the exhaust condenses on the stack walls. This is important in fuels containing significant quantity of sulphur as low temperature can lead to sulphur dew point corrosion. Generally, the stack temperatures are maintained in a range of 150–175 °C and a cushion of 15–20 °C is given if the boiler is using high sulphur fuel to avoid the dew point condensation in chimney. Stack temperatures greater than 200 °C indicate potential for recovery of waste heat. The waste heat, from the flue gas, can be recovered by following two methods.

7.5.1 Feed water preheating using economizer

As per the rule of thumb, for every 5–6 °C rise in boiler feed water temperature through heat recovery from flue gas or 20–22 °C reduction in flue gas temperature, there is one per cent saving in fuel consumption.

The flue gas exit temperature from a boiler, using high-sulphur fuel, is usually maintained around 200 °C, so that the sulphur oxides in the flue gas do not condense and cause corrosion in heat-transfer surfaces. When a clean fuel such as natural gas, liquefied petroleum gas and gas oil, or low-sulphur fuel is used, economy of heat recovery should be calculated considering that the flue gas temperature is below 200 °C.

7.5.2 Combustion air preheat

Combustion air preheating is an alternative to feed water heating. In order to improve thermal efficiency by one per cent, the combustion air temperature must be raised by 20 °C, using the waste heat available in flue gas. Most gas and oil burners used in a boiler plant are not designed for high air-preheat temperatures. Modern burners can withstand much higher combustion air preheat, so it is possible to consider such burner units as heat exchangers as an alternative to an economizer when either space constraint or a sufficiently high feed water return temperature are the limiting factors.

7.5.3 Improvement of condensate recovery

Returning steam condensate to the boiler can also reduce fuel consumption. The return condensate carries sensible heat, which can be as high as 20% to 25% of the total heat value of the steam generated by the boiler. Besides, it will also save the cost of make-up water, which would have otherwise been necessary to replace the discarded condensate.

7.5.4 Optimization of blowdown

Though blowdown needs to be carried out depending on the water quality and boiler pressure, the normal tendency in an industrial unit is to do more blowdown than the requirement. This results in loss of sensible heat of boiler water (at boiler pressure). The rate of blowdown must be adjusted in such a way that the concentration of solids is kept as close as possible to the design level. This would help in minimizing the boiler losses due to blowdown. Uncontrolled continuous blowdown is very wasteful. Automatic blowdown controls can be installed to sense and respond to boiler water conductivity and pH. A 10% more blowdown in a 15 kg/cm^2 boiler results in 2%–3% efficiency loss depending on feed water preheat temperature.

Performance of heat recovery system

It is also equally important to maintain the performance of the heat-recovery systems. Each system is designed to give a performance level that suits the boiler conditions. The inlet and outlet conditions of the cold and hot fluids must be monitored, and any deviation from the design level should be analysed.

In oil and solid fuel-fired boilers, soot build-up on tubes acts as an insulator against heat transfer. Any such deposits should be removed on a regular basis. Elevated stack temperatures may indicate excessive soot build-up. Similar results are seen due to scaling on the waterside as well.

High exit-gas temperatures at normal excess air indicate poor heat- transfer performance. This condition can result from a gradual build-up of gas-side or waterside deposits. Waterside deposits require a review of water treatment procedures and tube cleaning to remove deposits. An estimated one per cent efficiency loss occurs with every 22 °C increase in stack temperature.

Stack temperature should be checked and recorded regularly as an indicator of soot deposits. When the flue gas temperature rises to about 40 °C above the temperature for a newly cleaned boiler, it is time to clean the tubes. It is therefore recommended to install a dial-type thermometer at the base of the stack to monitor exhaust flue gas temperature.

It is also estimated that 3 mm of soot can cause an increase in fuel consumption by 2.5%. Periodic off-line cleaning of radiant furnace surfaces, boiler tube banks, economizers, and air heaters may be necessary to remove stubborn deposits.

7.5.5 Reduction of structural losses

Structural losses of the boiler normally account for less than 1%–3% of the heat input. Though this figure is small, it is possible to minimize the loss further by upgrading the insulation material that may have worn out over time.

7.5.6 Plugging the cold air ingress in the boiler system

Cold air ingress is normally observed in almost all large induced and balanced draught boiler systems. Air infiltration in the boiler takes place from joints, flanges, peep holes, inspection doors, brick walls, air seals in air heaters, and so on. Ingress of cold air into the flue gas path reduces the flue gas temperature and thereby the useful heat transfers back to the boiler system. It also increases the induced draft (ID) fan duty as it sucks infiltrated cold air from the nearby leakage points. This reduces the actual capacity of ID fan available for providing adequate suction in the boiler furnace.

Cold air infiltration through leaking air seals in rotary air heaters is very common. This is also illustrated in Figure 7.2. Part of the cold air fed by forced draft (FD) fans leaks to the flue gas side as it is on large suction because of close proximity to the ID fan. This quantity of infiltrated air also neutralizes some of the ID fan capacity and reduces the available capacity for the boilers.

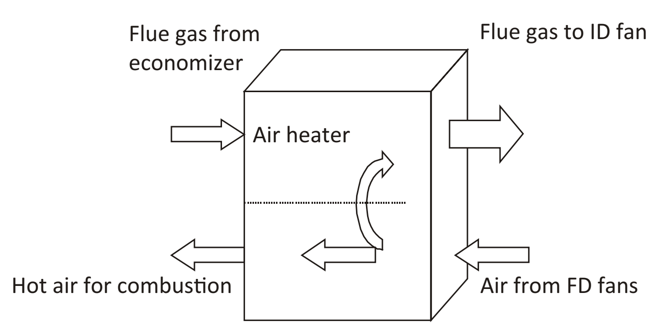


Figure 7.1: Cold air infiltration in air heaters

The losses due to cold air ingress are:

- lower flue gas temperature
- lower heat transfer from flue gas
- reduced available capacity of ID fan
- reduced available steam generation capacity of boiler
- higher specific energy consumption of ID fan due to the increased load on it
- lower boiler efficiency

Cold air infiltration can be checked by carrying out O_2 measurements at three different places in flue gas path. The measurements should be taken after the boiler, the economizer, and the air heater, depending on the availability of waste heat recovery equipment. If the O_2 content in the flue gas (after the economizer and air heater) is more than what is measured after the boiler, it shows the air's ingress from the atmosphere. The extent of infiltration can be ascertained by the level of O_2 present in flue gas.

It is therefore suggested to minimize this by keeping all peep holes, inspection windows, manholes, joints, seals, and gaskets tightly plugged. This will lead to better heat transfer in air heaters, improved suction in the furnace, lower load of ID fans, and so on, and hence to the overall improved efficiency of the boiler.

7.6 Case studies

7.6.1 Reduction in excess air and flue gas temperature

To minimize escape of heat through flue gases, reducing excess air (the air quantity over and above the theoretical amount needed for combustion) is one of the most important methods of improving boiler thermal efficiency.

Operating conditions (before)

Oxygen (%)	: 5.50
Flue gas temperature (°C)	: 196.00
Thermal efficiency (%)	: 73.21

Improved conditions after adjusting air flow rate (after implementation)

Oxygen (%)	: 4.40
Flue gas temperature (°C)	: 170.00
Thermal efficiency (%)	: 75.33
Fuel consumption (MT/h)	: 11.61
Fuel savings (MT/h)	: 0.33
Fuel saving per annum (MT)	: 2589.00
Monetary savings (GY$ million)	: 25.8 *(Considering Char Coal cost = GY$ 10,000 per MT)*

7.6.2 Reduction in unburnt in flue gas by increase in excess air

Incomplete combustion occurs when input fuel is not completely burned and escapes as CO in flue gases or as unburnt in refuse, both of which result in higher losses and low efficiency.

Operating conditions

Oxygen (%)	: 0.37
Carbon monoxide (%)	: >1.00
Thermal Efficiency (%)	: 75.32

Improved conditions (after implementation)

Oxygen (%)	: 4.20 (25% EA)
Carbon monoxide (%)	: 0.10
Thermal efficiency (%)	: 80.68
Fuel consumption (MT/month)	: 86598.00
Fuel savings (MT/month)	: 5750.00
Fuel saving per annum (MT)	: 68995.00
Monetary savings (GY$ million)	: 69 *(Considering rice husk cost = GY$ 1,000 per MT)*

7.6.3 Blowdown heat recovery by raising the feedwater temperature

Blowdown after giving off its latent heat in the heating coil or the heat exchanger of the process equipment. A sizable portion of the heat contained in the blowdown flash leaves the process equipment to heat up feed water. A rise in temperature feed water is returned to the boiler house, it will reduce the fuel requirements in the boiler.

Operating conditions

Boiler output (MT/h)	: 5
Operating pressure (kg/cm^2)	: 10
TDS (total dissolved solids) maintained in drums (ppm)	: 3000
Maximum allowable TDS (PPM)	: 3500
Feed water TDS (PPM)	: 300
Blowdown quantity (kg/h)	: 500
Temperature of blowdown water (°C)	: 183
Feed water temperature (°C)	: 32

Fuel used in boiler	: Furnace oil
Boiler efficiency (%)	: 83
Working hours per year	: 7200
Heat loss due to blow down (kcal/h)	: 75500

Improved conditions (after implementation)

Increased feed water temperature (°C)	: 45
Recoverable heat (kcal/h)	: 65000
Fuel saving per annum (KL)	: 54
Monetary savings (GY$ million)	: 0.9 *(Considering rice husk cost = GY$ 169 per Litre)*
Investment (GY$ million)	: 0.6
Simple payback period (months)	: 8

Tips

- A 1-mm (millimeter) thick scale (deposit) on the waterside could increase fuel consumption by five to eight percent.
- When flue gas temperature rises to about 40 °C above normal, it is time for removing the soot deposits.
- For every 6 °C rise in boiler feedwater temperature through condensate return, there is a one percent saving in fuel.
- For every 22 °C reduction in flue gas temperature by passing through an economizer or a preheater, there is a one percent saving of fuel in the boiler.
- In other words, with a 20 °C rise in combustion air temperature through an air preheater, there is a one percent saving of fuel.

7.7 Introduction – Steam System

Steam plays a vital role in today's process plants for heating and drives. The rising cost of fuel has made it necessary to adopt measures to reduce energy losses in the steam distribution network. The very purpose of generating steam at the highest thermal efficiency is lost if it is subsequently wasted through improper distribution or utilization. Reducing energy losses in the distribution system helps in improving end-use efficiency. Thus, the various losses associated with the steam-distribution pipes and fittings should not be overlooked.

This section aims to illuminate the many aspects of steam distribution and utilization.

7.8 Steam Distribution

The major aspects of steam distribution which need the attention of industry personnel are described below.

7.8.1 Layout of steam piping

Piping layout is an important aspect for efficient distribution of steam. Steam piping should follow the shortest possible distance from the point of generation to the point of utilization, rather than following aesthetics. Over ground/head piping should be preferred than underground one. Inactive or unused steam piping experiences the same losses as the rest of the system. It is necessary to isolate such lines immediately. The pipelines should be designed for maximum anticipated loads. It is desirable to keep the pipelines gradually sloping towards the receiving side (12 mm [millimetres] in 3 m [meters]) so that condensate is removed easily.

7.8.2 Pipe sizing

Proper pipe sizing is very critical for the good health of the steam-distribution system in a plant. It must be remembered that there is always a right size for the steam pipe for the amount of steam it has to carry at a particular pressure. If the pipes were too small, the pressure drop would be high and it will also result in steam starvation at the user points, but minimizing pipe diameters will reduce capital cost and surface heat losses. On the other hand, if it were too big, capital cost of installation will unnecessarily be high, as will be the running cost due to the higher radiation losses from the larger surfaces. Normally, pipe sizes are optimized based on velocity or pressure-drop. Typical velocities of steam are given in Table 7.3.

Table 7.3: Typical steam velocities

Steam	Velocity (meters/second)
Exhaust steam	20-30
Saturated steam for heating	18-30
Saturated steam of power	30-40
Superheated steam	45-65

If the specific volume is known, the flow W, in kilogram per hour, can be calculated as

$$W = 0.00287d^2V / U$$

where,

W = Steam flow (kg/h)

d = Diameter of the pipe in mm

V = Velocity in m/sec

U = Specific volume in m^3/kg

Apart from proper sizing of pipelines, there must be a proper arrangement to drain the condensate generated due to some heat loss to the atmosphere during steam travel. Mechanical moisture separators with traps should be provided at regular intervals to remove moisture immediately as it is formed. Similarly, an air vent should also be provided at the dead ends to remove the air from the steam pipes.

7.8.3 Steam quality

The best steam for industrial process heating is dry, saturated steam: neither wet nor superheated. If steam is wet, the trapped moisture particles reduce the total heat in the steam (since they carry no latent heat), and increase the resistance film of water on the heat-transfer surfaces. This slows down the rate of heat transfer. Such moisture also overloads the traps and other condensate handling equipment. On the other hand, superheated steam is not so practical or desirable for process heating because its temperature in the plant cannot be effectively controlled (unlike saturated steam whose temperature depends only on the pressure). Another reason is that it gives up its heat at a rate slower than the condensation heat transfer of saturated steam.

A boiler cannot generate dry saturated steam unless it is equipped with a superheater. At best, it can deliver only 95% dry steam. The dryness fraction of steam depends on various factors such as frequent load fluctuations, water level in the boiler drum, and load. Improper boiler water treatment can also lead to wet steam.

7.8.4 Moisture separation

Saturated steam tends to give up its latent heat as it travels in the pipeline and becomes wet. Therefore, the wet steam contains water droplets (due to condensation of some of the steam in pipes). As these droplets do not contain any latent heat, they do not contribute much to the heat transfer. More-over, it reduces the heat-transfer rate by forming a thin layer (film) on the heat-transfer surface. This thin film of condensate acts as a layer of insulating material between the heat-transferring agent (that is, steam) and heat-transferring area. If the condensate droplets are not removed as soon as they are formed, they will keep accumulating and moving at very high speed (that is, speed of the steam) along with the steam. When these (fast-moving condensate droplets) hit obstructions such as bends, valves, steam traps, or some other pipe fittings, the resulting shock is likely to cause severe damage to fittings and equipment, and result in leaking pipe joints. Hence, water should be removed from the steam before it enters any equipment. A moisture separator at the entrance of the equipment serves the purpose where the water droplets are separated out and drained out through a trap.

Reducing the pressure prior to usage can also reduce the wetness of steam. Steam is carried, at the generation pressure by pipes to its usage points where pressure reduction is affected. Reduction of steam pressure just prior to its utilization has two advantages:

- Larger proportion of heat available in the form of latent heat at lower pressure as compared to that at higher pressure

- The quality of steam also improves as the saturation temperature comes down, with the reduction in seam pressure, which lead to flashing of some of the condensate back into the steam. The conversion of the condensate to steam by flashing depends on the extent of steam pressure reduction.

7.8.5 Air removal

Another factor which can affect the steam quality and heat transfer to a great extent is air in the steam distribution system. Air enters the steam system from the atmosphere during the shutdown and stays there if proper venting is not provided. The situation can be improved by installing properly-sized air vents in the pipelines and the equipment at appropriate positions. The air vent should be so positioned that the trapped air is pumped out of the equipment as quickly as possible. The air vent should be positioned at the stagnant corner, far from the steam inlet point. Automatic air vents are available but they are relatively expensive and should be carefully maintained. The best automatic air vents are the balanced pressure or the liquid expansion types. The former is lighter, cheaper, and has a quicker response, whereas the latter is more robust.

Entrapped air in the steam system reduces the partial pressure and thereby the saturation temperature. Table 7.4 shows the effect of air entrapment on the steam saturation temperature.

Table 7.4: Temperature of steam mixed with air

Steam pressure		Percentage of air, temperature, °C			
Psi	Bar	0	20	50	80
10	0.69	115	108	95	73
20	1.30	125	119	105	80
30	2.00	134	127	112	86
40	2.70	141	133	118	92
50	3.40	147	139	124	96
60	4.13	153	145	128	101
70	4.80	156	149	132	103
80	5.50	162	152	136	107
90	6.20	166	157	138	110
100	6.90	170	161	140	113

Air is the most effective insulator and is 1500 times more resistant to heat transfer than iron or steel, and 13 000 times more resistant than copper. While the condensed steam would run away from the heat-transfer surface, the air molecules would remain there. The concentration of air on the heat-transfer surface builds up until an insulating layer is formed, after which the heat transfer is impaired fully.

Utilizing steam at the lowest acceptable pressure for the process

A study of steam tables would indicate that the latent heat in steam reduces as the steam pressure increases. It is only the latent heat of steam which takes part in the heating process when applied to an indirect heating system. Thus, it is important that its value be kept as high as possible. This can only be achieved if we go in for lower steam pressures. As a guide, the steam should always be generated and distributed at the highest possible pressure, but utilized at as low a pressure as possible since it then has higher latent heat.

However, it may also be seen from the steam tables that lower the steam pressure, the lower will be its temperature. Since temperature is the driving force for heat transfer at lower steam pressures, the rate of heat transfer will be slower and the processing time greater. In equipment where fixed losses are high (for example, big drying cylinders), there may even be an increase in steam consumption at lower pressures due to increased processing time. There are, however, several equipment in certain industries where one can profitably go in for lower pressures and realize economy in steam consumption without materially affecting production time.

Insulation

Continuous vigilance is essential to keep the insulation in good condition. All sections of the hot pipes, valve bodies, unions, flanges, and mechanical traps, such as floats, buckets, and bodies of disc traps, should be insulated. The condensate-return lines should also be insulated. As a rule of thumb, heat loss due to lack of insulation averages 2.7 kcal/m^2/h.

Insulation BIS standards for thermal insulation

Table 7.5 shows the International Standards for thermal insulation specifications.

Table 7.5: Standards for thermal insulation

Specification	Type of insulation
ASTM C592 CLASS II	Specification for bonded mineral wool
ASTM C547 TYPE II or III	Specification for performance fibrous pipe insulation, Group III
ASTM C653	Wrought aluminium and aluminium alloys, sheets, and strips

Selection of insulating material

The choice of selecting insulating material involves a number of factors.

- Operating temperature
- Thermal conductivity of insulating material
- Resistance to heat, weather, and adverse atmospheric conditions
- Ability to withstand vibration, noise, and mechanical damage
- Resistance to chemicals
- Resistance to fire
- Extent of shrinkage or cracking during use

- Jacketing for insulation (cladding, cementing, and so on)
- Total cost (including maintenance costs)

Properties of the most commonly used steam-line insulating materials are given in Table 7.6.

Table 7.6: Properties of insulation materials

Property	Insulating material		
	Mineral wool	Calcium silicate	Glass wool
Temperature range (°C)	Up to 750	Up to 950	Up to 450
Thermal conductivity (kCal/m h°C)	0.035 – 0.087	0.049 – 0.079	0.028 – 0.062
Density (kg/m³)	50 – 250	160 – 240	20 -80
Fire resistance	Incombustible	Incombustible	Incombustible
Passivity	Passive to all metals	Less passive	Passive to all metals
Water affinity	Very low	Low	Low
Noise absorption	Excellent	Poor	Excellent
Cost	Lowest	Highest	Intermediate

There are two costs associated with insulation, i.e., the cost of insulation itself, and the cost of energy loss occurring through the insulated surface. As the insulation thickness is increased, the law of diminishing returns sets in, and there comes a point where more insulation increases the cost, rather than help in savings. The optimum economic thickness of insulation provides the most cost-effective solution for insulation and is determined when the total cost is minimum.

7.9 Protective coverings

A covering is required over the insulation for the following.

- Protection against mechanical damage, weather, and chemical attacks
- Retardation of flame spread in case of fire
- Physical protection
- An easy-to-clean surface
- Identification of pipelines
- External appearance

The first three reasons mentioned above emphasize the need for protective covering.

The various types of protective coverings used in the process plants are as follows.

- Metal sheets (aluminium and galvanized iron sheets)
- Finishing cement
- Bituminous materials with wire netting (tar)

7.10 Insulation survey

An insulation audit essentially involves a survey of the surface temperatures of insulated pipes at specified fixed intervals. The average of the temperatures recorded should be taken for calculation. A simple thermocouple or a non-contact type instrument could be used for temperature measurement of the surface.

The ambient temperature and wind velocity should also be monitored since both have significant effects on convective and radiative losses from pipelines. A vane anemometer would help measure wind velocity. Other parameters like the location, steam conditions (for operating temperature), cladding material, insulation type, and insulation thickness should also be recorded. Whenever bare or degraded surfaces are noticed, the surface area and the location should be additionally noted. It is also a good practice to mark degraded patches with paint so that requisite action may be taken to reduce heat losses from these areas. The rate of heat loss per unit area of the insulated surface is calculated from the equation.

Q = h_a x (Ts – Ta)

where,

Q = rate of heat loss per unit area (kcal/m2h),

T_s = operating temperature (°C),

T_a = ambient temperature (°C), and

ha = heat transfer coefficient (kcal/m2 h °C), which is sum of the radiative and connective components

$$H = \frac{\left\{4.875 \mathrm{X} 10^{-8} \mathrm{x} \mathrm{E} \mathrm{x} \left[(\mathrm{T}+273)^4 - (\mathrm{T}_a+273)^4\right] + 1.683 \mathrm{x} (\mathrm{T}_s - \mathrm{T}_a)^{0.8} \mathrm{x} (2.857 \mathrm{x} \mathrm{V}+1)^{0.5}\right\}}{(\mathrm{T}_s - \mathrm{T}_a)}$$

where

E = emissivity of finished surface, and

V = air velocity (metre/second)

Values of emissivities

- Aluminium cladding = 0.2
- Bare pipe (oxidized steel) = 0.8

A walk-through survey of the steam lines should be carried out once every six months. This would help in identifying the status of insulation and any degraded or bare surface for necessary action. Such a survey also helps in reducing the problems of temperature drop along steam lines.

As a rule of thumb, the insulation needs to be changed/attended only if the surface temperature of the insulated steam pipeline is found to be 1.5 times the ambient temperature. It is very common to find valves and flanges uninsulated. The reason cited is that they prevent easy access for maintenance. However, the practice of insulating flanges needs to be emphasized by the management for energy economy.

7.11 Insulation thickness

The optimum insulation thicknesses at different operating temperatures for mineral wool-based insulation with following parameters are given in Table 7.7.

- Ambient temperature 40 °C,
- Surface temperature (55 °C),
- Wind velocity (2 metres/second)

Table 7.7: Guidelines for mineral wool insulation thickness of steam pipes (mm)

Temperature (°C)	4 inch	6 inch	8 inch	10 inch	12 inch	14 inch	16 inch
Up to 100	15	15	15	15	15	15	15
100–150	25	25	30	30	30	30	30
150–200	40	40	45	45	45	45	45
200–250	50	55	55	60	60	60	60
250–300	65	70	75	75	80	80	80
300–350	80	85	90	90	95	95	100
350–400	95	100	110	110	115	120	120

7.12 Steam traps

The effectiveness of the distribution and usage of steam in a system, to a large extent, depends on the correct application and operation of the steam traps. Steam trap functions like a valve, passes the condensate, and holds back the steam within the system preventing its escape. It should pass the condensate as soon as it is formed since the condensate, remaining within the system, reduces the heat transfer rate and also causes mechanical damages by water hammering etc. Steam traps also helps in maintaining a reasonable degree of dryness as the steam flows from the source to its point of use. They are also designed to separate air from the system. Steam traps are required to operate in the plant under varying conditions, including varying steam pressure (high, medium, and low), varying steam load, inadequate space, and exposed outdoor locations where there can be a difficulty for proper maintenance during severe summer. Thus, the steam trap plays a vital role in the performance of the plants.

Unfortunately, although all the steam traps are designed to do the functions as just discussed, they do not perform satisfactorily in all the situations. The steam systems and services differ, and so do the steam traps that serve them. To help specify the optimum steam trap for a particular service condition, it is necessary to understand the major types of steam traps. Some of the more common types of steam traps include the following. (*)

- Inverted bucket
- Float and thermostatic
- Thermodynamic or disc
- Bimetallic thermostatic
- Thermal element thermostatic

7.12.1 Inverted bucket traps

These are popular in every application because their discharge is intermittent. They are fairly resistant to the water hammer and can be used for very high pressures. While proper sizing is very important for these traps, the maintenance and repair aspects can be attended to online. Some of the drawbacks of this trap include steam loss during operation, poor air-removal capacity (often air-venting devices are required), and problems during installation of large traps.

7.12.2 Float and thermostatic traps

These are a combination of two systems: a float that operates the valve and a built-in thermostatic element which purges air upon start-up. These traps can handle a wide range of condensate loads and steam pressures but are susceptible to water hammer and corrosion. As in the case of the inverted bucket, proper sizing is very important. The maintenance of these traps requires overhauling of two valves and two seats.

7.12.3 Thermodynamic or disc traps

These are the most widely used steam traps today, largely due to their small size, wide pressure range, single-moving part, and resistance to water hammer and corrosion. Since the operation of each model depends on the manufacturer's seat and disc design, results obtained by the user may vary widely. These traps discharge condensate and entrapped air at steam temperatures regardless of the inlet pressure, with almost no steam loss. Wear and dirt are particular problems of this trap, and in outdoor applications, especially rain falling on the traps, may lead to rapid cycling causing it to pass and waste steam.

7.12.4 Bimetallic thermostatic traps

As the name suggests, the traps operate a bimetallic strip, opening the valve when it is cool and closing it when hot. The internal valve can be either downstream or upstream. Bimetals have a slower response time and can result in condensate being trapped in the system. However, they have to be adjusted to the operating conditions.

7.12.5 Thermal element thermostatic traps

In this case, the traps use thermal assembly made of special stainless-steel material. The construction makes these traps highly resistant to water hammer and shock. The older version of thermostatic traps using brass/bronze bellows is vulnerable to water hammers. The traps are very energy efficient and easy to maintain online. It is only necessary to close the upstream block valve and open the strainer blowdown valve. Moreover, the exact sizing of the valves is not important. A comparison of these trap types is given in Table 7.8.

Table 7.8: Comparison of commonly used steam traps

Characteristics	Inverted bucket	Float and thermostatic	Disc	Thermostatic
Method of operation	Intermittent	Continuous	Intermittent	Intermittent
Energy conservation (time in service)	Excellent	Good	Poor	Fair
Resistance to wear	Excellent	Good	Poor	Fair
Corrosion resistance	Excellent	Good	Excellent	Good
Resistance to hydraulic shock	Excellent	Poor	Excellent	Poor
Vents air and CO2 at steam temperature	Yes	No	No	No
Ability to vent air at very low pressure	Poor	Excellent	No	Good
Ability to handle start-up air loads	Fair	Excellent	Poor	Excellent
Operation against back pressure	Excellent	Excellent	Poor	Excellent
Resistance to damage from freezing	Good	Poor	Good	Good
Ability to purge system	Excellent	Fair	Excellent	Good
Performance on very light loads	Excellent	Excellent	Poor	Excellent
Responsiveness to slug of condensate	Immediate	Immediate	Delayed	Delayed
Ability to handle dirt	Excellent	Poor	Poor	Fair
Comparative physical size	Large	Large	Small	Small
Ability to handle flash steam	Fair	Poor	Poor	Poor
Mechanical failure (open–closed)	Open	Closed	Open	Open/closed

7.13 Steam traps testing

The first step for systematic steam trap testing is to prepare a list of all steam traps in the plant by giving each trap a unique identification number. A trap map is helpful for complex plants because the maintenance worker can then locate the traps quickly. The actual trap testing could be conducted by either a simple ultrasonic sound detector or a more sophisticated portable computerized steam trap tester. The computerized steam trap tester would give accurate data on the status of traps (blowing, leaking, blocked, and so on) and quantify the steam loss. The data could be stored and downloaded in a personal computer for detailed analysis along the lines of the plant trap and manufacturer trap-failure rates. However, for smaller plants, an ultrasonic sound detector should suffice. Each type of trap gives a unique sound when there is leaking or blowing steam, which could easily be detected with some practice.

In most industries, maintenance of steam traps is not a routine job and is neglected unless it leads to some definite trouble in the plant. In view of their importance as steam savers and to monitor plant efficiency, the steam traps require considerably more care than is given. One may consider a periodic maintenance schedule to repair and replace defective traps in the shortest possible time, preferable during regular maintenance shut-downs in preference to break down repairs.

7.13.1 Selection of steam traps

Most manufacturers offer a wide range of steam traps but the selection of the appropriate trap should be made from the capacity curve (to be provided by trap manufacturer) of the trap, which varies with every manufacturer. Depending on the condensate loading and differential pressure of the application, care must be taken to select a model, which would be somewhere in the middle of the capacity curve. The maximum rated temperature and pressure limits of the steam trap must also be obtained from the manufacturer to ensure that the limits are not exceeded under plant operating conditions. A ready reference for trap selection for some applications is given in Table 7.9.

Table 7.9: Steam trap selected guide

Application	First choice	Second choice
Air-heating coil	Float	
Shell and tube exchangers		
Small-high pressure	Balanced pressure thermostatic	
Large-low and medium pressure	Float	–
Re-boilers	Float	–
Steam-jacketed vessels	Thermodynamic	Float
High pressure	Float	–
Steam line drip traps		
0–1 kg/cm2 (g)	Float	–
1–9 kg/cm2 (g)	Thermodynamic	Float
9–45 kg/cm2 (g)	Thermodynamic	Float
High pressure superheated	Thermodynamic	Bi-metallic
Steam pipe coils (air heating)	Balanced pressure thermostatic	Thermodynamic
Steam radiators	Balanced pressure thermostatic	Thermodynamic

Contd...

Table 7.9: Steam trap selected guide

Application	First choice	Second choice
Steam separators		
0–1 kg/cm2 (g)	Float	–
1–9 kg/cm2 (g)	Thermodynamic	Float
9–45 kg/cm2 (g)	Thermodynamic	Bucket
Steam tracer lines	Balanced pressure thermostatic	Thermodynamic and bi-metallic
Storage tank coil	Float	Thermodynamic and bucket
Submerged heating coil		
High pressure	Float/thermostatic	Bucket/balanced pressure thermostatic
Low and medium pressure	Float	Balanced pressure thermostatic
Autoclaves	Float	Thermodynamic/bucket
Dryers	Thermodynamic	Float

7.13.2 Installation and maintenance of traps

The steam trap is an automatic valve capable of distinguishing between condensate and live steam. It opens to discharge the former (condensate) but closes to trap the latter (steam). It has been seen that the main causes of unsatisfactory condensate removal include the choice of the wrong type of steam trap for the application and bad installation. Any of these factors can seriously reduce the plant output. To ensure a trouble-free installation, careful consideration should be given to the drain point, pipe sizing, air venting, steam locking, dirt, water hammer, lifting of the condensate, and so on.

Dirt is one of the most common causes of steam traps blowing steam. Dirt and scale are normally found in all steam pipes. Since steam traps are connected to the lowest parts of the system, sooner or later this foreign matter finds its way to the trap. Once some of the dirt gets logged in the valve seat, it prevents the valve from shutting down tightly thus allowing steam to escape. The valve seal should therefore be quickly cleaned, to remove this obstruction and thus prevent steam loss.

In order to ensure proper working, steam traps should be kept free of pipe-scale and dirt. The best way to prevent the scale and dirt from getting into the trap is to fit a strainer. A strainer is a detachable, perforated, or meshed screen enclosed in a metal body. It should be borne in mind that the strainer collects dirt in the course of time and will therefore need periodic cleaning.

It is of course, much easier to clean a strainer than to overhaul a steam trap. At this point, we might mention the usefulness of a sight glass fitted just after a steam trap. Sight glasses are useful in ascertaining the proper functioning of traps and in detecting leaking steam traps. In particular, they are of considerable advantage when a number of steam traps are discharging into a common return line. If it is suspected that one of the traps is blowing steam, it can be quickly identified by looking through the sight glass.

7.13.3 Group trapping vs individual trapping

It is tempting to try and save money by connecting several units to a common steam trap as shown in Figure 7.3. This is known as group trapping. However, it is rarely successful, since it normally causes water logging and loss of output. The steam consumption of a number of units is never the same at a moment of time and therefore, the pressure in the various steam spaces will also be different. It follows that the pressure at the drain outlet of a heavily loaded unit will be less than in the case of one that is lightly or properly loaded. Now, if all these units are connected to a common steam trap, the condensate from the heavily loaded and therefore lower pressure steam space finds it difficult to reach the trap as against the higher-pressure condensate produced by lightly or partly loaded unit. The only satisfactory arrangement thus, would be to drain each steam space with its own trap and then connect the outlets of the various traps to the common condensate return main as shown in below Figure 7.2.

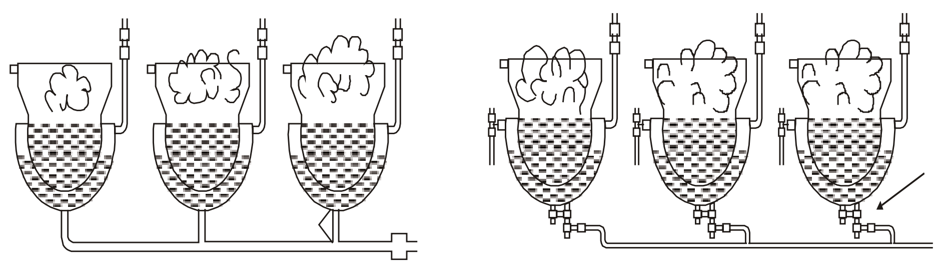


Figure 7.2: Group trapping vs. individual trapping

7.14 Condensate recovery

To ensure that the steam distribution system is more efficient, condensate recovery is equally important. When steam condenses, it transfers about 75% of the heat content to the process, and the remaining is withheld in the condensed water. An efficient condensate-recovery system should be practised to collect the condensate from the process and return it to the de-aerator/boiler-feed tank or used in the process.

7.14.1 Uses of condensate

In most applications, only the latent heat of steam is extracted, even as the condensate contains the sensible heat (about 25% of the original heat content). Since the condensate is a pure form of water, it can be used as boiler feed water without further treatment. This not only reduces the fuel consumption in the boiler, but also results in saving raw water and the chemicals required to treat it. For every 6 °C rise in the feed water temperature there could be a one per cent saving in boiler fuel consumption. It is thus imperative that a condensate-recovery system is installed whenever economical. The economics of condensate recovery depend on the quantum of condensate recovered, the temperature of condensate, condensate quality (level and type of contamination), type of boiler, plant layout, and the distance of transportation of the condensate. However, it is feasible in most plants to recover it. Ways must be devised to utilize the condensate to the maximum extent possible in any of the following ways.

- Boiler feed water
- Extracting flash steam
- Process hot water
- Heating medium in heat exchangers dryers
- De-superheating water

Many times, condensate discharge from the process is not clean due to the contamination with the process fluid, which could be corrosive in nature. Such condensate cannot be directly used in the boiler, flash steam extraction, etc. Heat in such condensate can be recovered indirectly by passing it through the heat exchanger, and it can be used for feed water heating, make-up water heating, heating of any other process fluid, and so on, depending on the heat content of condensate.

The condensate recovery in the plant and its individual sections can be easily estimated by carrying out a steam and condensate balance around the plant. The biggest problem, however, comes when flow meters are not installed on steam and condensate lines. Hence, it is important to first install adequate instrumentation to measure steam and condensate flows. Once this is done, the plant may prepare a steam and condensate flow diagram giving the flow rates of each stream.

7.15 Flash steam recovery

The recovery of flash steam from high-pressure condensate is an important heat saving measure. Flash steam is produced when condensate at a high pressure is released to a lower pressure and can be used for low-pressure heating. The flash steam quantity can be calculated by the following mathematical formula with the help of a steam table:

$$F\,(\%) = \frac{\{(S_1 - S_2)\ x\ 100\}}{L_2}$$

where,

F = percentage of flash steam generated (%),

S_1 = sensible heat of high-pressure condensate (kcal/kg),

S_2 = sensible heat of low-pressure flash steam (kcal/kg), and

L_2 = latent heat of low-pressure flash steam (kcal/kg).

Alternatively, it can be calculated from the nomogram given in Figure 7.3.

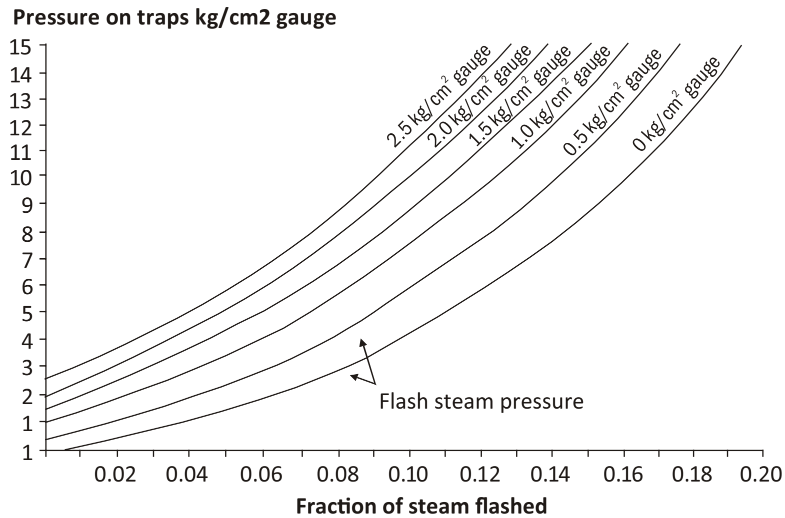


Figure 7.3: Nomogram to determine flash steam from condensate

For example, if condensate at 10 kg/cm^2 is discharged at atmospheric conditions (or 0 kg/cm^2/gauge or 1 kg/cm^2/ atmospheric), about 15% by weight of the condensate could be generated as flash steam. However, if the condensate is discharged at 3 kg/cm^2/atmospheric (or 2 kg/cm^2/gauge), flash steam quantity generated would be about 10%. Higher the steam pressure and lower the pressure of flash steam greater the quantity of flash steam that can be generated. This steam can be used on low-pressure applications like direct injection and can replace an equal quantity of live steam that would be otherwise required. The demand for flash steam should exceed its supply, so that there is no build-up of pressure in the flash vessel and the consequent loss of steam through the safety valve.

Flash steam from the condensate can be separated in an equipment called the 'flash vessel' (Figure 7.5). The diameter of the vessel is such that a considerable drop in velocity allows the condensate to fall to

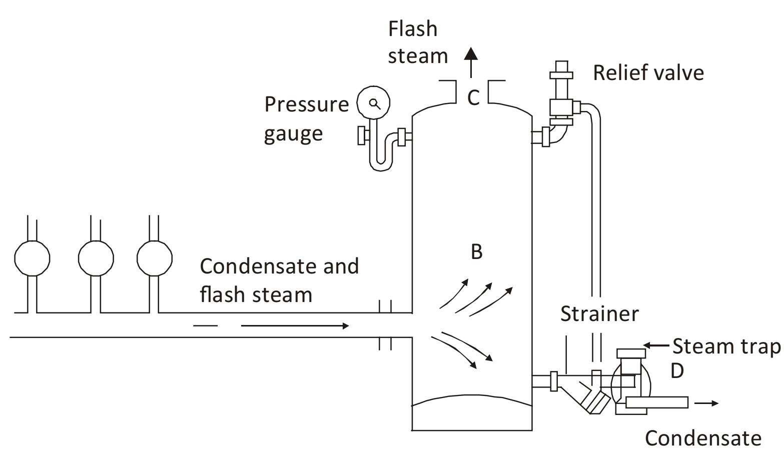


Figure 7.4: Flash system recovery

the bottom of the vessel from where it is drained out by a steam trap preferably a float trap. Flash steam itself rises to leave the vessel at the top. The height of the vessel should be sufficient to avoid water being carried over in the flash steam.

7.16 Steam leakage

Even in the well-maintained and relatively newer plants, steam loss through leakage is quite common. Due to improper maintenance and poor quality of fittings, many leaking joints can be identified in the plant. Steam leakage is a waste of energy and must be avoided as soon as it is discovered. Steam losses increase with steam pressure and the size of leaking point (orifice).

7.17 Case studies

7.17.1 Case study of utilization of condensate flash steam

In a dryer consuming steam at 4 T/h (tonnes per hour) of 18 kg/cm^2-gauge, the savings by flashing the condensate and using flash steam in a secondary air pre-heater is given below.

- Flash drum pressure = 1.4 kg/cm^2-gauge
- S_1 = 213 kcal/kg
- S_2 = 126 kcal/kg
- L_2 = 522 kcal/kg

Percentage flash = (213 – 125.9)/522.3

= 16.7% of 4 T/h

= 0.7 T/h

By utilizing the flash steam in the pre-heater, a saving of at least 0.5 T/h of 18 kg/cm^2-gauge steam could be achieved, which is equivalent to about GY$ 6 million per annum based on 8000 hours of operation per year, and cost of steam as GY$ 1,500/T.

Tips - Steam traps

The following points should be considered for better trap management in the complex.

- Steam traps should be fitted in the direction of flow. All steam traps bear mark showing flow direction.
- The condensate should flow to trap using the gravity force.
- Thermodynamic traps have no limitation as to position and can be fitted vertically.
- Free float traps should be fitted horizontally.
- Never use an inlet pipe smaller than trap size. Steam locking and air binding are bound to occur when the pipe size is lower.
- Never install steam trap at a higher level than the drainage point to avoid back pressure (condensate lifting), even when it is required that lift fitting is to be used.
- Size of the collector should have a cross-sectional area more than the sum of cross-sectional areas of all traps connected to it.
- Condensate discharge through two traps, which are operated at different pressures, should not be collected in a common collector.
- Each steam-using unit should always have an individual steam trap.
- Double trapping (both series and parallel) is a bad practice
- The trap outlet pipe must not be connected to the bottom of the header to collect the condensate. The header should not have a raiser which otherwise will exert back pressure on traps.

Steam distribution and utilization

- The heat loss from 100 feet of a bare 2-inch pipe carrying saturated steam at 150 psig is equivalent to a fuel loss of 1 T of coal every twelve days. If the pipe diameter is 12", the loss would be 1 T of coal every two days.
- Flanges, bends, and valves should also be insulated. Each bare flange is equivalent to 0.3 m of bare pipe of the same diameter and an un-insulated valve is equivalent to 1.5 m of bare pipe.
- For indirect heating by steam, provide the steam at lowest possible pressure. This will increase the availability of latent heat for heat transfer. Also, the heat transfer rate of the condensing steam is the highest.
- Keep the steam bypass line always closed except during the start-ups. Never bypass a trap. If the trap is faulty, replace the trap rather than opening the bypass valve.
- It is always beneficial to reduce the steam pressure (high to medium and medium to low) by expanding through turbines than using PRVs.

Calculation of Stoichiometric Air

The specifications of natural gas from lab analysis are given below:

Constituents	% By weight
Carbon	74.22
Hydrogen	23.45
Oxygen	0.99
Nitrogen	1.34
Sulphur	0
H2O`	0
Ash	0

GCV of fuel : 14,000 kcal/kg (9,100 K Cal/ sm^3)

Calculation for Requirement of Theoretical Amount of Air

Element	Molecular Weight, kg / kg mole
C	12
O_2	32
H_2	2
S	32
N_2	28
CO_2	44
SO_2	64
H_2O	18

Considering a sample of 100 kg of natural gas, the chemical reactions are:

C	+	O_2	$\rightarrow$	CO_2
H_2	+	O	$\rightarrow$	H_2O
S	+	O_2	$\rightarrow$	SO_2

Constituents of fuel

C	+	O_2	$\rightarrow$	CO_2
12	+	32	$\rightarrow$	44

12 kg of carbon requires 32 kgs of oxygen to form 44 kg of carbon dioxide therefore 1 kg of carbon requires 32/12 kg i.e 2.67 kgs of oxygen

$(74.22)\ C + (74.22 \times 2.67)\ O_2 \rightarrow 272.38\ CO_2$

$2H_2$	+	O_2	$\rightarrow$	$2H_2O$
4	+	32	$\rightarrow$	36

4 kg of hydrogen requires 32 kgs of oxygen to form 36 kg of water; therefore 1 kg of hydrogen requires 32/4 kg i.e., 8 kgs of oxygen

$(23.45)\ H_2 + (23.45 \times 8)\ O \rightarrow 211\ H_2O$

S	+	O_2	$\rightarrow$	SO_2
32	+	32	$\rightarrow$	64

32 kg of sulphur requires 32 kgs of oxygen to form 64 kg of sulphur dioxide; therefore 1 kg of sulphur requires 32/32 kg i.e 1 kgs of oxygen

$(0)\ S + (0 \times 1)\ O_2 \rightarrow 0\ SO_2$

Total Oxygen required = 385.76 kg *(198.16+187.6+0)*

Oxygen already present in 100 kg fuel (given) = 0.99 kg

Additional Oxygen Required = 385.76 – 0.99 = 384.77 kg

Therefore, quantity of dry air required = (384.77) / 0.232 = 1658.5 kg of air

(Air contains 23% oxygen by wt.)

Theoretical Air required = (1658.5) / 100 = 16.59 kg of air / kg of fuel

Calculation of theoretical CO_2 content in flue gases

Nitrogen in flue gas = 1658.5 – 384.77 = 1273.73 kg

Theoretical CO_2% in dry flue gas by volume is calculated as below:

Moles of CO_2 in flue gas = (272.38) / 44 = 6.19

Moles of N_2 in flue gas = (1273.73) / 28 = 45.49

Moles of SO_2 in flue gas = 0/64 = 0

Theoretical CO_2 % by volume = $\dfrac{\text{Moles of } CO_2}{\text{TotalMoles (Dry)}}$

$$= \frac{6.19x100}{(6.19+45.49+0)} = 11.9\ \%$$

Calculation of constituents of flue gas with excess air

% CO_2 measured in flue gas = 10% (measured)

% Excess Air = $\left(\frac{\text{Theoretical } O_2}{\text{Actual } O_2\ \%} - 1\right) \text{x } 100$

% Excess Air = $\left(\frac{11.9}{10} - 1\right) x100$ = 19%

Theoretical air required for 100 kg of fuel burnt = 1658.5 kg

Total qty. of air supply required with 19% excess air = 1658.5 X 1.19 = 1973.6 kg

Excess air quantity = 1973.6 – 1658.5 = 315.1 kg.

O_2 = 315.1 X 0.23 = 72.47

N_2 = 315.1 - 72.4 = 242.6 kg

The final constitution of flue gas with 19% excess air for every 100 kg fuel is as follows.

CO_2 = 272.38 kg

H_2O = 211 kg

SO_2 = 0 kg

O_2 = 72.47 kg

N_2 = 1273.73 + 242.6 = 1516.3 kg

Calculation of Theoretical CO_2% in Dry Flue Gas by Volume

Moles of CO_2 in flue gas ***= 272.38/44 = 6.19***

Moles of SO_2 in flue gas ***= 0/64 = 0***

Moles of O_2 in flue gas ***= 72.47/32 = 2.26***

Moles of N_2 in flue gas ***= 1516.3/28 = 54.15***

Theoretical CO_2% by volume **=** $\frac{\text{Moles } 6\ O_2}{\text{TotalMoles (Dry)}}$

$$= \frac{6.19}{(6.19+0.+2.26+54.15)} = \frac{6.19}{62.6}$$

= 9.9%

Theoretical O_2% by volume = $\frac{2.26}{62.6} = 3.6\%$

CHAPTER 8

Renewable Energy

8.1 Introduction

Renewable energy can be defined as "any form of energy from solar, geophysical, or biological sources that are replenished by natural processes at a rate that equals or exceeds its rate of use". In a broad sense, the term renewable energy refers to energy from biomass (wood and bagasse), hydro, solar, wind, geothermal, and ocean (tidal, wave, current, ocean thermal, and osmotic energy). Some of the renewable energy technologies suitable in Guyanese context are explained below:

8.1.1 Solar Energy

Humans have been harnessing solar energy for thousands of years—to grow crops, stay warm, and dry foods. With advancements in technology, we use the sun's rays to generate electricity, heat homes, warm water, or cook food. The most common way to harness solar energy are:

1. **Photovoltaic Solar System**: Photovoltaic (PV) solar cells convert solar energy into electric energy. A photovoltaic panel consists of several cells that can be used in small systems or large plants to generate energy from the sun. Solar photovoltaic systems are sub-classified into three categories:
    a. **Distributed Solar System**: This system generates electricity locally for homes through rooftop panels or community projects that power entire neighborhoods. This kind of system can either be connected with a grid or work in decentralized mode.
    b. **Solar Farms/ Solar Parks**: Large-scale solar installation where PV panels are used to generate electricity. These systems are generally connected with the electricity grid to transfer large amounts of electricity from solar parks to end-users.

Figure 8.1: Rooftop Solar Photovoltaic System

Figure 8.2: Solar Farms

c. **Floating Solar Systems**: Floating solar or floating photovoltaics, sometimes called “floatovoltaics”, are solar panels mounted on a structure that floats on a body of water, typically a reservoir or a lake. Floating solar farms can be an effective use of wastewater facilities and bodies of water that aren’t ecologically sensitive.

Figure 8.3: Floatovoltaics System

2. **Solar Thermal Energy:** Sun’s heat can be collected and transferred to a medium, and that stored energy is then used for purposes including heating and cooling a home, heating water, cooking food, or creating electricity. Solar thermal energy can be used in three temperature range applications: low-temperature, which is used for heating, cooling, and ventilation; mid-temperature, which is used for cooking, hot-water heating; and high-temperature, used to generate electricity.

Figure 8.4: Solar thermal system

8.1.2 Wind Energy

Wind energy is created using wind turbines that capture the kinetic energy of the earth’s natural air flows to generate electricity. The wind turbs the blades, the blades spin a shaft that’s connected to the generator which generates electricity. There are three major types of wind energy systems:

a. **Utility-Scale Wind Farms:** This defines wind turbines that range in size from 100 kilowatts to several megawatts, where electricity is supplied to the power grid and distributed to the end-user by electric utilities or power operators.

b. **Offshore Wind Farms**: Deployment of wind farms in large water bodies. Higher wind speeds are available offshore than on land, so offshore wind farms generate more electricity per capacity installed.

c. **Distributed or "Small" Wind Energy System:** This applies to wind turbines below 100 kilowatts that are used to directly power a home, farm, or small business that is not connected to the grid. This kind of units are currently being used in Guyana.

Figure 8.5: Utility-Scale Wind Farms

Figure 8.6: Offshore Wind Farms

Figure 8.7: Distributed Wind Energy System

8.1.3 Hydro Energy

Hydropower is the use of falling or fast-running water to produce electricity. This is achieved by converting water's potential or kinetic energy into electricity. Based on technology used and water storage capability, hydropower projects are classified into three categories:

a. **Run-of-river hydropower:** Flowing water from a river passes through a canal or penstock to spin a turbine. The run-of-river project would have little or no storage facility, and it provides a continuous supply of electricity (baseload), with some flexibility of operation for daily fluctuations in demand through water flow that the facility regulates.

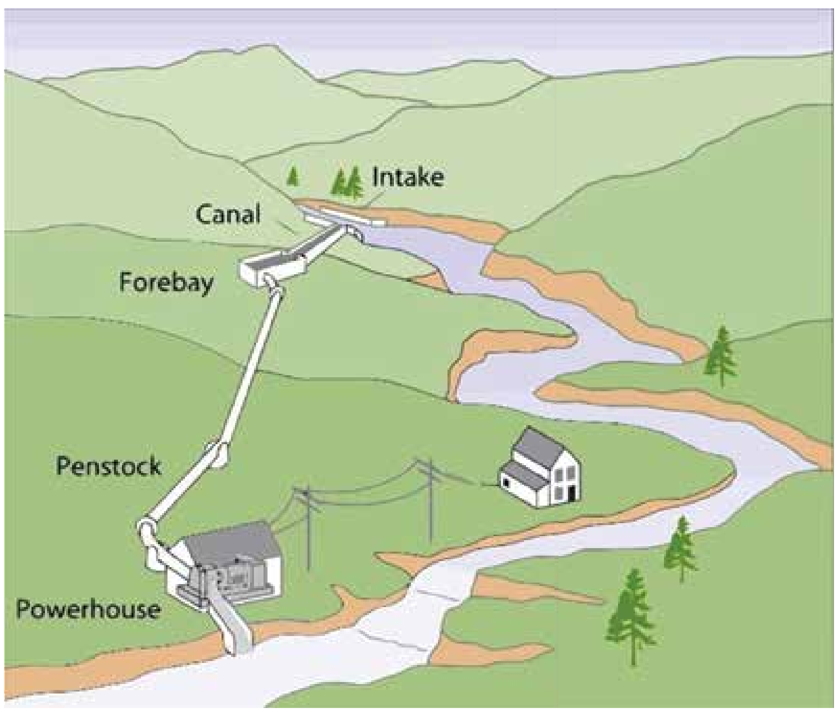


Figure 8.8: Run-of-river hydropower plant

b. **Impoundment hydropower:** It uses a large dam to store water in a reservoir. Electricity is produced by releasing water from the reservoir through a turbine. Storage hydropower provides baseload and the ability to be shut down and started up at short notice according to the system's demands (peak load).

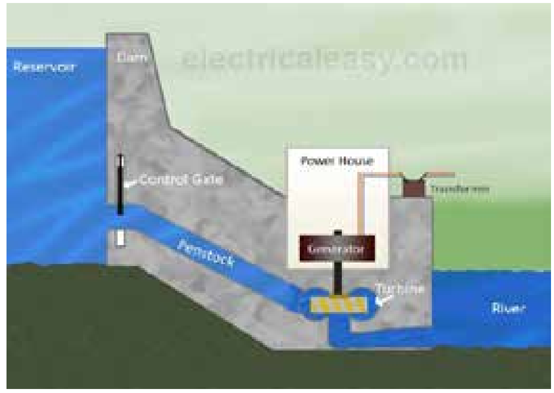


Figure 8.9: Impoundment hydropower

c. **Pumped storage hydropower:** It provides peak-load supply by generating electricity from water that is cycled between a lower and upper reservoir by pumps that use surplus energy from the system at times of low demand. When electricity demand is high, water is released back to the lower reservoir through turbines to produce electricity.

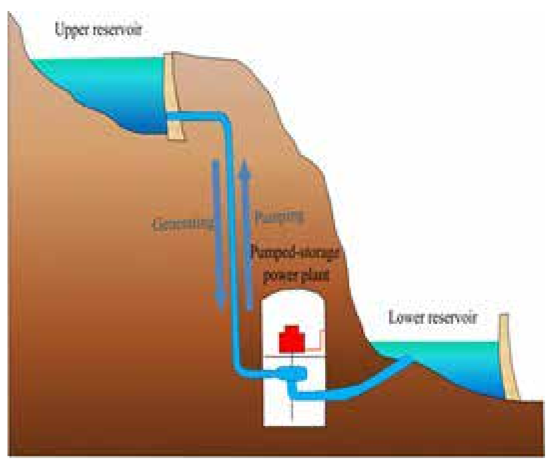


Figure 8.10: Pumped storage hydropower plant

8.1.4 Bioenergy

Bioenergy is energy made from biomass or biofuel. Bioenergy use falls into two main categories: "traditional" and "modern". Traditional use refers to the combustion of biomass in such forms as wood, crop residue and traditional charcoal. Example: wood, crop residue, and bagasse. Modern bioenergy technologies include liquid biofuels produced from bagasse and other plants; bio-refineries; biogas produced through anaerobic digestion of residues; wood pellet; and other technologies.

8.2 Advantages and Disadvantages of Renewables

Using modern conversion technologies, developing and exploiting renewable energy sources can be highly responsive to national and international policy goals formulated because of environmental, social, and economic opportunities, objectives, and concerns. The main advantages of renewables are:

- Enhance energy security by diversifying sources of primary energy to produce electricity and heat.
- Reducing pollution, environmental emissions, and safety risks from conventional energy sources.
- Mitigating greenhouse gas emissions down to levels that can be sustained.
- Improving access to clean energy sources, thereby helping to meet the Sustainable Development Goals (SDGs) while taking advantage of the local availability of renewables.
- Reducing dependence on and minimizing spending on imported fuels.
- Reducing conflicts related to the mining and use of limited available natural resources, as most renewable energy sources are well distributed.
- Spurring economic development, creating new jobs and local employment, especially in rural areas, as most renewable energy technologies can be applied in small, medium, and large-scale systems in distributed and centralized application.
- Balancing the use of fossil fuels, saving them for other applications and for future generations.

Making use of renewable energy sources also has some disadvantages and drawbacks, like:

- The spatial energy intensity (J/m^2) or density (J/m3) of renewable energy sources is often low compared with most fossil fuel and nuclear energy sources. Consequently, a large geographical area is needed to convert renewable energy into useful energy.
- Although the energy from renewable sources is most often available for free but renewable energy conversion technologies are often relatively capital-intensive.
- Renewable energy systems rely on natural resources such as sunlight, wind, and water, and therefore, their electricity generation can be as unpredictable as the weather. Example: Solar panels lose efficiency on cloudy days, wind turbines aren't effective in calm weather, and hydropower systems need consistent snow and rainfall to maintain reliable production.
- Due to the intermittent nature of renewables, it may require methods to predict renewable energy supplies many hours ahead for better management of energy demand and for grid stability. They also need forms of energy storage to capture and release electricity in a consistent and controlled way.

Different renewable energy conversion technologies are summarized in below table.

Table 8.1: Modern renewable energy conversion technologies

Technology	Energy Product	Status
Biomass energy		
Combustion (Domestic Scale)	Heat (cooking, space heating)	Widely applied;
Combustion (industrial scale)	Heat, steam, electricity, CHP	Widely applied;
Gasification/power production	Electricity, heat, CHP	Demonstration phase; large-scale deployment of small units in certain countries
Gasification/fuel production	Hydrocarbons, Methanol, Hydrogen	Development and demonstration phase
Hydrolysis and fermentation	Ethanol	Commercially applied for sugar/starch crops; production of fuels from lignocellulose under development
Pyrolysis/production liquid fuels	Bio-oils	Pilot and demonstration phase
Pyrolysis/production solid fuels	Charcoal	Widely applied commercially
Extraction	Bio-diesel	Commercially applied
Digestion	Biogas	Commercially applied
Marine biomass production	Fuels	R&D phase
Artificial photosynthesis	Hydrogen or other fuels	Fundamental and applied research phase
Hydropower		
Mini-hydro	Electricity	Remotely applied; well-known technology
Small & larger hydropower	Electricity	Commercially applied
Geothermal energy		
Power production	Electricity	Commercially applied locally
Direct heating	Heat, steam	Commercially applied locally
Heat pumps	Heat	Increasingly applied
Wind energy		
Small wind turbines	Movement, electricity	Water pumping / battery charging
Onshore wind turbines	Electricity	Widely applied commercially
Offshore wind turbines	Electricity	Demonstrated; initial deployment phase

Table 8.1: Modern renewable energy conversion technologies

Technology	Energy Product	Status
Solar energy		
Passive solar energy use	Heat, cold, light, ventilation	Demonstrations and application, combined with energy-efficient buildings
Low-temperature solar energy use	Heat (water and space heating, cooking, drying) and cold	Solar collectors commercially applied; solar drying and cooking locally applied
Photovoltaic solar energy	Electricity	Widely applied, remote and grid-connected; high learning rate
Concentrated solar power	Heat, steam, electricity	Demonstrated; initial deployment phase
Ocean energy		
Tidal head energy	Electricity	Applied locally; well-known technology
Wave energy	Electricity	Some experience; research, development, and demonstration (RD&D) phase
Tidal and ocean current energy	Electricity	Some experience; RD&D phase
Ocean thermal energy conversion	Heat, cold, electricity	Some experience; some application of cold use; other technologies mainly in RD&D phase
Salinity gradient / osmotic energy	Electricity	RD&D phase

8.3 Renewable energy potential in Guyana

Considering the hydrological and geological conditions, Guyana has considerably high untapped potential for a wide range of renewable energy projects. It has a low population density and abundant land and water resources for Hydroelectric and Biofuel developments. It also has all the benefits of a Caribbean destination for solar developments receiving an average of 7 hours of sunshine per day and having an average daily solar irradiation of 5.1 kilowatts per square meter.

In Guyana, solar energy, wind, and hydropower are good complementary resources. Solar energy is available during daylight hours, peaking at noon, while the wind is more potent during evening hours and at night. During monsoon seasons, wind potential is less, but hydropower is fully available.

A wide array of opportunities has arisen in Guyana within the renewable energy sector, as the government has set out ambitious targets to increase the power generated from renewable sources and reduce dependency on imported oil. The country already generates a significant energy requirement from wood and bagasse. However, additional opportunities exist in solar, wind, hydroelectricity, and biomass. Source wise, renewable energy potential in Guyana and government's strategy to increase renewable energy share in the country's energy mix is explained in the following sub-sections.

8.2.1 Hydropower

Guyana has a potential for 8.5 Gigawatt (GW) of hydropower on 33 hydropower plants (including storage capacity and run-of-river). It is anticipated that Guyana will build two hydro plants over the next 20 years. First is Amaila Falls hydropower plant with installed capacity of 165 MW and second site is still to be identified. It is anticipated that the new site will be identified by 2025, with the goal of providing 370MW of capacity by 2035 and a further 150MW of capacity by 2040.

Apart from large hydropower projects, Guyana is also implementing three small hydropower projects: First a 150kW in Kato; second is the rehabilitation of Moco-Moco hydropower site, which would increase the capacity up to 0.7MW and third is a new 1.5MW hydropower plant in Kumu. Moco-Moco and Kumu hydropower projects will provide energy to Lethem grid. It is expected those two projects, in combination with an ongoing solar PV project, will provide the Lethem grid with 100% renewable energy by 2023.

8.2.2 Solar Photovoltaic System

According to the Energy Sector Management Assistance Program (ESMAP), Guyana receives an average of 1,800 kWh/m2 annually. As a result, most locations across Guyana have excellent solar insolation levels and are ideal for solar PV generation. In 2020, the total installed capacity for Solar PV in Guyana is 8.00 MW with an estimated annual generation of 12 GWh.

Figure 8.11: Solar Map of Guyana

In Guyana, solar energy is used for several purposes, including drying agricultural produce, irrigation, and to improve electricity access in rural areas. Under the Hinterland Electrification Programme, 19,000 solar PV home energy systems had been installed in nearly 200 communities by 2018. Government is also planning to provide 150 watts-peak (Wp) solar PV home energy system (SHE) to 30,000 hinterland and riverine communities by the end of 2022. The standalone SHE system will provide electricity at individual level for lighting, cooling and charging battery operated small equipment's, such as a mobile phone.

To improve rural electrification, the government approved installing solar PV mini-grid systems in 10 villages, totaling 1.472 MWp (an average of 147kWp/village). These systems are expected to be in operation by 2022. In 2021, Guyana signed a grant agreement with the International Solar Alliance for a solar demonstration project in Orealla, Region Six. This will see the installation of a 9kWp grid-tie solar photovoltaic system in Orealla and will be accompanied by a battery energy storage system of 37kWh.

As per the country's Low Carbon Development Strategy (LCDS), by 2023 GPL will have its first solar on-grid PV farm in Berbice with a total capacity of 10 megawatts-peak (MWp) and additionally 27.8 MWp solar PV farms were developed in eight different grids. After commissioning these eight grids have an average of 30 percent of their electricity consumed generated by solar PV.

Figure 8.12: Solar Street Light

To date, Guyana Energy Agency (GEA), replaced inefficient sodium or mercury vapor streetlights, rated at 250 W in areas like National Park, with more efficient 80 W solar streetlights. A total of 486 solar streetlights were installed altogether, which saved 361,876 kWh energy and 260 metric tonnes of CO_2 emissions annually. This translates to over G$18.82 million yearly savings in electricity costs, with the payback period on this investment being about 4 years.

8.2.3 Wind Energy

Guyana's coast is exposed to the steady Northeast trade winds, due to which wind energy potential is significantly high. Wind assessments conducted thus far show that Guyana's coast has a favourable wind regime. Government of Guyana in collaboration with the Inter-American Development Bank (IDB) and the Global Environmental Facility (GEF) has been conducting wind measurements along the coast of Guyana. Apart from the potential of large wind turbines, government will continue to monitor and assess the potential for wind energy in various locations including hinterland and isolated riverine communities.

8.2.4 Biomass

Guyana's growing sugar and coconut industry has great potential for electricity generation from the waste generated from these industries. Bagasse, a by-product of the sugar industry and husks & shells from coconut industry has significant potential to generate electricity. Industries can earn additional revenue by generating electricity from waste. Even though electricity generation from biomass may not be feasible to meet Guyana's power demand, it can help to reduce the reliance of the sector on imported fossil fuels like diesel and petrol, while having a positive environmental impact through reduced carbon emissions. Other biomass resources available abundantly in the country are rice husk and wood.

To date, two dual fuel-fired power gasifiers (down draft) having total generation capacity of more than 1 MW have been successfully commissioned at rice mills on the Essequibo Coast and Berbice region. The producer gas (Syngas) generated from the rice husk in the gasifier is fed to the existing diesel generator set to generate power. The use of a power gasifier approximately reduced 70% of the diesel consumption across the generators.

Figure 8.13: Power gasifier installed at a rice mill

8.4 Advancement in Renewable Energy System

8.4.1 Hybrid Renewable Energy System

Hybrid systems, combine two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply. Hybrid systems provide a high level of energy security through the mix of generation methods, and often will incorporate a storage system (battery, fuel cell) or small fossil fueled generator to ensure maximum supply reliability and security.

Hybrid renewable energy systems are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. The most common hybrid electrical power generation combinations are:

Figure 8.14: Solar Wind Hybrid System

- Solar + Wind
- Solar + Hydropower
- Hydropower + Wind
- Solar + Biomass

Advantage of hybrid renewable energy system are:

1. Increase capacity utilization factor (CUF) of the renewable power plant.
2. Reduces the unpredictability inherent with renewable energy system and improves the stability of the electric grid.
3. Optimize the uses of electrical infrastructure like transformers and transmission line.

8.4.1 Decentralized microgrid

The term microgrid refers to a single electric power subsystem linked to a small number of distributed generators that can be powered by either renewable or conventional sources of energy, along with different load clusters. The key feature of microgrids is that they can operate independently of the central grid. This can help improve the power quality and reliability, as well as allow the local community to have more control over their power network. The basic microgrid architecture is comprised of the following components: electricity generation source, an energy storage system (optional), a distribution system, and a communication and control system.

The main criteria for distinguishing different kinds of microgrids are: (a) whether it is connected to a central grid; and (b) what kinds of generation sources are connected to the microgrid. When a microgrid is not connected with a central grid it is known as decentralized microgrid and when the source of power generation is renewable it is known as decentralized renewable microgrid.

Advantages of decentralized microgrid are:

1. **For small villages microgrids are more economical**: Many remote villages have less than 50 households and their immediate need for electricity is very low, with demand often only for lighting, phone chargers, television, and fan. For such household demand for electricity was about 6-7 kWh a month, which averages to about 0.2 – 0.25 kWh of electricity used per day. The cost of extending the grid for such a small load is often uneconomical as the capital cost for grid extension can be much higher than for microgrid development, especially for such low load levels.
2. **High cost of grid extension due to geographic distance:** Grid extension to remote rural villages can be enormously high due to their distance from the grid, and this cost is often much higher than developing decentralized renewable microgrids in these remote villages.
3. **Microgrid allows local control over power generation**: Microgrid provides ability to villagers to control and take part in power management. More specifically, they can control the load to increase reliability and decide how to allocate load use.
4. **Microgrid provide more reliable power supply to isolated rural areas**: Grid power is often not prioritized for rural areas. Load shedding often occurs for extensive time periods and at unplanned times. These unplanned load shedding will make power supply to isolated rural areas highly unreliable. Decentralized renewable microgrid power might be limited but it has the potential to provide more reliable electricity to rural areas.

Figure 8.15: Villagers with decentralized solar microgrid

CHAPTER 9

Financial Management

9.1 Introduction

Implementation of energy management in any facility requires some action like service or retrofits of equipment or change of process demands for investment and this leads to energy cost savings. Projects like energy transition require more modifications and a large investment, which can lead to suitability in the future from the use of energy. The proponent should make a judicious decision as it is critical to evaluate the implementation of energy conservation measures for the investments and realizable energy cost savings. Currently, there are several advanced clean and more cost-effective energy technologies that help in minimizing the environmental impact (e.g., mitigation of carbon emissions).

The various cost components of energy efficiency project management are highlighted in Figure 9.1.

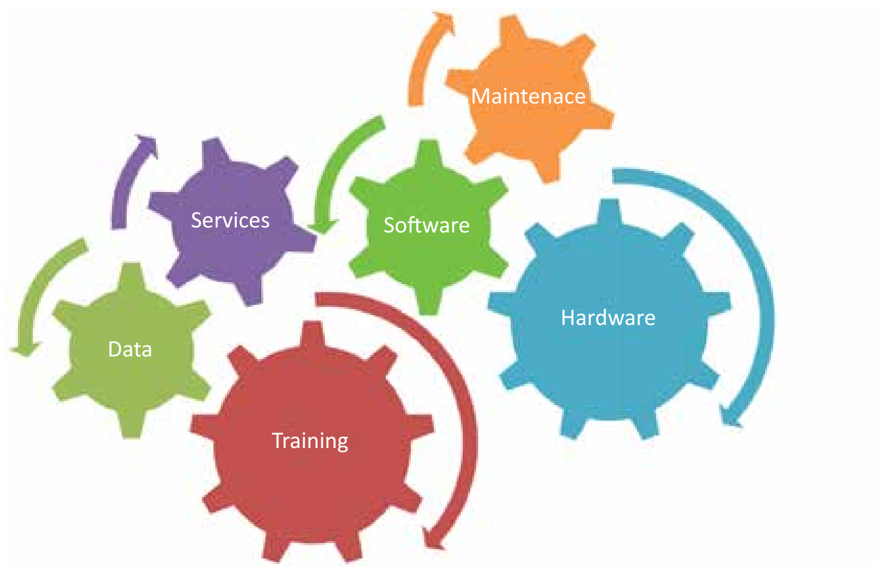


Figure 9.1: Various components of Energy Efficiency Projects

While evaluating energy efficiency projects, it is important to accrue all possible benefits that are anticipated from the project. The overall actual cost savings obtained based on the energy savings of the project may often exceed significantly the estimated figures. For example – in a textile mill, a traditional gas dryer was replaced with a radio frequency (RF) dryer to dry cotton. RF dryers can accelerate the drying process and shorten the production time. Besides, not only reducing the energy required for drying, but this retrofit measure also helps in minimizing the cotton fiber loss by almost 5 per cent. The overall cost saved per ton of material energy to raw fibers is 200 times the raw material cost savings and attracted the project feasibility.

9.2 Criteria for selection equipment for Energy Conservation

The energy-intensive equipment across any facility to be first listed is based on annual energy cost (E) and its depreciation (D). The E/D ratio has to be developed for various operational equipment. It is the ratio of the annual energy cost of the equipment over the annual simple depreciation of the equipment over its assumed technical life.

Equipment	Annual Energy Cost (E)	Annual Depreciation (D)	E / D ratio
 **Incandescent Bulb**	Rating of bulb: 60 Watts Life of bulb: 1000 hr Electricity cost: GY$ 55 per kWh	Investment cost: GY$ 325	$\frac{E}{D}$ ratio $= \frac{3300}{325}$ =~10
 **Refrigerator**	Energy consumption: 2 kWh/day Life of refrigerator: 10 years Electricity cost: GY$ 55 per kWh	Investment cost: GY$ 130,000 Depreciation: 130000/10 : 13,000	$\frac{E}{D}$ ratio $= \frac{40,150}{13,000}$ =~3
 **AHU fan motor**	Energy consumption: 11 kW Operating hours: 6000 per year Electricity cost: GY$ 55 per kWh	Investment cost: GY$ 1.2 million Technical life: 10 Years Depreciation: 1.2 million/10 : 0.12 million	$\frac{E}{D}$ ratio $= \frac{3.6}{0.12}$ =~30
 **AHU fan**	Energy consumption of fan: 11 kW Operating hours: 6000 per year Electricity cost: GY$ 55 per kWh	Investment cost: GY$ 0.45 million Technical life: 10 Years Depreciation: 0.45/10 : 600	$\frac{E}{D}$ ratio $= \frac{3.6}{0.045}$ =~80

The evaluated E/D ratio of the above-listed equipment varies from 3 to 80. Use E/D ratios to select the most financially attractive equipment for achieving energy conservation. However, developing such a list of equipment for any facility should factor in the present equipment replacement cost.

A high E/D ratio is ideal for detailed investigation to assess the energy conservation options (retrofit or change of process or capital investment of replaces) for any particular equipment. It is important to note that the actual investment budget includes all services for the implementation of energy conservation measures. When a high energy cost component is compared to the investment, we will find high E/D. A low E/D ratio of equipment is not important for selecting it for implementation. Sometimes the transaction cost to identify energy cost reduction measures of low E/D ratio equipment may be high compared to energy cost savings.

9.3 Financial Analysis

It is important to know the financial analysis of energy efficiency projects that needs to be carried out to make an investment decision. The energy efficiency project financial analysis includes greenhouse gas emissions and other resource conservation impacts on the project life cycle. The quantification of energy and cost savings, variation in values (like electricity tariff change) over the life span of the project is a critical parameter for project viability. It is equally important for the participation of all stakeholders because alternative options can be reviewed before making the final decision.

Various project implementation parameters such as investments, cost savings, cash flows and O & M cost changes for a different type of project. The common criteria followed by numerous methods are

a. Non-discounted (non-time value)

   a. Payback period method

$$\textit{Payback period} = \frac{\textit{Investment cost}}{\textit{Annual net savings}}$$

   b. Return on Investment (ROI) method

$$\textit{ROI} = \frac{\textit{Average annual net savings}}{\textit{Total investment cost}}$$

b. Discounted (time value)

Like other financial projects, the investment in an increased energy efficiency project should reveal a reduction in its energy consumption for capital investment. The complexity of financial analysis increases from a simple payback period or ROI to more precise and complex calculations such as Net Present Value (NPV) or Internal Rate of Return (IRR). Both NPV and IRR takes the time value of money into account for analysis.

The review of economic analysis of any investment project should include basic evaluation criteria which are listed below:

- A simple payback period is a criterion that gives information on how long it will take for the investment to realise profits.
- IRR and ROI are the economic analytic tool which allows comparison which investment option is attractive or not
- NPV and Cash flow analysis tools help in the effective planning of energy efficiency projects providing valuables information on cash inflow and outflows.

9.4 Economic Analysis of Investment

Economic analyses of energy conservation project investment using standard methods are discussed in this section.

Simple Payback period

The simple payback period refers to the total time that is required to recover the investment cost. In another way, it is the length of time an investment reaches a break-even point. This tool highlights the project's liquidity rather than its profitability. The projects with short duration paybacks are considered to be attractive for investment. Some of the advantages and disadvantages of the simple payback period method are listed below:

Advantages

- It is simple and easy to calculate;
- The energy conservation projects with a shorter payback indicate a smart investment;
- Energy conservation projects with sizable returns during initial years are preferred.

Disadvantages

- This method fails to reflect the cash inflows beyond the payback period which may lead to misjudging projects that have the potential to generate significant cash inflows in later years;
- Another drawback of this method is that it doesn't consider the timing of cash flows adequately;
- Investment decision based on simple payback period not advisable as it does not account for the time value for money.

Sample calculation

A new technology-based split air conditioner as a retrofit to the old air conditioner called for an investment of GY$ 0.5 million and the operation of the same led to annual revenue of GY$ 0.22 million. The annual maintenance contract is GY$ 0.1 million each year. Compute the simple payback period of this project.

$$\text{Simple Payback} : \frac{\textbf{Initial Investment, in GYD}}{\textbf{(Annual Revenues – Annual Expenses)in GYD/year}}$$

$$= \frac{\mathbf{0.5}}{\mathbf{0.22 - 0.1}} = \mathbf{4.2\ years}$$

The payback period of the retrofit project is calculated by dividing the initial investment cost by the difference in annual incomes and expenses. Thus, the payback period method indicates only the time for recovering the investment which is 4.2 years and does not indicate anything about the attractiveness of the project.

Net Present Value (NPV)

Before making any decision on any energy efficiency measures, various alternative options and their investment is compared. It is important to compare various options into a single equivalent value as total cash flow. The issue with comparing cash flows that are occurring at different periods (stages of project life cycle) is mainly due to continual change in the value of money with respect to time. For implementation of the project, the availability of several options and all future cash flows must be compared to a common basis which is called present value, which is nothing but the time value of money.

To showcase the time value of money a simple example is described:

An electrical contractor offered to a commercial building for the replacement of existing tube lights with LEDs and was ready to pay one of two options by making an investment and realizing of reduction of energy cost. The proposed offer will either pay you GY$ 1,000 now or GY$ 1,100 one year from now. You need to decide on the payment option.

Immediately, the kind of investment returns that the building owner can earn with the money at present will be assessed. Since GY$ 1,100 is 110% of GY$ 1,000, alternative capital investment measures should make more than a 10% return (as interest) on the money by investing it over the next year, or the decision should be to take the GY$ 1,000 now. If other options don't realize to yield more than 9% in the next year by investing the money, it is beneficial to take the future payment of GY$ 1,100 with the guaranteed mechanism.

If the interest rate was not 10%, then the corresponding present value of money would also get changed. The following formula gives the basic link between the present and future value.

$$\textit{Future Value (FV)} = NPV\ (1+i)^n \text{ or } NPV = FV/(1+i)^n$$

Where;

FV : Future value of the cash flow

NPV : Net Present Value of the cash flow

i : Interest or discount rate

n : Number of years

The NPV of a project is calculated by deducting the present value of the initial investment from the present value of all future cash inflows and expenses. The preferred value of Interest rate (i) for discounting future cash flows is usually considered either the prevalent market interest rate for availing finance or the rate of the returns that are currently earned by the facility on the invested amount. A positive value of the NPV implies that the investment made is attractive as the returns are greater than the discounted rate. NPV calculations can be easily performed using a personal computer or a discount table. Some of the advantage and disadvantages of the NPV criterion are listed below:

Advantages

- NPV method considers the time value of money with respect to the interest or discount rate chosen for evaluation;
- It helps in the decision making process for project managers.
- NPV is the amount by which equivalent receipt of cash flow exceeds or fail to receive minimum expenses of that cash flow.

Disadvantages

- Project cash flows (in and out) will be predicated for the total project lifetime and require equal time for comparing other alternative investment options;
- The ranking of alternative options varies with the selected discount rate;
- There are no set guidelines to calculate the required rate of returns
- This method cannot be used to compare projects of different sizes
- It cannot identify hidden costs involved during project execution

NPV of the project is equal to the sum of the present values of the cash flows over the lifetime of the project. The expression for calculating NPV is presented below:

$$\frac{FV_0}{(1+i)^0} + \frac{FV_1}{(1+i)^1} + \dots + \frac{FV_n}{(1+i)^n} = \sum_{t=0}^{n} \frac{FV_t}{(1+i)^t}$$

Where; t : time period

Sample calculation

A Hotel staff has proposed replacement of insulation for baking oven to increase productivity (by cycle time optimization). The capital investment is GY$ 15,000 and the new insulation has 5 years of expected shelf life. The increased productivity of the furnace is equal to an amount of GY$ 5,000 per annum after subtracting extra operating costs due to additional production. Comment on the attractiveness of this proposal by using the Net Present Value method.

The steps involved in the NPV method are given below:

- Select a suitable discount rate;
- Analyse the present value of the cash profits that are expected from the investment;
- Calculate the cumulative present value of the money required for the investment.

To determine the cumulative present value a table format can be developed with project investment and an expected life of 5 years. A discount rate of 10% and 20% can be used for comparison purpose.

Year	Value, GY$	Present Value		
		at 0% discount	at 10% discount	at 20% discount
0	-15,000	-15,000	-15,000	-15,000
1	5,000	5,000	4,545	4,166
2	5,000	5,000	4,132	3,472
3	5,000	5,000	3,756	2,893
4	5,000	5,000	3,415	2,411
5	5,000	5,000	3,104	2,009
Total (Net PV)		10,000	3,952	-49

Discount at 10%,

$$NPV = \frac{-15000}{(1+0.1)^0} + \frac{5000}{(1+0.1)^1} + \frac{5000}{(1+0.1)^2} + \frac{5000}{(1+0.1)^3} + \frac{5000}{(1+0.1)^4} + \frac{5000}{(1+0.1)^5}$$

NPV = -15000 + 4545 + 4132 + 3756 + 3415 + 3104 = (+)3,952

Discount at 20%,

$$NPV = \frac{-15000}{(1+0.2)^0} + \frac{5000}{(1+0.2)^1} + \frac{5000}{(1+0.2)^2} + \frac{5000}{(1+0.2)^3} + \frac{5000}{(1+0.2)^4} + \frac{5000}{(1+0.2)^5}$$

NPV = -15000 + 4166 + 3472 + 2893 + 2411 + 2009 = (**-**)49

The decision for implementation is related to the NPV principle. The project can be accepted if the NPV value obtained is 'Positive' and rejected if the NPV value obtained is 'Negative'. In the present case, the discount rate at 10% calculated NPV is greater than Zero.

Return on Investment (ROI)

Return on Investment (ROI) is a concept that is used to evaluate the profitability of an energy efficiency project investment or compare the efficiency of many different projects. It expresses the annual returns as a percentage of capital cost.

ROI is calculated as the percentage of the returns on the investment divided by the capital investment.

$$ROI = \frac{\textit{Annual net cash flow}}{\textit{Capital Cost}} X\,100$$

ROI should always be greater than the rate of interest. The higher the ROI, the more attractive is the investment. Some of the key takeaways of ROI are listed below:

- It is a popular profitability metric tool that evaluates the attractiveness of the investment.
- ROI can be used to make apple-to-apple comparison and rank investments in different projects or assets.
- ROI cannot assess the opportunity cost of investing in other areas as it does not account for the waiting period.

Internal Rate of Return (IRR)

The internal rate of return (IRR) is a kind of discounting cash flow technique that gives a rate of return earned by a project. It refers to the discount rate at which the sum of initial cash outlay and discounted cash inflows are equal to zero. In other words, IRR is the discount rate at which the NPV is equal to Zero. It is calculated by the trial and error method until NPV is reduced to zero. The expression to calculate IRR is presented below:

$$0 = \frac{FV_0}{(1+i)^0} + \frac{FV_1}{(1+i)^1} + \cdots \qquad + \frac{FV_n}{(1+i)^t} = \sum_{t=0}^{n} \frac{FV_t}{(1+i)^t}$$

IRR is measured mainly to investigate the profitability of a potential investment. The higher the value of IRR the more attractive the investment is. The advantages and disadvantages of IRR are listed below:

Advantages

- It is a widely accepted indicator of project profitability;
- There is no need to determine the discounted interest rate for the project as it can be related directly to profit goals;
- IRR concept is best suitable to compare two or more projects before finalizing the investment decision.

Disadvantages

- IRR method is a trial and error method and cumbersome;
- The result obtained in IRR calculations cannot differentiate the fund which is obtained either by lending or borrowing for project implementation.

Sample calculation

An investment of GY$ 100,000 can be made at a public-school building (replacing lighting fixtures, installing solar water heater, etc.) that will produce a uniform annual savings of GY$ 30,000 for 5 years. The management is ready to accept any project that can earn a discount rate of 10% or more excluding taxation on all invested capital. Justify the decision with the help of the IRR method.

The calculation steps involved in the IRR method are given below:

- Set the NPV as Zero and determine the discount rate;
- To find the discount rate at which the present value of cash inflow is equal to the present value of cash outlays.

The equation of IRR for the present investment is

$$0 = \sum_{t=5}^{n} \frac{100{,}000}{(1+i)^t}$$

The value 'i' is obtained by following the trial and error method substituting with different values of 'i' till the right-hand side of the above equation is equal to 100,000.

Initially 'i' value can be considered as 15% and substitute in the above formula

$$0 = \frac{-100000}{(1+0.15)^0} + \frac{30000}{(1+0.15)^1} + \frac{30000}{(1+0.15)^2} + \frac{30000}{(1+0.15)^3} + \frac{30000}{(1+0.15)^4} + \frac{30000}{(1+0.15)^5}$$

= -100,000 + 26,086 + 22,684 + 19,736 + 17,152 + 15,600 = **1,258**

The value obtained with i=15% is slightly higher than the target value (GY$ 100,000). Now, the 'i' value can be considered as 16% and substituted in the above formula:

$$0 = \frac{-100000}{(1+0.16)^0} + \frac{30000}{(1+0.16)^1} + \frac{30000}{(1+0.16)^2} + \frac{30000}{(1+0.16)^3} + \frac{30000}{(1+0.16)^4} + \frac{30000}{(1+0.16)^5}$$

= -100,000 + 25,862 + 22,294 + 19,230 + 16,574 + 14,285 = **(-)1,755**

From the above result, we can conclude that the value of 'i' lies between 15% and 16%. The project is justified with an IRR of 15%, which is above 10% of the set acceptance criteria. To substantiate the profitability and viability of the energy conservation project, a detailed analysis is to be carried to find NPV and IRR results.

9.5 Sensitivity and Risk Analysis

In a real-time situation, the project returns are spread over time and involve some sort of uncertainty concerning the initial estimation. Hence, the concepts of Sensitivity and Risk analysis are introduced in the project management which specifically deals with uncertainty. The main objective is to reduce the possibility of undertaking bad projects while not failing to accept good projects.

Sensitivity analysis is a financial concept that determines how target parameters are affected based on other input variables. This concept is also referred to as "What-if" or "simulation analysis". It is a method to predict the outcome of a decision given a certain range of variables.

Risk Analysis uses statistical concepts to study the underlying uncertainty and find the probability of a project's success or failure and possible future economic states. The risk analysis model allows a balance to be struck between taking risks and reducing them. Sometimes taking too much risk can lead to failure.

9.6 Financing options

At a certain time, the energy management process would need funding/ investment to reduce the consumption of energy of a process in a facility or plant utility. The investment will be higher for retrofitting or modifications or adopting new technologies. A systematic approach should be adapted to evaluate different investment options for the predicted energy savings. Identification of associated benefits and the intended benefits for energy savings of the proposed measure.

The costs that are involved in the proposed measures should be taken in totality, i.e;

- Equipment and installation (as direct) project costs
- Additional operations and maintenance costs
- Training of manpower on new technologies etc.

The need for investing in energy efficiency projects can arise under the following situations, i.e.;

- Installing new equipment for process improvements, etc.
- To implement or upgrade the energy information system
- To provide staff training
- Other priorities

Financial Structuring of Project

Immediately after the technical energy audit, requirements for larger-sized energy efficiency projects should include information on the financial structuring of the project. The information should include

i) Projects of projected cash flow before financing
   - » Capital investment
   - » Operation and maintenance costs
   - » Energy Savings
   - » Cost Savings

ii) Definition of project implementation option
   - » Internal financing
   - » International financing/supports
   - » Bank loans
   - » Third-party financing such as equipment manufacturers/suppliers

iii) Cash flows to various parties after financing
   - » City Council/ Municipal water utility / Private firm
   - » Financial Institution
   - » Third parties if involved in the implementation

The smart way of selecting energy conservation measures is by looking at cost-effectiveness which is assessed using economic models. Different economic models can be used with detailed analysis in different situations; but, the simple payback period for any investment should not be too long. However, during the study of different alternatives, the economic models should adequately consider savings throughout the project lifetime.

ESCO Model of Financing

ESCO is a company that provides technical competency for a comprehensive range of energy solutions. ESCO company enters into a performance contract with the Municipality (or) a building facility for the execution of energy efficiency measures to optimise energy consumption and minimise energy costs technically and commercially. For financing and implementation, ESCO contracts (a typical service or equipment supply) are considered viable business models across the globe.

Initially, an investment-grade energy audit (IGEA) is conducted, and commercially feasible energy efficiency measures will be implemented. The implementation project can be funded either by the ESCO or by the Municipality/facility. For project execution, an Energy Performance Contract (EPC) can be entered between the ESCO and the Building (or) Municipality that will offer smart returns in the form of reduced energy cost through energy usage optimisation with improved delivery of services. Such contracts may have benefits and setbacks that are built in the contract in the form of implicit or explicit sureties.

The duration of the ESCO contract has an impact on the risk perception. With a longer duration, the uncertainty and risk involved in the contract are higher. A similar situation might arise during the contract making if the ESCO is responsible for mobilising products for a longer duration.

Engaging the services of ESCO is either a one-step or a two-step process by the building (or) Municipality. Investment Grade Audit and the effects of energy savings by implementing recommended measures are done by ESCO in the single-step process. Similarly, for the two-step process, the beneficiary contracts initially with ESCO to carry an IGEA, and based on the results obtained in the process, the energy-saving measures shall be prioritised to proceed for implementation depending on the investment, installation time, and payback period.

The benefits of the energy efficiency projects will be realised only after effective implementation, verification, and validation of savings by the municipality or building management. The progress of the project should be monitored by the ESCO and the beneficiary and be prepared to undertake any midcourse correction if necessary to ensure the implementation is successful. The Municipality/ City council should be mindful that the foremost strength of ESCO is its technical expertise and key personnel along with its ability to organize financing, and sometimes the change in management or manpower may upset the quality of the project.

CHAPTER 10

Energy Data Recording and Analysis

Energy is defined as the ability to perform work. Different forms of energy are potential, kinetic, thermal, electrical, chemical, and nuclear, or others such as heat, light, etc. One form of energy can be transformed into another form of energy by employing specific mechanisms depending on the type of work or application. Different facilities or factories use different forms of energy. For example, fossil fuels such as heavy fuel oil (HFO), diesel, etc., are used as primary energy in power generators for electricity generation, where chemical energy is converted into electrical energy. Buildings predominantly use electrical energy for powering equipment such as lighting, air conditioning, water pumps, escalators, etc.

The energy consumption of equipment and overall performance of a facility or a building or a factory can be established by carrying a detailed energy audit, which is performed by collecting all the equipment design details, operating parameters with the help of sophisticated handheld instruments along with analysis of historical data available from facility metering and records (basic requirement of ISO 50001 documentation). Analyzing the collected information will help in understanding the historical and present performance levels of the respective facility. To maintain the day-to-day energy consumption efficiently, it is highly essential to start a monitoring programme with a benchmarking and targeting system to improve the overall energy performance of the facility and result in significant energy cost savings and carbon emission reduction. Energy management concepts are applied to large industries or buildings and even to small households, facilities, etc. It is based on the principle "we can't manage what we can't measure" The above explanation is collectively called an "Energy management system."

10.1 Measuring instruments - Electrical and Thermal

Depending on the type of equipment, there are several types of instruments available for collecting different operating parameters of the electrical and thermal sections of the facility. Such instruments provide reliable data for carrying a detailed performance analysis, thereby ensuring accurate results. Some of the instruments used to carry a detailed energy audit are provided in Table 10.1.

Table 10.1: List of instruments used to perform energy audits

Name	Description	Picture
Power quality analysers/Load analysers	To measure instantaneously and also to record various electrical power parameters such as • The fundamental value of Voltage and Current, • Voltage and Current total harmonic distortion, • Individual Voltage and Current harmonics • Active, Reactive and Apparent Power (P, Q, S); Power factor • Frequency • Voltage and Current Unbalance assessment • Demand analysis • Other power quality parameters such as surge/dip and transient analysis It is possible to download the recorded data to MS Excel for further analysis.	  
Tachometer/ Stroboscope	• Used for speed measurement of rotating equipment such as electric motors, pumps and blowers, conveyors etc. • Available in contact and non-contact types	
Lux meter	• Used for illumination level measurement. • Can be used to measure the instantaneous value or record the variation in lux level over a period.	

Contd...

Table 10.1: List of instruments used to perform energy audits

Name	Description	Picture
Flue gas analyzer	• Used to measure Oxygen (O2) and Carbon dioxide (CO2) levels in the flue gas • Other flue gas parameters such as Carbon monoxide (CO), Nitrogen Dioxide (NO2), Temperature and Humidity can also be measured	
Infrared Thermometers	• Used for measuring the temperature of liquids, air/gases, slurries, semi-solids, powders, electrical cables, bus bars, etc. • The images can be saved to a memory card and downloaded to carry out analysis using a software	
Ultrasonic flow meter	• Used for measurement of the flow of liquids through pipelines of various sizes using ultrasonic sensors mounted on the surface of the pipelines. • Flow can be recorded for the required period and downloaded for analysis	
Digital or analog hygrometer	• Used to measure temperature and humidity for measuring various properties using a psychrometric chart	

Contd...

Table 10.1: List of instruments used to perform energy audits

Name	Description	Picture
Anemometer	• Used to measure air velocity to estimate the volume of air intake	
Conductivity and PH meter	• To analyse water quality	
Digital manometer	• Used for measurement of differential pressure using pitot tubes	
Analog/Digital pressure gauge	• To measure the fluid or air pressure	

The details of the instruments provided in Table 10.1 present a broad understanding of the types of instruments used for carrying an energy audit. These instruments need to be calibrated as and when required so that the measured data is reliable for energy efficiency analysis. One has to carefully use the instruments as per the procedures specified by the manufacturer.

The above-mentioned instruments are available in handheld type or online type for industries where continuous data measurements are required for energy and various process parameters monitoring operations and controlling purposes.

10.2 Energy Management - Data collection and analysis

Energy management is defined as a "proactive, organised and systematic coordination of procurement, conversion, distribution and use of energy to meet the requirements, taking into account environmental and economic objectives". In simple words, it is a process involving optimisation of energy use for the best possible outcomes and taking steps for conserving energy. As the major portion of the energy being utilised in our day-to-day life is fossil fuel-based and has conversion efficiency involved, efficient energy management is a key component of Carbon emissions management or Net-Zero. The use of fossil fuel-based energy always involves greenhouse gas emissions, which negatively impacts the environment. Energy management concepts can be applied to all kind of building facilities big to small, large to micro industries and every aspect of domestic life. Hence, energy efficiency concepts are highly important to consider for ensuring the efficient use of energy resources.

In order to manage the energy costs of any facility or an industry, the present usage pattern of the energy and the parameters that are influencing it need to be clearly known. This will help identify what opportunities are available to reduce the present energy usage. Some of the key steps involved in energy management are outlined in the following sections and briefly presented in Figure 10.1.

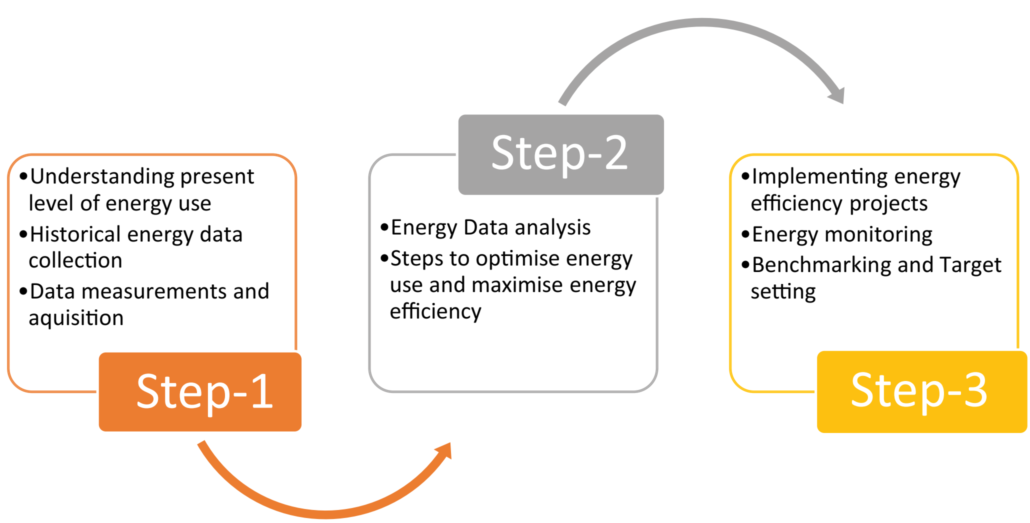


Figure 10.1: Various steps involved in Energy Management

10.2.1 Step 1: Data Collection

This step involves the collection of equipment design specifications, data measurement and recording critical parameters and historical energy consumption and production records of the facility. This helps to understand the present level of energy use for the current production levels. The energy-intensive areas can be identified either with available historical data or by using instruments, which are explained in the previous sections.

For example, the following are some of the list of sources from which information of different operating sections can be collected:

- Historical Electricity bills provide information on
  - » how the overall facility electricity demand is varying over a time period;
  - » how much electrical energy is consumed in a day or different shifts;
  - » How power factor is being maintained at the incomer;
  - » Section-wise energy meters installed in the facility to provide information on electrical energy consumption
  - » If there are no energy meters installed in the facility, then portable handheld instruments can record the power consumption data.
- Fuel consumption data
  - » Purchase receipts can be used to get information on the quantity of fuel being purchased.
  - » For solid fuels like rice husk or wood, weighed feeder data can be used to assess the quantity being consumed.
  - » For liquid and gas fuels, data obtained on the standard instruments can be collected or simple measuring techniques can be employed in case of non-availability of the instruments.
- Water consumption data
  - » Source of water to the facility such as municipal water supply or ground water pumps or river water pumps.
  - » Water flow rate measuring device can be used to get the actual consumption or municipality meter data can used to get the information on water consumption monthly.
  - » If no instrumentation is available, the pumps rated capacity can be used to estimate the consumption.

- All equipment level information can be obtained from nameplate data, run-time and schedule information, sub-metered data on specific energy consuming equipment.

In this way, a complete performance assessment of the energy intensive equipment can be assessed in a proper manner and the factors affecting the performance and energy consumption can be understood and measures planned for implementation to improve efficiency. Some of the factors that influence the energy consumption and cost are listed below as examples:

- Electrical system
  - » Electricity demand, power factor, actual energy consumption
- Steam Boilers
  - » Excess air to fuel ratio optimisation
- Diesel Power plants
  - » Heat rate optimisation

10.2.2 Step-2: Data Analysis

The access to energy data provides the managers of the facility with an opportunity to improve the energy management program. There are different varieties of numerical and statistical techniques that can be used to understand energy consumption patterns and associated costs. Some of the techniques involve quite simple calculations; others are more complex and require the use of information technology. The details of the techniques are discussed in detail below:

10.2.2.1 Basic Annual Energy consumption analysis

This is a basic assessment technique that allows assessing overall energy performance of a facility. The breakdown of annual energy consumption and associated costs can be assessed quickly and easily. The procedure to carry out the analysis of annual energy consumption data is illustrated below:

i. Compile the monthly energy consumption data of various fuels and energy types that are being used in the facility as per Table 10.2.

Table 10.2: Format for recording monthly energy consumption data of the facility

Month	Thermal Energy			Electricity consumption	Electricity Bill
	LPG	HSD	Energy cost		
	Kgs	KL	GY$	kWh	GY$
Jan					
Feb					
-					
-					
Dec					
Total					

ii. Energy consumption data of all types of fuels being used in the facility should be converted to uniform standard units (usually kCal or giga joules or toe (tons of oil equivalent)). Standard energy conversion figures are provided in Table 10.3.

Table 10.3: Standard values of energy conversion figures*

Energy source	Conversion factor	Unit
High Speed Diesel (HSD)	10,800	kCal/kg
Electricity	860	kCal/kWh
Natural gas	12,500	kCal/kg
Furnace Oil	9,520	kCal/kg
LPG	11,900	kCal/kg
1 ton of oil equivalent = 107 kilocalories		

**Compiled from various internet sources*

iii. A sample data of energy consumption data of an educational institute is shown below as an example in Table 10.4.

Table 10.4: Sample monthly energy consumption data

Month	Thermal Energy			Electricity bill details			Electricity Bill (B)	Total Energy bill (A+B)
	LPG	HSD	Energy cost (A)	Electricity consumption	Demand recorded	Avg. PF		
	kgs	Litres	GY$	kWh	kVA		GY$	GY$
Jan	100	950	323,477	1,03,889	357	0.98	6,399,547	6,723,024
Feb	115	1200	397,705	88,070	296	0.99	5,425,112	5,822,817
Mar	125	750	299,684	78,017	271	0.99	4,805,878	5,105,562
Apr	111	1200	393,855	89,192	278	0.98	5,494,258	5,888,113
May	120	1100	378,609	1,41,104	478	0.97	8,691,991	9,070,600
Jun	140	950	361,977	1,45,782	588	0.95	8,980,202	9,342,179
Jul	115	400	206,360	87,982	389	0.96	5,419,722	5,626,082
Aug	100	600	239,778	92,008	389	0.97	5,667,662	5,907,440
Sep	130	100	149,072	1,34,655	524	0.98	8,294,748	8,443,820
Oct	124	100	143,297	1,53,535	504	0.98	9,457,756	9,601,053
Nov	154	300	219,989	1,28,768	483	0.97	7,932,078	8,152,067
Dec	125	400	215,985	1,11,876	434	0.96	6,891,577	7,107,562
Total	**1,459**	**8,050**	**3,329,788**	**13,54,878**	**4,991**		**83,460,531**	**86,790,319**

From the table 10.4, it can be understood that the electricity and diesel consumption majorly vary seasonally whereas LPG consumption remains majorly unchanged.

- LPG consumption is given in kilograms (kgs). The cost of LPG is 48.6 GY$/kg. Calorific value of LPG is 11,900 kCal/kg.
- Diesel (HSD) consumption is given in litres. The cost of diesel is 185 GY$/litre and calorific value is 9241 kCal/litre.
- Electricity consumption is provided in kWh. The cost of electricity is 55 GY$/kWh with calorific value of 860 kCal/kWh.
- Converting all the energy consumption data to one common unit in kCal. The energy consumption details all converted to kCal is presented in Table 10.5.

Table 10.5: Energy consumption data in kCal

Month	Thermal Energy			B. Electricity consumption	Total Energy (A+B)	Total Energy (A+B)
	LPG	HSD	A. Total thermal energy			
	kCal	kCal	kCal	kCal	kCal	toe
Jan	1,190,000	8,778,950	9,968,950	89,344,540	131,486,959	13.1
Feb	1,368,500	11,089,200	12,457,700	75,740,200	127,289,505	12.7
Mar	1,487,500	6,930,750	8,418,250	67,094,620	107,215,280	10.7
Apr	1,320,900	11,089,200	12,410,100	76,705,120	127,659,425	12.8
May	1,428,000	10,165,100	11,593,100	121,349,440	170,772,241	17.1
Jun	1,666,000	8,778,950	10,444,950	125,372,520	173,464,939	17.3
Jul	1,368,500	3,696,400	5,064,900	75,664,520	104,251,788	10.4
Aug	1,190,000	5,544,600	6,734,600	79,126,880	111,223,408	11.1
Sep	1,547,000	924,100	2,471,100	115,803,300	138,011,055	13.8
Oct	1,475,600	924,100	2,399,700	132,040,100	153,355,355	15.3
Nov	1,832,600	2,772,300	4,604,900	110,740,480	142,258,744	14.2
Dec	1,487,500	3,696,400	5,183,900	96,213,360	126,288,128	12.6
Total	17,362,100	74,390,050	91,752,150	1,165,195,080	1,613,276,825	161.3

From Table 10.5, the energy consumption and cost figures can be summarised and the details are given in Table 10.6.

Table 10.6: Summary of energy consumption and cost

Description	Energy consumption, kCal	Energy Cost, GY$
LPG	17,362,100	1,404,326
Diesel	74,390,050	1,925,231
Electricity	1,165,195,080	59,614,610

The break-up of energy consumption and energy cost of different fuels used in the facility are graphically presented in Figure 10.2.

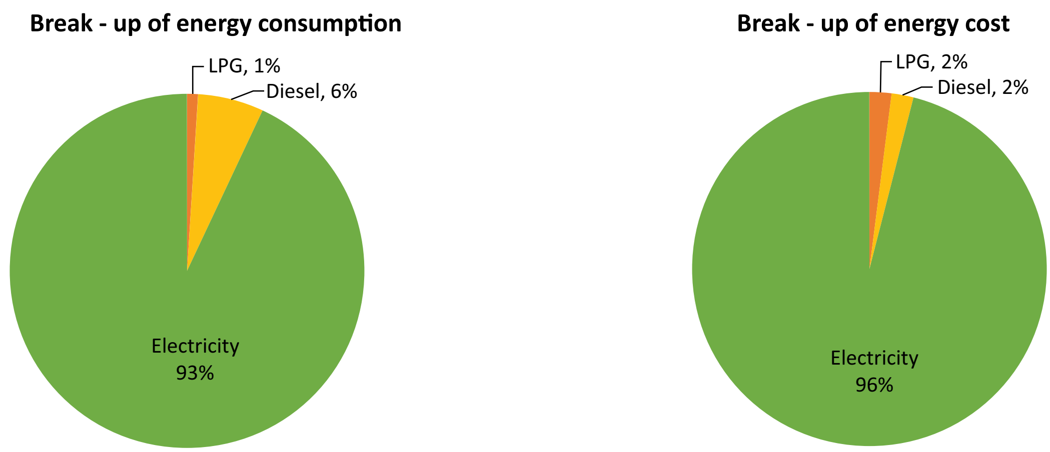


Figure 10.2: Break-up of Energy consumption and cost data

From Table 10.6, it can be understood that electricity consumption and cost is the major contributor, and electricity consumption reduction measures will help in significant cost savings to the facility. This type of analysis is made specific to the respective facility. It will depend on climatic factors as well as the type of occupancy and operational practices that are being followed in the facility. Hence, this analysis cannot be used to compare the facilities.

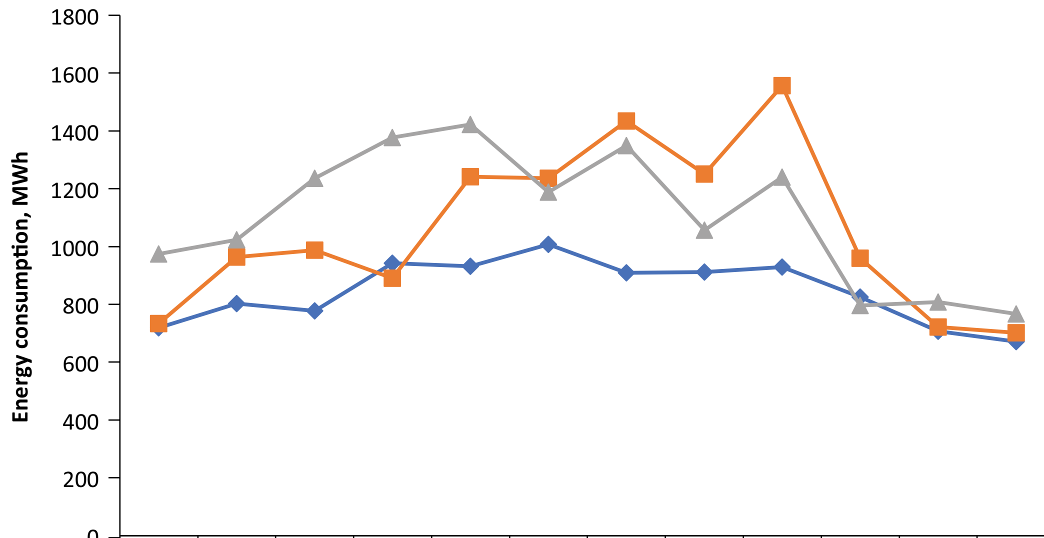
Energy data analysis depending on the time:

Monthly energy consumption data available for many years can be used to produce a simple graph where energy consumption is plotted against time. This kind of analysis makes it possible to identify general trends and seasonal patterns in energy consumption. The method of analysis has the limitation of finding out the certainty in the data plotted. Figure 10.3 shows the energy of consumption data for three years of a food processing industry.

From the above table, it can be seen that year 2017 has energy consumption less than the years 2018 and 2019 during the middle months. However, base energy consumption (during November, December, and January) was almost the same which approximately 700 MWh. Discussions with factory personnel revealed that there has been some increase in production during the summer months (i.e., May to September in the south Asian region) of 2018 and 2019 when compared with 2017.

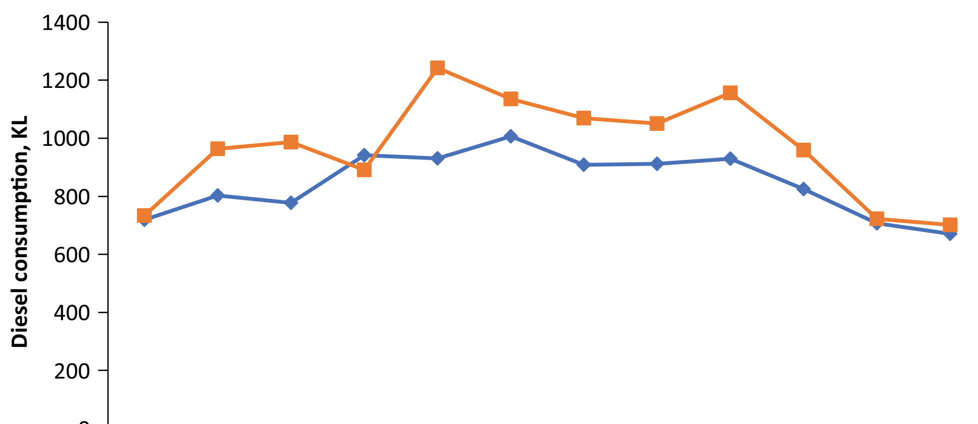
Energy consumption analysis using Norm Charts:

The Norm chart is a sequential plot comparing actual energy consumption with the target value. Both actual and the target (norm) data is plotted in the same scale of X and Y axes. The target values are decided based on the consumption pattern of previous years or the norms specified by OEM or specific standards. This helps to track the actual energy consumption and help factory managers and operating personnel to understand and compare the pattern easily. An example of the energy consumption data representation in Norm charts is presented in Figure 10.4.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2017	719	803	778	942	931	1007	909	912	929	825	707	671
2018	733	964	987	891	1242	1236	1434	1251	1556	959	722	701
2019	973.77	1023.2	1236.6	1376.7	1422.5	1188.3	1349	1056	1239.4	795.7	807.98	766.39

Figure 10.3: Three years electrical energy consumption data of food processing industry



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Target	719	803	778	942	931	1007	909	912	929	825	707	671
Actual	733	964	987	891	1242	1135	1069	1051	1156	959	722	701

Figure 10.4: Diesel consumption Pattern (Target (Norm) Vs Actual)

By analyzing the consumption pattern in Figure 10.5, managers can easily understand the changes and take measures to optimise consumption.

Energy consumption analysis using Deviance Charts:

Deviance charts are similar to the Norm Charts. The main difference is that the deviated values of the target and actual consumption are plotted with respect to the target (Norm) value. Higher consumption with respect to the target value is plotted on the positive side and lower consumption is plotted on the negative side. Upper and lower consumption norm limits can be clearly represented in the Deviance charts and any serious deviations can be easily noticed. The same data used to plot the Norm chart in the above section is used to plot the Deviance chart as an example which is shown in Figure 10.5.

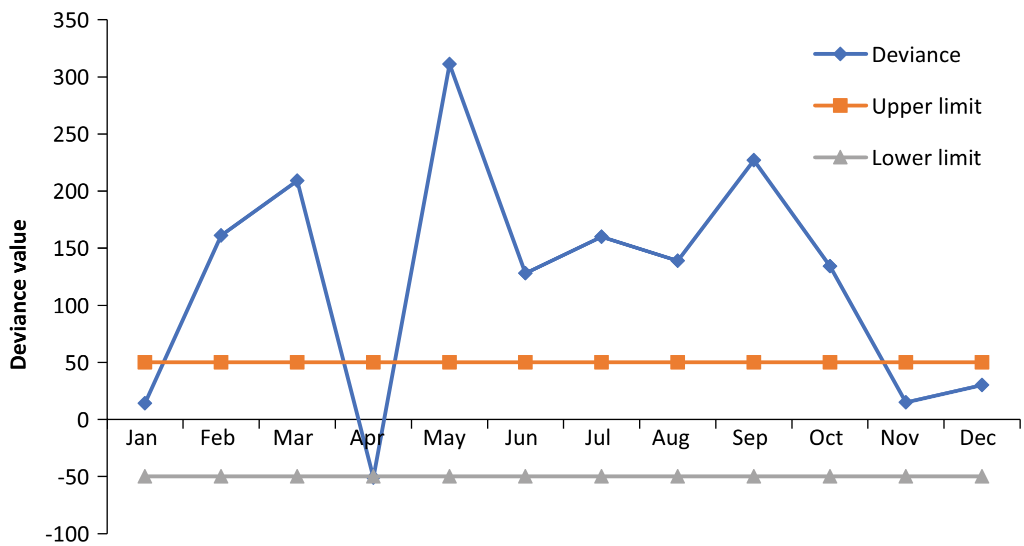


Figure 10.5: Deviance in diesel consumption Pattern

From Figure 10.5, it can be easily understood that the diesel consumption is very high for eight months in the year. This helps managers to target those months with higher consumption and take remedial action so that it will not repeat again during the next year.

Energy and Production Data analysis - Specific Energy Consumption (SEC)

Specific Energy Consumption (SEC) can be evaluated when energy and production figures are known. SEC gives a clear indication of how many units of energy are being consumed to produce one unit of the end product. Thus, SEC can be used as an analytic tool to compare with other similar industries and also to set norms or targets or Benchmarking. An example is shown in Figure 9.7 with energy and production data of a small chemical industry. The SEC derived is represented in the graph as Figure 10.6.

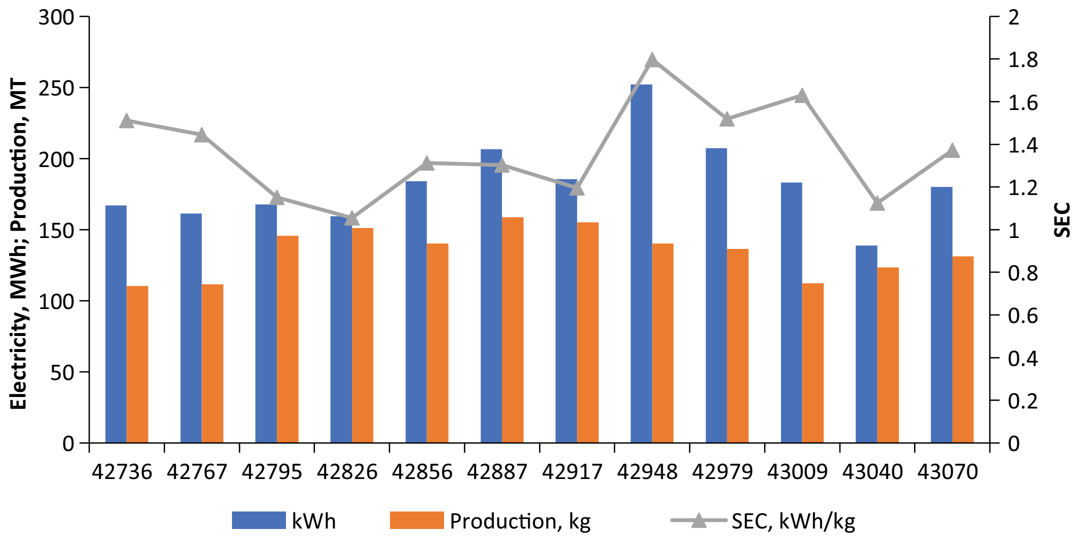


Figure 10.6: Plot showing trend of Energy, Production and SEC

SEC is an indication of how efficiently the product is being produced. When compared with the standard norm or benchmarks, actual SEC provides a valuable assessment of how best the plant or facility is performing and where it stands among its peers.

Energy and Production Data analysis – Moving Annual Total (MAT)

Moving Annual Total is another method of effectively representing the energy and production figures. To plot this chart, 12 months of energy and production data is required and each point plotted in the chart represents the sum of the previous 12 months data. In this way, each point has the full range of data that includes seasonal variations, holidays, etc. This method also smoothens out all manual errors due to improper recording. An example is shown in Figure 10.7 with energy and production data of a small petro-chemical industry.

MAT gives a clear picture of energy consumption variation (energy efficient usage or wastage). It also provides good analytic observation on how energy efficiency measures are making a positive impact as seen in Figure 10.7 as an example.

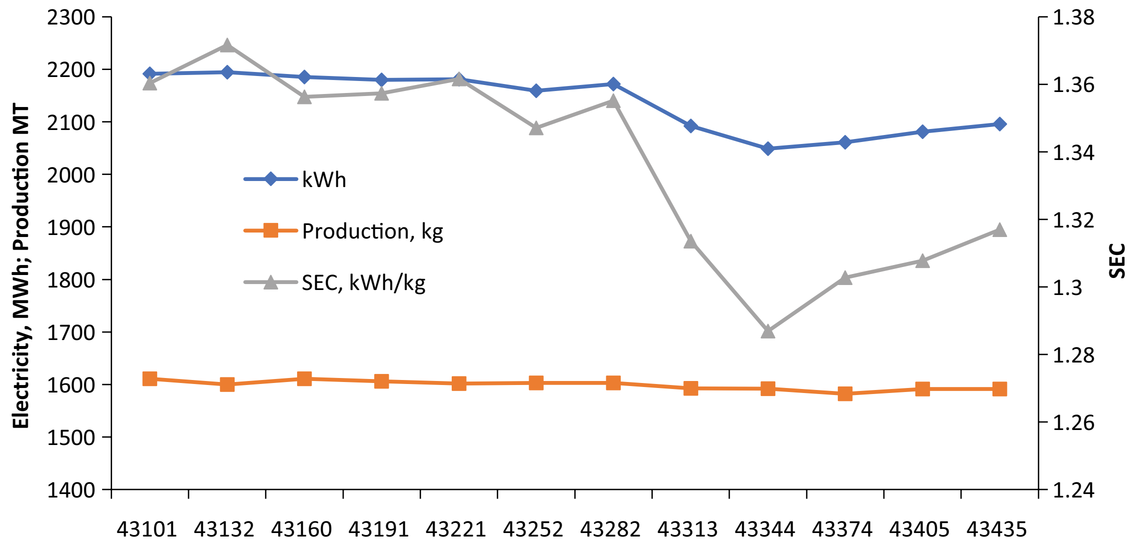


Figure 10.7: Plot showing monthly trend of Energy, Production and SEC

10.2.2.2 Statistical tools for Energy data analysis

Apart from the basic energy data analysis methods, several statistical techniques are available which can be used to determine and quantify the relationship between variables. Especially, when there is a huge volume of data available from organisations and businesses which have to be correctly interpreted for getting rightful assessments and results. With the current technology development and fascination over "big data analytics"; analysts have produced a lot of fancy tools and techniques for large organisations. However, several simple statistical tools are available for carrying data analysis, which can be used for proper decision-making. Some of them are detailed below:

Regression analysis:

Regression analysis is a widely used energy management statistical tool used to quantify the relation between dependent variables and one or more independent variables. It can be utilised to assess the strength of the relationship between variables and for modelling the future relationship between them. Type of regression analysis is shown in Figure 10.8.

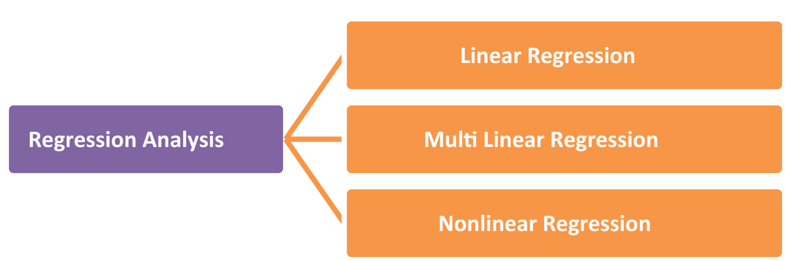


Figure 10.8: Different methods of Regression Analysis

Linear Regression Analysis is the most commonly used method among the Linear and Nonlinear methods of regression analysis. Nonlinear regression analysis is used for more complicated data sets where the dependent and independent variables show a nonlinear relationship. Regression analysis concepts can be applied in several disciplines such as energy, finance and research. Some of the basic assumptions followed for Linear regression analysis are listed below:

- The slope and intercept of the plot between independent and dependent variables should follow a linear relationship.
- The independent variable is not random.
- The values of the residual error are not correlated and are constant across all observations. They also follow the normal distribution.

For example in the energy context, some of the parameters that are commonly analysed with this method are listed below:

- Consumption of fuels such as diesel, furnace oil with respect to the number of units in operation.
- Electricity consumption versus production.
- Water consumption assessment with respect to the plant operation capacity
- Lighting power consumption with respect to the occupancy level in the facility.

Availability of high quality and a sufficient quantity of data is the main requirement of Regression analysis. The variables that are being analysed play an important factor in obtaining the results. For example Table 10.7 shows some of the factors which influence energy consumption in different applications.

Table 10.7: Parameters that influence the energy consumption

Type of Energy	Application	Influencing factor
Electricity	Water pumps	Quantity of water delivered
Rice Husk/HFO	Steam Boilers	Quantity of steam generated
Diesel	Diesel power generators	Number of electrical unit generated
Electricity/Steam	Production process	Production Volume

Linear Regression analysis can be carried with a single variable or multiple variables. The methodology to carry out the analysis is explained below:

1. **Regression analysis using single Independent Variable**

This model is called as Simple linear regression that evaluates the relationship between a dependent variable and an independent variable. This model uses n XY scatter plot to represent the data and follows the expression of a straight line, i.e;

$$Y=a+bX$$

Where: Y : Dependent Variable

X : Independent variable

a : Intercept

b : Slope

If the above equation is best fit to a set of sample data points, then the coordinate are represented by (x_1,y_1) (x_2,y_2) (x_3,y_3) .... (x_n,y_n). Here, 'n' is the number of data points.

The normal equations of the problem to establish 'c 'and 'b' are given below:

$$an+b\sum x= \sum y, \text{ Where 'n' is the number of data points}$$

$$a\sum x+b\sum x^2= \sum xy$$

Example: A sample data of energy and production of a small process industry is given in Table 10.8.

Table 10.8: Energy and Production data of a process industry

n	Month	1	2	3	4	5	6	7	8	9	Total
x	Production in Tonnes	382	442	462	522	322	522	242	622	602	4114
y	Energy use, toe	342	342	382	382	302	402	282	426	422	3278
x2		145619	195011	213075	272067	103427	272067	58371	386387	361923	2007943
xy		130355	150851	176147	199043	96995	209475	68035	264553	253635	1549085

Substituting the values in the above equations

n = 9; x = 4114; y = 3278; x^2 = 2007943; xy = 1549085

$$9a + 4114b = 3278$$

$$4114a + 2007943b = 1549085$$

$$a = \frac{3278-4114b}{9}$$

$$4114\left(\frac{3278-4114b}{9}\right) + 2007943\ b = 1549085$$

$$1498410 - 1880555b + 2007943b = 1549085$$

$$127388\ b = 50675$$

$$b = 0.3964$$

$$a = \frac{3278-(4114\ x\ 0.3964)}{9} = 183$$

Therefore, the best fit straight line equation:

$$y= 183+0.3964x$$

From the obtained result, it can be seen that the estimated baseline energy consumption of the plant is 181 toe. When the data mentioned in table 10.8 is plotted in MS Excel, the best fit linear equation shown is presented in figure 10.9.

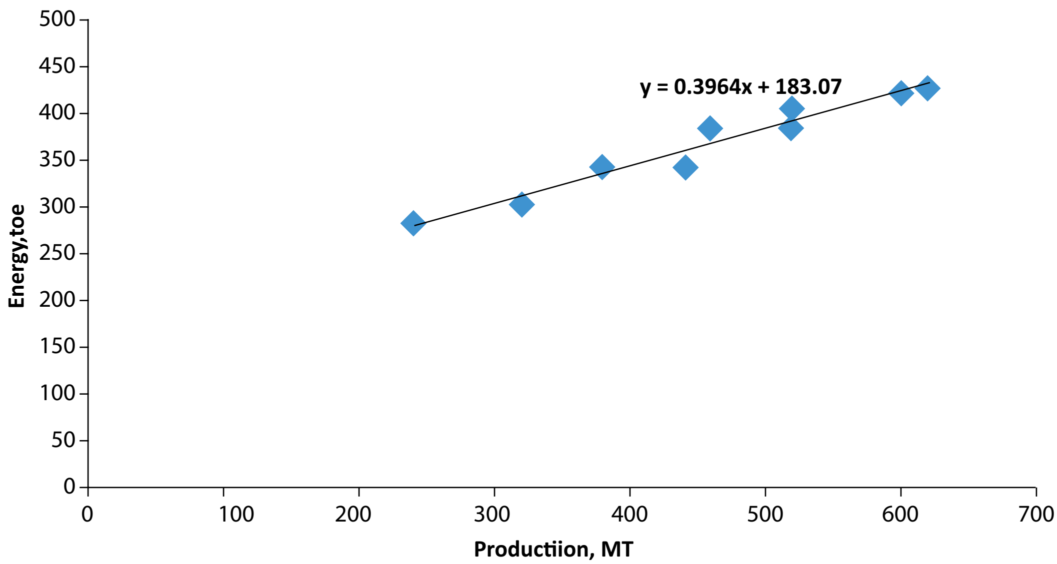


Figure 10.9: Energy and Production data with linear regression equation.

The equations obtained in both the methods are almost same. This chart shows a low degree of scatter, which indicates best fit. With poor data, the degree of scatter will be very high, leading to poor analysis and estimation of dependent variables.

Correlation Coefficients:

Linear regression method explained in the above section enables a best fit equation to be determined for sample data. Sometimes, the sample data points may be very scattered and the derived equation may not provide proper results as anticipated. Hence, it is important to determine how well the best fit line correlates to the sample data. This can be done by calculating the Pearson correlation coefficient represented by "r". This gives an indication of the reliability of the regression analysis made, the value of 'r' lies between '0' and '1', with value of '1' representing 100% correlation. The equation used to determine the Pearson correlation coefficient (r) is given below:

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{[\sum(x-\bar{x})^2\sum(y-\bar{y})^2]}}$$

Where: x,y are the data plotted on x and y axes

are the average of all values of x and y

Correlation coefficients are calculated for the data provided in Table 9.8 and the co-efficient details are provided in Table 10.9.

Table 10.9: Correlation coefficients of data provided

x	y	(x –	(y –	(x – * (y –	(x – 2	(y – 2
382	342	-76	-23	1712.6	5708.6	513.8
442	342	-16	-23	352.6	242.0	513.8
462	382	4	17	77.0	19.8	300.4
522	382	64	17	1117.0	4153.1	300.4
322	302	-136	-63	8494.8	18375.3	3927.1
522	402	64	37	2405.9	4153.1	1393.8
242	282	-216	-83	17819.3	46464.2	6833.8
622	426	164	61	10085.9	27042.0	3761.8
602	422	144	57	8281.5	20864.2	3287.1
4114	3278	0	0	50346.7	127022.2	20832.0

To calculate the coefficient correlation 'r'

$$r = \frac{50346.7}{\sqrt{127022.2 * 20832.0}} = 0.98$$

The obtained 'r' value is 0.98 which close to '1'. Hence the sample data and the obtained linear regression equation can be considered as the best fit.

2. **Regression analysis using multiple variables**

Regression analysis for multiple variables is similar to the simple single variable linear regression model, with the exception that multiple variables are used in this model. The mathematical representation of the multiple linear regression is:

$Y = a + bX_1 + cX_2 + dX_3 + \ldots\ldots\ldots\ldots$

Where: Y : Dependent variable

$X_1, X_2, X_3, \ldots X_n$: Independent variables

a : Intercept

b, c, d...... : Slope

Since there are multiple variables to be analysed, it is very difficult to do by hand calculations. Hence, it is advised to use specialised computer software which can estimate the statistical relationship between the variables.

The energy performance of any facility can be effectively established with the basic energy data analytic tools as well as regression analysis methods. However, there will be many instances, where basic data of energy consumption and production are not available and in such cases the baseline energy consumption shall be established by carrying a detailed energy audit. Energy efficiency/performance of all energy intensive equipment can be assessed during an energy audit which will help to draw the outline for energy efficiency improvement. This provides a baseline for the future energy performance assessment as well as initial targets. The baseline figures can be set not only for energy consumption, but also for water as well as other important consumables.

10.2.3 Step-3: Monitoring, Benchmarking, and Target setting

Based on the results obtained in step-2 targets are set for each category. The actual consumption has to be continuously monitored in comparison with the set targets for achieving cost savings and improving energy performance. Targets can also be set based on the external benchmarking with similar facilities or organisations or historical achievement of least energy consumption of the same facility. The definitive goal of energy monitoring and targeting is to control and reduce energy costs through energy efficiency and effective energy management. Energy monitoring and benchmarking will help the facility managers or decision-makers to make wise decisions based on effective assessment of performance.

Some of the benefits are listed below:

- How the energy is being consumed in the facility with respect to the processes that are being followed. Energy consumption trends can be drawn weekly, monthly, or yearly
- Effectively monitor the Key Performance Indicators (KPI).
- To determine future energy use when the change in process operations are taking place
- Diagnose specific areas of energy wastage and see whether the energy performance is improving or getting worse
- By setting up necessary energy metering system, the consumption of energy at various sections can be effectively managed for performance improvement
- The energy savings and cost reduction due to the implementation of potential energy saving measures can be quickly assessed.
- Develop energy action plans

10.3 Advanced Energy Management System (EMS)

We have learned in the previous section about the benefits and importance of energy management concepts that can be followed in any facility to effectively monitor and control energy use. To make use of energy management concepts better, industries or any facilities should incorporate a software-based energy management system.

Using such state-of-the-art instrumentation and monitoring through software driven PC based energy accounting and management will lead to uncovering hidden energy saving opportunities, which may be at least be to the extent of 2 to 5% of the plant's total energy consumption. When connected to a computer with package-driven software, these meters make it possible to download the energy parameters in the given formats. Considering the activities in different sections, the energy wasted, especially the idle operating equipment, needs a closer look. The energy consumption pattern from each section needs to be correlated to the usage activities and identify the causes of large variation. The equipment operating schedule and operating parameters will indicate the utilization/idling time of the equipment.

The state-of-the-art instrumentation & monitoring helps in achieving the following two goals:

- Expenditure budgeting for each cost centre for accounting the expenditure
- Energy cost reduction

Energy information & related saving measures have to be introduced as a daily exercise backed by an energy management team.

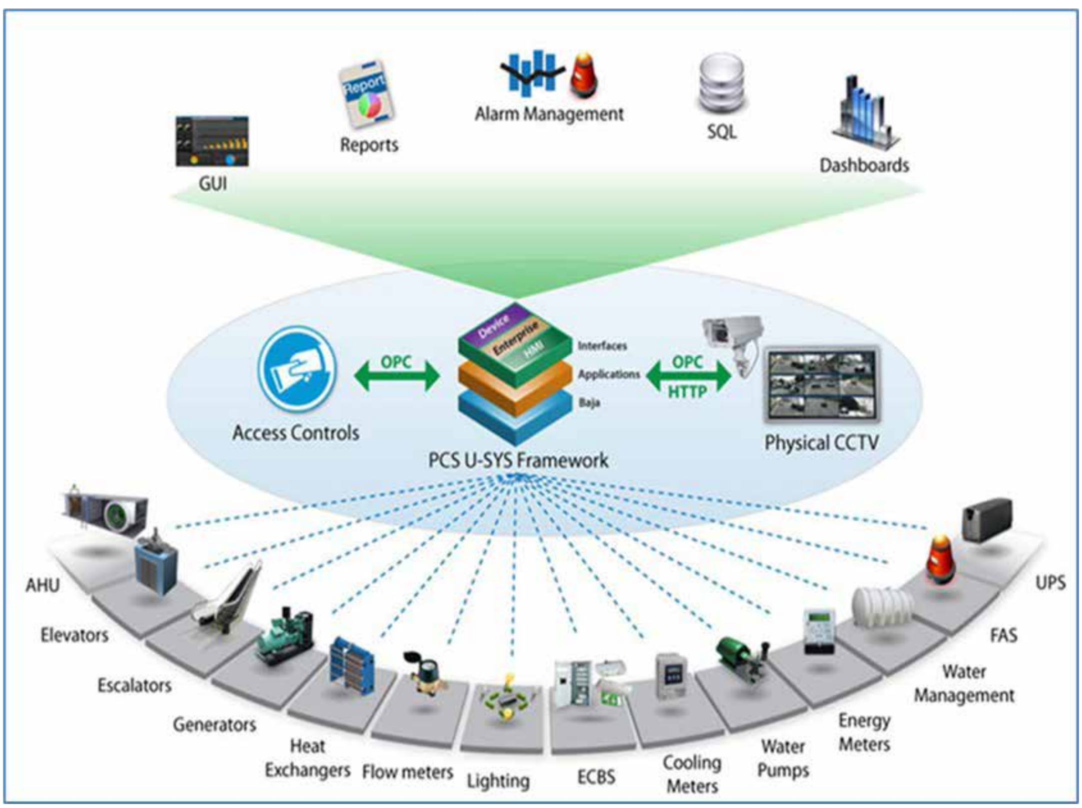


Figure 10.10: Sample picture showing a Facility incorporated with Energy management system

EMS system can be implemented in a customised manner specific to a building, industry etc. Figure 10.10 is a pictorial representation of EMS system incorporated for an industry. It shows that almost all components in the facility can be interconnected with central energy management system software. By means of this, performance monitoring and controlling becomes very easy and effective. An intelligent software-based Monitoring and Verification system of Energy management helps gather the energy consumption data (of buildings, factories and city municipalities) from conventional energy measuring devices or smart meters, monitors the factors affecting energy consumption, and sets energy efficiency targets reporting potential energy-saving areas. A sample advanced EMS dashboard is shown in Figure 10.11.

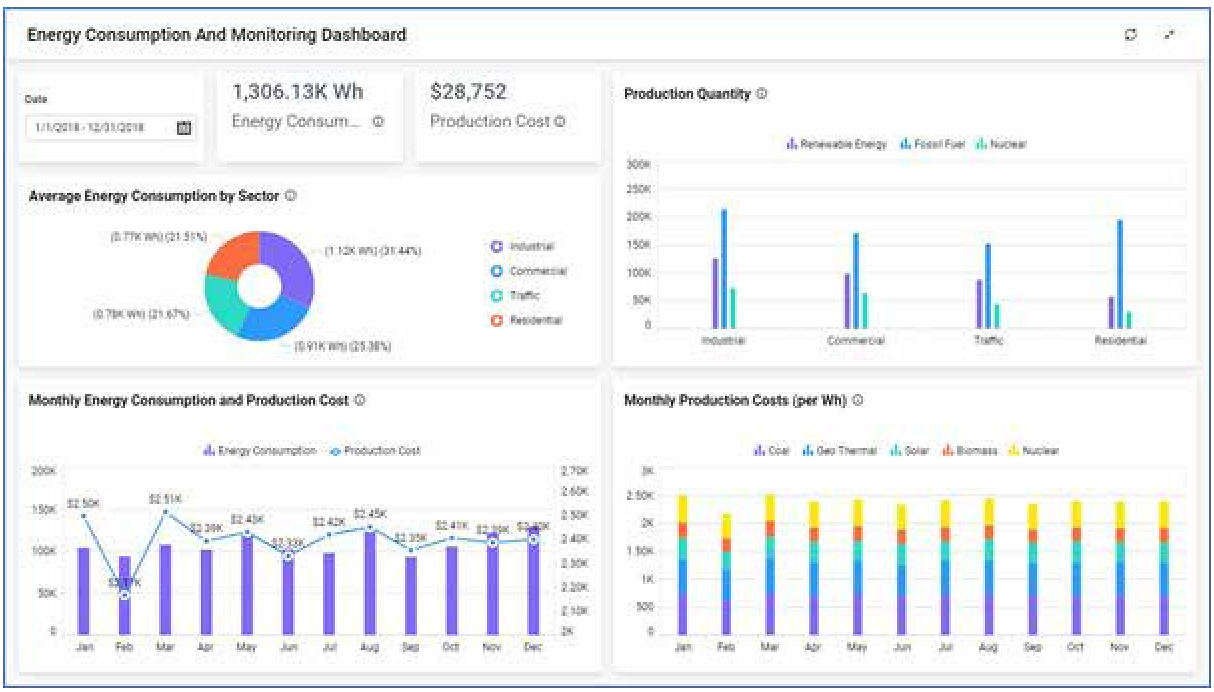


Figure 10.11: Sample Energy consumption and monitoring dashboard

Some of the common features that most of the EMS system possesses are listed below:

- The system has a database capable of storing large information on a regular basis specific to the energy consumption of different equipment and utilities. This information can be retrieved at any given time either locally or remotely.
- The retrieved information can be downloaded to Excel sheets for further analysis or can be directly connected to other online analytical tools.
- It can have the ability to manage electricity demand to control the utility electricity bills.
- Benchmarking and target setting can be made with ease specific to each equipment and monitored on a real-time basis.
- Energy consumption can be quickly summarised and reports can be generated in an easy manner.

Smart Energy monitoring system is the current technology developments of Internet of Things (IoT). It works on Artificial intelligence (AI) and Machine Learning (ML) concepts. IoT devices contain sensors and mini-computer processors that act on the sensors' data and transferred over a wireless network without human intervention. The goal behind the IoT based energy management system is to collect, process and transmit real-time information efficiency and bring important information to the facility management more quickly than an EMS system that is dependent on human intervention.

10.4 References

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   https://www.nrcan.gc.ca/energy-efficiency/energy-star-canada/energy-star-buildings/energy-benchmarking-basics/18260

CASE STUDIES

Case Study 1	Impact of integrating Reactive Power Compensator devices for improving power system grid stability
Case Study 2	Energy Efficiency improvements in Water Utility
Case Study 3	Energy Efficiency Retrofits for Public Building
Case Study 4	Energy Efficiency Motors as an opportunity for operating cost reduction
Case Study 5	Green Power from rice husk to reduce energy cost in Rice mills

Case Study 1: Impact of integrating Reactive Power Compensator devices for improving power system grid stability

1. Description:

In a power system network, voltage drops and technical losses in high voltage transmission and distribution are the significant areas of concern. Voltage drop in electrical cables of short and medium transmission lines occurs due to inherent resistance and thus resulting in increased line current, leading to power losses and minimized grid stability. On the other hand, the Ferranti effect occurs in long-distance high voltage transmission lines due to an increase in the capacitance between line and ground. Severe voltage drop also occurs due to equipment ageing, the vulnerability of the power grid, and the concentration of power generators in the same area.

Every country has a standard grid code to ensure the stable operation of the power system network. According to the grid code of Guyana, the voltage regulation should be less than 5%. Increased voltage drop tends to increase the voltage regulation beyond the standard limits and disturb the grid stability, causing increased power interruptions. Reactive power compensator, wire, power factor compensator, and pole-mounted transformers are effective equipment and materials for minimising voltage drop and leading to reduced technical losses.

2. Equipment Details - Reactive power compensator:

To improve grid stability, devices such as Static Condenser and STATCOM can control voltage dynamically as options of reactive power compensator. Static Condenser is connected parallel to the load side when large low power factor loads (reactive load) such as electric motors are operated. Reactive power can be supplied from the static condenser to the load side, thus reducing reactive power supply from the generator side. It also minimises voltage drop and power loss in the transmission line. So, in general, a Static condenser is operated by switching according to the load amount. The static condenser has a longer life and provides reliable operation for extended periods without failure.

Static condenser and shunt reactors can be dynamically controlled by power electronics technology called STATCOM. The voltage of the power grid can be improved by supplying reactive power of advance phases and lag phases according to power grid voltage fluctuation and loads fluctuations. However, the structure becomes complicated with thyristors. Operation and maintenance require a high level of technical capability, and the cost also becomes high. Hence, in areas where huge loads are handled (such as electrical substations) and where reliability is the primary factor of consideration, static condensers are commonly used for improving voltage instead of STATCOMs.

3. Power system network description:

The existing power system network has a transmission voltage level of 69 kV followed by power distribution at 13.8 kV, 440V, 240 V/120 V. The voltage of 69 kV is stepped down to 13.8 kV at the substations, and power is supplied to customers through the primary and secondary distribution lines.

The total available capacity of all the power generators is about 180 MW. The power is being generated at 13.8 kV level. All Transmission lines connecting substations are single circuits. When a fault accident occurs at one transmission line, the power supply through this route is interrupted, and a power outage occurs. Therefore, the power supply reliability is currently very low.

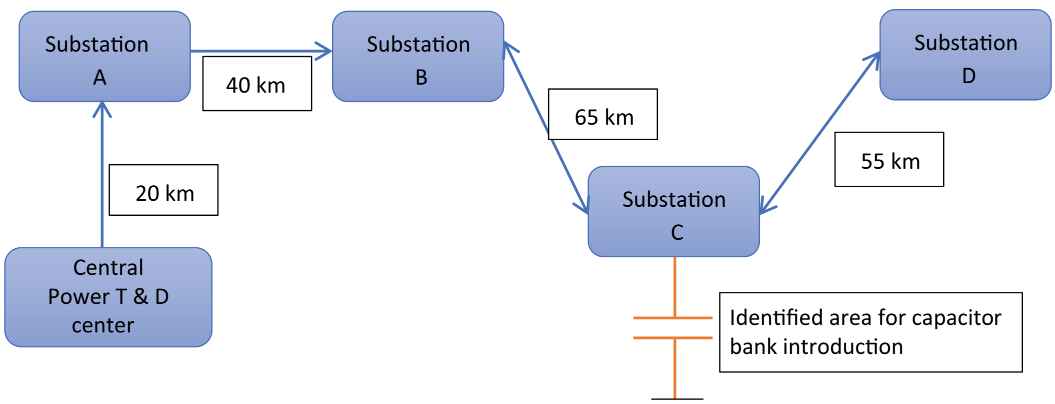
Power loss due to voltage drop is a serious problem, especially in distant places from the central power receiving and transmission centres. Severe voltage drop has also occurred due to equipment ageing, the vulnerability of the power grid, and the concentration of power generators in the same area. The survey results have shown a high voltage drop at 69 kV transmission line. The actual voltage was 60.5 kV, and this value had more than 10% fluctuation from the reference voltage of 69 kV. Due to this low primary voltage, the secondary voltage (13.8 kV) was not maintained at the reference level even if transformer tap positions were adjusted to the maximum level. This results in poor power quality at the distribution side and thus results in significant power loss. The primary and secondary voltage levels at three substations which are receiving power from the central power transmission centre is shown in the following table:

Description	Primary Voltage (Reference 69 kV)	Secondary Voltage (Reference 13.8 kV)
Substation C	60.5 kV (-12.3%)	13.32 (-3.5%)
Substation B	63.4 kV (- 8.1%)	13.49 kV (-2.2%)
Substation A	66.1 kV (-4.2%)	13.92 kV (+0.9%)

The distance between Substations A, B, and C are approximately 20 km, 40 km, and 65 km, respectively, from the main power transmission center. Although some power generation is happening at Substation C, power is being drawn from the main power transmission center to meet the additional demand. As the transmission lines are single circuit and have large line impedance, power loss increases. Further long-distance feeders with a low power factor (approx. 0.7) is another contributing factor to low voltage within the vicinity of Substation C. Later when a new power generation unit was installed in Substation C, the voltage level improved from 60.5 kV to 66 kV level. To further stabilize the power system network and improve voltage close the reference level, it is suggested to add a reactive power compensator that can boost or synchronize the voltage to the reference level.

4. Sizing of Reactive power compensator:

To adequately size the reactive power compensator for introducing it in any power system, there is a need to thoroughly assess the operating conditions of the existing power transmission and distribution network. Historical load curves and variation patterns (daily and monthly) need to be analysed, and future load growth needs to be estimated for at least the next 10 to 15 years. Field observations such as voltage levels, power factor, and demand of all substations are recorded and fed into a sophisticated software simulation tool such as ETAP to evaluate various grid discrepancies such as voltage regulation, system reliability, power factor, and technical losses, etc. The highest priority areas are identified based on the simulated results for positioning the reactive power compensator along with system size. A sample layout of the power distribution network and identified area of reactive power compensator is shown in the following figure:



According to the historical data, present, and future load handled by the substation C and load flow simulation analysis, it was concluded that a 2 x 5 MVAr reactive power compensator would be a suitable size that can meet the requirement to improve real-time voltage level above the reference 69 kV level. The following figure shows the reactive power compensator connected with the main 69 kV transmission line.

Reactive power compensator in line

5. Results:

It is becoming more challenging for the Transmission System Operators to maintain grid stability and voltage control in steady-state and transient conditions. Moreover, it is expected that a larger share of renewable energy will be connected with the grid shortly, old base-load plants will be retired. All these activities are making grid stability more complex. Also, power loss is a severe problem, especially in distant places from the main power transmission and distribution center. The use of reactive power compensators in the 69 kV network will yield the following benefits:

- Local grid strengthening and VAR support for higher productivity and power quality;
- Helps reduce network expansion investment costs;
- Meets grid code compliance requirements by improving voltage;

- Easy control of 13.8 kV distribution feeder voltage;
- Easy to integrate into the existing grid infrastructure;
- Low (or Zero) maintenance cost.

The installed reactive compensator has a faster response time and can generate the required reactive power, reducing voltage drop and thus improving reliability and availability.

After installing reactive power compensators, the voltage level at substation C has improved from 66 kV to >70 kV. This also resulted in tap setting reduction at the primary side of transformers in all associated neighbouring substations. The details of voltage improvement and tap setting of the transformers at substation C and its neighbouring substations are given in the following table:

Shunt Capacitor Installation Status	Transformer Tap Position					
	Substation B		Substation C		Substation D	
Number of Taps	5		13		33	
Before	5		13		30/33	
After	3		5		20	
Capacitor bank Status	69 kV line voltage at Substation C					
	69 kV line voltage from Substation B			69 kV line voltage from Substation D		
	V_{R-Y}	V_{Y-B}	V_{B-R}	V_{R-Y}	V_{Y-B}	V_{B-R}
OFF	66.5	68.1	67.7	66.6	68.1	67.7
ON	70.1	71.5	71.3	70.1	71.5	71.4

The shunt capacitor installation has dramatically helped improve the 69 kV line voltage by almost 5% in all three phases. During the field visit to Substation C, it was found that the voltage is continuously maintained in the range >69 kV to < 72 kV.

6. Replication:

The use of capacitor banks in the power system has a lot of advantages. The present case study explains about one such advantage of improving voltage regulation and system reliability. Other advantages include demand-side management (DSM) activities such as power demand reduction and minimizing energy losses in the power distribution network. With the government's support, GPL should promote the installation of power capacitor banks of suitable size at all commercial and industrial facilities. This indirectly saves operational costs and also minimizes reactive power load on the power generating units. Also, it saves energy bill for the commercial and industrial owners.

Case Study 2: Energy Efficiency improvements in Water Utility

1. Introduction

The Guyana Water Incorporated (GWI)) is one of the leading government agencies responsible for the inhabitants' water supply and sewage disposal services. GWI is responsible for bulk water production, water treatment, and the downstream water supply distributor, and it is a significant energy consumer. The water utility is one of the largest energy consumers within community services and it is maintained close to 146 numbers water supply facilities (including water treatment plants). In 2020, GWI spent more than US$13.7 million on electricity, and GWI's electricity load was approximately five per cent of the total electricity generated by the country.

Guyana Water Inc.'s sphere of operations is vulnerable to the dynamism of country's tropical climate and geography. The water pumping facilities of GWI comprises the following: (1) Borehole pumps, (2) Raw water supply and pumping stations with water treatment plants and (3) Wastewater collection facilities (in Georgetown only). Groundwater is 90% of all water resources in Guyana, and most of the rural areas take water from wells supplied by GWI. GWI owns around 30 water treatment plants (WTPs), including three recently added facilities. The water utilities under GWI face severe resource scarcity and disproportionately high electricity costs caused by water pumping in several towns. By improving the efficiency of the existing pumping systems within these towns, resources can be used more efficiently.

2. The importance of energy efficiency of existing water treatment plants

The peak operating load of water facilities together works out to be over 6 MW. The share of 30+ water treatment facilities energy consumption and operating load (kW) is 55% of the total GWI's electrical energy use. All the water treatment plant facilities come under the electricity tariff category of D (connected load > 100 kW). This particulate tariff category constitutes two parts (demand, kW and energy consumption, kWh). Improving the efficiency of the existing treatment facilities pumping systems will bring down energy cost savings.

A water treatment plant in the Barbice region was commissioned in 2000. It has an installed capacity of 10,000 m3 per day (10 MLD) to meet the water demand of the surrounding 18 villages. The treated water is currently distributed to the eastern and western parts of PMWTP, extending up to 3 km in each direction. The facility receives electricity from GPL at 13.8 kV, which is stepped down to 415V using a 500 kVA power transformer. A diesel power generator of 513 kVA (410.4 kW) rated capacity was installed as an emergency backup during power cuts. The facility's connected load comprises Borehole pumps, treated water transfer pumps, backwash water pumps and blowers. The depth of borewell#1 is 1300 ft, and borewell#2 is 1060 ft. Both borewell pumps are being used 24 x 7 unless the power supply is interrupted. The water from the bore wells is passed through the three filtration tanks to remove bugs, leaves, twigs and debris. Chlorination is done to disinfect the water, and the treated water is stored in a ground-level storage tank of 3000m3 capacity.

High pressure pump and overhead water storage tank

After the water treatment, the treated water (clear) is transferred using a high-pressure pump to the overhead tank. Four pumps have been installed near the water treatment plant and designed to operate two pumps regularly from 4 am to 10 pm to meet the demand. One transfer pump is switched OFF between 12 pm to 4 pm as the water distribution requirement is low. Installed pumps are horizontal split type and high pressure to match the 108 ft (33 m) overhead tank. The delivery header line is connected directly to the overhead tank (750 m^3 Capacity). The Pumps delivery line (upstream) is installed with a control valve, and the same is opened to 100% for filling the overhead tank. The water supply is directly connected to the distribution in two branches (East& West) for users from the overhead tank. Water flow meters are installed for both delivery branches, and the water quality is monitored daily (around 9,000 m^3). The technical specification of transfer water pumps is provided in the following table.

Specifications of transfer water Pumps

Particulars	Value
Make	SPX
Flow, m3/h	370
Head, m	35.5
Pump Speed, rpm	1780
Pump Input power, kW	42.1
Pump efficiency, %	85
Motor Speed, rpm	1775
Connected Motor, kW	45

- The measured delivery water flow rate from individual pumps is 325 m3/hr
- The delivery pressure of the clear water pump is 51 and 55 psig, while two / one pumps operation and the available positive suction pressure is 4 -5 psig
- Operating efficiency of transfer pumps is 82 -83% as against 85%, which is found to be satisfactory
- Energy consumption per day by transfer pumps is 1225 kWh

The water distribution from the overhead tank is regulated using control valves; it is mainly to maintain water consumption and avoid distribution pipe blast (due to high pressure). Due to minimum household consumption, the water distribution was switched off at night (10 pm to 4 am).

Single transfer pump (4 am to 10 pm) : 13 PSIG (east) and 18 PSIG (west)

Peak water demand two pumps (12 pm to 4 pm) :10 PSIG (each direction is maintained)

The water delivery pressure from the overhead tank is available around 45 PSIG and same is being regulated using a controlling valve to < 18 psig, which is nothing but a pump energy loss in the form of throttling. The reduction in flow rate has to be affected by a throttle valve. In other words, we are introducing artificial resistance in the system. Initially, the transfer pump must lift water to a height (overhead tank). This represents the static head while using additional resistance to deliver the reduced flow.

3. Technological advancements

A centrifugal pump is a dynamic device with the head generated from a rotating impeller. There is, therefore, a relationship between impeller peripheral velocity and generated head. Peripheral velocity is directly related to shaft rotational speed for a fixed impeller diameter, and so varying the rotational speed directly affects the pump's performance.

The pump's operating point, relative to its best efficiency point, remains constant, and the pump continues to operate in its ideal region. The affinity laws are obeyed, which means a substantial power reduction was absorbed in the flow and head reduction, making variable speed the ideal control method for systems with friction loss.

The rotor of the alternating current (AC) induction motor with a variable frequency drive (VSD) significantly changes how AC induction motors could be used by providing an efficient, electronic way to vary the supply current frequency, which then varied the speed of the motor. VSDs improve efficiency, reduce wear on mechanical components and improve system performance. Fundamentally, they are used to control the frequency and voltage supply to the motor and match the application's speed requirements (like pumps).

Use of VFDs to provide variable speed control to transfer pump will avoid overhead tank, and operate pump to match with water distribution lines head for required water flow.

4 . Achieving reductions of energy consumption in water treatment plants

Water utility to its recent water treatment facilities integrated VSDs for its transfer (distribution) pumps, avoided using overhead tanks. Also, two sets of pumps were installed to regulate the capacity of water flow full and half capacity. It has been practised for consumption of less energy, during non-peak hours small capacity two pumps are in operation. While peak load period two higher capacity pumps are operated at half (lower) speeds to meet the demand. The pump's operation regulating parameter is distribution header line pressure (maintained between 15 and 18 PSIG). A VSD connected transfer pumps configuration for a water treatment plant of 10 MLD capacity.

VFD connected water pump

Particulars	High	Low
Rated Parameter		
Flow, m3/h	380	190
Head, m	35	35
Pump Input Power, kW	42.7	22
Pump Efficiency, %	85	82
Connected Motor, kW	55	30
Measured (Actual) Parameters		
Period	Peak	Off-peak
Flow, m3/h	255	125
Head, m	20	16
Pump Input Power, kW	20.3	9
Pump Efficiency, %	76	72

Different combinations of low and higher capacity pumps are in operation to meet water demand from distribution. The monitored average daily delivery water quantity is over 8.8 MLD, and the energy consumption of transfer pumps is 720 kWh.

The reduction in energy consumption by using VSDs for distribution pumps is 505 kWh (1225 – 720) and also avoid the use of overhead tank. The realisation of energy savings to the tune of 41% from the use of VSDs for distribution water supply pumps. Evaluated cumulative monetary savings of GY$ 10.8 million per year through the technology advancement to minimise pressure losses across water distribution was done using variable frequency drive. The return on investment for such retrofit application (use of VSDs) is four years.

5. Replication

Behavioural change has the potential to expand energy efficiency's reach at the national level. Continuous demographic growth and expansion of the urban regions put more pressure on Guyana Water Inc. (GWI) to provide efficient energy and water services. Keeping up with the demand for sustainable infrastructure, energy efficiency, including water supply and sanitation, is challenging with rapid economic growth. Application / Use of VSDs for upcoming infrastructure projects needs to be thoroughly reviewed.

A variable frequency drive is capable to vary the power supplied to match the energy requirement of the driven equipment (like a pump, fan, blow, compressor, conveyor etc.,) and it saves energy or optimizes energy consumption. So, energy savings, intelligent motor control and reduction of peak-current drawn are three great reasons to choose a VSD as the controller in every motor-driven system. Various buildings and industries can start using VSD or retrofit their existing drives to realise energy savings.

Case Study 3:
Energy Efficiency Retrofits for Public Buildings

1. Introduction

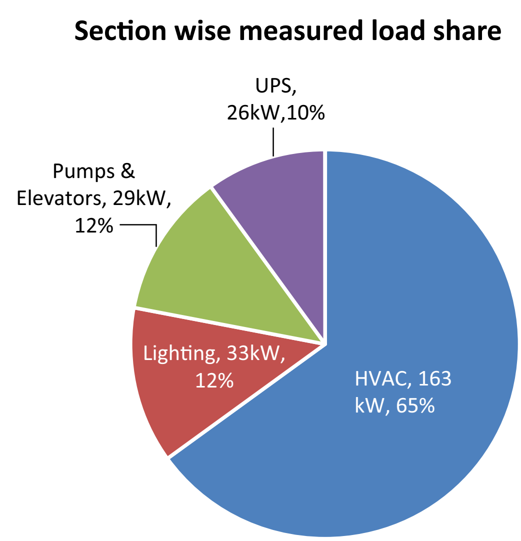
As part of the Government of Guyana Low Carbon Development Strategy (LCDS), energy efficiency and renewable energy generation are considered a method to reduce greenhouse gas (GHG) emissions from the building sector. Guyana Energy Efficiency (GEA) carries out energy performance studies of public buildings and supports them with investments. The underlying strategy was to achieve improved energy use in buildings by adopting an energy management system. The energy performance studies demonstrated that public buildings have a high consumption energy per annum of> 300 kWh/m2. Incorporating more energy-efficient solutions and renewable energy technologies within the framework of an energy management system in buildings will benefit the respective institutions economically and savings in the national exchequer.

The energy efficiency assessment was carried out for one of the public buildings in Georgetown, with an area of approximately 4000 Square Meters. It is an old-fashioned banking building and has ground plus four roomy floors and ample space. It has a distinct double wall shade envelope feature meant to keep the heat ingress minimum. The least amount of glass area was another built-in feature to contain the heat gain. The lime concrete covering has been provided on the terrace to minimize heat ingress through the exposed ceiling, which helps reduce the air conditioning load.

2. Building Energy Consumption Profile

The main source (primary) of electricity for the bank facility is Guyana Light and Power (GPL). The facility has also installed Diesel Generator sets used during GPL power failure. Electricity is mainly used for air conditioning, lighting and operating the building infrastructure, such as computers and servers. During the energy audit in 2014, it was observed that the annual electrical energy consumption was 1.25 million kWh with a demand of 360 kVA. The share of electricity consumption in the building is shown in the below figure.

A significant share of electrical energy is being used for Air Conditioning.



Energy consumption in the building

3. Building Retrofits

Building retrofitting is an important measure to reduce total energy usage. There are several approaches for building retrofitting, which mainly focused on the technological aspects such as lighting, air conditioning, pumping, and installing renewable energy systems. While implementing retrofits for any building type and climatic conditions without affecting indoor thermal comfort, energy efficiency needs to be achieved. The following retrofits were identified as suitable for the public building.

Lighting: The Bank's technical team identified the lighting system as a potential area and scheduled to replace the old lamps with energy-efficient LED lamps that have high luminous efficacy (>110 lm/W) and a long working life (~50,000 hours).

Air Conditioning System: The inefficient old ACs were replaced with Variable Refrigerant Flow (VRF) systems. VRF systems are energy-efficient air conditioning units using scroll compressors. A VRF system typically consists of an outdoor unit with multiple compressors and indoor units for different zones. The installed VRF units with a highly sophisticated electronic control centre enable zone wise temperature control. VRF systems offer a wide range of indoor units – ductable units to cool large halls, wall mounted splits for cabins and conference rooms, or cassettes for open spaces. All this is, in turn, part of a single air-conditioning system.

Windows: The sun-facing windows of the building were modified, and titanium heat resistant coated glass is used to reduce the heat ingress into the building, which helped minimize the AC load.

Solar PV System: Installed a rooftop solar PV system to minimize its electricity bill and increase its dependency on clean energy resources. Initially, a 30.24 kW solar rooftop PV system was installed, and the PV system capacity was enhanced by 6 kW after two years.

4. Results – Impact of Retrofit

The Public building has realized the benefits of energy conservation measures (ECM) and renewable energy integration from its own experience. Initially, priority was given to easily implementable and high energy saving measures followed by complex ones. The power reduced in each section of the Bank is shown in the following table.

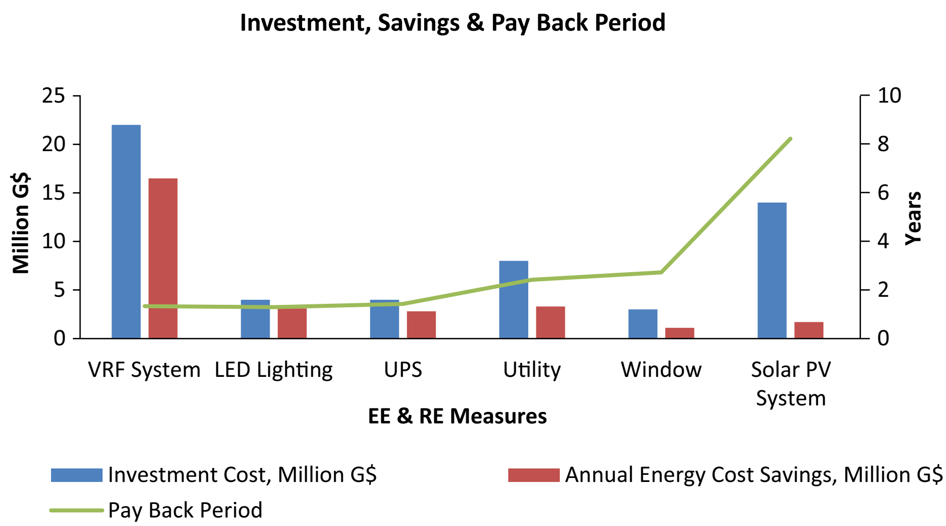
Status	HVAC	Lighting	UPS	Other (Pumps & Elevators)	Total
Baseline (kW)	162.6	33.2	25.8	28.6	250.3
After ECM implementation (kW)	94.5	23.3	20.2	23	161
% Reduction	42%	30%	22%	20%	36%

Public building experience has shown how to effectively reduce operating costs by incorporating energy efficiency and renewable energy and set as a benchmark. After the retrofit, it was able to bring down its energy performance index (EPI) from 317 to 175 kWh/m^2/year.

5. Economics of Public Building retrofit

In an occupied and functional building, the additional investment cost for reductions in energy consumption (10 to 30%) is more prominent for retrofitting the equipment than opting for entirely new construction. The realized annual energy saving from implementing various retrofit options with the latest technologies is 0.5 million kWh, which is less than 44% of the baseline energy consumption. The present tariff amounts to G$ 30 million annual energy cost savings. The total investment towards energy efficiency measures and solar PV power project integration is G$ 55 million.

The return on investment was less than two years for the implemented Energy Efficiency projects. In contrast, the return on investment (ROI) for the Solar PV system was over eight years as shown in below figure, owing to high investment costs.



From the above graph, it becomes evident that the air conditioning system of the building constitutes the most effective intervention.

CO_2 Emission

The annual electrical energy consumption is 1.25 million kWh (of the baseline year). The amount of CO_2 emission is around 900 tons. After implementing energy efficiency measures, the annual electrical energy consumption is reduced to 0.7 million kWh. The amount of CO_2 emission is about 504 tons. The annual co_2 emission is reduced by 396 tons.

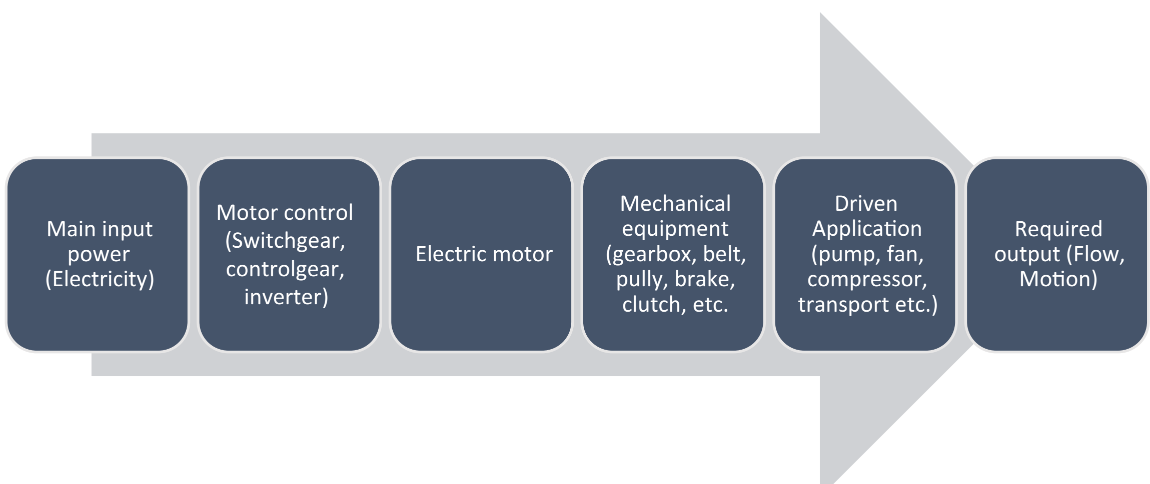
6. Replication

In general, each building is unique and has various appliances in use. No solution fits for all type of buildings. However, retrofitting equipment's / technologies of upgrade will suit public buildings uniformly. Nonetheless, it is possible to outline generic recommendations and factors that can contribute to an energy-efficient retrofit's success regardless of the building's specific features.

Case Study 4: Energy Efficiency Motors as an opportunity for operating cost reduction

1. Introduction

Electric motors have many applications in different industries, residential and commercial buildings. Due to their widespread use, motors represent over 45% of global electricity consumption. Electric motors are typically responsible for transferring electrical power to mechanical power, and they consume about 50 to 70% of total industrial energy consumption, depending on the type of industry. The main industries in Guyana are agro-processing (sugar, rice, timber, and coconut) and mining (gold and diamonds). Motors of different capacities are used in these industries, which operate continuously to do a particular task. It is widely accepted that the efficiency improvement and the subsequent energy savings in electric motor driven systems can be achieved with an integrated system consisting of well-matched and highly efficient individual components that are operated according to the required load efficiently.



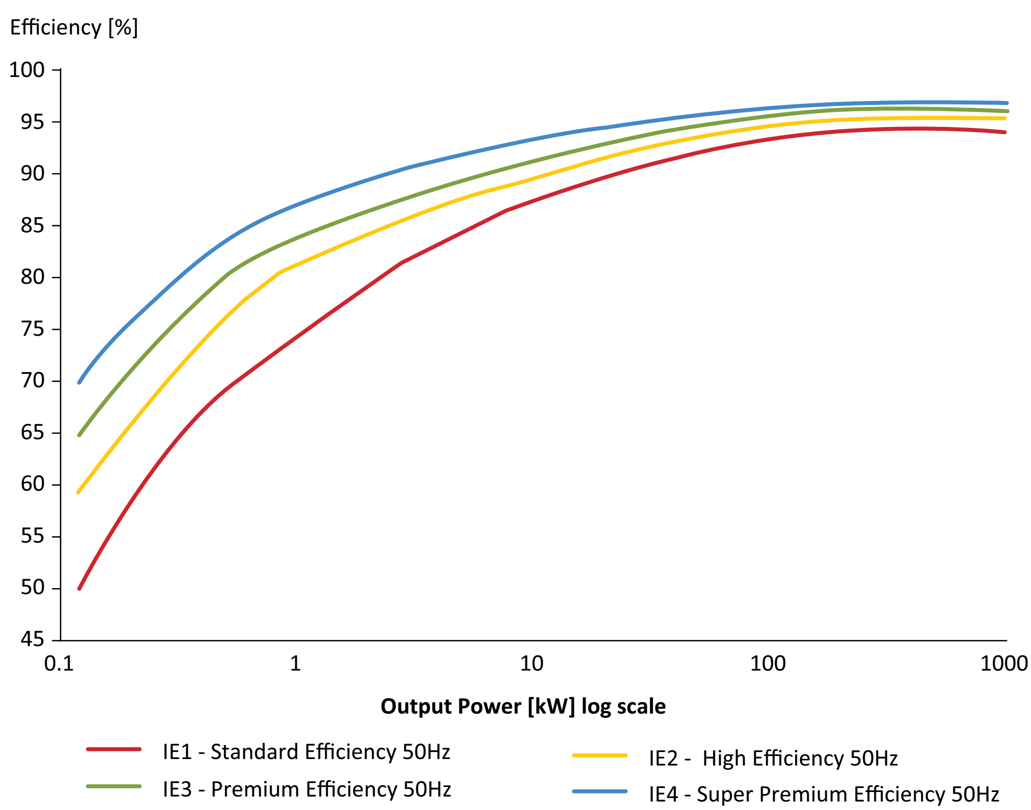
Based on the energy efficiency studies conducted by TERI, around 70% of the motors being used in Guyana's industries have rated capacities ranging from fractional kW to 90 kW. The operational practices followed are also very inefficient leading to high energy costs for different operations. In addition to that, most of the motors are very old and several times rewound. As per the research conducted on electric motor rewinding, it was found that the motor's efficiency is dropped for every single rewind, which can be in the tune of 1 to 2%. Hence, it is inefficient to operate the motors by rewinding more than three times. Hence, one of the best available opportunities for improving the energy efficiency of electric motors is by adopting energy-efficient motor technology.

2. Energy-Efficient motor Technology

Energy-efficient motors (EEM) are the ones in which design improvements are incorporated, especially to increase operating efficiency over motors of standards design. Design improvement focuses on:

- reducing intrinsic motor losses,
- use of lower loss steel,
- a longer case (to increase active material),
- thicker wires (to reduce resistance),
- thinner laminations,
- smaller air gap between stator and rotor,
- superior bearings and smaller fan etc.

EEMs are designed to operate without loss in efficiency at loads between 75% to 100% rated capacity. This may result in achieving significant benefits in varying load applications. The power factor is about the same or higher than standard motors. Furthermore, EEMs have lower operating temperatures and noise levels, a more remarkable ability to accelerate to high inertia levels, and are less affected by supply voltage conditions.



According to the International Energy Agency (IEA), electric motor-driven systems are responsible for 53% of global electricity use. It was considered that increasing the efficiency of electric motors is one of the biggest energy-efficiency improvement opportunities. National Electrical Manufacturers Association (NEMA) and International Electrotechnical Commission (IEC) are international organisations for setting electric motors and motor controls standards. NEMA has three motor efficiency classes: Standard, Energy Efficient and Premium Efficiency. IEC has contributed to the definition of energy-efficient electric motor systems through the internationally relevant test standard IEC 60034-2-1 for electric motors and the IEC 60034-30-1 classification scheme comprising five motor efficiency levels (IE-code).

- IE1 Standard Efficiency
- IE2 High Efficiency
- IE3 Premium Efficiency
- IE4 Super Premium Efficiency
- IE5 Ultra Premium Efficiency

IE5 is the latest development in the field of energy-efficient motors. IE5 motor will have a 20% loss reduction with respect to an IE4 motor. The following table gives a motor efficiency comparison of different IE standards.

Rated output, kW	Standard nominal efficiency(%) 4Pole motor				% of efficiency improvement IE1 to IE3
	IE1	IE2	IE3	IE4	
4.0	82.7	86.3	88.6	89.7	7.1
5.5	84.7	87.7	89.6	90.6	5.8
7.5	86.0	88.7	90.4	91.4	5.1
9.3	86.9	89.3	91.0	91.9	4.7
11.0	87.6	89.8	91.4	92.3	4.3
15.0	88.7	90.6	92.1	92.9	3.8
18.5	89.3	91.2	92.6	93.3	3.7
22.0	89.9	91.6	93.0	93.7	3.4
30.0	90.7	92.3	93.6	94.2	3.2
37.0	91.2	92.7	93.9	94.5	3.0
45.0	91.7	93.1	94.2	94.8	2.7
55.0	92.1	93.5	94.6	95.1	2.7

It can be seen from the above table that efficiency improvement is huge in the case of smaller capacity motors.

3. Estimating the Savings from a Motor Upgrade

According to UNEP´s United for Efficiency Country Saving Assessment, a market transformation to International Minimum Energy Performance Standards for Electric Motors and Pumps in Guyana can provide a range of economic, social and climate benefits, including the reduction of energy electricity use by over 18 GWh annually by 2030, which constitutes saving some 3 % of current national electricity consumption in the country. Additionally, the annual savings from the market transition will be $USD 5,200,000 in reduced electricity bills for consumers and over 20 thousand tonnes of CO_2 emission avoided. The government and utilities can also avoid the need to secure and finance some 4 MWe of additional power generation capacity.

To assess the quantity of energy savings in an industry or a utility, the following activities need to be performed:

- Motor nameplate details
- Motor load survey has to be conducted, which is part of energy audit activity
  - » Motor load survey helps to understand whether the motors are operating in underloaded/ Overloaded/optimum load condition.
- Re-winding history of the electric motors
- Operating schedule of the motors (Load factor and running hours)
- Demand factor of the motor.
  - » Demand factor can be calculated by dividing the measured power by the rated input power of the motor.
- Electricity tariff details
- Life of motors installed in the facility
- Eelectriic motor maintenance practices (Preventive maintenance techniques and condition monitoring)

The above information gives a good overview of the operational practices being followed. It helps in decision making for replacing the standard old and multiple times rewound electric motors for replacing with energy-efficient motors.

4. Intervention

An energy audit was performed in one of the food processing industries to estimate the energy-saving potential and opportunities for efficiency improvement. The facility has several motors whose rated capacities range from a fractional kW to 75 kW. Based on the nameplate details, it was understood that all the motors are old and belong to the standard efficiency class (IE1). A total of 15 motors that are considered for replacement with EEMs were studied. The total measure motor load is around 225 kW. The total losses of all the existing motors were computed from the IE1 motor efficiency table (mentioned above), and energy loss is computed from the number of operating hours. Similarly, the total losses of all the new equivalent rated EE motors were computed from the IE3 motor efficiency table (mentioned above).

5. Result and Analysis

The operational losses with respect to the old and new motors are assessed based on the demand factor and nameplate details. The summary of the results are provided in the following table:

Description	Old motors	New EE motor
Number of motors identified for replacement	15	15
Measure Motor load, kW	224.7	216.2
Energy-saving per hour	4.9	
Annual Energy savings, kWh	29,412	
Annual energy cost savings @ USD 0.26/kWh	7647.2	
Investment, USD	11,160	
Simple payback period, years	1.46	

The results show that a significant quantity of energy savings is possible with EE motors, which ultimately reduces energy costs.

6. Replication

Energy efficiency and conservation concepts are increasingly attracting the attention of experts, policy-makers, manufacturers, corporations, businesses, and homeowners as they look to decrease losses and protect the environment. In this regard, the enterprises will benefit significantly by incorporating energy-efficient products in their facilities.

The Guyana National Bureau of Standards (GNBS), as the National Standards Body, has been promoting energy-efficient motors in Guyana's commercial building and industriesGuyana. This initiative effectively reduces Guyana's Carbon footprint through astute energy management and supports the Low Carbon Development Strategy (LCDS).

Case Study 5:
Green Power from rice husk to reduce energy cost in Rice mills

1. Introduction

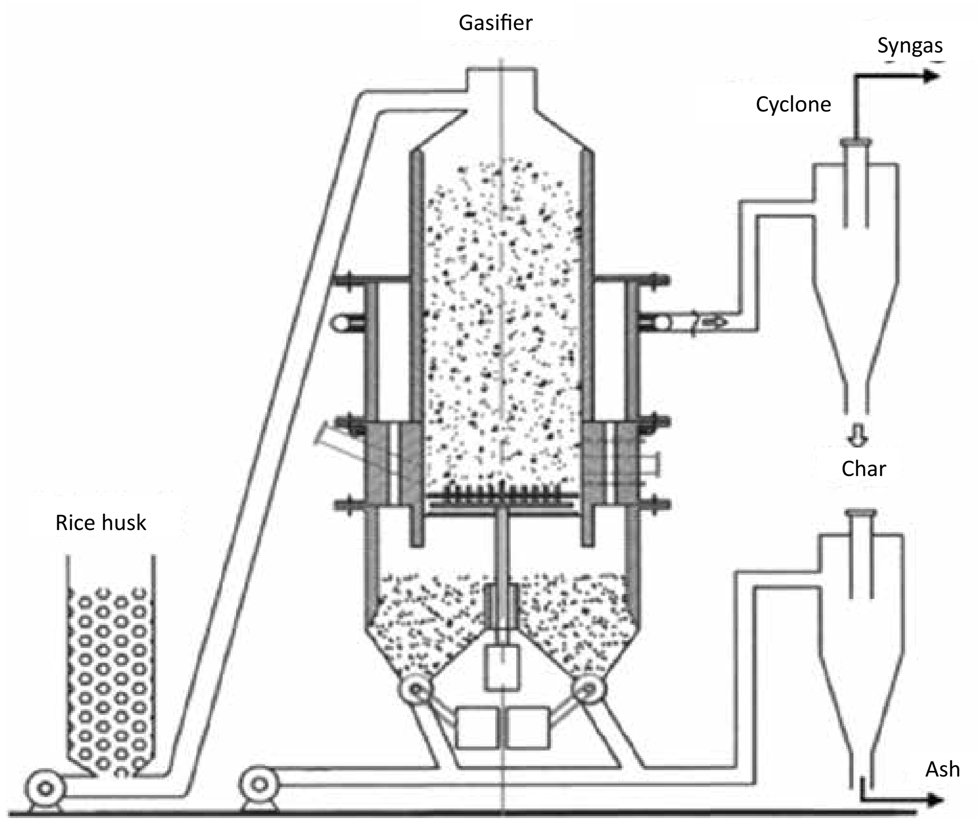
The rice industry contributes significantly to Guyana's economic development, accounting for 11 percent of GDP. In recent years, it produced over 1 million tonnes of paddy, equivalent to approximately 700,000 tonnes of rice. In rural areas, the rice industry is a major source of income, employment and an important source of foreign exchange.

To enhance production and increase efficiency in the rice mills, the Guyana Rice Development Board (GRDB), in collaboration with the Office of Climate Change (OCC), Guyana and The Energy Resources Institute (TERI), India conducted energy audits at a number of rice mills. Recognizing that over 60 rice mills are in regular operation with installed capacities varying from 0.5 - 10 tonnes per hour (TPH), the study highlighted that the rice mills have significant potential to transform their operations and apply technology leading to low carbon footprints.

2. Gasification Technology

Rice husk was for a long time considered to be waste from the rice milling process and was often dumped and burned. Since, it is cheap and easily available sustainable source, rice husk has always been used as an energy source for some small applications in rice mills, but a significant part of the husk is being burned or dumped as landfill. After a detailed study of the Rice sector in Guyana, TERI identified appropriate sector-specific eco-friendly technologies that can fit and yield effective results.

The idea is explained below: Gasification is the process of converting rice husk to synthesis gas (syngas) or producer gas in a downdraft gasifier with a controlled amount of air (Schematic figure shown below). The gas is produced through a thermochemical process, and the resultant gas can be used for heat and power generation applications.



Syngas generated from the gasifier is cleaned and fed into a diesel generator to produce electricity.

3. Energy Consumption Profile of rice mill

Energy is one of the key requirements for rice mills. The energy both in terms of electrical and thermal energy is required for the milling of rice. Generally, for thermal energy rice husk, or wood is used. Around 35% of the rice mills' direct expenses (production cost) goes towards electrical energy cost. Electricity is either from the grid or the diesel generator sets. Around 8 to 10 rice mills were used grid power (GPL). The rest were using their diesel generators for meeting their electricity demand. This was mainly due to high unit cost and power quality issues of GPL grid power.

The rice milling operation produces a large rice husk (around 22% of paddy by weight). Parboiling and drying processes consume about 90% of the total energy needed in rice mills. Based on the data collected from the Guyanese rice mills, a comparative table of annual energy consumption based on the mill capacity is given below.

Capacity of Rice Mill	Energy consumption per year (kWh)	Yearly rice production, MT	Specific Energy KWh / MT
1.5 tph			
Rice Mill A	52020.0	840	61.9
Rice Mill B	18761.8	133	141.3
2 tph			
Rice Mill A	86361.6	1140	75.7
5 tph			
Rice Mill A	886554	4863	182.0
Rice Mill B	6460.0	280	73.8
6 tph			
Rice Mill A	88320.0	1152	100.0

Based on the Energy audit studies, the specific energy consumption of rice mills varies from 60 to 100 kW/MT of rice production, which is very high against the international benchmark value of 40 to 50 kW/MT of rice production. Higher specific energy consumption is due to various operational issues.

4. Intervention

In an operational rice mill, the cost of energy accounts for close to US$15.50 per metric tonne of paddy processed. This was linked mainly to the use of diesel for power generation. It was observed that some rice mills were using wood as fuel to meet thermal energy demand, but little use was being made of the rice husk. Dumping of rice husk as waste has become a serious environmental problem. The use of rice husk for power generation can be an excellent cost reduction opportunity for Rice millers. It is ideal to use an existing diesel generator (engine) in dual fuel mode for power generation. Initially, the engine is started using diesel. The cleaned gas (Syngas) from the gasifier is fed to the engine at the stabilised condition. The engine runs with 70% syngas and 30% diesel at optimum condition.

A rice mill located at Essequibo Coast had come forward initially to invest in power gasifier technology. With the technical assistance from the Government, the mill successfully commissioned a 400 kWP dual fuel-based power gasifier and connected the same to the existing diesel generators. The producer gas (Syngas) generated from the gasifier is fed to the existing 250kW diesel generator set to generate power. The use of a power gasifier replaced 70% of the diesel consumption across the generator. The brief design details of the duel fuel gasifier are given in below table:

Gasifier Rating	400 kW
Gasifier Model	CPW 480T
Gasifier type	Downdraft, dual fuel-fired
Fuel	Rice husk and diesel (replace 70% of diesel with rice husk
Connected DG set	250 kW / 288kVA

Images of dual-fuel gasifier are given in figure

Dual Fuel Power Gasifier Installed at Ramlakhan and Sons rice mill, located at Exmouth, Essequibo Coast

5. Result and Analysis

During the baseline energy audit period, it was observed that the rice mills in Guyana operate for two seasons (September to November and March to May). The rice mill caters for the power from the diesel generator, and the electricity consumption is around 140 kWh; at the same period, diesel consumption is 48litres/hours.

After the installation of the gasifier, the rice mill electricity consumption (demand) increases to 155 kWh. Incremental power consumption is from auxiliary gasifier equipment. The diesel consumption is reduced to 23 litres /hour. Rice husk consumption was 260 kgs/hours, and monitored diesel consumption savings is around 51%. Since the Diesel generator is operated at partial load, fuel savings is limited to 51% instead of 70%.

Description	Unit	Baseline Data	After Gasifier
Rice Mill Average electrical demand	kWh	140	155
Diesel Consumption	Litres/h	48	23
Rice husk consumption	Kg/h	Nil	260
Auxiliary power	kWh	Nil	15
Monitored Diesel savings	Litres /h	25	
Diesel saving percentage	%	52.1	
Rice mill operating days	Days/year	130	
Operating hours per day	Hours/day	20	
Annual diesel savings	Litres	65000	
Diesel cost	GY$/litres	220	
Annual cost savings (G 200/litres	Million GY$	14.3	
Investment for duel fuel Power gasifier	Million GY$	40	
Simple payback period	Years	2.8	

6. Replication

National Energy Policy and Strategies should emphasize the promotion and production of biomass (like rice husk) based energy which is available locally in abundance. Rice mills, sawmills, and Small remote Industries can use rice husk as fuel and produce electrical energy requirements.