Energy Auditing & Reporting Guidelines for Buildings

Department of Renewable Energy,
Ministry of Economic Affairs,
Royal Government of Bhutan

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DEPARTMENT OF RENEWABLE ENERGY
MINISTRY OF ECONOMIC AFFAIRS
Royal Government of Bhutan
Thimphu: Bhutan

Foreword

The Department has conducted numerous studies to scrutinize the energy consumption pattern of various energy intensive sectors in the Country. One such study was carried out in 2014 which revealed that the Buildings and the Industries are the major energy consuming sectors. The Building sector alone consumed around 42 % of the total energy followed by Industries at 37 %[1] The Department therefore sees potential for substantial energy savings through the implementation of energy efficiency interventions in these sectors.

The studies have shown that the traditional and modern construction techniques in Bhutan do not include air and wind barrier layers in building envelope as a result of which, majority of the energy losses occur due to air infiltration.[2] Thus, the energy consumption pattern has to be evaluated to identify major causes of energy losses in the building.

Therefore, the Department deems it necessary and timely to develop Energy Auditing and Reporting Guideline for Buildings to guide all the energy auditors and managers to conduct a well-structured and effective energy audit.

The Department aspires that this guideline will promote the practice of energy auditing in Bhutan and thus, contribute towards achieving optimum energy efficiency for the Building sector in the country.

Tashi Delek

Phuntsho Namgyal
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[1] Energy Efficiency Roadmap 2019
[2] Study of heat loss through air gaps in Bhutanese window fittings and wall- a case study 2019

Executive Summary

These Energy Auditing and Reporting Guidelines for Buildings are designed to serve as a practical guide for an energy professional to gain a strong background on energy auditing through the detailed explanations on the components of an energy audit, the general methods and procedures to be followed as well as the reporting practices of an effective energy audit.

A survey was conducted with managers of several buildings in Bhutan to determine their awareness level of energy conservation practices. This survey along with detailed interactions with local experts helped shape the structure of these guidelines. Chapter 3 of these guidelines helps the reader select the type of energy audit most suitable for the specific building to be audited, and to prepare for the audit before commencing the audit.

These guidelines contain a brief introduction to the key energy consuming equipment commonly used within buildings in Bhutan, followed by steps for carrying out the energy assessment at that equipment. For the benefit of the reader of these guidelines, this information is always presented under six distinct sections for each of the equipment covered. The six sections are: introduction to the equipment, data collection required for assessment of that equipment, instruments required, performance terms and definitions, performance assessment techniques and energy saving opportunities commonly associated with the specific equipment.

With this approach and the steps explained, an energy professional would be able to carry out energy performance assessment of a wide variety of equipment and to identify energy conservation measures best suited for the concerned building.

Building and site level energy use assessment, as well as ways to compute energy saving potential, are explained in step by step manner in these guidelines. Data collection templates and tips are provided to support the auditors along with energy saving calculation formulas.

The authors have practical experience of conducting over 700 energy audits in several countries in South Asia. They have leveraged this experience and conducted detailed primary and secondary research covering best energy management practices from seven countries, to optimally balance theoretical background with practical inputs on how to carry out effective energy audit at buildings, especially for Bhutan.

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Acronyms

AC	Alternating Current
ASHRAE	American Society of Heating, Refrigerating & Air-Conditioning Engineers
BEE	Bureau of Energy Efficiency
COP	Coefficient of Performance
DC	Direct Current
DG	Diesel Generator
DRE	Department of Renewable Energy
EER	Energy Efficiency Ratio
HVAC	Heating, Ventilation, Air Conditioning
IE	International Efficiency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IR	Infra-Red
ISO	International Organisation for Standardisation
MD	Maximum Demand
PF	Power Factor
PPD	Predicted Percentage Dissatisfied
ROI	Return on Investment
SA	STENUM Asia Sustainable Development Society
SEC	Specific Energy Consumption
Solar PV	Solar Photo Voltaic
VFD	Variable Frequency Drive
VSD	Variable Speed Drive

Units

°C	Degree Celsius
A	Ampere
hr	hours
kcal	kilo calorie
kg	kilogram
kJ	kilo Joules
kl	kilo litre
kVA	kilo Volt Ampere
kVAr	kilo Volt Ampere reactive
kWh	kilo Watt hour
l	litre
m	meter
t	ton
toe	tonne of oil equivalent
TR	Tonne of Refrigeration
V	Volt

1 Building Sector in Bhutan – an Overview

Bhutan recorded a 7.5% GDP growth in 2017 (National Statistical Bureau, 2018) and is amongst the fastest growing economies in the world (World Bank 2019). The impact of this is visible in the rapid expansion of urban centres like Thimphu and Paro, which have grown in leaps and bounds. Thimphu has tripled in size from about 8 km^2 in 2002 to almost 26 km^2 at present (Bhutan Ecological Society, 2018) and the local administration there has approved 503 new concrete buildings from 2011- 2015 (National Statistical Bureau, 2017). By 2018, Thimphu had an estimated 5295 houses (Bhutan Ecological Society, 2018).The tourism sector has also grown very fast in recent years and there is a substantial increase in new proposals for hotel buildings and this trend remains strong for near future.

The building sector in Bhutan accounts for 41.6 % of electricity consumption with the residential sector alone accounting for 33% of the total energy consumption of the Bhutanese economy (IRENA, 2019). Bhutan has committed to remain carbon negative and to ensure this, the building sector must be provided with the right guidance to so that energy requirements (for example for comfort needs like cooling or heating) are met using energy efficiency practices.

As per the EE Road map 2019, published by the DRE under MoEA, the expected savings amounts to 17,033.51 TOE with emission reduction potential of 87,384 tCO_2e over a period of 15 years with the selected EE interventions.

There are several different uses of energy in building. The major uses are for lighting, heating, cooling, power delivery to equipment and appliances and supply of domestic water. The amount that each contributes to the total energy use varies accordingly to the climate, type of building, number of working hours and time of year. In areas where severe winter occurs, heating load will be greater than cooling load in terms of the total energy use. In some type of buildings in certain climatic zones, the lighting load might be greater than either the heating or cooling load.

Industries and buildings are dissimilar in terms of energy use. Industries primarily use large quantities of energy for manufacturing operations whereas the majority of energy in buildings is for providing human comfort. It is difficult to generalise energy use by type of building because there are many variables that determine the energy use in a building. Therefore, in these guidelines, where appropriate, specific approaches for different building types are provided.

A well conducted energy audit of a building is a very useful tool to identify energy savings opportunities. Energy auditing will lay the foundation for energy conservation efforts at buildings in Bhutan, thus making the Energy Auditing and Reporting Guidelines relevant for the buildings sector in Bhutan.

2 Introduction to Energy Audit

2.1. Energy audit definition

There are several relatively similar definitions of an energy audit. As per ISO 50002, energy audit definition is:
"Systematic analysis of energy use and energy consumption of audited objects, in order to identify, quantify and report on the opportunities for improved energy performance".

As per Indian Energy Conservation Act 2001, an energy audit is defined as:

"Verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption".

2.2. Objective and benefits of energy audit

In simple terms, an energy audit is usually conducted to understand a given facility and then to find opportunities for improving overall energy savings. There are many reasons for undertaking an energy audit at including:

- To improve energy performance and minimise the environmental impacts of the building or facility's operations.
- To identify behavioural change opportunities by evaluating current operations and maintenance practices.
- To identify technical opportunities by evaluating significant energy consuming equipment or utilities including pump motors, heating systems, boilers, refrigeration plants and lighting devices.
- To provide clear financial information regarding energy savings opportunities and to prioritise the energy savings opportunities in a way that would help top management for decision making.
- To gain a greater understanding of a part or all of the facility's energy usage patterns.
- To identify potential for using renewable energy supply technologies.
- To achieve compliance with legal requirements (if any) and comply with corporate social responsibility goals.
- To contribute to the process for certification to a formal energy management system in accordance with ISO 50001 guidelines.

2.3. Overview of energy audit procedures

An overview of the procedure for a detailed energy audit is shown in **Figure 1.** A walk-through audit contains some of the same steps of the procedure shown, but the depth of the data collection and analysis might be different depending on the scope and objectives of the audit. Overall, there are three main steps (excluding the post-audit activities) each of which has several sub-steps. These three main steps are energy audit planning, execution, and reporting.

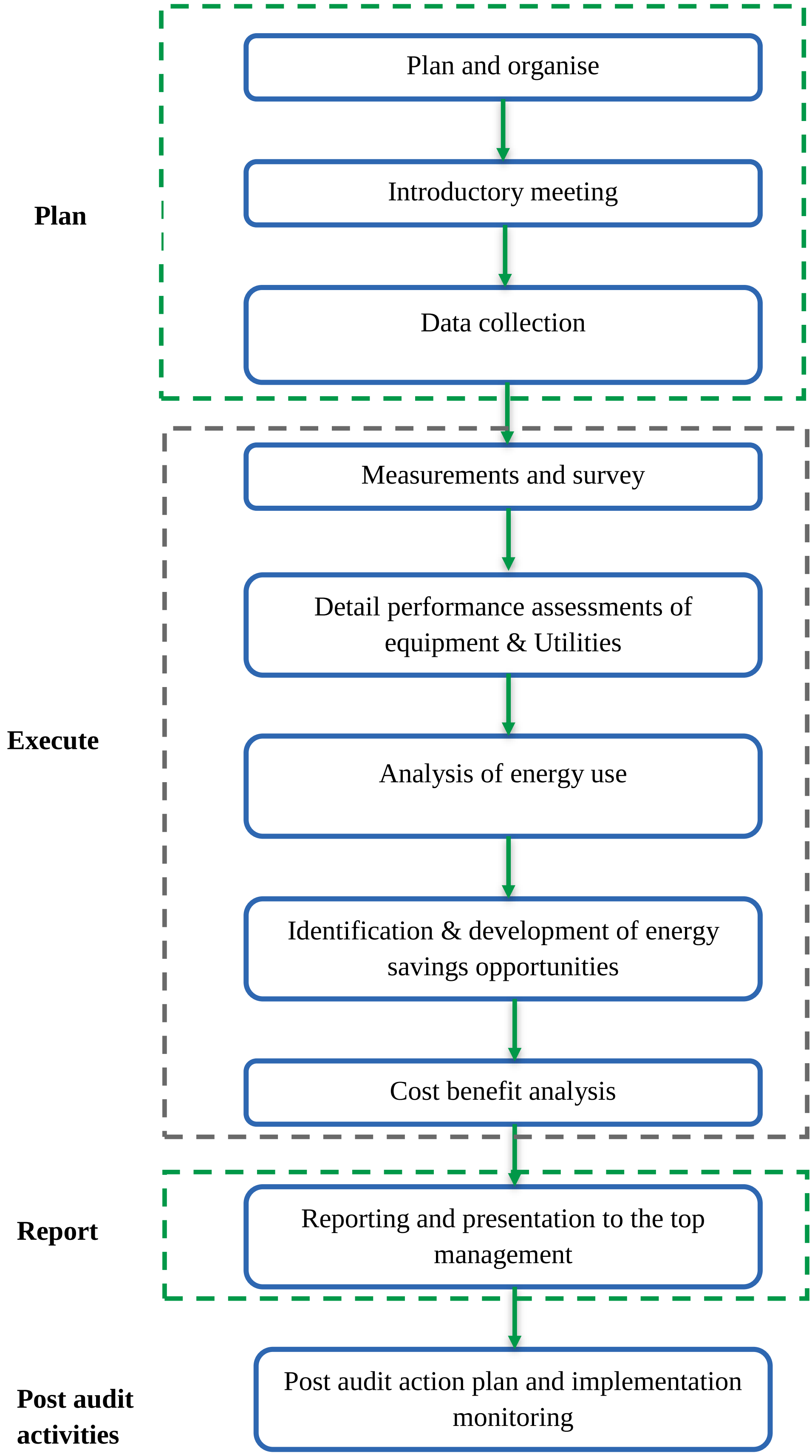


Figure 1: Overview of detail energy audit procedure

3 Types of Energy Audit and Approach

The type of energy audit to be performed depends on the type of facility, the depth to which final audit is needed, and the potential and magnitude of cost reduction desired. Thus, energy audit can be classified into the following types: Walk-through audit, Targeted Energy Audits and Detailed Energy Audit.

3.1. Walk-through energy audit

In a walk-through energy audit, readily available data are mostly used for a simple analysis of energy use and performance of the facility. This type of audit does not require a lot of measurement and data collection. These audits take a relatively short time and the results are more general, providing common opportunities for energy efficiency. The economic analysis is typically limited to calculation of the simple payback period.

3.2. Targeted energy audit

The need for targeted energy audit is often identified following a detailed analysis of the results of a walk-through audit with client / management. The targeted audit provides data and detailed analysis on specified target utilities or area within the entire facility. For example, a building may target its lighting system or boiler system or HVAC system with a view of effecting energy savings.

Targeted audits therefore involve detailed surveys of the target subjects and analysis of the energy flows and cost associated with the targets. Final outcome is the recommendations regarding actions to be taken for energy conservation. Details on how to carry out targeted audit on certain utilities or equipment are provided in respective sections under **Chapter 7**

3.3. Detailed energy audit

Detailed energy audit is a comprehensive audit which results in a detailed energy project implementation plan for the entire facility since it accounts for the energy use of all major equipment. It considers the interactive effects of various utilities or equipment and offers the most accurate estimate of energy savings and cost. It includes detailed energy cost saving calculations and project implementation costs. One of the key elements in a detailed energy audit is the energy balance. This is based on an inventory of energy-using systems, assumptions of current operating conditions, measurements, and calculations of energy use. Detailed energy auditing is carried out in three phases as shown in **Figure 1.**

4 Walk-through Energy Audit

As briefly described in **Section 3.1**, a walk-through energy audit uses readily available data for a simple analysis of energy use and performance of the facility. The following section provide information needed to conduct an effective walk-through audit.

4.1. Objectives of walk-through energy audit

- Identification and basic evaluation of low-cost opportunities that can be easily implemented.
- Understanding of energy consumption at a facility or equipment/utility level
- Improved awareness of energy costs and the potential benefits of managing energy
- Understanding of the extent of more capital-intensive opportunities.
- Indications of potential savings and benefits from undertaking more detailed investigations such as targeted or detailed energy audit.

The savings potential identified from conducting a walk-through audit can help the client to determine whether they should proceed to undertake targeted audit or a detailed audit. Simultaneously, a walk-through audit helps the audit team to prepare a more effective audit plan (which includes composition of audit team and allocation of time or certain section of client facility, selection of instruments to carry) when proceeding with targeted or detailed audit.

4.2. Preparations for walk-through energy audit and resources required

Walk-through audit by itself can give significant benefits, provided it is carried out by an experienced energy audit team as limited time and resources are available and detailed measurements are not feasible.

Resources required

1. Team: 1 to 2 members
2. Basic instruments for quick assessments (if available) such as:
    - Non-contact type Infra-red thermometer,
    - Hand-held clamp meter
    - Pen-type thermometer
    - Sling Psychrometer
    - Anemometer
    - Measuring tape
    - Electric tester, etc.

Refer **Chapter 12** for list of instruments and their usage.

3. Others
    - Data collection format
    - Audit checklist,
    - Log sheet
    - Diary/notebook

4.3. Process of carrying out walk-through energy audit

4.3.1. Introductory meeting

The walk-through audit generally begins with an introductory meeting with facility management personnel. The purpose of the preparatory meeting is to understand the facility and major processes before actual visit to the facility operation area so that the audit goals reflect the operations of the facility. The energy auditor shall start the meeting with a short presentation apprising the management about the audit goals and possible benefits to the facility. The energy auditor shall take the management views on which aspects of operation should be the focussed area during the audit and shall identify the key issues of the clients. The energy auditor shall collect energy consumption (electricity and fuel bills for 12 months) and corresponding output or service delivery data (as introduced in **Section 5.2**) for same 12 months. The energy auditor shall try to get a detailed description of building type, significant energy consumers, type of users in buildings and other relevant information.

4.3.2. Walk-through

The next step is to walk-through the facility with appropriate facility personnel who are familiar with all the installed equipment and utilities related operation. During walk-through, the energy auditor shall identify key issues of the client and gather inputs on the areas of concern, record observations, note the nameplate and meter readings, identify low cost and easily implementable energy savings measures. The energy auditor shall ensure covering all functional areas while conducting a walk-through. The reader may refer audit checklist given in **Annexure-14.1** to select appropriate and relevant energy savings opportunities that may be applicable.

4.3.3. Closing meeting

The energy auditor shall hold a short wrap-up meeting to review main points observed during the walk-through, highlight any observation or finding which needs immediate attention by facility management. Fix the date for walk-through audit report presentation and submission with facility management.

4.3.4. Analysis & report preparation

Start analysing the collected data, reviewing the notes taken during the walk-through, and start preparing the energy savings recommendations. Recommendations to facility shall be specific and supported by data to the extent possible and presented in order of monetary savings (highest savings on top or shortest return on investment on top). These shall contain estimated costs (checked from local market), estimated savings and simple payback calculations. Consider the priority set by facility while preparing the walk-through audit report.

4.3.5. Report presentation and action plan

The energy auditor shall personally hand over the walk-through audit report to the facility on the agreed date, explaining the recommendations made to the top management. The energy auditor shall help the facility management to prepare an action plan with selection of recommendations along with timeline for implementation.

Typical content of Walk-through audit report:

1. Executive Summary
    - Summary of energy savings potential
    - Recommendations breakup in payback and savings categories
2. Current facility Situation
    - Facility processes
    - General information on energy consumption
    - Energy performance analysis (including explanation on the output or service delivery metric used)
3. Energy Savings recommendations in a format as shown in **Table 1**
4. Annexure

Table 1: Energy savings recommendation table format for walk-through audit

Sl. No.	Description of the present situation and the problem observed	Description of recommended actions	Amount of the annual savings		Investment Costs (Nu.)	Simple payback period (months)
			Energy savings (kWh/year or kl/year) (as appropriate)	Amount (Nu. /year)		

4.4. Focus area according to building type

According to building type, focus on certain specific utilities or equipment is required since those utilities or equipment play a bigger role in determining energy consumption pattern in type of building being audited. Commonly observed utility or equipment emphasis according to building type is shown in **Table 2**. In this table "High" or "Low" is used to indicate the recommended level of focus by energy auditor while auditing specific types of buildings

Table 2: Focus area according to building type

Building type / Focus area	Hospital	Hotels	Institutional[3]	Commercial	Residential
Lighting	High	High	High	High	High
Water heating	High	High	High	High	High
water pumps	High	High	High	High	High
Heat pump	High	High	High	High	High
Electrical equipment/ appliances	High	High	High	High	High
DG set	High	High	High	High	Low
HVAC	High	High	High	High	Low
Cooking	High	High	Low	Low	High
Refrigeration	High	High	Low	Low	High
Laundry	High	High	Low	Low	High
Air compressor	High	Low	Low	Low	Low

The approach for carrying out energy assessment for above listed utilities or equipment is provided in detail in **Chapter 7**

[3] Institutional buildings include government offices, banks, and educational buildings

5 Preparation for Detailed Energy Audit

5.1. Audit scope

As per ISO 50002, definition of scope is “activities the energy auditor and the organisation agree are necessary for the energy audit”.

The audit scope needs to consider the available resources such as staff, time, audit boundaries, level of analysis, expected results, the degree of detailing, and the budget for conducting the energy audit. The audit scope will depend on the purpose of the specific audit and may be defined by an overall government or company audit program. It should also define the share of utilities or equipment included in the audit with respect to the building’s total energy use as well as comprehensiveness and the level of detail for the final recommendations. Therefore, the scope of the audit may be defined in terms of the utilities to be covered or the areas or sections of the building that need to be covered, from within the entire building. In many cases the entire building would be the scope of the audit.

It is responsibility of the energy auditor to clarify and define the scope of the energy audit before starting the audit, by considering all the points mentioned in previous paragraph.

5.2. Preliminary data collection

In case of buildings, energy performance is the amount of energy consumed to meet the different needs associated with the standard use of that building or the output / service delivered by the building. The output or service delivered by building may be expressed in terms of the number of persons occupying/utilising the building or the area (in m^2) for which conditioned air is provided or other appropriate metric, depending on the type of building. For example, while auditing a hotel, the number of room-nights occupied (occupied rooms) every month is an indicator for the service delivery by the building. When auditing an office complex, the sum of persons hours spent in the office could be an appropriate indicator of service delivery. In case the building to be audited is a restaurant, the number of meals served in a month may be considered as a metric of service delivery.

The energy auditor shall obtain an understating of the type of building to be audited and accordingly (preferably in consultation with the building management) compile a list of appropriate metrics that describe the output or service delivery of the building.

At the beginning of the audit process, analysis of historical energy performance of the building is required. This analysis comprises primarily of comparing the energy consumed to the output or service delivery metrics for the building over a period of time. The more historical data available, the better the auditor can understand the performance of the building facility at differing times of day, in various seasons, and under diverse service delivery situations. The suitable time to conduct energy audit in a building is over the period when the building is delivering service close to capacity. The collected energy performance analysis will thus give some indication of appropriate time duration for completing an effective energy audit.

The data that shall be collected at the beginning of an energy audit may include the following:

- Month wise electricity bills and fuel bills for the last 1 to 2 years
- Monthly output or service delivery metric (or raw data to compute the metric) for the same period
- List of major energy consuming equipment with their nameplate ratings.
- Status of energy management and any energy-saving measures implemented in the recent past (by the building on their own or as part of external consultancy or agency driven improvement programme).
- General information about the building (year of construction, ownership status, renovations, types of services delivered, operation schedule particularly for certain equipment that does not operate throughout the operating shifts, operating hours, scheduled shutdowns and such other relevant information).

The energy auditor shall study the collected preliminary data and analyse the building's historical energy performance from audit planning point of view.

5.3. Audit plan

An audit plan outlines the audit strategy and procedure. The plan helps the auditors to check the consistency and completeness of the audit process and ensure that nothing important is neglected or overlooked. The audit plan, after taking into consideration the preliminary data collected, should provide the following

- Scope of the audit
- Time of the audit and its duration as well as the timeline for each step of the audit process
- Elements of the audit that have a high priority
- Responsibilities and tasks of each audit team member
- Format of the audit report and its outline

5.3.1. Selection of energy audit team

Upon reviewing the collected preliminary data and defining the audit scope, a competent team for energy audit shall be constituted. The team competence can be shown by:

- Appropriate education and/or training for energy audit
- Relevant technical, managerial, and professional experiences and skills
- Familiarity with appropriate local regulations, and energy auditing & reporting guidelines
- Familiarity with the energy equipment, utilities and process being audited
- Familiarity with energy audit instruments and competent enough to operate and handle the energy audit instruments safely.

In case, any of above-mentioned criteria are not met within the available team, an external professional may be hired/consulted to be part of the audit team.

It is a good practice to prepare a documented audit plan and to share it with the building management upfront. To the extent possible the audit team should follow the audit plan, however, in view of new observations / issues notice or ground situation changes, the audit plan may be modified during the audit. In such cases, the updated audit plan may be shared with the client subsequently.

5.3.2. Safety considerations

Ensure that relevant personal protective equipment (PPE) is available to all team members. Commonly relevant PPEs are: Electrical safety gloves, industrial safety boots, heat resistant gloves, face masks, protective eyewear, safety helmet (hard hat). Loose clothing (such a necktie or shawl) is to be strictly avoided to safely operate plant(s) and machineries to prevent accidents at site.

It is strongly recommended to comply with the health and safety guideline and procedures as defined by the relevant local authorities.

Energy auditors shall ensure their own safety by following safe practices while carrying out energy audits. Following safe pathways, not touching objects that may be hot, keep safely away from any live wires, cables and other conductive surfaces are a few basic safety considerations that must be followed at all times by the auditors. Moreover, the auditors need to study and put into practice all the relevant safety considerations on their own at each site and in each audit depending upon the nature of activities undertaken by the clients.

5.4. Introductory meeting

The purpose of the introductory meeting is to set the context for the energy audit, confirm its scope, engage all relevant facility personnel in the audit process and request specific additional energy information from the facility manager. This information should enable appraisal of the client organisation’s current energy use and energy management system.

In the introductory meeting, the energy auditor shall request the facility manager to:

- Identify a person to liaise with the energy auditor, where necessary supported by other appropriate individuals constituted as a team for the purpose.
- Inform all the divisional or functional heads and other interested parties about the energy audit and any requirements placed on them in connection with it.
- Disclose any unusual conditions, maintenance work or other activities that will occur during the energy audit.
- Ensure cooperation of the facility engineering or facility management team and other interested parties.
- Nominate a management representative to take responsibility for evaluation and implementation of energy performance improvement measures identified during the audit.

The energy auditor shall agree with the organization on:

- Arrangements for access to the audited objects for the energy auditor
- Health, safety, security and emergency rules and procedures
- Resources and data to be provided
- Proposed visit and other schedules
- Requirements for special measurements, if needed
- Procedures to be followed for installation of measuring equipment, if needed
- Aspects of data confidentiality (pertaining to the data already provided or yet to be collected), if required.

The energy auditor shall share the audit plan, describe the processes, means and schedule of the energy audit and the possible need for additional metering equipment.

5.5. Initial walkthrough visit

The purpose of the initial walk-through visit is for the energy audit team to become familiar with the facility to be audited. The auditors shall go through the building areas and utilities that they will audit in detail later.

The audit team shall also meet with the managers of the areas to be audited to provide an introduction and establish a common understanding of the audit process. The auditors can solicit comments from the facility staff and can collect readily available data during the walk-through visit. The outcome of this visit should be:

1. To finalise the energy audit team
2. To identify the main energy consuming areas/facility items to be surveyed in detail during the audit.
3. To identify and prepare list of specific instruments required for energy audit
4. To collect macro data on facility energy resources, major energy consuming equipment.
5. To build up awareness and support for detailed energy audit.
6. To update the audit plan, if necessary.

6 Conducting Detailed Energy Audit

6.1. Energy mapping

Before the start of actual field measurements, the energy auditor shall identify the major energy consumers in a facility through energy mapping. The purpose of energy mapping is to rank the major or significant energy consumers in different areas of a facility with the help of historical energy bills, rated electrical parameters of different equipment, running hours of equipment, electric sub-meters installed at equipment and by interviewing the facility manager. To collect information pertaining to energy mapping a comprehensive data collection sheet shall be prepared, which is explained in next **Section 6.2**. Completed energy mapping is a visualisation of all energy consumers in different areas of facility that helps the energy auditor to identify energy saving potential to focus on during the detailed audit.

Identifying and categorizing different loads in a facility through energy mapping can be useful. Often, the process of identifying categories of use allows energy waste to be easily identified, and this frequently leads to low-cost savings opportunities. Identifying high-consumption loads lets the auditor consider the best savings opportunities first. Because the inventory also quantifies the demand (i.e. how fast electricity is used) associated with each load or group of loads, it is invaluable for further interpretation of the demand profile.

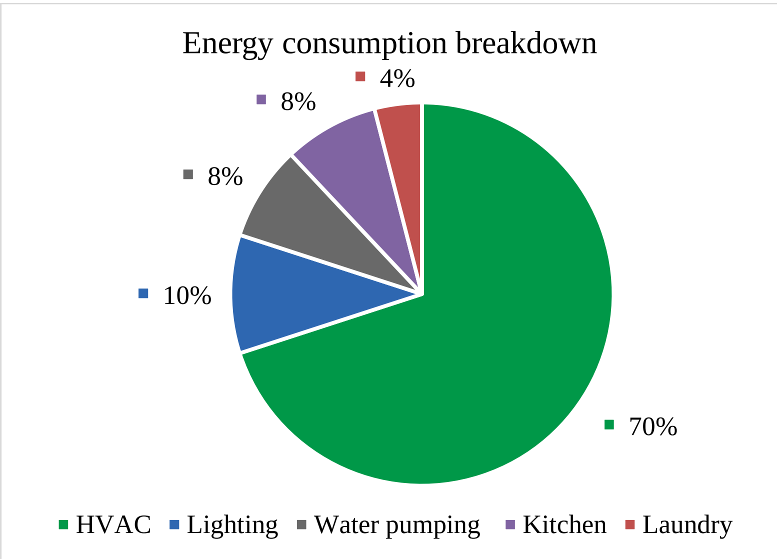


Figure 2: An example of energy consumption breakdown

An example of energy consumption breakdown or an energy mapping diagram of a hotel building in Bhutan is shown in **Figure 2**

6.2. Comprehensive data collection

Based on the preliminary data collection, the energy auditor shall prepare a customised data collection spread sheet to suit the building type. The data collection spread sheet shall have clear and descriptive headings with appropriate rows and columns for different energy consumers. A general data collection sheet shall be avoided as it will not serve meaningful purpose.

In addition to data collected at preliminary data collection stage, the energy auditor shall also collate the following information during energy audit:

- List of energy consuming utilities and equipment
- Detailed characteristics of the audited object(s) including known relevant variables and how the organization believes they influence energy consumption
- Current and historical data of
    - energy consumption
    - relevant variables
    - relevant related measurements
- Monitoring equipment configuration, and analysis information such as local gauges, distributed control systems, instrumentation types.
- Future plans that affect energy use such as planned expansions, contractions or planned changes in replacement of equipment or systems that have significant energy implications.
- Design, operation, and maintenance documents
- Energy audits or previous studies related to energy and energy performance
- Current or a reference tariff of electricity and fuel to be used for financial analysis and other relevant economic data
- Knowledge on how the organization manages its energy and relative configuration of the energy distribution system and the management structure

The data collected should be comprehensive enough to determine the energy baseline period.

Energy baseline period is a suitable period in which the organisation account for operating cycles, regulatory requirements or variables that affect the energy consumption and energy efficiency, so that the data period adequately demonstrates a full range of performance. Data that the facility has, can be data what it has internally generated (e.g. through measurements, log sheets) or data which it has access to electricity bills, fuel bill and annual reports).

Energy reduction target year: The building management may have established quantifiable objectives of energy performance improvement. If so, there would be some data analysis done by the facility to develop, track the energy reduction over a period. Review of this data would help the energy auditor determine further opportunities for energy saving as well as to obtain insights into the facility focus and approach to energy conservation.

6.3. Energy bills analysis

6.3.1. Understanding energy costs

Contrary to common belief, energy costs are not a fixed overhead, there is often a huge potential for cost savings, understanding energy cost is a vital factor for awareness creation and savings calculation. In some facilities, sufficient meters may not be available to measure all the energy used. In such cases, bills for fuels and electricity will be useful. The annual company balance sheet is the other sources where fuel cost and power are given with other related information.

Energy bills shall be analysed by auditor since they:

- Provide a record of energy purchased in a given year which gives a baseline for future reference
- Indicate the potential for savings when related to output or service delivery requirements.
- Provide the basis of maximum demand tariff.
- Allow comparison of energy cost (and changes in energy consumption) over time.

6.3.2. Fuel costs

Following are the most common types of fuels used in building facility in Bhutan for thermal energy supply are

- Diesel
- Liquefied Petroleum Gas, LPG

Understanding fuel cost is simple and it is purchased in tons (t) or kilolitres (kl) and generally defined in Tonnes of Oil Equivalent (TOE). The three main factors that affect the diesel and LPG costs are:

- Price at source, transport charge, type of transport
- Quality of Diesel (contaminations, moisture, etc.)
- Taxes and subsidies (if any)

6.3.3. Electricity bill analysis

The electricity billing by utilities for medium and large facility is often done on two-part tariff structure, i.e. one part for capacity (power or demand) drawn and the second part for actual energy drawn during the billing cycle. Capacity or demand is in kVA (apparent power) or kW terms. The reactive energy, i.e. kVAr drawn by the service is also recorded and billed for in some utilities, because this would affect the load on the utility. Accordingly, utility charges for maximum demand, active energy, and reactive power drawn (as reflected by the power factor) in its billing structure. In addition, other fixed and variable expenses are also levied.

The tariff structure generally includes the following components:

- **Maximum demand Charges** also called as normative availability of a power plant, relates to the maximum demand registered during month/billing period and corresponding rate of utility.
- **Energy Charges** relate to energy (kilowatt hours) consumed during month or billing period and corresponding rates, often levied in slabs of use rates.
- **Power factor** penalty or bonus rates, as levied by most utilities, and includes cost of reactive power drawn from the grid.
- **Time of day (TOD)** rates like peak and non-peak hours are also prevalent in tariff structure provisions of some utilities.

- Penalty for exceeding **contract demand**. Contract demand means the maximum amount of apparent power (kVA) demand that the customer expects to use and for which the customer has contracted the utility.
- Any other charges, taxes, or subsidy as applicable.

Analysis of utility bill data and monitoring its trends helps energy auditors to identify ways for electricity bill reduction through available provisions in the tariff framework.

The utility employs an electromagnetic or electronic tri-vector meter, for billing purposes. The minimum outputs from the meters are:

- Maximum demand registered during the month, which is measured in pre-set time intervals (15- or 30-minute duration) and this is reset at the end of every billing cycle.
- Active energy in kWh during billing cycle
- Reactive energy in kVArh during billing cycle
- Apparent energy in kVAh during billing cycle

It is important to note that while maximum demand is recorded, it is not the instantaneous demand drawn, as is often misunderstood but the time integrated demand exceeding the predefined cycle, that in fact gets recorded. As an example, in a facility if the drawl over a recording cycle of 30 minutes is

1. 1000 kVA for 4 minutes
2. 1200 kVA for 12 minutes
3. 1100 kVA for 6 minutes
4. 900 kVA for 8 minutes

The energy meter will be computing maximum demand as:

$$\frac{(1000\ X\ 4) + (1200\ X\ 12) + (1100\ X\ 6) + (900X\ 8)}{30} = 1073.3kVA$$

The month's maximum demand will be the highest among such demand values recorded over the month. The energy meter registers only if the value exceeds the previous maximum demand value and thus, even if, average maximum demand is low, the facility has to pay for the maximum demand charges for the highest value registered during the month, even if it occurs for just one recording cycle duration i.e. 30 minutes during whole of the month.

Electricity Bill data collection: An energy auditor shall try to collect electricity bill data in a prescribed spread sheet format for analysis as shown in below example **Table 3**

Table 3: An example of data collection sheet for electricity bill

Month & Year	Maximum Demand (kVA)	Energy consumption (kWh)	Power Factor (PF)	Maximum Demand charges (Nu.)	Energy charges (Nu.)	Total bill (Nu.)	Effective rate[4] (Nu. per kWh)
Jan-XX							
Feb-XX							
……							
……							
Dec-XX							

Based on the components in electricity bill for the facility being audited, more columns can be added or removed from the **Table 3**

6.4. Analysis of historical energy use and SEC

Consumption of energy resources for providing services needs to be tracked in relation to the service output provided by a facility. Suitably developed energy indicators provide valuable information on the efficiency and effectiveness of the facility's control on energy consumption. This is an important tool for analysing the effectiveness of the building systems and maintenance practices and an indicator of building energy performance. There could be more than one energy indicator for a facility depending on the energy input and service output. Hence, an energy auditor shall develop suitable customised indicators based on the available data of a facility and type of building.

The developed energy indicators which give valuable information on the energy performance of one building may not be relevant for another building.

An example case study of a specific energy consumption indicator of a 5-star hotel has been described below:

Specific energy consumption **(SEC)** is an important indicator that is determined by dividing the energy consumed in a month by the number of occupied rooms of that month. Ideally this should stay level; energy consumption should increase only when more guests stay in the hotel therefore the ratio of electricity use to number of occupied rooms should stay almost the same. However, in practice, there are many energy consuming areas such as lobby, outdoor lights that do not consume less energy when fewer guest stay in the hotel. Therefore, some variation in the value of this (specific energy consumption) indicator is acceptable. 12-month electricity consumption data was used to generate the below **Figure 3** Here the left vertical axis and the green line show the monthly variation of the specific energy consumption (kWh/occupied rooms) The right side axis and blue bars show the variation in occupied rooms for the

[4] Total electricity bill amount for the month divided by total energy consumed in the month (Nu/kWh)

corresponding month. Occupied rooms per month is calculated by multiplying numbers of rooms occupied per day and number of days per month.

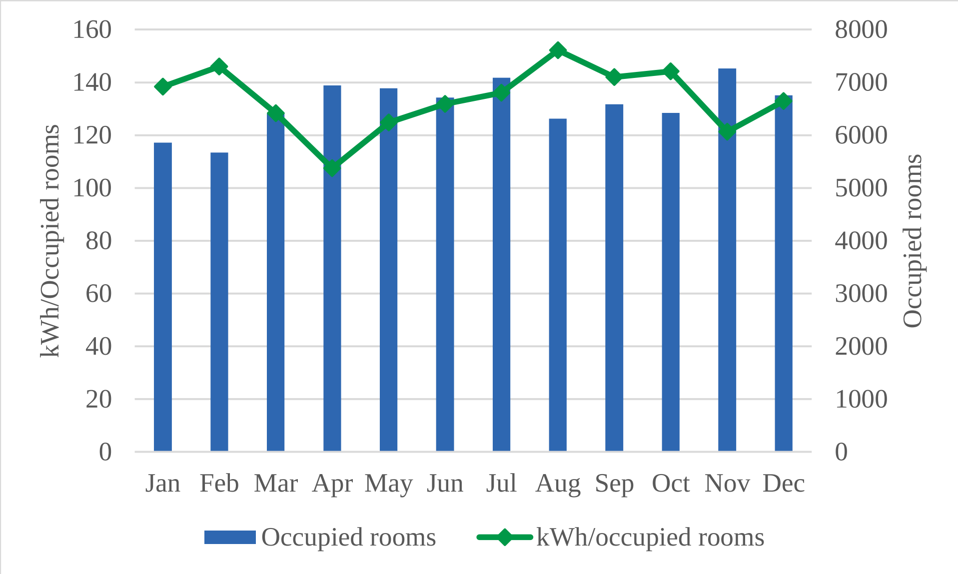


Figure 3: Energy consumption versus occupied rooms

Referring to above example, indicators shall be developed for the building being audited and analysed for reporting to the management.

6.5. Measurements, survey, and verification of measured data

Gathering data through measurement and survey is one of the main activities of energy auditing. Without adequate and accurate data, an energy audit cannot be successfully accomplished. Some data are readily available and can be collected from different divisions of the facility being audited. Some other data can be collected through measurement and recording.

6.5.1. Verification of the measured data

Verify the measured values of the equipment and utilities with rated parameters of the respective equipment and utilities and if a very wide variation observed between measured values and rated parameters, this is an indication of following:

- The equipment or utility under observation is faulty and immediate attention is needed by the facility engineering team.
- The equipment or utility under observation is partially loaded or not fully utilised, the energy auditor shall investigate further to find energy saving opportunities.
- The method of measurement used by energy auditor may be wrong. Energy auditor shall check whether their instruments are functioning well and shall take the measurements again to verify.

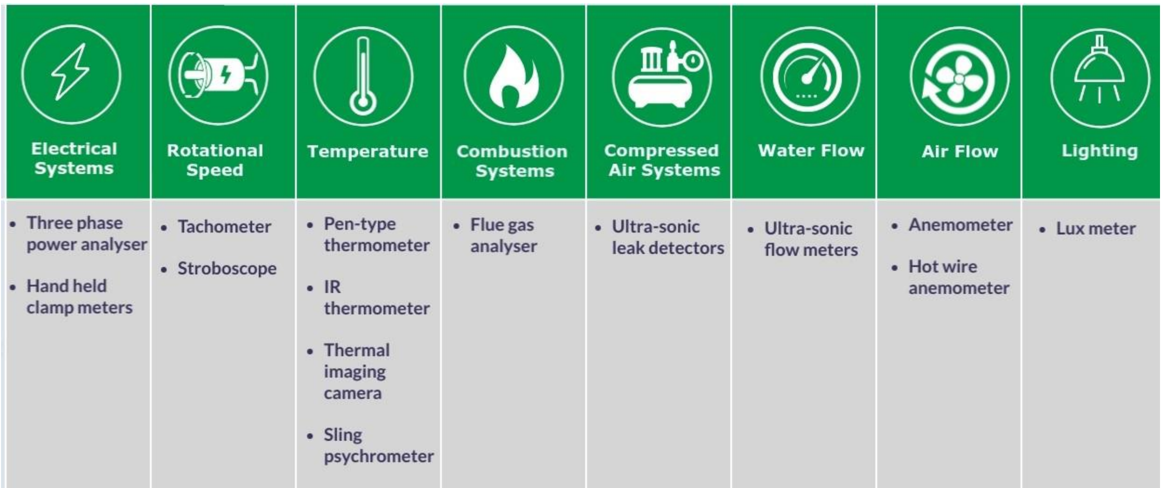
6.5.2. Portable measuring instruments for energy audit

The energy audit team should be well-equipped with all the necessary measurement instruments. The instruments used for measurements shall be well calibrated with valid calibration certificate and functioning properly. Modern portable meters can store data collected for a longer duration (24 hours or more) and can then be uploaded either directly or remotely for analyses off site.

The energy auditor shall ensure:

- The instruments are well calibrated, and their calibration certificates are valid.
- The instruments calibration certificates are attached/pasted on the instruments
- The instruments are functioning well and safe to operate.

Refer **Chapter-12** for detailed list of instruments required for energy audit.



Electrical Systems	Rotational Speed	Temperature	Combustion Systems	Compressed Air Systems	Water Flow	Air Flow	Lighting
• Three phase power analyser • Hand held clamp meters	• Tachometer • Stroboscope	• Pen-type thermometer • IR thermometer • Thermal imaging camera • Sling psychrometer	• Flue gas analyser	• Ultra-sonic leak detectors	• Ultra-sonic flow meters	• Anemometer • Hot wire anemometer	• Lux meter

Figure 4: Appropriate portable measuring instruments for various systems

7 Detailed Energy Performance Assessment

7.1. Electrical systems & Power Factor

7.1.1. Introduction

The network through which the consumers get electricity from the source is called electrical supply system. An electrical supply system consists of generating units that produce electricity, high voltage transmission lines that transport electricity over long distances, and distribution lines that deliver electricity to consumer.

Figure 5 is an illustration of electricity transmission and distribution system, and linkages from electricity sources to end user.

The power generation units typically produce 50 Hertz alternating current (AC) electricity with voltages between 11 kV and 33 kV. At the power generation units, the three-phase voltage is stepped up to a higher voltage for transmission on cables strung on cross country towers. Extra high voltages (EHV) like 265 kV to 275 kV and high voltages (HV) like 110 kV, and above transmission is the next stage from power generation units to transport A.C. power over long distances. Sub-transmission network at 132 kV, 110 kV, 66 kV or 33 kV constitutes the next link towards the end user. Distribution at 11 kV/6.6kV/3.3 kV constitutes the last link to the consumer, who is connected directly or through transformers depending upon the drawn level of service.

The transmission and distribution network includes sub-stations, lines and distribution transformers. High voltage transmission is used so that smaller, more economical wire sizes can be employed to carry the lower current and to reduce losses. Sub-stations, containing step-down transformers, reduce the voltage for distribution to industrial users.

There is no difference between a transmission line and a distribution line except for the voltage level and power handling capability. Transmission lines are usually capable of transmitting large quantities of electric energy over great distances. They operate at high voltages. Distribution lines carry limited quantities of power over shorter distances.

Voltage drops in line are in relation to the resistance and reactance of line, length and the current drawn. For the same quantity of power handled, lower the voltage, higher the current drawn and higher the voltage drop. The current drawn is inversely proportional to the voltage level for the same quantity of power handled.

The power loss in line is proportional to resistance and square of current. (i.e. $P = I^2R$). Higher voltage transmission and distribution thus would help to minimize line voltage drop in the ratio of voltages, and the line power loss in the ratio of square of voltages. For instance, if distribution of power is raised from 11 kV to 33 kV, the voltage drop would be lower by a factor 1/3 and the line loss would be lower by a factor $(1/3)^2$ i.e., (1/9). Lower voltage transmission and distribution also calls for bigger size conductor on account of current handling capacity needed.

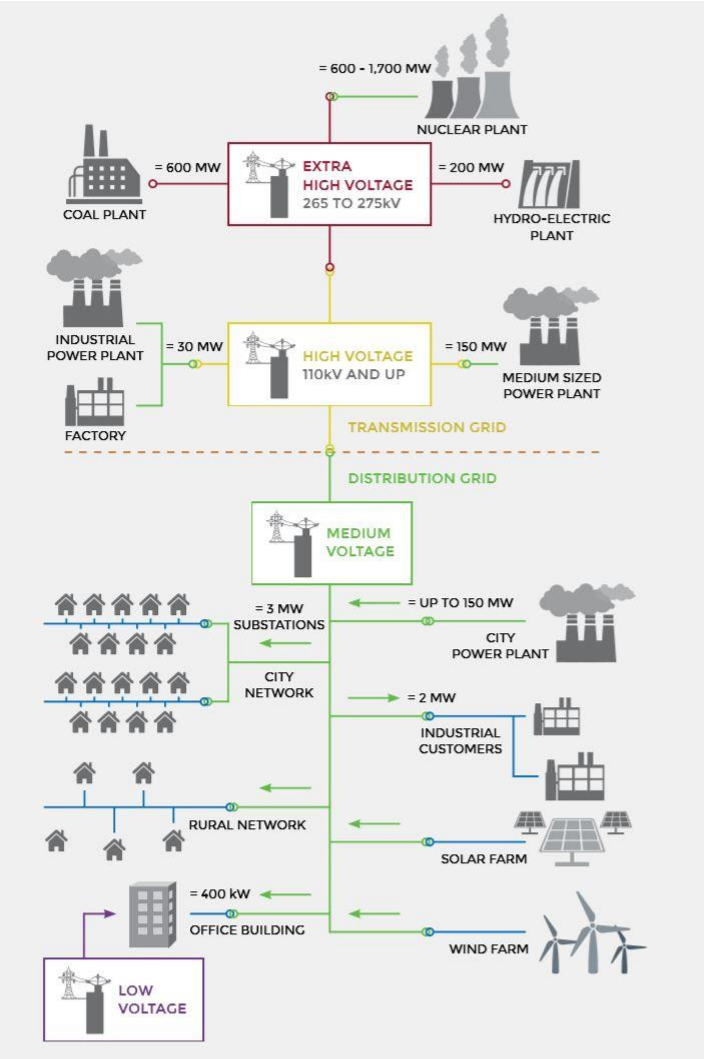


Figure 5: Illustration of electricity transmission and distribution system (Source: UNEP)

7.1.2. Data collection

Following data shall be collected during audit with support from building manager:

- Electricity Bill for preceding 12 months (minimum)
- Log sheet related to electrical fault caused by overheating or overvoltage
- Any recurring electrical faults recorded by building manager

In addition to above, the following data shall be collected through measurements

- Power logging at mains panel up to 24 hours (duration of logging should be decided mutually with building manager)
- Power measurements at sub-panels
- Thermal images of inside electrical panels (to check overheating)

7.1.3. Instruments required

- Three-phase power analyser
- Hand-held clamp meter

- Thermal imaging camera (to check overheating inside electrical panels)

7.1.4. Observation parameters

- Maximum demand or Peak demand
- Power factor

7.1.5. Measurements

The following electrical parameters can be measured using hand-held clamp meter or three-phase power analyser.

- Voltage (V)
- Current (A)
- Power (kW)
- Power factor (PF)
- Apparent power (kVA)
- Reactive power (kVAr)
- Harmonics
- All other remaining electrical parameters

7.1.6. Electrical load management and maximum demand control

Need for electrical load management

In a macro perspective, the growth in the electricity use and diversity of end use segments in time of use has led to shortfalls in capacity to meet demand. As capacity addition is costly and only a long-time prospect, better load management at user end helps to minimize peak demands on the utility infrastructure as well as better utilization of power plant capacities. The utilities (Distribution companies) use power tariff structure to influence end user in better load management through measures like time of use tariffs, penalties on exceeding allowed maximum demand, night tariff concessions etc. Load management is a powerful means of efficiency improvement both for end user as well as utility.

As the demand charges constitute a considerable portion of the electricity bill, from user angle too there is a need for integrated load management to effectively control the maximum demand.

Step by step approach for Maximum Demand (MD) control

1. Load curve generation

Presenting the load demand of a consumer against time of the day is known as a 'load curve'. If it is plotted for the 24 hours of a single day with the help of a **three-phase power analyser**, it is known as 'hourly load curve' and if daily demands plotted over a month, it is called 'daily load curve'. A typical hourly load curve for a facility is shown **Figure 6.** These types of curves are useful in predicting patterns of drawl, peaks and valleys and energy use trend in a section or in an facility or in a distribution network as the case may be.

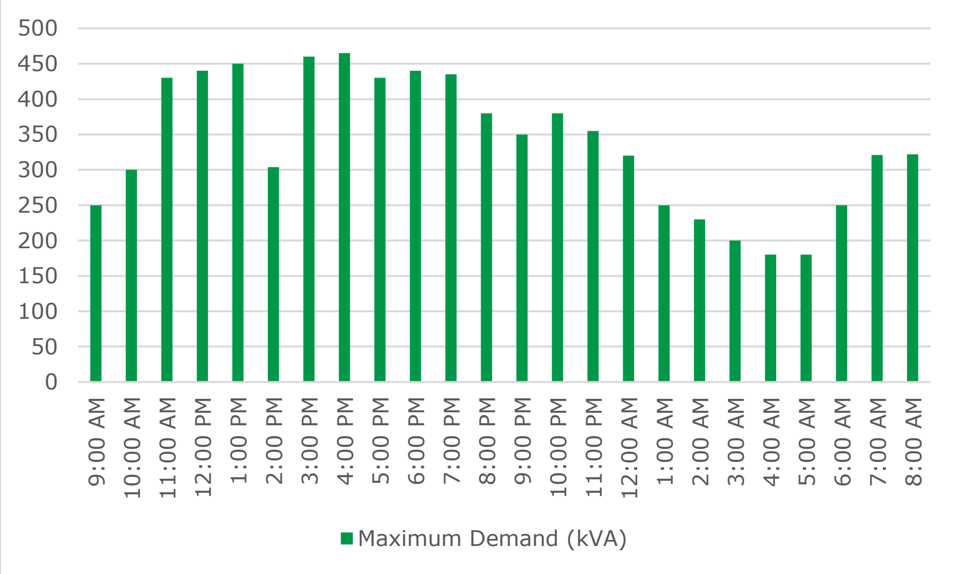


Figure 6: Hourly load curve

2. Rescheduling of loads

Rescheduling of large electric loads and equipment operations, in different shifts can be planned and implemented to minimize the simultaneous maximum demand. For this purpose, it is advisable to prepare an operation flow chart and a process chart. Analysing these charts and with an integrated approach, it would be possible to reschedule the operations and running equipment in such a way as to improve the load factor which in turn reduces the maximum demand.

3. Storage of products/in process material/ process utilities like refrigeration

It is possible to reduce the maximum demand by building up storage capacity of products/ materials, water, chilled water *I* hot water, using electricity during off peak periods. Off peak hour operations also help to save energy due to favourable conditions such as lower ambient temperature etc. Example: Ice bank system is used in milk & dairy industry. Ice is made in lean period and used in peak load period and thus maximum demand is reduced.

4. Shedding of non-essential loads

When the maximum demand tends to reach pre-set limit, shedding some of non-essential loads temporarily can help to reduce recorded peak demand. It is possible to install direct demand monitoring and control systems which will switch off non-essential loads when a pre-set demand is reached. Simple systems give an alarm, and the loads are shed manually. Sophisticated microprocessor-controlled systems are also available, which provide a wide variety of control options like:

- Accurate prediction of demand
- Graphical display of present load, available load, demand limit
- Visual and audible alarm
- Automatic load shedding in a predetermined sequence
- Automatic restoration of load
- Recording and metering

5. **Operation of captive generation and Diesel Generation (DG) sets**

When diesel generation sets are used to supplement the power supplied by the electric utilities, it is advisable to connect the D.G. sets for durations when demand reaches the peak value. This would reduce the load demand from the utility to a considerable extent and minimize the demand charges.

6. **Reactive power compensation**

The maximum demand can also be reduced at the plant level by using capacitor banks and maintaining the optimum power factor. Capacitor banks are available with microprocessor-based control systems. These systems switch on and off the capacitor banks to maintain the desired Power factor of system and optimize maximum demand thereby.

7.1.7. Power factor

Power factor basics

All AC electrical networks consume two types of power: active power (kW) and reactive power (kVAr):

Active power P (in kW) is the real power transmitted to loads such as motors, lamps, heaters, electrical appliances, etc. The electrical active power is transformed into mechanical power, heat, or light. Active power is measured in kW.

Reactive power Q (in kVAr) is used only to supply the magnetic circuits of machines, motors, and transformers. Reactive power is measured in kVAr

Apparent power S (in kVA) the vector sum of the active power and reactive power make up the total apparent power used. Total apparent power measured in kVA. This is the power generated by the power generation units for the user to perform a given amount of work.

The power generation units supply both active power and reactive power as shown in below **Figure 7**

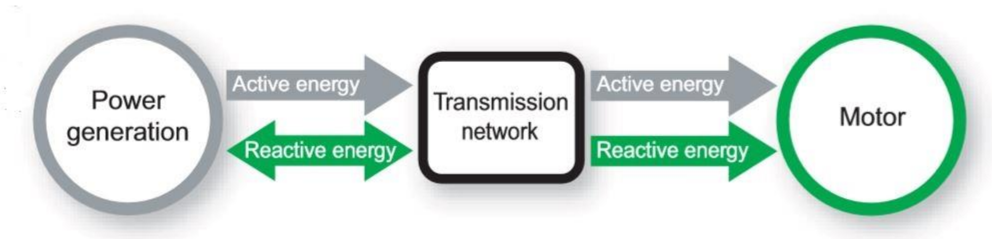
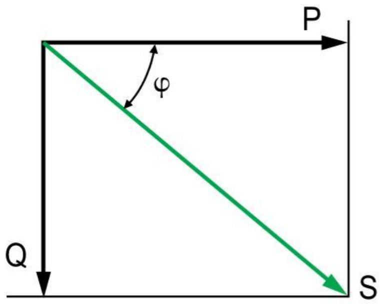


Figure 7: Reactive energy supplied and billed by the energy supplier or utility

Power triangle

The active power in kW and the reactive power in kVAr required are 90° apart vectorially in a pure inductive circuit i.e., reactive power in kVAr lagging the active power kW. The vector sum of the active power, P in kW and reactive power, Q in kVAr is called apparent power, S in kVA. The ratio of active power to apparent power is called the Power Factor (P/S), which is always less than or equal to unity and also represented by cosφ. **Ideally power factor of a facility should be 1 (unity) or near to unity.**



$$\cos \Phi = \frac{P\ (kW)}{S\ (kVA)}$$

Figure 8: Power triangle

7.1.8. Improving power factor

The circulation of reactive power in the electrical network has major technical and economic consequences. For the same active power P, a higher reactive power means a higher apparent power and thus, a higher current must be supplied. Due to this higher supplied current, circulation of reactive energy on distribution networks results in:

- Overload of transformers
- Higher temperature rise of the supply cables
- Additional losses
- Large voltage drops
- Higher energy consumption and cost
- Less distributed active power

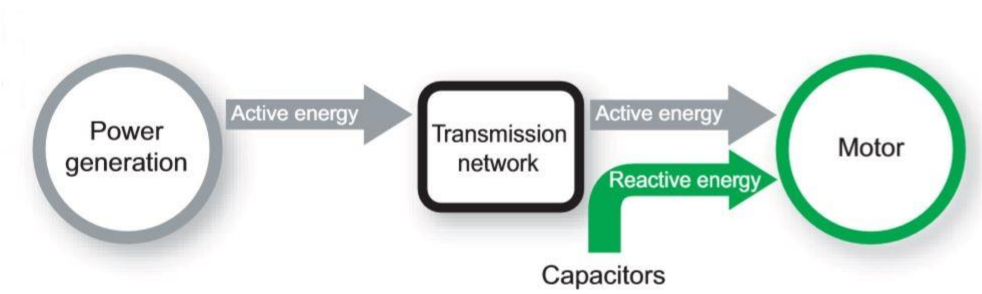


Figure 9: Connection of capacitors at load level

For these reasons, there is a great advantage to generate reactive energy at the load level in order to prevent the unnecessary circulation of current in the network. This is what is known as “Power Factor Correction”. This is obtained by the connection of capacitors, which produce reactive energy in opposition to the energy absorbed by loads such as motors. The result is a reduced apparent power, and an improved power factor.

The power generation and transmission networks are partially relieved, reducing power losses and making additional transmission capability available. Since the reactive power is supplied by capacitors there is no billing of reactive power by the utility (energy supplier).

7.1.9. Advantages of power factor improvement

- Reduction of I^2R losses in cables, thus reduced distribution losses (kWh) within the facility's electrical network system, which results in energy savings
- Reduction of voltage drop at motor terminals and improved performance of motors.
- Increase in available power by improving the power factor of a load supplied from a transformer, the current through the transformer will be reduced, thereby allowing more load to be added. In practice, it may be less expensive to improve the power factor to unity, than to replace the transformer by a larger unit.
- Reduced maximum demand (kVA) charges in electricity bill.

7.1.10. Power Factor correction guidelines

The selection of the Power Factor correction equipment can follow a 4-step process:

1. Calculation of the required reactive energy
2. Selection of the compensation mode:
    - Central compensation, for the complete installation
    - Group compensation at section feeders
    - Individual compensation such as at large motors
3. Selection of the compensation type:
    - Fixed, by connection of a fixed-value capacitor bank,
    - Automatic, by connection of different number of steps, allowing the adjustment of the reactive energy to the requested value,
    - Dynamic, for compensation of highly fluctuating loads.
4. Taking account of operating conditions and effects of harmonics

1. Calculation of the required reactive energy

a) Power factor correction for transformer no-load compensation

The transformer works on the principle of Mutual Induction. The transformer will consume reactive power for magnetizing purpose. Following equivalent circuit of transformer provides the details of reactive power demand inside the transformer.

kVA rating of the Transformer	kVAr required for No-load compensation
Up to and including 2000 kVA	2% of the kVA rating

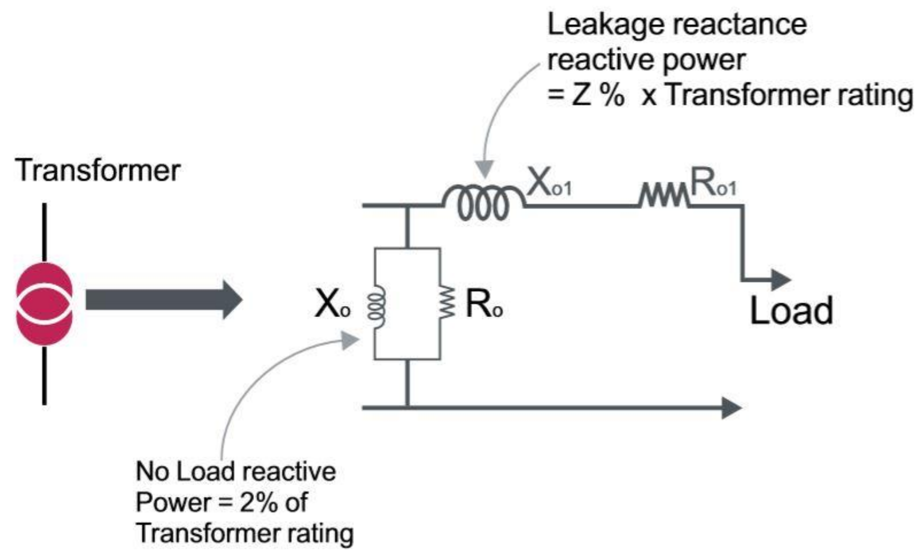


Figure 10: No-load compensation for transformer

b) Power factor correction where load and present power factor is known

The objective is to determine the required reactive power Q_C (kVAr) to be installed, in order to improve the power factor cosφ and reduce the apparent power S. For φ' < φ, we will get: cosφ' > cosφ and tanφ' < tanφ, this is illustrated in the below **Figure 11**

Q_C, required capacitor rating in kVAr can be determined from the formula:

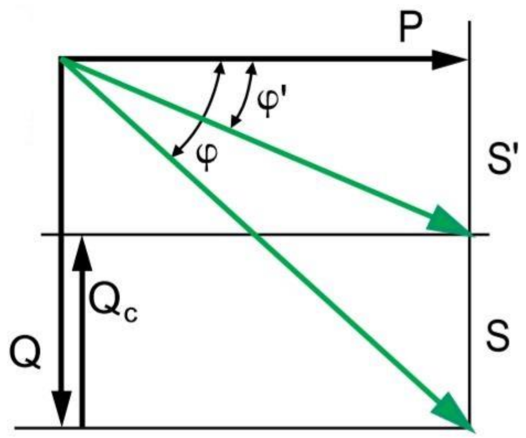


Figure 11: Power factor correction triangle

Q_C = Active power (kW) X (tanφ - tanφ')

Where,
tanφ: tangent of the phase angle - before compensation,
tanφ': tangent of the phase angle - after compensation
The parameters φ and tanφ can be obtained from the billing data, or from direct measurement in the installation.

Alternatively, the following **Table 4** can be used for direct determination.
The figures given in the **Table 4** are multiplication factors which are to be multiplied with the active power (kW) to obtain the required capacitor rating in kVAr to improve the present power factor to a new desired power factor.

Table 4: Multipliers to determine capacitor kVAr requirements for power factor correction (Source: adapted from Schneider Electric)

Before compensation		Reactive power (kvar) to be installed per kW of load, in order to get the requested tanφ' or cosφ'							
tanφ	cosφ	tanφ'	0.75	0.62	0.48	0.41	0.33	0.23	0.00
		cosφ'	0.8	0.85	0.9	0.925	0.95	0.975	1.00
1.73	0.5		0.98	1.11	1.25	1.32	1.40	1.50	1.73
1.02	0.7		0.27	0.40	0.54	0.61	0.69	0.79	1.02
0.96	0.72		0.21	0.34	0.48	0.55	0.64	0.74	0.96
0.91	0.74		0.16	0.29	0.42	0.50	0.58	0.68	0.91
0.86	0.76		0.11	0.24	0.37	0.44	0.53	0.63	0.86
0.80	0.78		0.05	0.18	0.32	0.39	0.47	0.57	0.80
0.75	0.8			0.13	0.27	0.34	0.42	0.52	0.75
0.70	0.82			0.08	0.21	0.29	0.37	0.47	0.70
0.65	0.84			0.03	0.16	0.24	0.32	0.42	0.65
0.59	0.86				0.11	0.18	0.26	0.37	0.59
0.54	0.88				0.06	0.13	0.21	0.31	0.54
0.48	0.9					0.07	0.16	0.26	0.48

Example: The electricity bill shows an average power factor of 0.8 (cosφ = 0.8) with an average active power of 1000 kW. How much kVAr is required to improve the power factor to 0.95?

Solution:
Using formula:

1. Q_C = Active power (kW) X (tanφ - tanφ')
2. Existing power factor cosφ = 0.8, tanΦ = 0.75
3. Desired power factor cosφ`= 0.95, tanΦ` = 0.329
4. Required capacitor rating Q_c = 1000 (0.75- 0.329) = 420 kVAr

Using **Table 4:**
1. Locate existing power factor 0.8 in column 2
2. Read across desired power factor to 0.95 column, we find multiplier 0.42
3. Multiply 1000 kW by 0.42 = 420 kVAr
4. Install 420 kVAr to improve power factor to 0.95.

2. Selection of compensation mode for PF improvement

The location of low-voltage capacitors in an installation constitutes the mode of compensation, which may be central (one location for the entire installation), by group (section-by section), at load level, or some combination of the latter two. In principle, the ideal compensation is applied at a point of consumption and at the level required at any instant. In practice, technical and economic factors govern the choice.

The place for connection of capacitor banks in the electrical network is determined by:

- Global objective (avoid penalties on reactive energy, relieve of transformer or cables, avoid voltage drops and sags),
- Operating mode (stable or fluctuating loads),
- Foreseeable influence of capacitors on the network characteristics,
- Installation cost.

Central compensation

The capacitor bank is connected at the head of the installation to be compensated in order to provide reactive energy for the whole installation. This configuration is convenient for stable and continuous load factor.

Group compensation

The capacitor bank is connected at the head of the feeders supplying one particular sector to be compensated. This configuration is convenient for a wide installation, with workshops having different load factors.

Compensation of individual loads

The capacitor bank is connected right at the inductive load terminals (especially large motors). This configuration is well adapted when the load power is significant compared to the subscribed power. This is the technical ideal configuration, as the reactive energy is produced exactly where it is needed and adjusted to the demand.

3. Selection of the compensation type

Different types of compensation shall be adopted depending on the performance requirements and complexity of control:

- Fixed, by connection of a fixed-value capacitor bank
- Automatic, by connection of different number of steps, allowing the adjustment of the reactive energy to the requested value
- Dynamic, for compensation of highly fluctuating loads.

Fixed compensation

This arrangement uses one or more capacitor(s) to provide a constant level of compensation. Control may be:

- Manual: by circuit-breaker or load-break switch
- Semi-automatic: by contactor
- Direct connection to an appliance and switched with it.
- These capacitors are applied:

- At the terminals of inductive loads (mainly motors),
- At bus bars supplying numerous small motors and inductive appliances for which individual compensation would be too costly
- In cases where the load factor is reasonably constant.

Automatic compensation

This kind of compensation provides automatic control and adapts the quantity of reactive power to the variations of the installation in order to maintain the targeted cos φ. The equipment is applied at points in an installation where the active-power and/or reactive-power variations are relatively large, for example:

- At the busbars of a main distribution switchboard
- At the terminals of a heavily loaded feeder cable.

Where the kVAr rating of the capacitors is less than, or equal to 15% of the supply transformer rating, a fixed value of compensation is appropriate. Above the 15% level, it is advisable to install an automatically controlled bank of capacitors. Control is usually provided by contactors. For compensation of highly fluctuating loads, fast and highly repetitive connection of capacitors is necessary, then static switches must be used.

Dynamic compensation

This kind of compensation is requested when fluctuating loads are present, and voltage fluctuations should be avoided. The principle of dynamic compensation is to associate a fixed capacitor bank and an electronic var compensator, providing either leading or lagging reactive currents. The result is a continuously varying and fast compensation, perfectly suitable for loads such as lifts, crushers, spot welding

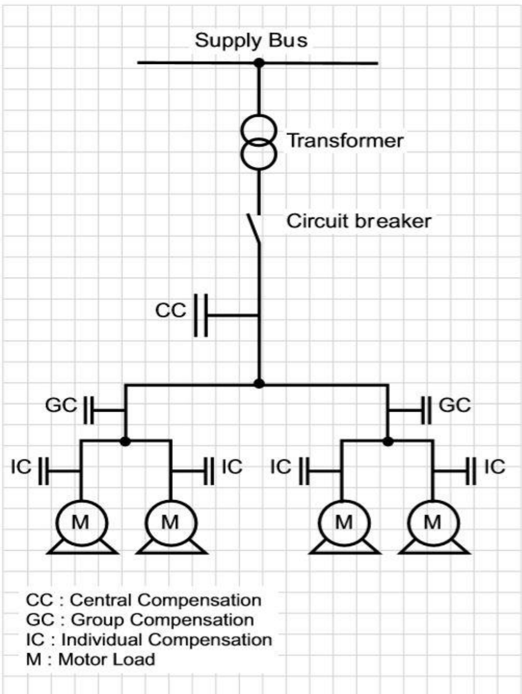


Figure 12: Different compensation modes for power factor improvement

4. Effects of harmonics

Harmonics in electrical installations

The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms.

Harmonic currents are currents circulating in the networks and which frequency is an integer multiple of the supply frequency. Harmonic currents are caused by non-linear loads connected to the distribution system. A load is said to be non-linear when the current it draws does not have the same waveform as the supply voltage. The flow of harmonic currents through system impedances in turn creates voltage harmonics, which distort the supply voltage.

The most common non-linear loads generating harmonic currents are using power electronics, such as variable speed drives, rectifiers, inverters, etc. Loads such as saturable reactors, welding equipment, arc furnaces, also generate harmonics.

Influence of harmonics in Capacitors

Capacitors are particularly sensitive to harmonic currents since their impedance decreases proportionally to the order of the harmonics present. This can result in a capacitor overload, shortening steadily its operating life. In some extreme situations, resonance can occur, resulting in an amplification of harmonic currents and a very high voltage distortion.

Amplification of Harmonic currents is very high when the natural resonance frequency of the capacitor and the network combined happens to be close to any of the harmonic frequencies present. This situation could result in severe over voltages and overloads which will lead to premature failure of capacitors.

To ensure a good and proper operation of the electrical installation, the harmonic level must be taken into account in the selection of the power factor correction equipment. A significant parameter is the cumulated power of the non-linear loads generating harmonic currents.

7.1.11. Capacitor selection based on operating conditions

The operating conditions have a great influence on the life expectancy of capacitors. For this reason, different categories of capacitors, with different withstand levels, must be selected according to operating conditions.

Capacitors must be selected in function of the following parameters:

- Ambient Temperature (°C),
- Expected over-current, related to voltage disturbances, including maximum sustained over voltage,
- Maximum number of switching operations/year,
- Requested life expectancy.
- Capacitors are particularly sensitive to harmonics. Depending on the magnitude of harmonics in the network, different configurations shall be adopted.

7.1.12. Troubleshooting of electrical power systems

System problem	Common cause	Possible effects	Solutions
Poor connections in distribution or at connected loads	Loose bus bar connections, loose cable connections, lose or worn contactors	Produces heat, causes failure at connection site, leads to voltage drops and voltage imbalances	Use Thermal imaging camera to locate hot-spots and correct.
Undersized conductors	Facilities expanding beyond original design, poor power factors	Reduces current-carrying capacity of wiring, voltage regulation effectiveness, and equipment life	Add capacitors to counter reactive loads
Cable insulation leakage	Degradation over time due to extreme temperatures, abrasion, moisture, chemicals	Variable energy waste	Replace cables
Low power factor	Inductive loads such as motors, transformers, and lighting ballasts non-linear loads, such as electronic loads	Reduces current-carrying capacity of wiring, voltage regulation effectiveness, and equipment life.	Add capacitors to counter reactive loads

7.2. Transformers

7.2.1. Introduction

Transformers are electrical devices consisting of two or more coils of wire used to transfer electrical energy by means of a changing magnetic field. A transformer can accept energy at one voltage and deliver it at another voltage. This permits electrical energy to be generated at relatively low voltages and transmitted at high voltages and low currents, thus reducing line losses and voltage drop.

Types of transformer

Transformers are classified as two categories: power transformer and distribution transformers. Power transformers are used in transmission network of higher voltages, deployed for step-up and step-down transformer application, usual voltage ratings are 440 kV, 200 kV, 110 kV, 66 kV, 33kV.

Distribution transformers are used for lower voltage distribution networks as a means to end user connectivity, usual voltage ratings are 11 kV, 6.6 kV, 3.3 kV, 440 V, 230 V.

Rating of transformer

Rating of the transformer is calculated based on the connected load and applying the diversity factor on the connected load, applicable to the particular industry and arrive at the kVA rating of the Transformer.

Diversity factor is defined as the ratio of overall maximum demand of the facility to the sum of individual maximum demand of various equipment. Diversity factor varies from facility to facility and depends on various factors such as individual loads, load factor and future expansion needs of the facility. Diversity factor will always be less than one.

Location of transformer

Location of the transformer is very important as far as distribution loss is concerned. Transformer receives HT voltage from the grid and steps it down to the required voltage. Transformers should be placed close to the load centre, considering other features like optimization needs for centralized control, operational flexibility etc. This will bring down the distribution loss in cables.

7.2.2. Data collection

Following data shall be collected during audit of transformer from transformer manufacturer's test report and by interviewing the operator or building manager:

- Transformer rating
- Type of transformer
- Age of transformer
- Rated transformer efficiency
- Rated No-load loss
- Rated load loss

7.2.3. Instruments required

- Three-phase power analyser (2-sets, if applying method-2 to determine transformer efficiency)
- Thermal imaging camera

7.2.4. Performance terms and definitions

The transformer efficiency varies between 96 to 99%. The efficiency of the transformer depends on the design of the transformer and the effective operating load.

$$Transformer\ efficiency\ (\eta) = \frac{Output\ power}{Output\ power + total\ loss}\ X\ 100$$

Transformer losses consist of two parts: No-load loss and Load loss

No-load loss also called core loss is the power consumed to sustain the magnetic field in the transformer's steel core. Core loss occurs whenever the transformer is energized, core loss does not vary with load. Core losses are caused by two factors: hysteresis and eddy current losses. Hysteresis loss is that energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction. Eddy current loss is a result of induced currents circulating in the core.

Load loss (also called copper loss) is associated with full-load current flow in the transformer windings. Copper loss is power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings. Copper loss varies with the square of the load current. ($P=I^2R$).

For a given transformer, the manufacturer can supply values for no-load loss and load loss. The total transformer loss, at any load level can be calculated from below formula:

Total transformer loss = No load loss + [(Loading (%) of transformer)^2 X full load loss]

Transformer losses as a percentage of load is given in **Figure 13**

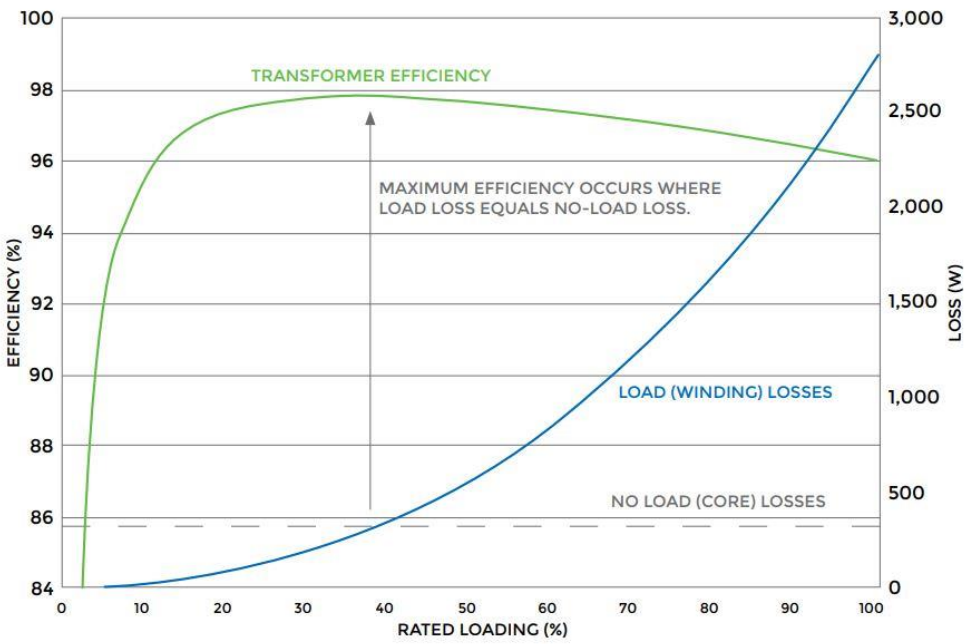


Figure 13: Transformer losses as a percentage (%) of load (Source: UNEP)

7.2.5. Performance assessment of transformer

Determine transformer efficiency

Method-1

Follow the below steps to determine transformer efficiency:

1. Using a three-phase analyser, measure the average apparent power (kVA) at the primary side of transformer by CT (current transformer), PT (potential transformer) ratio conversion method. **Caution:** Never attach voltage clips directly to primary side of transformer, it may lead to injury and sudden death.
2. Note the transformer No load loss and load loss from the transformer's manufacturer test report which is generally available with facility manager.
3. Also, note the transformer rating from manufacturer test report.
4. Using the below formula, calculate the transformer total loss (kW)

$$Total\ loss\ (kW) = \ No\ load\ loss + \left(\left(\frac{Measured\ apparent\ power\ (kVA)}{Rated\ apparent\ power\ \ (kVA)}\right)^2\ X\ full\ load\ loss\right)$$

5. Using a three-phase power, measure the output power (kW) (at secondary side) of the transformer.
6. Using the below formula, calculate transformer efficiency

$$Transfomer\ efficiency\ (\eta) = \frac{Output\ power}{Output\ power + total\ loss}\ X\ 100$$

Method-2

1. By using 2 sets of three-phase power analyser, measure simultaneously primary side input power (kW) and secondary side output power (kW) of transformer.
2. Using the below formula, calculate transformer efficiency

$$Transformer\ efficiency\ (\eta) = \frac{output\ power}{input\ power}\ X\ 100$$

Compare the obtained transformer efficiency with rated efficiency of existing transformer or new energy efficient transformer. If there is wide variation in efficiencies, use the below formula to calculate power loss.

Power (kW) loss = Average load (kW) X $[(1/\eta_{measured} - 1/\eta_{rated\ or\ new})]$

7.2.6. Energy saving opportunity

Replace old (20 years and above) transformers with energy efficient transformers

Most energy loss in dry-type transformers occurs through heat or vibration from the core. The new high-efficiency transformers minimize these losses. The conventional transformer is made up of a silicon alloyed iron (grain oriented) core. The iron loss of any transformer depends on the type of core used in the transformer. However, the latest technology is to use amorphous material-a metallic glass alloy for the core. The expected reduction in core loss over conventional (Si Fe core) transformers is roughly around 70%, which is quite significant. By using an amorphous core- with unique physical and magnetic properties- these new types of transformers have increased efficiency even at low loads which is **98.5%** efficiency at 35% load. Electrical distribution transformers made with amorphous metal cores provide excellent opportunity to conserve energy right from the installation.

On a life-cycle cost basis, an energy-efficient transformer is very appealing given its non-stop operation and 25-year service life. These savings translate into reductions in peak loading, lower electricity bills and greater reliability of supply. These points should be kept in mind by the auditor while recommending replacement of inefficient transformers with more efficient ones. Payback periods vary with the equipment and electricity costs and can be as short as one year or as long as six years or more. For transformers, a six-year payback on a product that typically lasts more than 25 years is considered attractive (Source: UNEP)

7.3. Motors and application of Variable Frequency Drive (VFD)

7.3.1. Introduction

An electric motor is a device that converts electrical energy into mechanical energy by the interaction between the magnetic fields set up in the stator and rotor windings. Electric motors are used in driving a broad range of industrial applications such as pumps, compressors, fans, blowers, conveyors, and other machines. Motor systems have been identified as being the major electricity consumer in the industrial sector and the poor efficiency of the substandard motors leads to more energy consumption and energy cost. Therefore, improvement in the efficiency of the motor must be a part of any comprehensive energy savings effort.

7.3.2. Data collection

Following data shall be collected during audit of motor from motor name plate and by interviewing the motor operator or building manager:

- Motor manufacturer/make
- Model and type
- Rated motor power (kW)
- Rated motor efficiency and efficiency class
- Rated speed
- All other motor nameplate details
- Motor rewound status (if yes, no. of times rewound)
- Motor operating hours (daily & annual)
- Whether equipped with VFD or not (if yes, note operating frequency and signal feedback to VFD is manual or automatic)

In addition to above, following data shall be collected through measurements:

- Voltage (V)
- Current (A)
- Power Factor
- Power (kW)
- Motor operating speed (RPM)
- Motor surface temperature

7.3.3. Instruments required

- Hand-held clamp meter
- Three-phase power analyser
- Non-contact type thermometer or thermal imaging camera
- Stroboscope or non-contact type tachometer
- Resistance meter or multi-meter

7.3.4. Motor performance terms

Motor efficiency: The efficiency of the motor is given by following relation:

$$\eta = \frac{\text{Output power of the motor}}{\text{Input power of the motor}}$$

Motor Loading: The motor loading in percentage (%) is given by following relation:

$$\text{Motor loading } (\%) = \frac{\text{Input power drawn by the motor (kW)at existing load}}{\frac{\text{Name plate full load (kW)rating}}{\text{Name plate full load motor efficiency}}} \; X\ 100$$

7.3.5. Motor load survey methodology

Large facilities have huge numbers of low tension (LT) motors ranging from low rated power (<1 kW) to high rated power (>200 kW). To identify improvements options a load survey methodology shall be established as per following factors:

Prioritising motors for audit

The objective of prioritising motor for audit is to select those motors first which are major energy consumers and representative of all the motors installed in a facility, following criteria shall be considered for prioritisation:

- Regardless of the motor rated power, preference shall be given to those motors with continuous running operation or high utilisation factor for example, 18 to 24 hours per day.
- Motors with high rating power (kW) among the all installed motors shall be given preference.
- Motors which has been identified as running with inefficient capacity controls on the machine side or with fluctuating load systems shall be given preference.
- In case, there is a large quantity (>10) of small sized motors in a system (<5 kW) with same rated power (kW) and due to some constraints measurements on each motor is not feasible, sample representative method shall be used where measurements and analysis of one or two motors can be reasoned as representative for all same size motors in the rest of the system.

Measurements

Studies on motors involves measurement of electrical parameters namely voltage (V), current (A), power factor (PF), and power drawn (kW) with hand-held clamp meter or three-phase power analyser without affecting the motor routine operation. Motors running with fluctuating load shall be chosen for recording the various electrical parameters using three-phase power analyser over a period as suitable.

Using a non-contact type infra-red thermometer or thermal imaging camera, measure the motor surface temperature to check motor overheating.

Observations

Following parameters shall be observed while conducting motor audit:

- Motor loading (%)
- Voltage unbalance & Motor overheating
- Motor efficiency
- Motor load (kW)
- Motor power factor
- Motor rewound status
- Motor idle, load and unload running conditions

7.3.6. Determine motor loading

The simplest method to determine motor loading is by input power measurements, as per following steps:

- Measure motor input power with a hand-held clamp meter or three-phase power analyser.
- Note the full load rated power (kW) and efficiency (η) from the motor nameplate. The rated power mentioned on the motor nameplate by manufacturer is motor output i.e. mechanical power output delivered at shaft in kW.
- To obtain rated input power, divide motor nameplate rated power at full load by rated efficiency (η)

$$Motor\ rated\ input\ power\ = \frac{Motor\ nameplate\ full\ load\ rated\ power\ (kW)}{Motor\ nameplate\ full\ load\ rated\ efficiency (\eta)}$$

- The motor loading percentage loading can now be calculated as follows

$$Motor\ loading\ (\%) = \frac{Motor\ measured\ input\ power\ (kW)}{Motor\ rated\ input\ power\ (kW)} X\ 100$$

To illustrate the above steps an example has shown below:

Example: The nameplate details of a motor are noted as, full load rated power = 11 kW, full load rated efficiency = 0.88. Using a three-phase power analyser the measured input power drawn found to be 7 kW. Determine the loading of the motor?

Solution:

$$Motor\ rated\ input\ power\ = \frac{11}{0.88} = 12.5\ kW$$

$$Motor\ loading\ (\%) = \frac{7}{12.5} X\ 100 = \ 56\%$$

Hence, the motor loading is 56%

7.3.7. Determine voltage unbalance in motors

Voltage unbalance in a three-phase motor is a condition, where the voltages in the three phases of motor are not equal. Voltage unbalance typically occurs because of supplying single-phase load disproportionately from one of the phases. It can also result from the use of different sizes of cables in the distribution system. Voltage unbalance is detrimental to motor performance and motor life. The effect of voltage unbalance on motor performance is shown below **Table 5**

Table 5: Effect of voltage unbalance on motor performance (source: BEE)

Effect of voltage unbalance on motor performance			
Impact on below parameters due to voltage unbalance	Voltage unbalance in percentage (%)		
	0.30	**2.30**	**5.40**
Unbalance in current (%)	0.4	17.7	40
Increased temperature rise (°C)	0.18	10.6	58

The NEMA (National Electrical Manufacturers Association of USA) standard definition of voltage unbalance is given by the following equation:

$$Voltage\ unbalance\ (\%) = \frac{Maximum\ deviation\ from\ mean\ of\ v_{Ry}, v_{yB}, v_{BR}}{Mean\ of\ v_{Ry}, v_{yB}, v_{BR}} X\ 100$$

Where,

V_{RY} is voltage measured between R & Y phases
V_{YB} is voltage measured between Y & B phases
V_{BR} is voltage measured between B & R phases
To illustrate the above steps an example has shown below:

Example: The line voltages measured in three phases of motor are V_{RY} = 415, V_{YB} = 426, V_{BR} = 418. Determine the voltage unbalance in motor?

Solution: Mean of $V_{RY,}$ $V_{YB,}$ V_{BR} = (415 + 426 + 418) / 3 = 419.6

Maximum voltage among $V_{RY,}$ $V_{YB,}$ V_{BR} = 426

$$Voltage\ unbalance\ (\%) = \frac{426 - 419.6}{419.6} X\ 100 = 1.52\%$$

Hence, the voltage unbalance is **1.52%**

It is recommended that voltage unbalance at the motor terminal shall not **exceed 1%,** anything above this will lead to de-rating of the motor. The common causes of voltage unbalance are:

- Unbalanced incoming supply from energy supplier
- Unequal tap settings of transformers
- Large single-phase distribution transformer on the system
- Open phase on the primary of a three-phase transformer on the distribution system
- Faults or ground in the power transformer
- Open delta connected transformer banks
- A blown fuse on a three-phase bank of power factor improvement capacitors
- Unequal impedance in conductors of power supply wiring
- Unbalanced distribution of single-phase loads such as lighting
- Heavy reactive single-phase loads such as welders

Voltage unbalance causes overheating of the motor and leading cause of premature failure of motors. Voltage unbalance causes extremely high current imbalance. The magnitude of current imbalance may be 6 to 10 times higher as the voltage imbalance. The additional temperature rise in motors or motor overheating due to voltage unbalance is estimated by following equation:

Additional temperature rise = 2 X (Voltage unbalance in %)^2

For example, *if the voltage unbalance is 2% for a motor operating at 100°C, the additional temperature rise will be 8°C.*

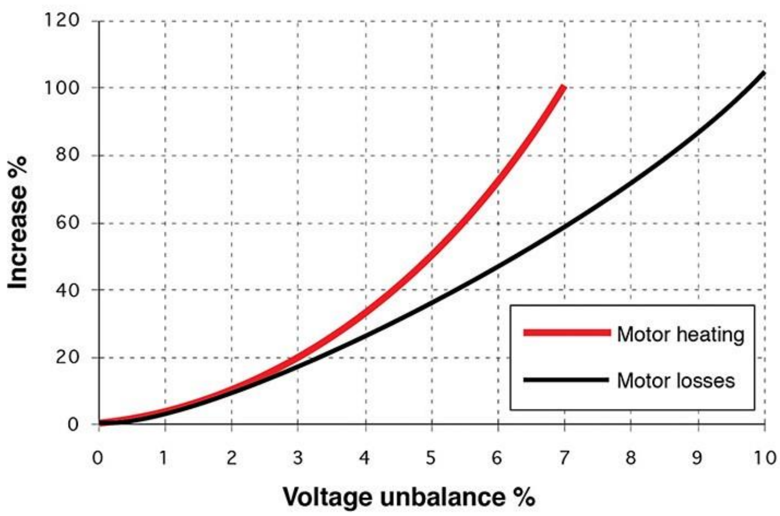


Figure 14: Voltage unbalance (%) versus motor losses & motor heating (Source: BEE)

The winding insulation life is reduced by one half for each 10°C increase in operating temperature. The motor losses also increase due to voltage unbalance as shown in **Figure 14**

7.3.8. Motor Efficiency

Two important attributes relating to efficiency of electricity use by A.C. induction motors are efficiency (η), defined as the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals, and power factor (PF). Motors, like other inductive loads, are characterized by power factors less than one. As a result, the total current draw needed to deliver the same real power is higher than for a load characterized by a higher PF. An important effect of operating with a PF less than one is that resistance losses in wiring upstream of the motor will be higher since these are proportional to the square of the current. Thus, both a high value for η and a PF close to unity are desired for efficient overall operation in a plant.

Squirrel cage motors are normally more efficient than slip-ring motors, and higher-speed motors are normally more efficient than lower-speed motors. Efficiency is also a function of motor temperature. Totally enclosed fan-cooled (TEFC) motors are more efficient than screen-protected, drip-proof (SPDP) motors. Also, as with most equipment, motor efficiency increases with the rated capacity.

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design. Intrinsic losses are of two types: fixed losses- independent of motor load, and variable losses – dependent on load.

Fixed losses consist of magnetic core losses and friction and windage losses. Magnetic core losses (sometimes called iron losses) consist of eddy current and hysteresis losses in the stator. They vary with the core material and geometry and with input voltage. Friction and windage losses are caused by friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts.

Variable losses consist of resistance losses in the stator and in the rotor and miscellaneous stray losses. Resistance to current flow in the stator and rotor result in heat generation, that is proportional to the resistance of the material and the square of the current (I^2R). Stray losses arise from a variety of sources and are difficult to either measure directly or to calculate but are generally proportional to the square of the rotor current. Part load performance characteristics of a motor also depend on its design. Both the η and PF fall to very low levels at low load. The **Figure 15** shows the effect of load on power factor and efficiency. Power factor drops sharply at part loads. The **Figure 16** shows the effect of speed on power factor.

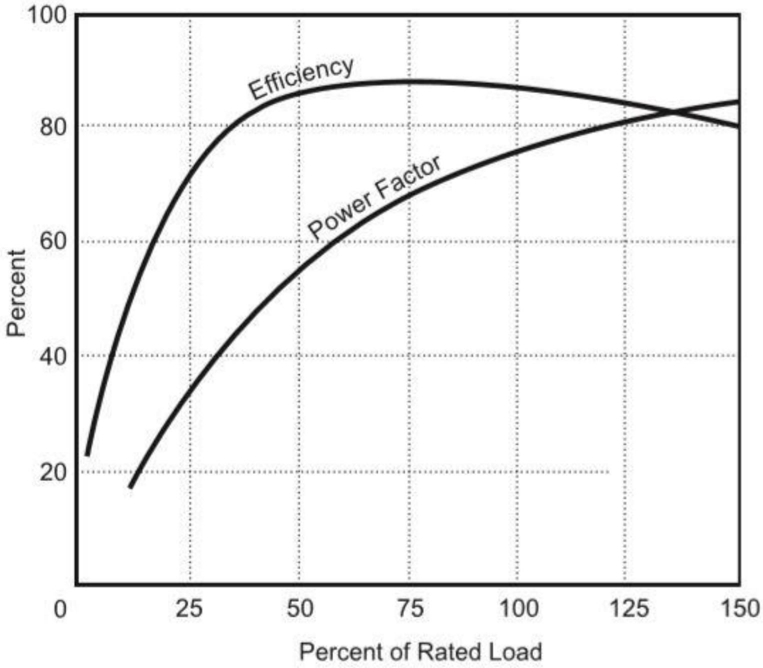


Figure 15: Effect of motor loading on efficiency & power factor (Source: BEE)

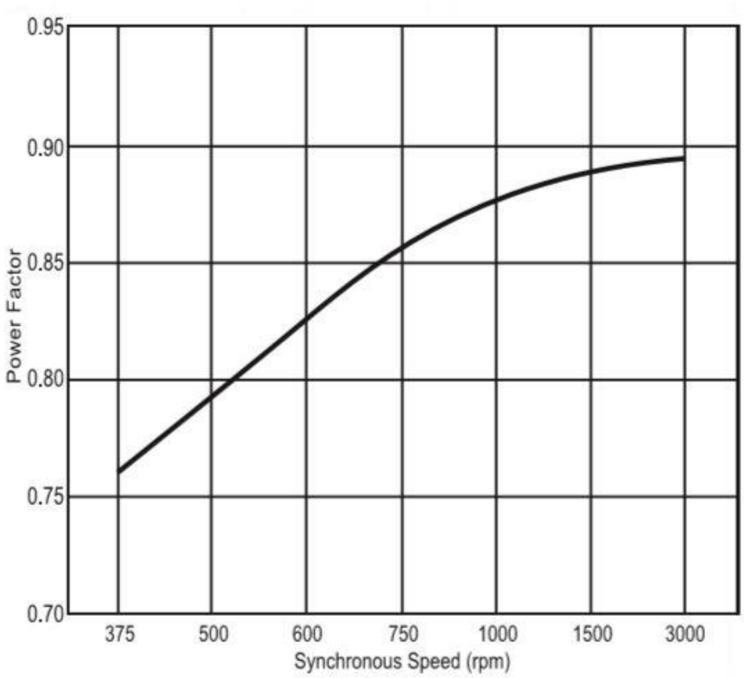


Figure 16: Effect of motor speed on power factor (Source: BEE)

7.3.9. Determine motor efficiency

The efficiency of induction motors remains almost constant between 50% to 100% loading (refer, **Figure 17**) hence for simplicity motor nameplate efficiency rating may be used for calculations if the motor is operating in the range of 50 to 100% loading.

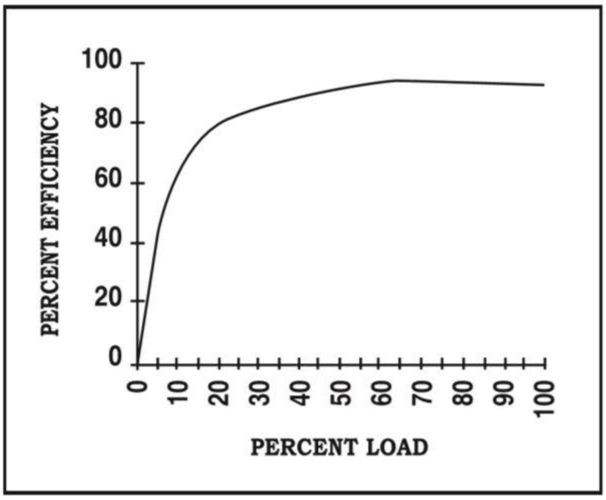


Figure 17: Effect of motor loading on efficiency (Source: BEE)

However, the following method can be also used to determine the motor efficiency.

Step-1: Perform the following actions under no load conditions

- Using a resistance meter, measure stator resistance at ambient temperature.
- Run the motor at rated voltage and frequency without any shaft load
- Using a hand-held clamp meter or three-phase power analyser, measure the power (Watts) and current.
- Calculate the iron plus friction and windage loss using below formula
- *Iron plus friction and windage loss (Watts) =No load power (Watts) - (no load current)^2 X Stator resistance*

Step-2: Perform the following actions under load conditions

- Run the motor at rated voltage and frequency with full load
- Using a hand-held clamp meter or three-phase power analyser, measure the power (Watts) and current
- Using a non-contact type infra-red thermometer, measure operating temperature of motor
- The stator resistance measured at ambient temperature must be corrected for the operating temperature. The correction factor is as follows:

$$R_{operating} = R_{ambient}\ X\ \frac{235 + \text{operating temperature}}{235 + ambient\ temperature}$$

Where,
$R_{operating}$ is resistance corrected for operating temperature
$R_{ambient}$ is resistance measured at ambient temperature

- Calculate the stator copper loss at full load using below formula

Stator copper loss at full load (Watts) = I² (full load current) X $R_{operating}$

Step-3: Calculate the rotor power

- Run the motor at rated voltage and frequency with full load
- Using a stroboscope or non-contact type tachometer, measure the speed of the motor in RPM (revolutions per minute) at full load.
- Calculate slip by using below formula. Where, synchronous speed is the motor nameplated rated speed

$$Slip\ (S) = \frac{Synchronous\ speed - full\ load\ speed}{Synchronous\ speed}$$

- Calculate rotor power using below formula

$$Rotor\ power\ (Watts) = \frac{Motor\ nameplate\ rated\ power}{1 - Slip}$$

Step-4: Calculate motor full load input power

- Use the below formula to calculate the motor full load input power

Motor full load input power = Iron plus windage and friction loss + Stator copper loss at full load + Rotor power + Stray losses

- Use the below **Table 6** adapted from IEEE for stray losses as measurement of stray losses is a complicated process which is not possible on shop floor.

Table 6: Motor rating versus stray losses (adapted from IEEE)

Motor rating	Stray losses
0.75 – 93 kW	1.8%
93 – 373 kW	1.5%
373 – 1863 kW	1.2%
1864 and above	0.9%

Step-5: Calculate motor efficiency

- Use the below formula to calculate the motor efficiency

$$Motor\ efficiency\ (\eta) = \frac{Motor\ nameplate\ rated\ power}{Motor\ full\ load\ input\ power}$$

7.3.10. Energy savings opportunities in motor

1. Improve motor loading

For motors, which consistently operate at loads below 40% of rated capacity, an inexpensive and effective measure is to operate in star mode. A change from the standard delta operation to permanent star operation involves re-configuring the wiring at terminal box and resetting of the over-current relay.

Operating in the star mode leads to a voltage reduction by a factor of '√3'. Motor is electrically downsized by one-third (1/3rd) in star mode operation, but performance characteristics as a function of load remain unchanged. For example, if a motor is rated for 15 kW in delta mode, its de-rated capacity is 5kW in star mode. Thus, full-load operation in star mode gives higher efficiency and power factor than partial load operation in the delta mode. However, motor operation in the star mode is possible only for applications where the torque-to-speed requirement is lower at reduced load.

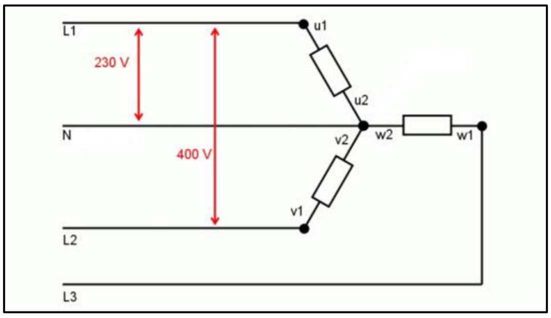


Figure 18: Star connection

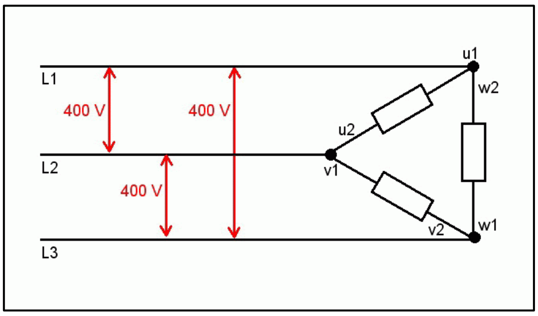


Figure 19: Delta connection

As speed of the motor reduces in star mode this option may be avoided in case the motor is connected to a production facility whose output is related to the motor speed. Further, in star mode the motor loading should not be allowed to cross de-rated capacity. For example, in above case of 15 kW delta connected electric motor, should not be loaded above 5 kW when delta to star switchover takes place.

For applications with high initial torque and low running torque needs, automatic Star-Delta-Star converters are also available, which help in load following de-rating of electric motors after initial start-up.

2. Motor power factor (PF) correction

Induction motors which operate at power factors less than unity, leads to lower overall efficiency and higher overall operating cost associated with a facility's electrical system. Capacitors connected in parallel (shunted) with the motor are typically used to improve the power factor. The benefits of PF correction are as below:

- Reduced apparent power (kVA) demand and hence reduced utility demand charges.
- Reduced copper losses (I^2R) in cables upstream of the capacitor and hence reduced energy charges.
- Reduced voltage drop in the cables leading to improved voltage regulation.

- Increase in the overall efficiency of the plant electrical system.

The various methods of power factor correction are central compensation, group compensation and individual compensation. Depending upon the size and the rate of change of loads in an facility, any one or combination of the above methods can be employed. Specifically, in case of some small-scale facilities with a few motor loads, the power factor correction can be done by connecting shunt capacitors directly to the motors. This method of compensation is called direct compensation. This is simple and ideal method for reactive power compensation, as this would result in rating optimization of all the upstream switchgear and cables, which reduces overall system losses.

Direct motor compensation can be done in two methods, configuration of both methods is described below:

Method-1

As shown in the **Figure 20,** the capacitor is connected directly to the motor terminals, after the starter. The capacitors would start supplying reactive power as soon as the motor is switched ON. This method of compensation can be used for motors with direct online starters. Usually the kVAr rating for a particular motor is given by the respective motor manufacturers, as the kVAr ratings are motor specific.

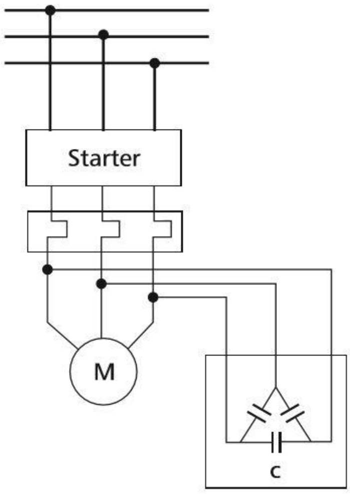


Figure 20: Method 1- Capacitor is connected directly to the motor

Even though this is the effective method of power factor compensation, there is a limitation in sizing of the capacitors. That is, *the maximum kVAr should be decided such that, the rated capacitor current is less than 90% of the motor's no-load current*. If this condition is not met, self-excitation may occur, in which the motor acts as a generator. This happens when a motor has enough inertia to keep rotating even after being disconnected from the power system and the capacitor is large enough to supply the reactive power needs of the motor. Self-excitation would result in high voltage at the terminals of the motor and this can damage the contactor and the capacitor.

Method – 2

In this method, the capacitor is connected to the motor before the starter and it is switched through a separate capacitor duty contactor as shown in **Figure 21**. The capacitors are disconnected as soon as the motor is switched off hence, self-excitation is avoided. There is no need of any limitations in capacitor sizing and unity power factor can be achieved by this method.

The capacitor size (in kVAr) can be calculated by the below formula:

$$kVAr = kW\ (\tan\Phi_1 - \tan\Phi_2)$$

Where, $\Phi_1 = \cos^{-1}$ (initial PF) and $\Phi_2 = \cos^{-1}$ (target PF)

The limitations in this method are the manual switching of the capacitors and the extra cost incurred for the contactors. Moreover, when the number of motors increase in future, managing all at a time would be difficult.

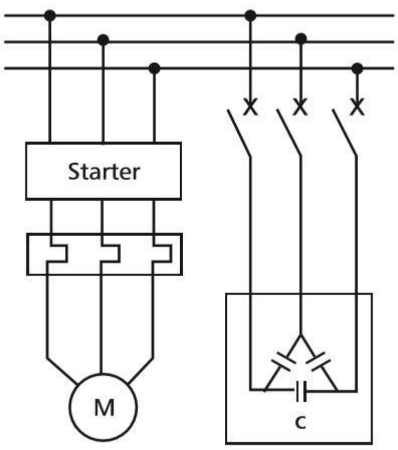


Figure 21: Method 2 - Capacitor is connected to the motor before starter

Points to remember:

- The operating power factor varies with respect to the percentage loading of the motors. Hence with the varying load, the fixed capacitors would not be able to maintain the unity power factor continuously.
- After switching off the capacitor, it is very important to maintain a minimum time delay of 60 seconds, for switching ON the capacitor again. Else, there are more chances of contactor damage because of charged capacitor.
- If the motor is operated with any drives/converters, it is recommended to detune the capacitors by adding series reactors.
- It is recommended to use capacitor duty contactors for minimizing the inrush current and hence to maximize the life of contactors and the capacitors.

3. Energy efficient motor technical characteristics

The IEC (International Electrotechnical Commission) has contributed to the development 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 four levels of motor efficiency:

- IE1 Standard Efficiency
- IE2 High Efficiency
- IE3 Premium Efficiency
- IE4 Super premium Efficiency

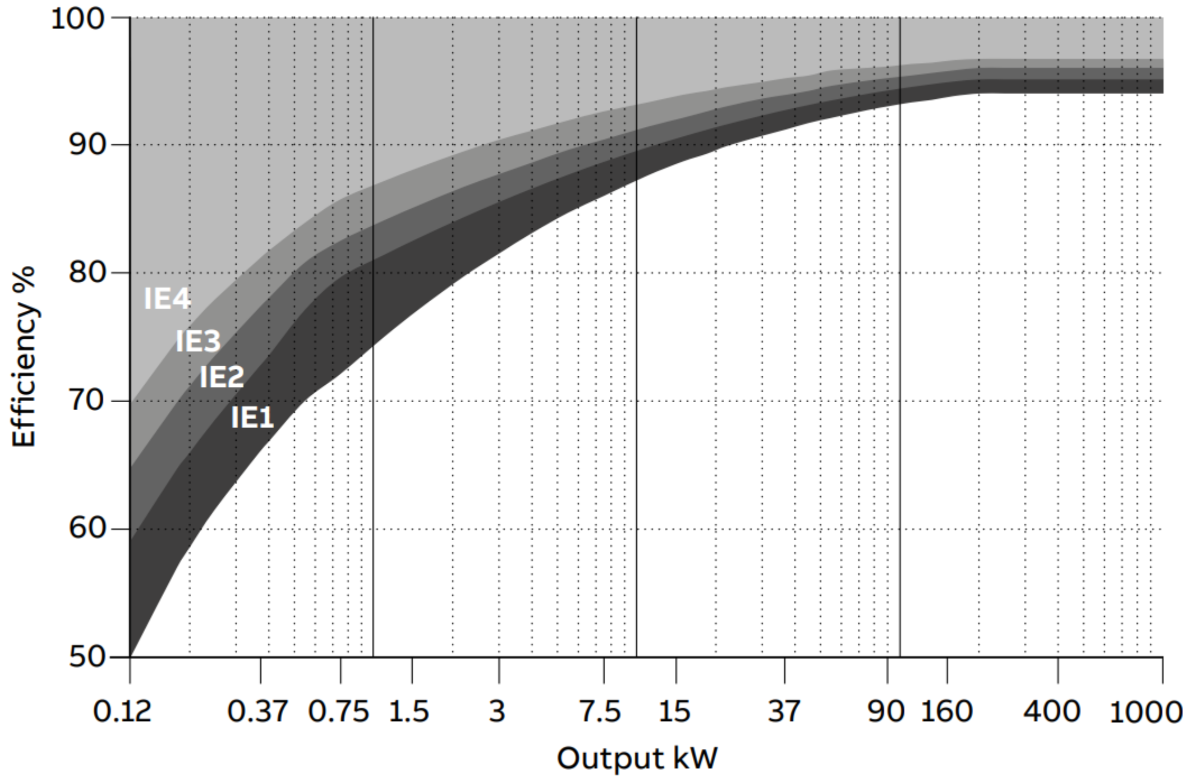


Figure 22: IE efficiency classes for 4 pole motors at 50 Hz (Source: ABB)

Acknowledging the need for energy saving in view of the energy scarcity, climate change mitigations and the potential that exists with energy efficient motors, number of countries have issued directives to withdraw lower efficiency classes and adopt higher efficiency class motors as per IEC 60034-30-1: 2014, thus defining minimum efficiency performance standards (MEPS) in their countries. Such regulations are expected to impose technical barriers to all the imports of motors which are with lower efficiency classes than the MEPS into their countries.

The European Union sets motor MEPS levels at IE3 (or IE2 in combination with VFD) from 2017 covering motors with 0.75 kW up to 375 kW.

In 2018, India also sets efficiency class IE2 as Minimum Energy Performance Standard (MEPS) for LT motors.

4. Cost effectiveness of energy efficient motors

The energy savings by motor replacement can be worked out by a simple formula:

$$Power\ savings\ (kW) = \ Power\ output\ (kW)\ \ X\ \frac{1}{\eta_{old}} - \frac{1}{\eta_{new}}$$

Where, η_{old} is efficiency of the existing old motor

Where, η_{new} is efficiency of the proposed new motor

Annual energy savings = Power savings (kW) X annual operating hours of the motor

To illustrate the above formula, an example has shown below:

Example: During an energy audit following data were obtained on a 3-phase induction motor: Rated values: 37 kW, 415 V, 66 A, PF = 0.88, η = 0.88

Measured values: 410 V, 49 A, PF = 0.76 pf, P = 26.44 kW

The building operates for 7000 hours per year, and it is proposed to replace the existing motor by a 30 kW, new energy efficient motor with rated efficiency of 92%.

a) Determine loading% of the existing motor.
b) Determine the energy savings with new energy efficient motor

Solution: Rated input power of the motor = Rated power / efficiency (η)

Parameters	Calculations
Rated input power of the existing motor at full load	= 37 / 0.88 = 42 kW
Loading of the existing motor	= measured power / rated input power = 26.44 / 42 = **63%**
Shaft power or motor output of the existing motor	= 37 X 63% =23.31 kW
New energy efficient motor rating	= 30 kW
Actual shaft power or motor output required	= 23.31 kW
Loading% of new energy efficient motor	= 23.31 / 30 = 77.7%
Power savings	= 23.31 (1/0.88 – 1/0.92) = 1.16 kW
Annual energy savings	= 1.16 X 7000 = **8,120 kWh**

Points to be noted: *Though the new energy efficient motor is of 30 kW, but the energy savings will be calculated at the actual shaft power delivered by the motor or the motor output required.*

5. Motor rewinding effects on energy efficiency

It is common practice in industry to rewind burnt-out motors. Careful rewinding may sometimes maintain motor efficiency at previous levels, but in most cases rewinding results in efficiency loss.

Loss in efficiency of rewound motors is due to several reasons. For example, a common problem occurs when heat is applied to old strip windings, the insulation between laminations can be damaged, thereby increasing eddy current losses. A change in the air gap may affect power factor and output torque.

The impact of rewinding on motor efficiency and power factor can be easily assessed if the no-load losses of a motor are known before and after rewinding. Maintaining documentation of no-load losses and no-load speed from the time of purchase of each motor can facilitate assessing this impact.

For example, comparison of no load current and stator resistance per phase of a rewound motor with the original no-load current and stator resistance at the same voltage can be one of the indicators to assess the efficacy of rewinding. A relatively simple procedure for evaluating rewinding quality is to keep a log of no-load input current for each motor installed in the facility and to update the log each time a motor is returned after rewinding.

Small and medium range motors (say up to 30 kW rating) have a significant repair/rewinding cost (around 45% of its purchase price) so it is recommended that after 3 time rewinding the motor should be replaced with a premium efficiency (IE3) motor. Many large facilities have a made a policy of replacing small & medium LT motors which have been rewound thrice previously.

6. Stop idle running of motors

Motors running during periods when the equipment or process they are driving is idle is called idle running of motors. Idle running of motors causes unnecessary energy loss which can be control by following method:

a. Reduce equipment operation time to minimum required by turning off the equipment during lunch and breaks, or other times when it is not required. But this method is only as reliable as the operator.
b. Interlock equipment with a related process i.e. if a particular piece of equipment is dedicated to specific process that requires additional equipment, they can all be interlocked so all will be de-energised when the operator turns off one piece of equipment.
c. Operate equipment such as a grinder in batches then shut off. A piece of equipment like a grinder may run continuously although material only runs through it occasionally. An alternative approach with no installation cost is to allow material to collect and assign someone to periodically turn it on to process the material in batches but remember:

i. If material collection is left unmonitored, the collection bin can overflow requiring additional labour for clean-up. Jamming problems could also develop.
ii. Batch processing also has potential for increasing demand charges if the equipment is more heavily loaded.

d. Install timers, level sensors, material sensors, or other controls for automatic operation and/or to shut off equipment as required. For example: Install material sensor and timer on equipment such as a grinder – set to turn on with set accumulation of material and turn off after allowable idle time and care must be taken to avoid creating a safety hazard.

7. Motor speed control with variable frequency drive (VFD) or variable speed drive (VSD)

Concept of Variable frequency drive

The speed of an induction motor is proportional to the frequency of the alternating current (AC) voltage applied to it, as well as the number of poles in the motor stator. This is given by the equation:

RPM = (120 X f) / No. of poles

Where, f is the frequency in the hertz

Therefore, if the frequency applied to the motor is changed, the motor speed changes in direction proportion to frequency changes. The basic function of the VFD is to act as a variable frequency generator in order to vary speed of the motor as per the user setting.

The VFD's basic principle of operation is to convert the electrical system frequency and voltage to the frequency and voltage required to drive a motor at a speed other than its rated speed. The two most basic functions of a VFD are to provide power conversion from one frequency to another and to enable control of the output frequency.

As shown in **Figure 23**, there are two basic components, a rectifier and an inverter, to accomplish power conversion. The rectifier receives the 50-Hz AC voltage and converts it to direct current (DC) voltage. A DC bus inside the VSD functions as a parking lot for the DC voltage. The DC bus energizes the inverter, which convert it back to the AC voltage again. The inverter can be controlled to produce an output frequency of the proper value for the desired motor shaft speed.

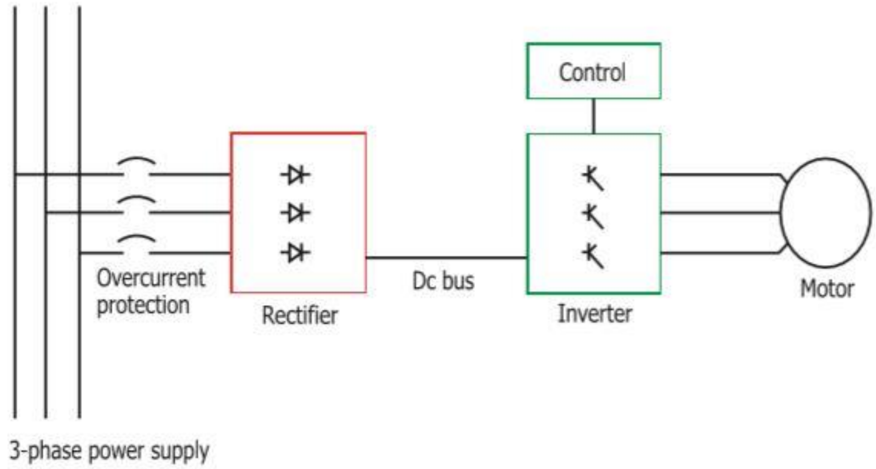


Figure 23: Component of VFD system

In many applications, the input power is a function of the speed like fan, blower, pump, conveyor and so on. In these types of loads, the torque is proportional to the square of the speed and the power is proportional to the cube of speed.

Power α $(\text{speed})^3$

Variable speed, depending upon the load requirement, provides significant energy saving. A reduction of 20% in the operating speed of the motor from its rated speed will result in an almost 50% reduction in the input power to the motor. This is not possible in a system where the motor is directly connected to the supply line. In many flow control applications, a mechanical throttling device is used to limit the flow. Although this is an effective means of control, it wastes energy because of the high losses and reduces the life of the motor valve due to generated heat.

7.3.11. Factors for successful implementation of variable frequency drives

a) Understanding load type for Variable Frequency Drives (VFD)

The main consideration is whether the variable frequency drive application requires a variable torque or constant torque drive. If the equipment being driven is centrifugal, such as a fan or pump, then a variable torque drive will be more appropriate. Energy savings are usually the primary motivation for installing variable torque drives for centrifugal applications. For example, a fan needs less torque when running at 50% speed than it does when running at full speed. Variable torque operation allows the motor to apply only the torque needed, which results in reduced energy consumption.

Conveyors, positive displacement pumps, punch presses, extruders, and other similar type applications require constant level of torque at all speeds. In which case, constant torque variable frequency drives would be more appropriate for the job. A constant torque drive should have an overload current capacity of 150% or more for one minute. Variable torque variable frequency drives need only an overload current capacity of 120% for one minute since centrifugal applications rarely exceed the rated current.

b) Collecting motor information

The following motor information will be needed to select the proper variable frequency drive:

Full load current rating: Using a motor's power rating is an unreliable way to size variable frequency drives. Full load current rating of the motor shall be considered to estimate VFD size.

Speed range: Generally, a motor should not be run at any speed less than 20% of its specified maximum speed allowed. If it is run at a speed less than this without auxiliary motor cooling, the motor will overheat. Auxiliary motor cooling should be used if the motor must be operated at very slow speeds.

Multiple motors: To size a variable frequency drive that will control more than one motor, add together the full load current ratings of each of the motors. All motors controlled by a single drive must have an equal voltage rating.

c) Efficiency and Power Factor of VFD

The variable frequency drive should have an efficiency rating of 95% or more at full load. Variable frequency drives should also offer a true system power factor of 0.95 or more across the operational speed range, to save on demand charges, and to protect the equipment (especially motors).

d) Protection circuits for VFD

Motor overload Protection for instantaneous trip and motor over current should be provided. Additional protection circuits shall also be provided for over and under voltage, over temperature, ground fault, control or microprocessor fault. These protective circuits should provide an orderly shutdown of the VFD, provide indication of the fault condition, and require a manual reset (except under voltage) before restart. Under voltage from a power loss shall be set to automatically restart after return to normal. The history of the previous three faults shall remain in memory for future review.

e) Selection of equipment for VFD operation

The first step is to identify the operating hours of the equipment at various load conditions. This can be done using a power analyser with continuous data storage or by a simple energy meter with periodic reading being taken.

To determine if the equipment under consideration is the right choice for a variable speed drive, the load patterns should be thoroughly studied before exercising the option of VFD. In effect the load should be of a varying nature to demand a VFD

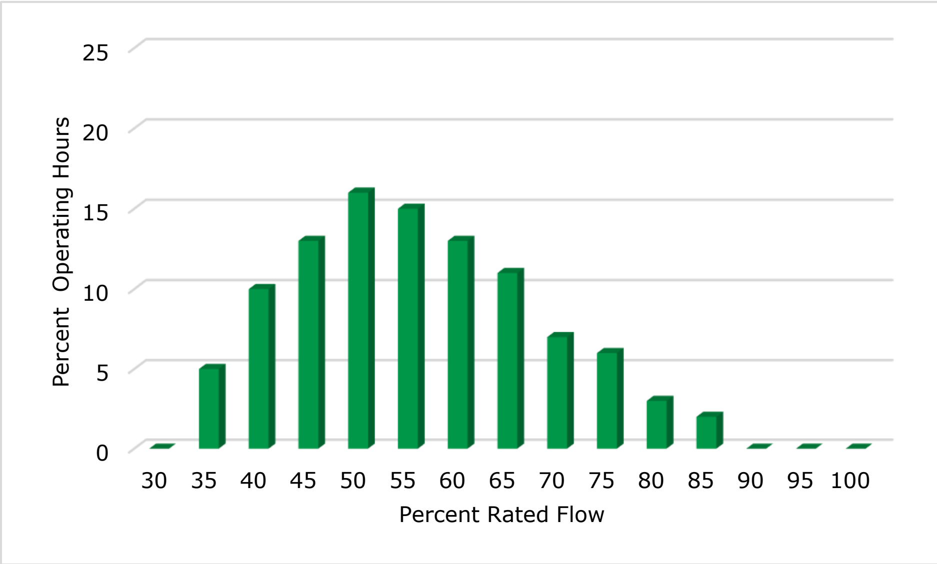


Figure 24: Example of an excellent variable speed drive candidate

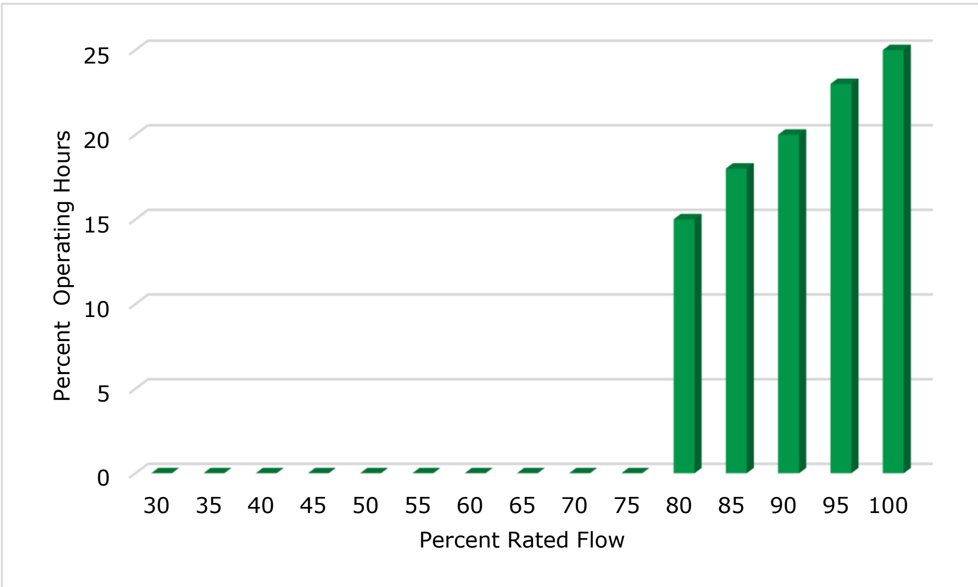


Figure 25: Example of a poor variable speed drive candidate

7.4. Heating, ventilation, air conditioning & refrigeration systems

7.4.1. Introduction

The Heating, Ventilation, Air Conditioning (HVAC) and refrigeration system transfers the heat energy from or to the building environment for human comfort. Energy in form of electricity or heat is used to power mechanical equipment designed to transfer heat from a colder, low-energy level to a warmer, high-energy level.

Refrigeration deals with the transfer of heat from a low temperature level at the heat source to a high temperature level at the heat sink by using a low boiling refrigerant. There are several heat transfer loops in the refrigeration system as described below:

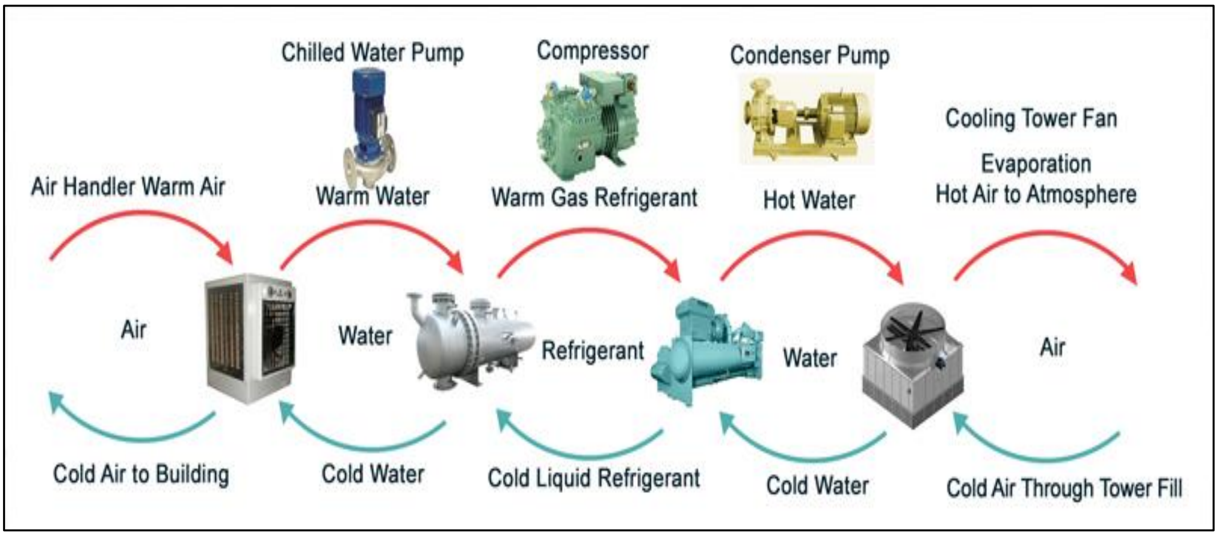


Figure 26: Heat Transfer Loops in refrigeration system

In **Figure 26** thermal energy moves from left to right as it is extracted from the space and expelled into the outdoors through five loops of heat transfer:

Indoor air loop: In the leftmost loop, indoor air is driven by the supply air fan through a cooling coil, where it transfers its heat to chilled water. The cool air then cools the building space.

Chilled water loop: Driven by the chilled water pump, water returns from the cooling coil to the chiller's evaporator to be re-cooled.

Refrigerant loop: Using a phase-change refrigerant, the chiller's compressor pumps heat from the chilled water to the condenser water.

Condenser water loop: Water absorbs heat from the chiller's condenser, and the condenser water pump sends it to the cooling tower.

Cooling tower loop: The cooling tower's fan drives air across an open flow of the hot condenser water, transferring the heat to the outdoors.

7.4.2. Psychrometries and air-conditioning processes

Psychrometric is the science of moist air properties and processes, which is used to illustrate and analyse air-conditioning cycles. It translates the knowledge of heating or cooling loads (which are in kW or tons) into volume flow rates (in m^3/s or cfm) for the air to be circulated into the duct system.

Water vapour is lighter than dry air. The amount of water vapour that the air can carry increases with its temperature. Any amount of moisture that is present beyond what the air can carry at the prevailing temperature can only exist in the liquid phase as suspended liquid droplets (if the air temperature is above the freezing point of water), or in the solid state as suspended ice crystals (if the temperature is below the freezing point).

The most commonly used psychrometric quantities include the dry and wet bulb temperatures, dew point, specific humidity, and relative humidity.

Psychrometric Chart

Psychrometric chart is a chart indicating the psychrometric properties of air such as dry-bulb temperature, wet-bulb temperature, specific humidity, enthalpy of air in kJ/kg dry air, specific volume of air in m^3/kg and relative humidity (Φ) in percentage (%). It helps in quantifying and understanding air conditioning process. A sample Psychrometric chart is shown in **Figure 27**.

Example: Assume that the outside air temperature is 32°C with a relative humidity of Φ = 60%. Use the psychrometric chart to determine the air properties (Use **Figure 27)**.

Solution: Air properties of air at 32°C dry bulb temperature and relative humidity (RH) of 60%

Specific humidity ω = 18 gm-moisture/kg-air

Enthalpy, h = 78 kJ/kg-air

Wet-bulb temperature T_{wb} = 25.5°C

Dew-point temperature, T_{dp} = 23°C

Specific volume of the dry air V = 0.89 m^3/kg

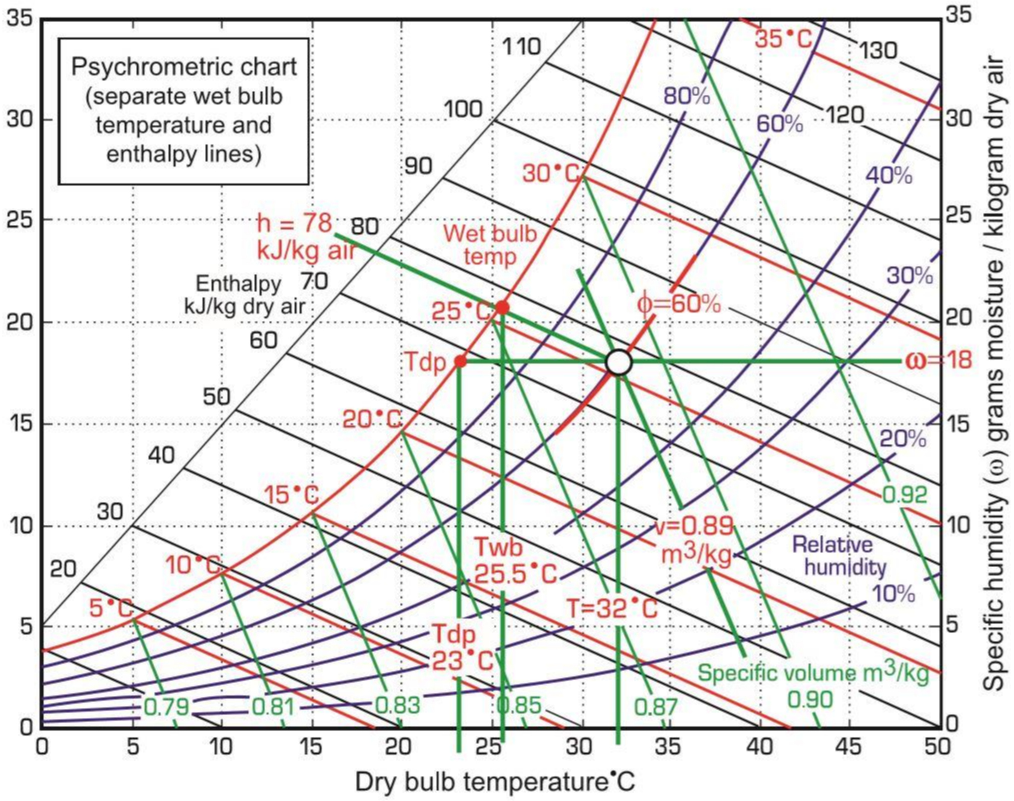


Figure 27: Psychrometric chart (Source: BEE)

7.4.3. Purpose of the HVAC performance test

The purpose of performance assessment is to verify the performance of a refrigeration system by using field measurements. The test will measure net cooling capacity (tons of refrigeration) and energy requirements at the actual operating conditions. The objective of the test is to estimate the energy consumption at actual load vis-a-vis design conditions.

7.4.4. Performance terms and definitions

Tons of Refrigeration (TR): One ton of refrigeration is the amount of cooling obtained by one ton of ice melting in 24 hours, which is equivalent to 3,024 kcal/h, 12,000 Btu/h or 3.516 thermal kW.

Net Refrigerating Capacity: A quantity defined as the mass flow rate of the evaporator water multiplied by the difference in enthalpy of water entering and leaving the cooler expressed in kcal/h or tons of Refrigeration. In general, it refers to the actual operating TR.

kW/ton rating: The ratio of power input to the compressor motor to the tons of cooling produced. This term is commonly referred as efficiency. Lower kW/ton indicates higher efficiency of equipment.

Coefficient of Performance (COP): The COP is the ratio of heating or cooling provided to work required. The most basic formula to COP is Q/W, where Q is the heat supplied to or removed from the reservoir and W is the work done by the compressor. Chiller efficiency measured in Watt output (heating) divided by Watt input (electric power).

In general, COP refers to heating efficiency of an air conditioner or heat pump. For example, if an air conditioner generates 5 kW of heat from one kW electrical input, its COP is said to be 5.0. Higher COP indicates higher efficiency of the equipment.

Energy Efficiency Ratio (EER): Performance of smaller chillers and split AC's is frequently measured in EER rather than kW/ton. EER is calculated by dividing a chiller's cooling capacity (in Watts) by its power input (in Watts) at full-load conditions.
In general, EER is the cooling efficiency of an air conditioner. For example, if an air conditioner generates 4000 W (1.14 TR) of cooling from 1000 W electrical input, its EER is said to be 4.0. Higher EER indicates higher efficiency of the equipment.

7.4.5. Components of HVAC system

The main components of HVAC systems are:

- Evaporator unit
- Compressor unit (in Vapour compression refrigeration system)

or

Absorber and Generator Unit (in vapour absorption refrigeration system)

Condenser Unit (air cooled / water cooled and condenser fans / cooling tower fans)

- Air Handling Units (AHU), with fans and blowers
- Primary and secondary chilled / cooling water pumps

The most widely used and commonly found systems are vapour compression refrigeration system, hence only performance evaluation of vapour compression systems are explained in detail in next section.

7.4.6. Vapour compression refrigeration

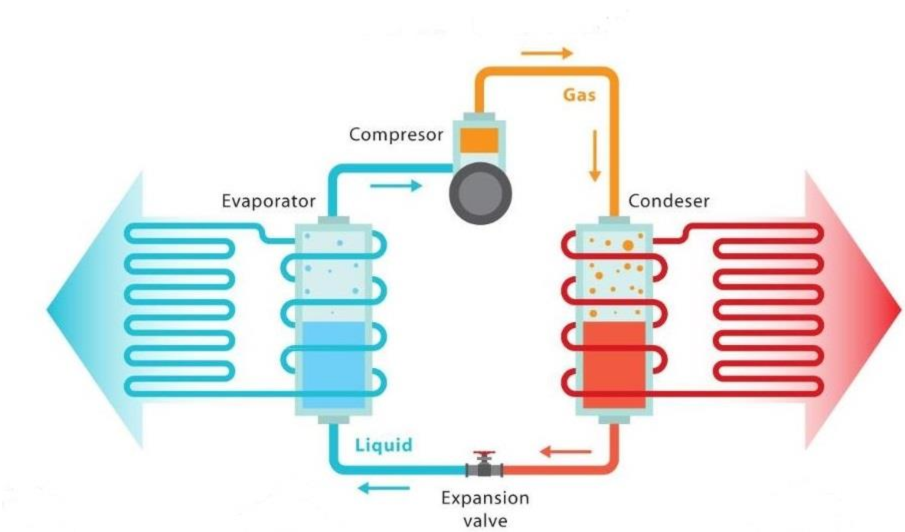


Figure 28: Vapour compression refrigeration system

Heat flows naturally from a hot to a colder body. In a refrigeration system the opposite must occur i.e. heat flows from a cold body to a hotter body. This is achieved by using a substance called refrigerant, which absorbs heat and hence boils or evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained to ambient air or water and turns back (condenses) into a liquid. In this way heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source.

The refrigeration cycle can be broken down into the following stages (see **Figure 28**):

1. Low pressure liquid refrigerant in the evaporator absorbs heat from its surroundings, usually air, water, or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

2. The superheated vapour enters the compressor where its pressure is raised. There will also be a big increase in temperature, because a proportion of the energy input into the compression process is transferred to the refrigerant.

3. The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process de-superheats the gas before it is then turned back into liquid. The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver, so that the refrigerant liquid is sub-cooled as it enters the expansion device.

4. The high-pressure sub-cooled liquid passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.

7.4.7. Instruments required

Following instruments are required for performance test of vapour compression refrigeration system:

- Three phase power analyser
- Ultrasonic Water flow meter
- Pen type thermometer
- Anemometer
- Hygrometer

7.4.8. Procedure for performance evaluation of vapour compression refrigeration system

After establishing steady state conditions of HVAC system, three sets of data shall be taken preferably at a minimum of five-minute interval. To minimize the effects of transient conditions, test readings should be taken simultaneously to the extent possible in all components of HVAC system.

1. **Determine the compressor power**

Using a three-phase power analyser, measure the compressor power. It is suggested to set-up the three-phase analyser at the beginning of assessment and start the recording for the full duration of assessment period

2. **Determine the net refrigeration capacity at the evaporator**

Step-1: Using a portable ultrasonic water flow meter, measure the chilled water flow rate (m_e) flowing through the evaporator pipes. *This is a non-invasive method; flow shall be measured without disturbing the routine operations.*

Step-2: Using a pen-type thermometer, measure the chilled water (inlet) temperature (t_{in}) entering to the evaporator by slightly opening the valves installed near the chiller. Ensure to close the valves firmly after taking the readings. *The accurate temperature measurement is very crucial in refrigeration and air conditioning and least count should be at least one decimal.*

Step-3: Using a pen-type thermometer, measure the chilled water (outlet) temperature (t_{out}) leaving from the evaporator by slightly opening the valves installed near the chiller. Ensure to close the valves firmly after taking the readings.

Step-4: The heat removed from the chilled water is equal to the product of the chilled water flow rate, the temperature difference of chilled water, and the specific heat of water. The net refrigeration capacity in TR shall be obtained by the following equation:

$$Net\ refrigeration\ capacity\ \ at\ Evaporator\ (TR) = \frac{m_e\ X\ c_P\ X\ (t_{in} - t_{out})}{3024}$$

Where,

m_e – mass flow rate of chilled water, kg/h

C_p – Specific heat of water, kcal/kg°C

t_{in} – Chilled water temperature inlet, °C

t_{out} – Chilled water temperature outlet, °C

3. **Determine the heat rejected at the condenser**

The heat rejected by the condenser can be derived by following relation:

Heat rejected at condenser = cooling load + work done by compressor

$$Heat\ rejected\ (TR) = \ (Net\ refrigeration\ capacity\ at\ Evaporator\ TR) + \frac{Shaft\ power\ (kW)}{3.516}$$

Where, Shaft power (kW) absorbed (work done) by the compressor can be derived by following formula:

Shaft power (kW) = Motor input power X rated efficiency (η)

Heat rejected at the condenser can be measured as follows:

a) For water-cooled condenser

Step-1: Using a portable ultrasonic water flow meter, measure the cooling water flow rate (m_c) flowing through the condenser pipes. *This is a non-invasive method; flow shall be measured without disturbing the routine operations.*

Step-2: Using a pen-type thermometer, measure the cooling water (inlet) temperature (t_{in}) entering to the condenser by slightly opening the valves installed near the condenser. Ensure to close the valves firmly after taking the readings.

Step-3: Using a pen-type thermometer, measure the cooling water (outlet) temperature (t_{out}) leaving from the condenser by slightly opening the valves installed near the chiller. Ensure to close the valves firmly after taking the readings.

Step-4: The heat rejected at the condenser is equal to the product of the cooling water flow rate, the temperature difference of cooling water, and the specific heat of water. The heat rejected in TR shall be obtained by the following equation:

$$Heat\ rejected\ \ at\ Condenser\ (TR) = \frac{m_c\ X\ c_P\ X\ (t_{out} - t_{in})}{3024}$$

Where,

m_c – mass flow rate of cooling water, kg/h

C_p – Specific heat of water, kcal/kg°C

t_{out} – Cooling water temperature at condenser outlet, °C

t_{in} – Cooling water temperature at condenser inlet, °C

b) For air-cooled condenser

Step-1: Using an anemometer, measure the air quantity flowing across condenser coil. The least count for anemometer should be 0.1m/s. Air flow rate is calculated as the multiplication product of the average air velocity in the plane of measurement and flow area.

Step-2: Using digital thermometer, measure the inlet and outlet temperature of air at condenser.

Step-3: The heat rejected at the condenser is equal to the product of the mass flow rate of the air, the temperature difference of cooling air, and the specific heat of air. The heat rejected in TR shall be obtained by the following equation:

$$Heat\ rejected\ \ at\ Condenser\ (TR) = \frac{m_a\ X\ c_P\ X\ (t_{out} - t_{in})}{3024}$$

Where,

m_a – mass flow rate of air, kg/h

C_p – Specific heat of air, kcal/kg°C

t_{out} – Cooling air temperature at condenser outlet, °C

t_{in} – Cooling air temperature at condenser inlet, °C

7.4.9. Performance evaluation of air handling units (AHU)

For centralized air conditioning systems, the air flow at the air handling unit (AHU) can be measured with help of an anemometer. Using a hygrometer, the dry bulb and wet bulb temperatures can be measured at the AHU inlet and outlet. The data can be used along with a psychrometric chart to determine the enthalpy (heat content of air at the AHU inlet and outlet). The following relation can be used to calculate the heat load:

$$Heat\ load\ (TR) = \frac{m_a\ (h_{in} - h_{out})}{4.18\ X\ 3024}$$

Where,

m_a – mass flow rate of air, kg/h
h_{in} – enthalpy of inlet air at AHU, KJ/kg
h_{out} – enthalpy of outlet air at AHU, KJ/kg

Heat load can also be calculated theoretically by estimating the various heat loads, both sensible and latent in the air-conditioned room (refer standard air conditioning handbooks).The difference between these two indicates the losses by way of leakages unwanted loads, heat ingress etc.

7.4.10. Energy savings opportunities in HVAC system

1. Significance of Building Envelope

The building envelope is the interface between the interior of the building and outdoor environment including the walls, roof and foundation. By acting as a thermal barrier, the building envelope plays an important role in regulating interior temperature and helps in determining the amount of energy required to maintain thermal comfort. The envelop design and orientation also determines the amount of artificial required in the building.

The energy performance of a building envelop is influenced by number of factors. For example, these may include design elements such as the physical orientation of the building and the amount of sunlight that penetrates the interior workspaces. Other factors may also be influenced by any natural air infiltration through the building envelope (e.g cracks). The sources of heat gain into the building space are depicted in **Figure 29.**

An integrated building design considers the envelope, the heating, ventilation, cooling (HVAC) system and the lighting system as a whole, rather than dealing with these independently. Changing the specification of one system can affect the performance of the other two significantly. For instance, investment in good insulation of the roof, energy-efficient windows or increased envelop air tightness can result in a smaller HVAC system, thereby reducing its first cost as well as recurring energy cost. Similarly, an inefficient lighting system not only increases lighting energy consumption but could also increase the cooling load on HVAC system, thereby increasing the energy consumption further.

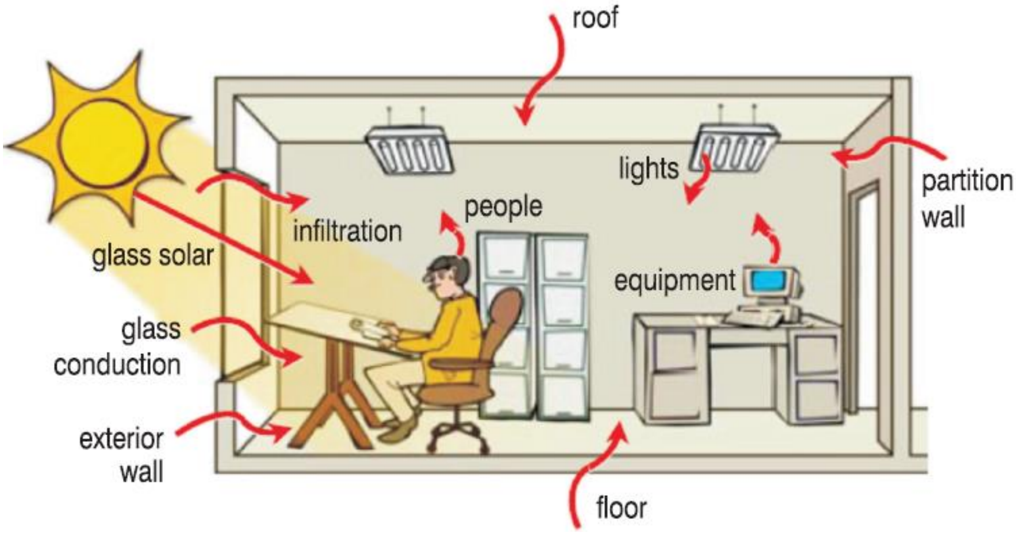


Figure 29: Heat gain sources in building envelope (Source: BEE)

The following areas of the enclosed building envelope shall be sealed, caulked, gasketed, or weather stripped to minimize air leakage:

a) Joints around fenestration and door frames
b) Opening between walls and foundation and between walls and roof and wall panels
c) Opening at penetration of utility services through, roofs, walls and floors
d) Site- built fenestration and doors
e) Building assemblies used as ducts or plenums
f) All other openings in the building envelope

When a building is in cooling mode, solar heat gains need to be minimized within the building space while optimizing daylight and intake of outside air. Outside air could be introduced particularly during the evening/night hours when the ambient temperature drops. This strategy cools the thermal mass in the building during night and reduces overall cooling load during the next day. On the other hand, if the building is in a heating mode, the envelope needs to be designed with appropriate glazing selection coupled with shading strategy to enhance solar heat gains during daytime. Therefore, in practice, the architects and building designers need to integrate and balance these varying requirements consideration while designing an energy-efficient building.

2. Building heat loads minimization

Minimise the air conditioning loads by measures such as roof cooling, roof painting, efficient lighting, pre-cooling of fresh air by air- to-air heat exchangers, variable volume air system, optimal thermo-static setting of temperature of air conditioned spaces, sun film applications, etc.

3. Maintenance of heat exchanger surfaces

Effective maintenance holds key to optimizing power consumption. Heat transfer can also be improved by ensuring proper separation of the lubricating oil and the refrigerant, timely defrosting of coils, and increasing the velocity of secondary coolant (air, water, etc.). However, increased velocity results in larger pressure drops in the distribution system and higher power consumption in pumps /fans. Therefore, careful analysis is required to determine the most effective and efficient option.

Fouled condenser tubes force the compressor to work harder to attain the desired capacity. For example, a 0.8 mm scale build-up on condenser tubes can increase energy consumption by as much as 35%. Similarly, fouled evaporators due to residual lubricating oil or infiltration of air result in increased power consumption. Equally important is maintenance of cooling towers; reduction of 0.5°C temperature in water returning from the cooling tower reduces compressor power consumption by 3%.

4. Temperature and timer-based control

It is common practice in large space cooling large numbers of package ACs are installed and which are all ON throughout the day until someone stops all from main MCBs. During the peak times it is fully occupied, and all the air conditioners are kept working while in off peak hours, the occupancy in is scattered. In this case a/c machines can be controlled cyclically by using programmable timers so that the whole space is air-conditioned work comfortably according to the heat load in a much uniform fashion.

Programming can be done based on average occupancy with time like in lunch, tea hours, shifts change etc. These timer-based switches are simple and not expensive. Based on the experience at other installations, the minimum energy saving potential is about 5-10% per air conditioner.

5. Possible solutions for maintenance of Condensers

With time the fouling of tube in condenser shell and tube heat exchanger of chiller starts. The reason behind is the cooling tower water because it contains minerals, such as calcium and magnesium that precipitate to form deposits on heat transfer surfaces. Cooling water systems are also commonly plagued by biological growth that forms slime or algae on heat transfer areas. Additional foulants include mud, silt, corrosion products, petroleum products, etc. All of these foulants reduce the heat transfer efficiency of even the best-designed heat exchangers, induce localized corrosion leading to early equipment failure, and force shutdowns of the cooling process. So, with time practice various cleaning methodologies which require periodic shutdown of the process for heat exchanger cleaning via hydro blasting, scrapers, nylon or metallic brushes, or chemical cleaning. But the major disadvantages of an off-line cleaning approach are that the processing unit has to be removed from service for cleaning, and that the process efficiency immediately degrades after being placed back into service.

Also, there is option of installation of **Automatic Tube Cleaning System** (ATCS) if the cost economics allows. This system allows continuous online cleaning of tubes of the heat exchanger.

Figure 30 shows the energy savings increases with time. And there are instances in continuous running plants often cleaning done in twice a year. The average saving potential varies from 10~15%.

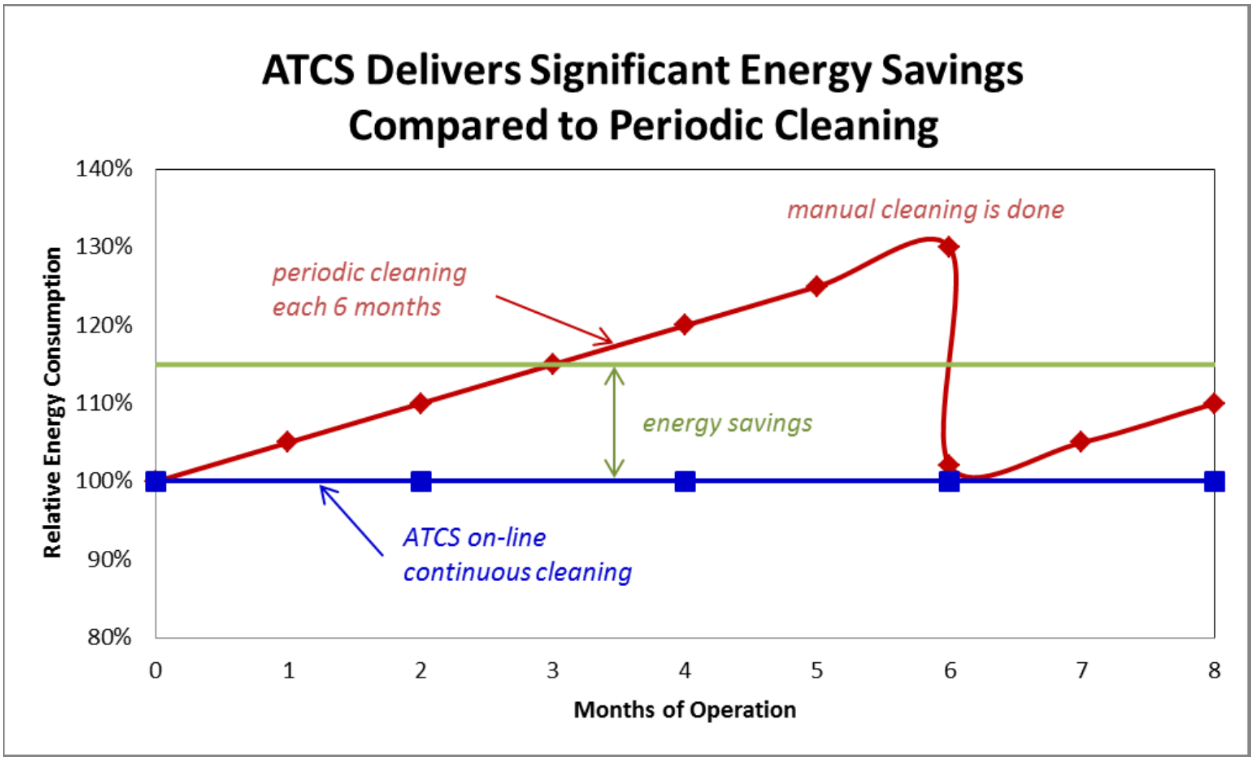


Figure 30: Benefit of automatic tube cleaning system (Source: Trane)

6. Throttling of valve

Throttling of valves are common practice and seen very commonly at the pumps and at various pipelines. In evaporator also throttling of chill water chiller inlet pipeline is practiced. In this situation primary pump consumes same energy as when valve is fully open. In this case it is always recommended to practice the use of VSD at the primary pump which will lead to energy saving at pump also energy consumption will minimize when the chiller is also VSD driven.

7.4.11. Heat pumps

A heat pump is same as an air conditioner except that the heat rejected in air conditioner becomes the useful heat. Heat flows naturally from a higher temperature to a lower temperature. Heat pumps, however, can force the heat flow in the other direction, using a relatively small amount of high-quality drive energy (electricity, fuel, or high-temperature waste heat). As shown in **Figure 31** the heat pumps take 2-3 units of energy from atmosphere and with an additional one unit by way of compressor is able to provide four units of energy at a higher temperature. Thus, heat pumps can transfer heat from natural heat sources in the surroundings, such as the air, ground, or water, or from man-made heat sources such as industrial or domestic waste, to a building or industrial application.

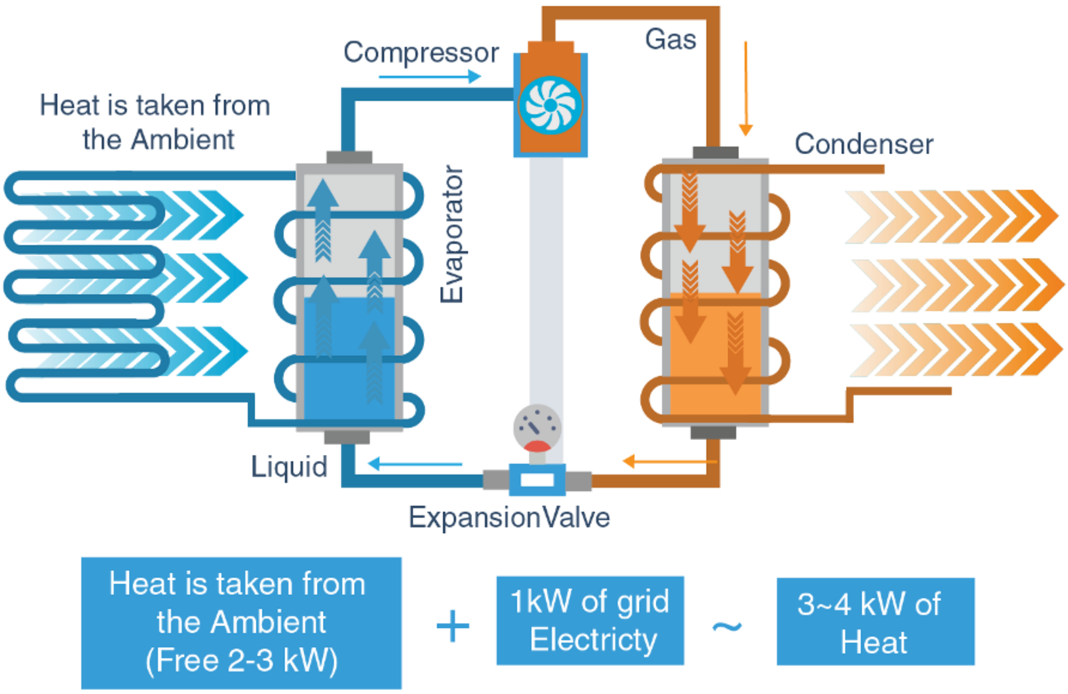


Figure 31: Heat Pump working (Source: Aspiration energy)

In order to transport heat from a heat source to a heat sink, external energy is needed to drive the heat pump. Theoretically, the total heat delivered by the heat pump is equal to the heat extracted from the heat source, plus the amount of drive energy supplied. Electrically driven heat pumps for heating buildings typically supply 100 kWh of heat with just 20-40 kWh of electricity. Many industrial heat pumps can achieve even higher performance and supply the same amount of heat with only 3-10 kWh of electricity.

Heat pumps usually can be used either in heating mode or cooling mode.

Technically the heat pump uses a mechanical compression cycle refrigeration system that can be reversed to either heat or cool a controlled space.

They are also increasingly used to heat domestic hot water, the hot water used for kitchens, bathrooms, clothes washers, etc. Heat pumps are significantly more energy efficient than simple electrical resistance heaters therefore can save a lot of money where heat is required. The majority of heat pumps work on the principle of the vapor compression cycle. The most common design of a heat pump involves a condenser, an expansion valve, an evaporator and a compressor. The heat transfer takes place using refrigerants.

The heat pump was developed as a space heating system where low temperature energy from the ambient air, water, or earth is raised to heating system temperatures by doing compression work with an electric motor-driven compressor. The potential for application of heat pump is growing and number of facilities have been benefited by recovering low grade waste heat by upgrading it and using it in the main process stream.

Types of heat pumps are categorized on the type of source and sink. There are three types of heat pumps:

1. Air-to-air
2. Water source
3. Geothermal

Performance terms and definitions

Common terms use to define the heat pump performance are: Energy Efficiency Ratio (EER) or Coefficient of performance (COP), The higher the number, the more efficient a heat pump is, the less energy it consumes, and the more cost-effective it is to operate. There are several factors that will affect the efficiency of a heat pump, such as auxiliary equipment, technology, size and control system, but also temperature and humidity conditions. The efficiency drops when the temperature difference increases or when freezing can occur.

Performance evaluation of Heat Pumps

The main components of heat pumps are evaporator, compressor and condenser, refer **Section 7.4.8** for performance evaluation procedure.

Application of heat pump

In buildings the heat energy can be used as waste heat flows. Waste heat flows are for example wastewater, hot humid air, condenser heat from refrigeration systems, etc. An analysis may be performed to assess the suitability of waste heat integration into the buildings. For homes without ducts, air-source heat pumps are also available in a ductless version called a mini-split heat pump. In addition, a special type of air-source heat pump called a "reverse cycle chiller" generates hot and cold water rather than air, allowing it to be used with radiant floor heating systems in heating mode.

Geothermal heat pumps achieve higher efficiencies by transferring heat between house and the ground or a nearby water source. Although they cost more to install, geothermal heat pumps have low operating costs because they take advantage of relatively constant ground or water temperatures.

Geothermal heat pumps have some major advantages. They can reduce energy use by 30%-60%, control humidity, are sturdy and reliable, and fit in a wide variety of buildings.

Misconception #1: Heat pumps are expensive

Renewable energy technology is often considered as an expensive investment. The truth is heat pumps are very affordable when one compares it with other types of heating systems. Heat pumps work for both heating and cooling, so one does not need to install two separate systems to provide these services. Heat pumps are also cheaper to operate.

Misconception #2: Cannot be integrated with existing heating system
It is not true always. Except with the heating system that uses biomasses as fuel, the heat pumps are very easy to integrate with an existing system, even if it is a complex heating system. What is so appealing about a heat pump is that it can be integrated in parallel to an existing system and can operate it as a hybrid system.

Misconception #3: Heat pumps are noisy
Back in the day, heat pumps and other heating systems were quite loud. However, with today's advances in technology, the amount of noise a heat pump produces are comparative to the noise or sound that is produced from a boiler. So, though it might produce some noise, it will not be any more than the sounds any other industrial machine makes.

Misconception #4: Not efficient in cold climate
One of the biggest misconceptions about heat pumps is that they only work in more temperate climates — not true. Since the ground source heat pump or water source heat pump takes heat from the constant temperature source, it can ensure an efficiency rate that is consistent all year round, regardless of the outside weather conditions. In contrast, the cost-efficiency of an air source heat pump is directly influenced by the outside temperatures, given that a pump like this extracts heat from the outside air masses. The efficiency of an air source heat pump will gradually diminish with the decrease in outside temperature levels. Still, the latest technological advancements in the field of thermodynamics, an air to water heat pump can work effectively at temperatures that do not fall below the 10°C mark.

Misconception #5: Costlier to operate
Heat pumps can help save over 30% on energy bill, compared to other conventional heating systems. While the upfront cost may be more than other options, an efficient heat pump paired with proper insulation will save money in the long run. Installing a heat pump requires careful consideration in a lot of factors.

7.5. Thermal analysis of Building

The thermal performance of the building can vary with orientation, adjacent space, level of exposure, the use of the space and the time of assessment.

7.5.1. Introduction

The thermal analysis of the building is to be conducted under the following conditions only:

- The calculated EPI is very high or very low (Base EPI can be correlated with EE codes for buildings)
- The assessment of the thermal comfort indicates high predicted percentage dissatisfied.

It is not necessary to conduct the thermal performance audit of the whole building. If a complete building is to be audited, then each room must be assessed separately. The selection of the specific location/area of building must be supported with rationale based on the experience of the energy auditor and the requirement set by the client.

7.5.2. Data collection

The following data must be collected:

- The orientation and context of the building (or specific location/area of building) should be drafted, this information can be collected based on the site plan.
- The building plan and section or detail of the specific location/area of building to be audited (In the absence of drawing and detail, the drawing shall be drafted by energy auditor).
- The weather data of the time or period during which the assessment is being conducted.

7.5.3. Instruments required

The following instruments will be required

- Measuring tape
- Heat flux meter (if available)
- Digital or Analogue thermometer with data logger
- Hygrometer with data logger
- Anemometer
- Thermal imaging camera
- Blower door assembly

7.5.4. Performance terms and definition

Thermal performance of the building determines the steady state heat loss/gains of a building and hence the capacity of heating/cooling system in a building required to maintain specified inside design conditions under design external conditions.

The following determine the thermal performance of the building:

- Thermal transmittance (U-value) of the building envelope
- Ventilation and ventilation heat/cool loss

- Solar radiation (especially over the transparent construction)
- Heat gains from people, equipment, and lights

The heat is lost from buildings through building fabric and by ventilation.

Thermal Comfort is assessed for the level of comfort (operative) temperature, relative humidity, air velocity where assumptions are made for the occupant such as work rate and level of clothing. Thermal comfort can be assessed by calculating the predicted percentage dissatisfied (PPD) or the adaptive method.

The **U-value** is the rate of heat loss per meter squared of envelope area when there is a one degree temperature difference across the element. Its unit is in W/m^2K

The **R-value** is the thermal resistance per unit area. The higher the R-value, the more effective the material is at preventing heat transfer.

The **K-value** is the thermal conductivity. It is the time rate of steady state heat flow through a unit area of a homogeneous material induced by a unit temperature gradient in a direction perpendicular to that unit area.

The **heat loss coefficient** is used to calculate the whole building heat loss.

$H_t = \Sigma(A\ U) + \Sigma(L\ \Psi) + (N\ V\ 0.33)$

where, H_t is the transmission heat loss coefficient (W/K)

$\Sigma(A\ U)$ is the sum over all the components of the building (i.e. roof, walls, floor, windows) of the product of the area of each component and its *U*-value ($W/m^2 \cdot K$)

$\Sigma(L\ \Psi)$ is the sum over all thermal bridges of the product of the length of each thermal bridge (m) and its linear thermal transmittance (W/mK).

N is the number of air changes per hour, V is the volume of the space in m^3 and 0.33 is a constant.

The thermal bridge or linear thermal transmittance is measured in psi. It typically arises at junction between building components, such as junctions of floor and roof with external walls and around window and door openings. It is denoted by (ψ). Examples of thermal bridges are column, beam, sill and lintel

Air change rate is the rate of ventilation divided by the volume of the ventilated space. Typically, it is expressed in units of air changes/hour. The volume could represent an individual room or an entire building.

Air change rate per hour at 50 Pa (ach): This is the leakage rate in m^3/hr determined at 50 Pa divided by the volume of the closed space.

7.5.5. Thermal Comfort

One of the major applications of the Psychrometric chart is in air conditioning, and we find that most humans feel comfortable when the temperature is between 22°C and 27°C, and the relative humidity between 40% and 60%. This defines the "comfort zone" which is portrayed on the Psychrometric Chart as shown in **Figure 32.** Thus, with the aid of the chart we either heat or cool, add moisture or dehumidify as required to bring the air into the comfort zone.
It is also defined as that condition of mind which expresses satisfaction with the thermal environment. Thermal comfort is calculated by **predicted percentage dissatisfied** (PPD) or by adaptive method.

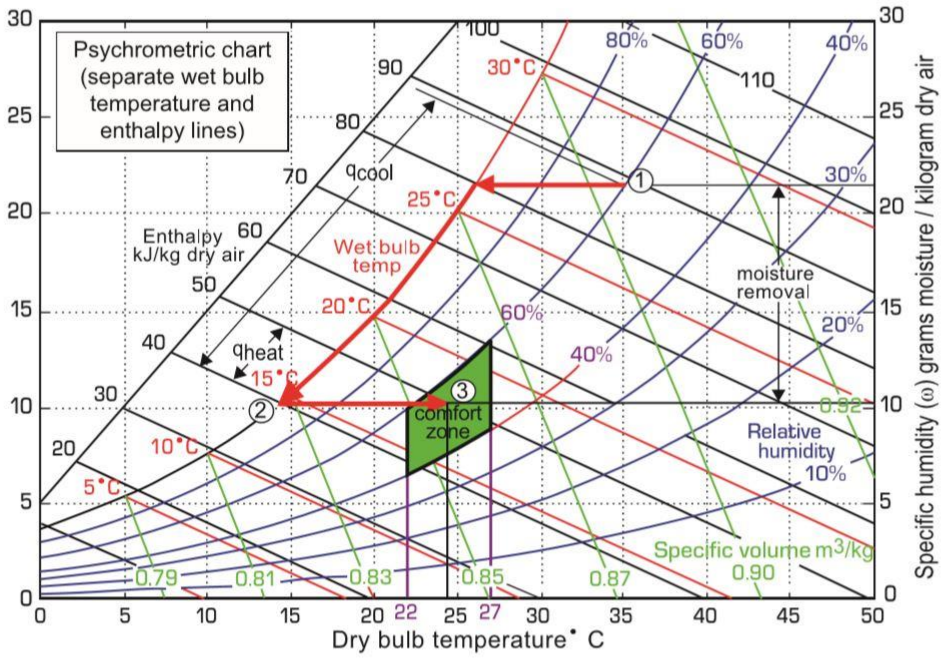


Figure 32: Psychrometric chart depicting human comfort zone (Source: BEE)

Data collection for thermal comfort

Following three physical variables shall be collected through measurements:

- Air temperature (Ta)
- Relative Humidity (RH%)
- Mean air velocity (Va)

In addition to above, following two Personal Variables shall also be collected:

- The Metabolic rate (Met)
- Clothing thermal resistance (Clo)

Steps to assess thermal comfort by PPD method

1. Measure the air temperature
2. Measure the mean air velocity
3. Calculate the mean radiant temperature (T_{mr}) using given formula for calculating mean radiant temperature.

4. Calculate the operative temperature depending on the air velocity using given formula for calculating operative temperature.
5. Consider met value of 1.2 for buildings occupants
6. Note the clothing of the occupants and assign the clo value, it can be assumed that the clo value applicable in the Bhutanese context ranges from 0.5 to 1.0 given the traditional dress (refer **Table 7**)
7. Find the predicted percentage dissatisfied (PPD).

Table 7: Clo value applicable in Bhutanese context

Clo value applicable in Bhutanese context	
Summer wear	0.5
Light winter wear	0.75
Winter wear	1.0

Formula for calculating mean radiant temperature

$$T_{mr} = T_g\left(1 + 2.35\sqrt{V_a}\right) - \left(2.35\, T_a\sqrt{V_a}\right)$$

Where T_g is the globe temperature, V_a is the air velocity

Formula for calculating operative temperature

Condition 1: The air velocity less than 0.1m/s then

$$T_O = 0.5\, T_a + 0.5\, T_{mr}$$

Condition 2: The air velocity is greater than 0.1m/s

$$T_O = \frac{T_a\sqrt{10v} + T_{mr}}{1 + \sqrt{10v}}$$

Generally, the activity level of 1.2 met is used for most activities as it captures a day to day activity at work or at home**.** The PPD for 1.2 met is as shown in **Table 8**

Steps to assess thermal comfort by adaptive method

1. Measure the indoor air temperature
2. Measure the indoor mean air velocity
3. Calculate the mean radiant temperature (T_{mr}) depending on the air velocity as explained above (use above given formula for calculating mean radiant temperature)
4. Table and calculate the outdoor running mean temperature during trial (T_{rm})
5. Calculate the acceptable maximum (max) or minimum (min) temperature using following equation

Formulae for calculating max and min of acceptable temperature ranges by adaptive method.

T_max = 0.33T_{rm}+21.8°C
T_min= 0.33T_{rm}+ 15.8°C

A space satisfies the adaptive thermal comfort condition if the operative temperature T_o is within the acceptable temperature range.

Thermal comfort can also be calculated using on freely available tool such as the **https://comfort.cbe.berkeley.edu/** (The tools help calculate thermal comfort under both adaptive as well as using PPD for ASHRAE as well as EN thermal comfort)

Table 8: Predicted Percentage Dissatisfied (PPD) value for 1.2 Met

Clothing (clo value)	Operative temperature °C	Relative air velocity							
		<0.10	0.1	0.15	0.2	0.3	0.4	0.5	1
0.5 (Summer wear)	18	-2.01	-2.01	-2.17	-2.38	-2.7			
	20	-1.41	-1.41	-1.58	-1.76	-2.04	-2.25	-2.42	
	22	-0.79	-0.79	-0.97	-1.13	-1.36	-1.54	-1.69	-2.17
	24	-0.17	-0.2	-0.36	-0.48	-0.68	-0.83	-0.95	-1.35
	26	0.44	0.39	0.26	0.16	-0.01	-0.11	-0.21	-0.52
	28	1.05	0.98	0.88	0.81	0.7	0.61	0.54	-0.31
	30	1.64	1.57	1.51	1.46	1.39	1.33	1.29	1.14
	32	2.25	2.2	2.17	2.15	2.11	2.09	2.07	1.99
0.75 (light winter wear)	16	-1.77	-1.77	-1.91	-2.07	-2.31	-2.49		
	18	-1.27	-1.27	-1.42	-1.56	-1.77	-1.93	-2.05	-2.45
	20	-0.77	-0.77	-0.92	-1.04	-1.23	-1.36	-1.47	-1.82
	22	-0.25	-0.27	-0.4	-0.51	-0.66	-0.78	-0.87	-1.17
	24	0.27	0.23	0.12	0.03	-1.1	-0.19	-0.27	-0.51
	26	0.78	0.73	0.64	0.57	0.47	0.4	0.34	0.14
	28	1.29	1.23	1.17	1.12	1.04	0.99	0.94	0.8
	30	1.8	1.74	1.7	1.67	1.62	1.58	1.55	1.46
1.00 (Winter wear)	16	-1.18	-1.18	-1.31	-1.43	-1.59	-1.72	-1.82	-2.12
	18	-0.75	-0.75	-0.88	-0.98	-1.13	-1.24	-1.33	-1.59
	20	-0.32	-0.33	-0.45	-0.54	-0.67	-0.76	-0.83	-1.07
	22	0.13	0.1	0	-0.07	-0.18	-0.26	-0.32	-0.52
	24	0.58	0.54	0.46	0.4	0.31	0.24	0.19	0.02
	26	1.03	0.98	0.91	0.86	0.79	0.74	0.7	0.58
	28	1.47	1.42	1.37	1.34	1.28	1.24	1.21	1.12
	30	1.91	1.86	1.83	1.81	1.78	1.75	1.73	1.67

Steps to obtain heat loss coefficient

1. Calculate the U-value of the building components (walls, windows, floor, and ceiling)
2. Multiply the arrived U-value with the area of the corresponding building component
3. Sum the results of step 2 to arrive at Σ(A U)
4. List the thermal bridges and note the running lengths

5. Obtain the psi value and calculate the total transmittance heat loss from each of the elements
6. Sum the results of step 5 to arrive at Σ(L Ψ)
7. Conduct the blower door test to arrive at the air exchange rate
8. Multiply the result with the space volume and calculate the ventilation heat losses
9. Sum the results under step 3, 6 and 8 to calculate the heat loss coefficient.

The thermal camera can be used to for qualitative evaluation to detect heat losses, air leakages, thermal bridges, sources of moisture, missing materials, and defects in insulation materials.

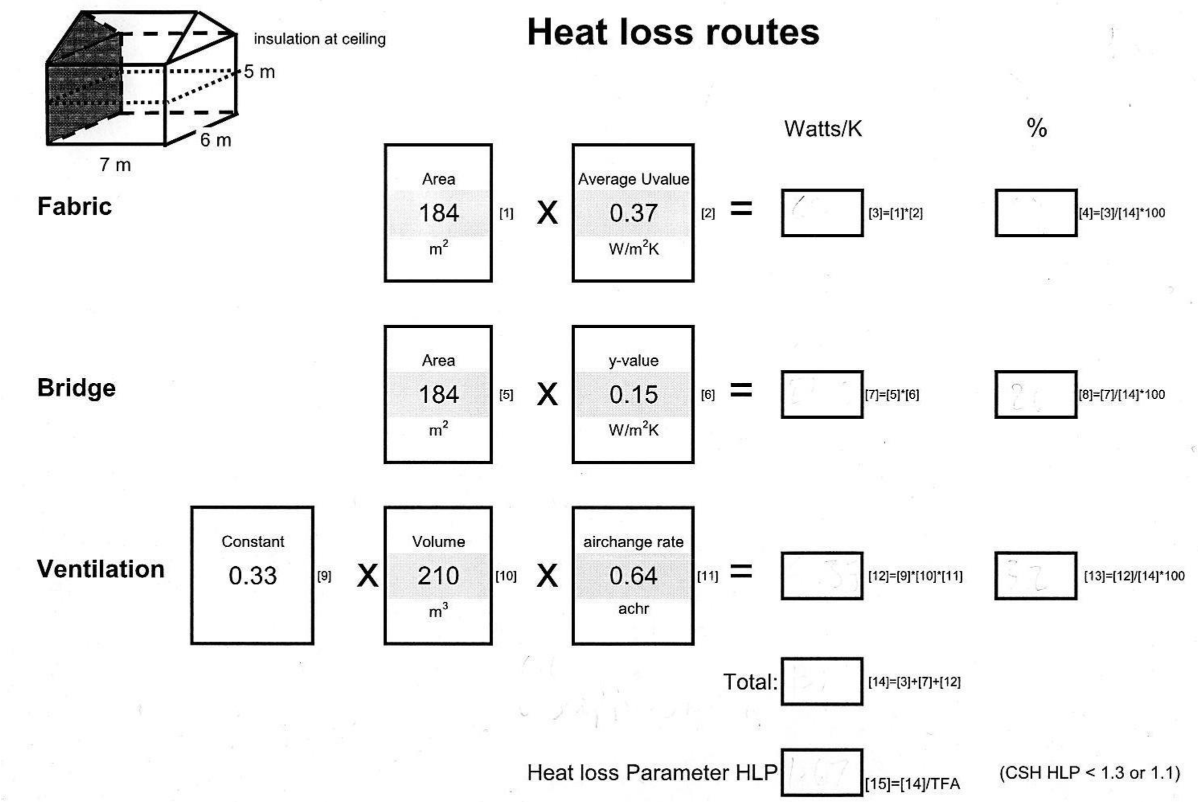


Figure 33: Heat loss routes

In the absence of working drawing or any knowledge on the construction, the **U value** of the wall should be calculated by following steps. However, some conditions will have to be met (the U value calculation using this method is detailed here under).

1. The thermal imaging camera should be used to identify the best representative location in the wall for the test
2. The heat flux sensor is installed on the inside surface of the test wall as shown in **Figure 34**
3. Two thermocouples mounted on the inside surface near the heat flux sensor and on the opposite outside surface with adhesive tape as shown in the **Figure 34**
4. The inside air temperature and wind speed are measured in the vicinity of the test wall
5. Measure the outside air temperature and local wind speed
6. The measurements were recorded using a data logger with a sampling period of 1 min.
7. Analysis of the data as described in condition 1, 2 & 3.

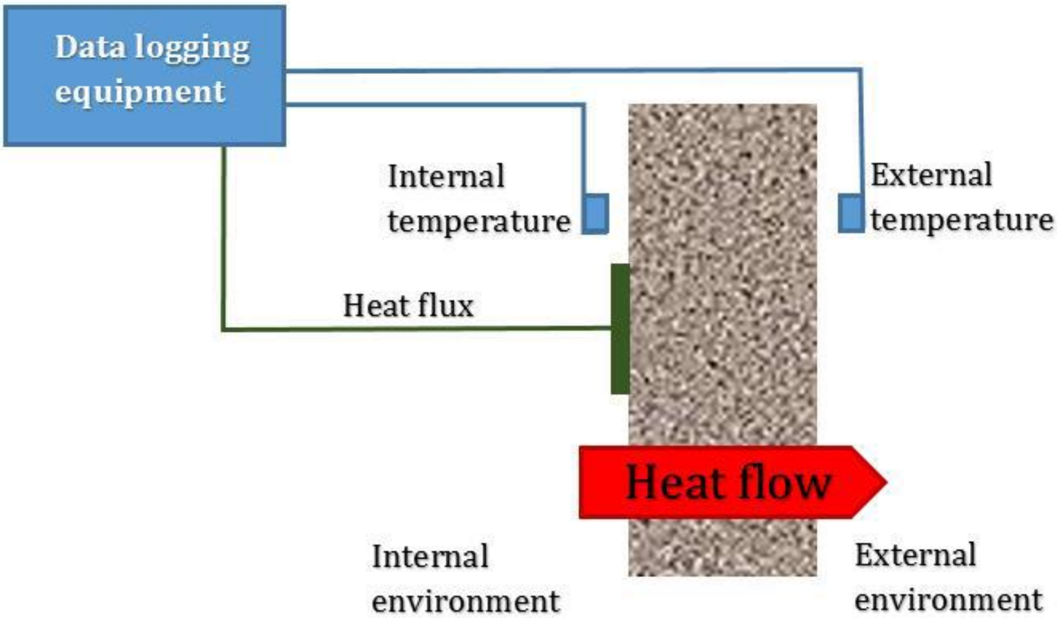


Figure 34: Schematic diagram of measurements u value

Condition 1 — the duration of the test exceeds 72 hours (three days) if the temperature is stable around the heat flow meter, otherwise the duration may be much longer; however, the actual duration of test shall be determined by applying criteria to values obtained during the course of the test. These values shall be obtained without interrupting the data acquisition process. In building with large heat capacities, the average thermal transmittance of a component can be obtained by measurement over an extended period (not less than 96 hours) and thermal mass factors are used in the analysis, or the apparent transmittance of the part can be estimated by a dynamic analysis of its thermal absorption response.

Condition 2 — the R-value obtained at the end of the test does not deviate by more than ± 5 % from the R-value obtained 24 h before.

Condition 3 — the R-value obtained by analysing the data from the first time period during INT(2 x DT/3) d does not deviate by more than ± 5 % from the values obtained from the data of the last time period of the same duration. DT is the duration of the test in days; INT is the integer part.

7.5.6. Energy saving opportunities

The independent results of the heat losses from whole building heat losses can help identify energy saving opportunity as

1. Determining which is the largest contributor to the heat loss from above calculation of heat loss
2. In case it is the components then the component which contributed the most can be arrived at and suggestions as insulating, or replacement can be decided on.

3. In case it is the element than insulation, then the element that contributed the most can be arrived at and suggestions as insulation can be decided on.
4. In case it is due to high ventilation losses, then suggestions as using weather stripping or changing the opening with improved profile can be decided on.

7.5.7. To calculate the U-value of wall, floor, and ceiling

$U = 1 / (R\text{si} + R1 + R2 + ... + R\text{a} + R\text{se})$

where U is the thermal transmittance (W/m^2 · K), Rsi is the internal surface resistance (m · K/W), R1 and R2 are the thermal resistances of components 1 and 2 (m^2 · K/W), Ra is the thermal resistance of the airspaces (m^2 · K/W) and Rse is the external surface resistance (m^2 · K/W).

The values for internal surface resistance used in BS EN ISO 6946 (BSI, 2007a) are shown in **Table 9.** These values represent a simplification of the heat transfer processes that occur at surfaces.

Table 9: Internal surface resistance, Rsi

Building elements	Direction of heat flow	Surface resistance (m^2K/W)
Walls	Horizontal	0.13
Ceiling or roofs (flat or pitched), floors	Upward	0.10
Ceiling or floors	Downward	0.17

The external surface resistance is assumed to be independent of surface roughness, temperature differences between radiating surfaces, differences between surface and air temperatures, etc.

Table 10: External surface resistance, Rse

Building elements	Direction of heat flow	Surface resistance (BS EN ISO 6946 normal design value)
Walls	Horizontal	0.04
Roof	Upward	0.04
Floor	Downward	0.04

Thermal transmittance of solid ground floors

The U-value of a solid floor in contact with the ground, see **Figure 35** below, depends on a ‘characteristic dimension’ of the floor, B', and the ‘total equivalent thickness’, $d$ef, of the factors that in combination restrict the heat flow (i.e. wall thickness, surface resistances, thermal insulation).

The characteristic dimension is defined thus:

$B' = \frac{A_{fg}}{0.5P_f}$ where, A_{fg} is the area of floor in contact with the ground (m2) and P_f is the exposed perimeter of the floor (m).

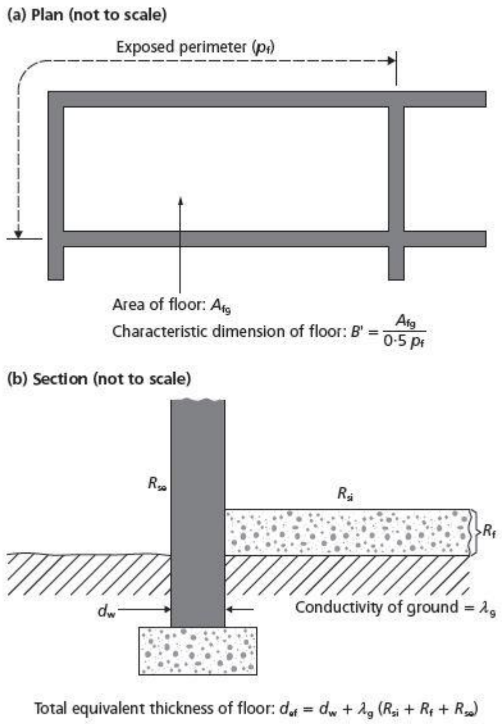


Figure 35: Total equivalent thickness of floor

The total equivalent thickness is given by:

$d_{ef} = d_w + \lambda_g (R_{si} + R_f + R_{se})$

where d_{ef} is the total equivalent thickness of the floor (m), d_w is the thickness of the wall surrounding the ground floor (m), λg is the thermal conductivity of the ground (W/m · K), Rsi is the inside surface resistance (m^2 · K/W), R_{se} is the external surface resistance (m^2 · K/W) for the outside ground surface and R_f is the thermal resistance of the floor (m^2 · K/W). R_f includes the thermal resistance of any all-over insulation layers above, below or within the floor slab, and that of any floor covering. The thermal resistance of dense concrete slabs and thin floor coverings may normally be neglected.

Hardcore below the slab is assumed to have the same thermal conductivity as the ground and its thermal resistance is therefore not included.

For $d$ef<B', as is usually the case, the thermal transmittance is given by:

$$U_f = \frac{2\lambda_g}{\pi B' + d_{ef}} In\left(\frac{\pi B'}{d_{ef}} + 1\right)$$

If $def \geq B'$, as may occur for a small, well insulated floor:

$$U_f = \frac{\lambda_g}{0.457\, B' + d_{ef}}$$

For a complete building P_f is the total perimeter of the building and A_{fg} is its total ground floor area. Unheated spaces outside the insulated fabric of the building (e.g. porches, attached garages or storage areas) are excluded when determining P_f and A_{fg}, but the length of the wall between the building and the unheated space must be included in the perimeter. The ground heat losses are assessed as if the unheated spaces were not present.

Table 11 gives representative values of λ_g for three broad categories of ground.

Table 11: Thermal conductivity of soils

Soil Type	Thermal conductivity, λ_g(W/m·K)
Clay or Silt	1.5
Sand or gravel	2.0
Homogeneous rock	3.5

Roofs

For simple pitched roofs, the U-value is calculated normal to the plane of the roof. However, if the pitched roof includes a horizontal ceiling and an unheated loft, the U-value is defined with respect to the plane of the ceiling.

Table 12: Thermal properties of typical roof constructions

Construction	Transmittance U(W/m²·K)	Admittance	
		Y (W/m²·K)	ω (h)
1.Pitched roof (insulated at ceiling level)			
(a)12.5mm plaster board, no insulation, roof space, tiling	2.3	2.05	0.6
(b)12.5mm plasterboard,25mm mineral wool quilt between ceiling joist, roof space, tiling	1.1	1.11	1.6
(c)12.5mm plasterboard,50mm mineral wool quilt between ceiling joist, roof space, tiling	0.71	0.85	2.6
(d)12.5mm plasterboard,100mm mineral wool quilt between ceiling joist, roof space, tiling	0.42	0.72	3.7
(e)12.5mm plasterboard,100mm mineral wool quilt between ceiling joist,50mm mineral quilt over joist, roof space, tiling	0.28	0.7	4.5

Construction	Transmittance $U(W/m^2 \cdot K)$	Admittance	
		Y $(W/m^2 \cdot K)$	ω (h)
(f)12.5mm plasterboard,100mm mineral wool quilt between ceiling joist,100mm mineral quilt over joist, roof space, tiling	0.21	0.68	4.5
(g)12.5mm plasterboard,100mm mineral wool quilt between ceiling joist,150mm mineral quilt over joist, roof space, tiling	0.17	0.68	4.7
(h)12.5mm plasterboard,100mm mineral wool quilt between ceiling joist,200mm mineral quilt over joist, roof space, tiling	0.14	0.72	4.8
2.Pitched roof (insulated at after level)			
(a)12.5mm plasterboard,25mm pu insulated between rafters, ventilated air space, roofing felt,25mm ventilated airspace, clay tile	0.95	0.98	2.1
(b)12.5mm plasterboard,50mm pu insulated between rafters, ventilated air space, roofing felt,25mm ventilated airspace, clay tile	0.56	0.76	3.3
(c)12.5mm plasterboard,100mm pu insulated between rafters, ventilated air space, roofing felt,25mm ventilated airspace, clay tile	0.31	0.7	4.4
(d)12.5mm plasterboard,150mm pu insulated between rafters, ventilated air space, roofing felt,25mm ventilated airspace, clay tile	0.22	0.71	4.8
(e)12.5mm plasterboard,150mm pu insulated between rafters and 50mm over rafters, ventilated air space, roofing felt,25mm ventilated airspace, clay tile	0.15	0.73	4.9
3.Sheet metal construction			
(a) 0.4mm inner sheet,150mm Z spacer with mineral wool insulated, 0.7mm outer sheet	0.35	0.28	1.2
(b)0.4mm inner sheet,85mm mineral wool insulation,40mm mineral wool insulation between rails, 0.7mm profiles outer sheet	0.35	0.31	0.5

Thermal transmittance of basement floors and walls

This is to be used only if the basement is heated. The *U*-value for the floor depends on the ratio of the perimeter of the floor to its area, and on the depth of the basement floor below ground level. The *U*-value for the walls depends on the depth of the basement and the properties of the materials used in the wall construction. The *U*-value may also be defined for the basement, as follows:

$$U_b = \frac{A_b U_{bf} + h_b P_{bf} U_{bw}}{A_b + h_b P_{bf}}$$

where U_b is the average thermal transmittance of the basement (W/m^2 · K), A_b is the area of the basement floor (m^2), U_{bf} is the thermal transmittance of the basement floor (W/m^2 · K), h_b is the depth of the basement below ground level (m), P_{bf} is the perimeter of the basement (m) and U_{bw} is the thermal transmittance of the basement wall (W/m^2 · K). Values of U_{bf} and U_{bw} are given in **Table 13** and **Table 14**, respectively.

Table 13: U-Values for uninsulated basement floors

Ratio, P_b/A_b (m^{-1})	*U*-Value of basement floor, U_{bf}(W/m^2·K), for seated basement depth, h_b(m)				
	0.5	1.0	1.5	2.0	2.5
0.1	0.20	0.19	0.18	0.17	0.16
0.2	0.34	0.31	0.29	0.27	0.26
0.3	0.44	0.41	0.38	0.35	0.33
0.4	0.53	0.48	0.44	0.41	0.38
0.5	0.61	0.55	0.5	0.46	0.43
0.6	0.68	0.61	0.55	0.50	0.46
0.7	0.74	0.65	0.59	0.53	0.49
0.8	0.79	0.70	0.62	0.56	0.51
0.9	0.84	0.73	0.65	0.58	0.53
1.0	0.89	0.77	0.68	0.60	0.54

Table 14: U-Values for basement walls

Thermal resistance of basement walls, R_{bw} (m^2·K/W)	U-Value of basement walls, U_{bw} (W/m^2· K), for seated basement depth, h_b(m)				
	0.5	1.0	1.5	2.0	2.5
0.2	1.55	1.16	0.95	0.81	0.71
0.5	0.98	0.78	0.66	0.58	0.52
1.0	0.61	0.51	0.45	0.40	0.37
2.0	0.35	0.3	0.27	0.25	0.24
2.5	0.28	0.25	0.23	0.21	0.20

The basement floor area (A_b) is measured between the finished internal faces of the walls bounding the basement. The perimeter (P_b) is measured along the finished internal faces, the basement depth (h_b) is measured between the outside ground level and the finished internal surface of the basement floor. The depth (h) will often be less than the internal height of the basement storey, in which case the U-value obtained by U_b will apply to the floor and the area of basement wall below ground level. Any wall above ground level should be assessed using the methods for walls given for wall. To obtain a U-value for split-level basements and basements on sloping sites, the average depth of the basement below ground level should be used, averaged around its perimeter.

$h_b = (h_{b1} + h_{b2}) / 2$

It is not feasible to list U-values of all construction materials, **Table 15** provides the thermal conductivity (K) of some generic construction material used in the country. The R value against each of the material of different densities can be calculated by dividing thickness of the material by the given K value. The thickness of the material must be in metres (m). The U value then calculated from the arrived R value

Table 15: K-value of generic construction materials to obtain U-value

Description	Thermal Conductivity (K)	Specific heat capacity	Density	Source
CONCRETE-Block aircrete (460 kg/m^3)	0.11	1000	460	Aircrete Bureau 'Use of Aircrete Products', table 6 (2004)
CONCRETE-Block aircrete (600kg/m^3)	0.15	1000	600	Aircrete Bureau 'Use of Aircrete Products', table 6 (2004)
CONCRETE-Block dense	1.33	1000	2000	Mineral Products Association
CONCRETE-Block lightweight aggregate	0.47	1000	1450	Mineral Products Association
CONCRETE-Block ultra light weight aggregate	0.36	1000	1000	Mineral Products Association
CONCRETE-Insitu	1.75	1000	2300	CIBSE Guide A-Table 3.47
CONCRETE-Precast	1.46	1000	2100	CIBSE Guide A-Table 3.47
FLOORING-Carpet or Underlay	0.6	1300	200	CIBSE Guide A-Table 3.47
FLOORING-Ceramic tiles	0.8	850	1700	Inventory of Carbon and Energy (ICE) version 2.0 University of Bath
FLOORING-Rubber	0.13	2010	1100	The Engineering Toolbox
FLOORING-Screed	0.46	1000	1200	CIBSE_Guide_A-Table_3.47

Description	Thermal Conductivity (K)	Specific heat capacity	Density	Source
FLOORING-Timber hardwood	0.18	1260	700	SBSA_technical_guide_2007-Table_6.A.18
FLOORING-Timber softwood plywood chipboard	0.13	1600	500	CIBSE Guide A-Table 3.47
FLOORING-Vinyl covering	0.17	900	1390	CIBSE_Guide_A-Table_3.47
INSULATION-Cellulose (recycled newspaper)	0.039	2000	32	Green spec (shc value: constructionresources.com)
INSULATION-Expanded polystyrene (EPS)	0.036	1450	25	Green spec (shc value: CIBSE Guide A Table 3.47)
INSULATION-External wood fibre board	0.043	2100	180	Pavatex_Diffutherm_product_information_(www.natural-building.co.uk)
INSULATION-Extruded polystyrene_(XPS)	0.032	1400	30	Green spec (shc value: CIBSE Guide A Table 3.47)
INSULATION-Flax	0.037	1600	30	Construction Resources (www.constructionresources.com)
INSULATION-Foam glass	0.041	830	120	www.foamglas.co.uk and www.unitedperlite.net
INSULATION-Glass wool	0.04	670	25	The Engineering Tool Box
INSULATION-Mineral wool batts	0.038	1030	25	CIBSE Guide A-Table 3.47
INSULATION-Phenolic	0.021	1400	40	Kingspan (thermal conductivity value for insulation > 45mm)
INSULATION-PIR board (foil faced)	0.022	1400	32	Kingspan
INSULATION-Rock wool	0.04	840	120	www.wilhams.com.my
MASONRY-Brick exposed	0.96	2000	1750	CISBE Guide A Table 3.1
MASONRY-Brick protected	0.7	2000	1750	CIBSE Guide A-Table 3.1
MASONRY-Sandstone	1.8	1000	2300	CIBSE Guide A-Table 3.47
METAL-Aluminium	215	870	2712	The Engineering Toolbox

Description	Thermal Conductivity (K)	Specific heat capacity	Density	Source
METAL-Copper	370	390	8930	The Engineering Toolbox
METAL-Structural steel	50	450	7800	CIBSE Guide A-Table 3.47
METAL-Zinc	116	380	7135	The Engineering Toolbox
MISCELLANEOUS-Ceiling tiles	0.058	590	290	CIBSE Guide A-Table 3.38 (building board, tile and lay-in panel)
MISCELLANEOUS-Cement bonded particle board	0.23	1500	1200	CIBSE Guide A-Table 3.47
MISCELLANEOUS-Gypsum Fibre Board (Fermacell)	0.17	1090	2300	The Engineering Toolbox
MISCELLANEOUS-Single ply EPDM	0.0648	1040	200	www.matweb.com and www.clariant.de
MISCELLANEOUS-Timber stud and insulation	0.052	1115.5	96.25	BRE (15% Softwood 85% Mineral wool batts)
SURFACE FINISHES-External render (cement and sand)	1	1000	1800	CIBSE Guide A-Table 3.47
SURFACE FINISHES-Plaster dense	0.57	1000	1300	CIBSE Guide A-Table 3.47
SURFACE FINISHES-Plaster lightweight	0.18	1000	600	CIBSE Guide A-Table 3.47
SURFACE FINISHES-Plasterboard	0.21	1000	700	CIBSE Guide A-Table 3.47
WOOD-Chipboard	0.14	1700	600	CIBSE Guide A-Table 3.47
WOOD-Hardwood	0.18	1600	700	CIBSE Guide A-Table 3.47
WOOD-Plywood sheathing	0.13	1600	500	CIBSE Guide A-Table 3.47
WOOD-Softwood	0.13	1600	500	CIBSE Guide A-Table 3.47
CAVITY-Unlined	0.025	1008	1.23	-
CAVITY-Foil lined	0.025	1008	1.23	-

Windows

The thermal transmittance of windows is made up of three components:

- centre-pane *U*-value of the glazing
- frame or sash
- interaction between glazing and frame, include the effect of the glazing spacer bars in multiple glazing. These components are determined separately as shown in the following sections. The overall *U*-value of the window is given by:

$$U_w = \frac{\Sigma(A_g U_g) + \Sigma(A_{wf} U_{wf}) + \Sigma(\rho_{wf} \psi_s)}{\Sigma(A_g) + \Sigma(A_{wf})}$$

Where, U_w is the thermal transmittance of the window (W/m^2・K), A_g is the projected area of the glazing (m^2), A_{wf} is the projected area of the window frame or sash (m^2), U_g is the thermal transmittance of glazing (W/m^2・K), U_{wf} is the thermal transmittance of frame or sash (W/m^2・K), P_{wf} is the length of inner perimeter of frame or sash (m) and Ψ_s is the linear thermal transmittance for the glazing/frame (W/m・K).

The dimensions defined are shown in **Figure 36**

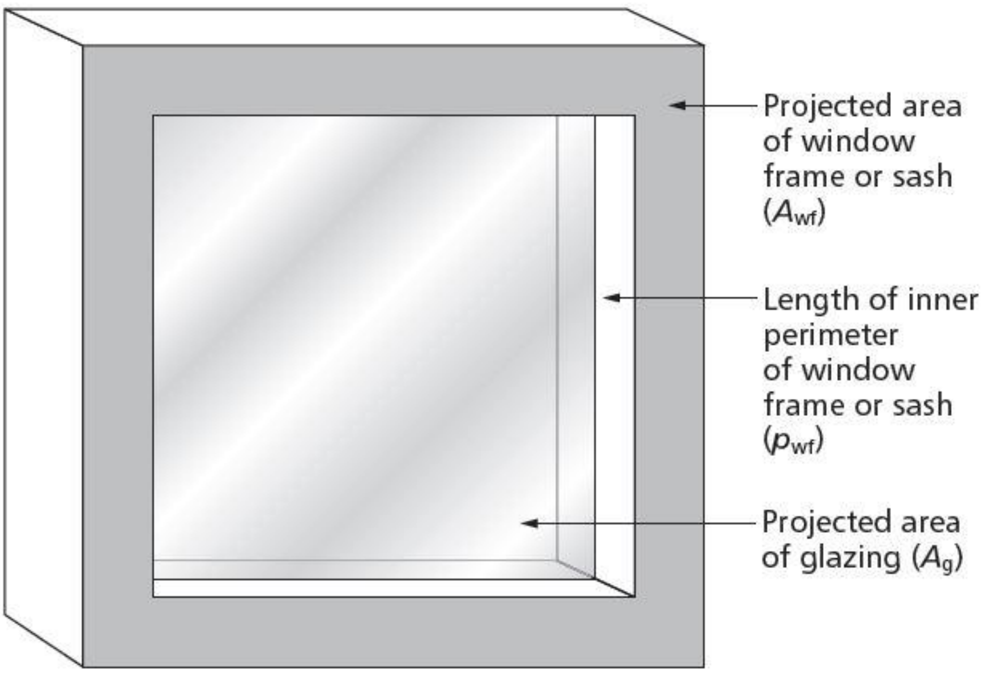


Figure 36: Defined Dimension

Glazing (excluding frame or sash)

The thermal conductivity of glass is approximately 1.0 W/m・K.

The **Table 16** below provides generic U value for vertical glazing

Table 16: U value of vertical glazing

Type of glazing	Spacing (mm)	U-value (W/m^2. k) for stated exposure of panes†		
		Normal (0.13/0.04)	Sheltered (0.13/0.06)	Severe (0.13/0.02)
Single	-	5.75	5.16	6.49
Double	25	2.76	2.60	2.90
	20	2.74	2.60	2.90
	16	2.73	2.59	2.90
	12	2.85	2.70	3.02
	9	3.01	2.84	2.9
	6	3.28	3.08	3.51
Triple	25	1.72	1.67	1.78
	20	1.71	1.66	1.77
	16	1.78	1.72	1.84
	12	1.89	1.83	1.97
	9	2.04	1.96	2.12
	6	2.29	2.19	2.4
Coated double $\varepsilon = 0.2$	20	1.85	1.78	1.92
	16	1.82	1.76	1.89
	12	2.02	1.95	2.11
	9	2.29	2.19	2.39
	6	2.71	2.57	2.87
Coated double $\varepsilon = 0.1$	20	1.60	1.55	1.65
	16	1.57	1.53	1.63
	12	1.80	1.74	1.87
	9	2.10	2.01	2.19
	6	2.57	2.44	2.71
Coated double $\varepsilon = 0.05$	20	1.45	1.41	1.49
	16	1.42	1.38	1.46
	12	1.67	1.61	1.72
	9	1.98	1.91	2.06
	6	2.48	2.37	2.61
Coated double Argon filled $\varepsilon = 0.2$	20	1.65	1.6	1.71
	16	1.63	1.58	1.69
	12	1.76	1.70	1.82
	9	1.98	1.90	2.06
	6	2.35	2.24	2.46
Coated double Argon filled $\varepsilon = 0.1$	20	1.38	1.34	1.42
	16	1.36	1.32	1.40
	12	1.50	1.46	1.55
	9	1.75	1.69	1.81
	6	2.16	2.07	2.26
Coated double Argon filled $\varepsilon = 0.05$	20	1.21	1.18	1.24
	16	1.19	1.16	1.22
	12	1.34	1.31	1.38
	9	1.61	1.56	1.66
	6	2.05	1.97	2.14

Frames and sashes (excluding glazing)

The **Table 17** below provides generic U value for frames and sashes

Table 17: U value for frames and sashes

Material	Description	U-value ($W/m^2. K$)
Wood	Average thickness 30 mm	2.30
	Average thickness 40 mm	2.15
	Average thickness 50 mm	2.02
	Average thickness 60 mm	1.90
	Average thickness 70 mm	1.78
	Average thickness 80 mm	1.67
	Average thickness 90 mm	1.57
	Average thickness 100 mm	1.48
Plastic	Without metal reinforcement	
	polyurethane	2.8
	PVC, two hollow chambers	2.2
	PVC, three hollow chambers	2.0
Aluminium	with thermal barrier	
	4 mm thermal break	4.4
	8 mm thermal break	3.9
	12 mm thermal break	3.5
	16 mm thermal break	3.2
	20 mm thermal break	3.0
Aluminium or steel	Without thermal barrier	6.9

Thermal barrier must be continuous and totally isolate the interior side of the frame or frame sections from the exterior side.

The U value of typical window is provided in below Table 18

Table 18: U value of window

Type of glazing	Type of frame					
	Window with wood or PVC-U frame (for roof windows use adjustment in note 1)			Window with metal frame with 4 mm thermal Break (use adjustments in notes 1 and 2)		
	6 mm gap	12 mm gap	16 mm gap or greater gap	6 mm gap	12 mm gap	16 mm gap or greater gap
Double-glazed, air filled	3.1	2.8	2.7	3.7	3.4	3.3
Double-glazed, air filled, low E:						
ε_n = 0.2 (hard coat)	2.7	2.2	2.1	3.3	2.8	2.5
ε_n = 0.15 (hard coat)	2.7	2.2	2.0	3.3	2.7	2.6
ε_n = 0.1 (Soft coat)	2.6	2.1	1.9	3.2	2.6	2.4
ε_n = 0.05 (Soft coat)	2.6	2.0	1.8	3.2	2.5	2.3
Double-glazed, argon filled	2.9	2.7	2.6	3.5	3.3	3.2
Double-glazed, argon filled, low E:						
ε_n = 0.2 (hard coat)	2.5	2.1	2.0	3.0	2.6	2.5
ε_n = 0.15 (hard coat)	2.4	2.0	1.9	3.0	2.5	2.4
ε_n = 0.1 (Soft coat)	2.3	1.9	1.8	2.9	2.4	2.3
ε_n = 0.05 (Soft coat)	2.3	1.8	1.7	2.8	2.2	2.1
Triple-glazed, air filled	2.4	2.1	2.0	2.9	2.6	2.5
Triple-glazed, air filled, low E:						
ε_n = 0.2 (hard coat)	2.1	1.7	1.6	2.6	2.1	2.0
ε_n = 0.15 (hard coat)	2.1	1.7	1.6	2.5	2.1	2.0
ε_n = 0.1 (Soft coat)	2.0	1.6	1.5	2.5	2.0	1.9
ε_n = 0.05 (Soft coat)	1.9	1.5	1.4	2.4	1.9	1.8
Triple-glazed, argon filled	2.2	2.0	1.9	2.8	2.5	2.4
ε_n = 0.2 (hard coat)	1.9	1.6	1.5	2.3	2.0	1.9
ε_n = 0.15 (hard coat)	1.8	1.5	1.4	2.3	1.9	1.8
ε_n = 0.1 (Soft coat)	1.8	1.5	1.4	2.2	1.9	1.8
ε_n = 0.05 (Soft coat)	1.7	1.4	1.3	2.2	1.8	1.7
Windows and doors, single glazed	-	4.8	-	-	5.7	-
Windows with secondary glazing	-	2.4	-	-	-	-
Solid wooden door to outside	-	3.0	-	-	-	-
Solid wooden door to unheated corridor	-	1.4	-	-	-	-

7.5.8. Airtightness testing by pressurization

The rate of air leakage through the fabric of buildings can be measured using an air pressurization technique. Air is supplied to the building under test at a range of air flowrates, and the resulting pressure differential across the building envelope is measured for each rate of flow. It is recommended that the range of pressure differentials be extended to up to 100 Pa. This pressure is low enough to avoid damage to the building but sufficiently high to overcome the detrimental effects of moderate wind speeds.

To conduct a test, a fan system is temporarily coupled to a suitable doorway or similar opening in the building envelope. For a large or leaky building, this requires a high capacity fan system. For small buildings, a device known as a 'blower door'is commonly used. This is an assembly that includes one or more fans, some means of controlling airflow rate and instrumentation for measuring pressures. It is designed to fit into a normal door frame, with facilities to clamp and seal it in place. Buildings are tested with all external doors and windows closed, and with all internal doors wedged open. Any natural and mechanical ventilation openings are also sealed with polythene sheet and adhesive tape. Smoke extract fans or vents are left closed but not sealed. Other integral openings such as lift shafts are left unsealed. Measurements should preferably be carried out under calm or light air conditions e.g. with wind speed less than about 2 m/s to achieve the best results.

However, some minimum ventilation rates for indoor air quality must be maintained to minimize the concentration of harmful pollutants. The **Table 19** and **Table 21** provide minimum ventilation for dwellings and for other building types respectively.

Table 19 shows extract ventilation rates for dwellings in England and Wales (reproduced from Building Regulations Approved Documents F (TSO 2010 a/b) (Crown copyright)) (for Scotland and Northern Ireland, see Scotland (2013a/b) and DFPNI (2012c))

Table 19: Ventilation rates for dwellings

Room	Intermittent extract	Continuous extract	
	Minimum rate	Minimum High Rate	Minimum Low Rate
Kitchen	30 l/s adjacent to hob or 60 l/s elsewhere	13 l/s	Total extract rate should be at least the whole dwelling ventilation rate given in Table 4.3(e)
Utility room	30 l/s	8 l/s	
Bathroom	15 l/s	6 l/s	
Sanitary accommodation	6 l/s	6 l/s	

Table 20 shows minimum whole building ventilation for dwellings in England and Wales (reproduced from Building Regulations Approved Documents F (TSO 2010 a/b) (Crown copyright)) (for Scotland and Northern Ireland, see Scotland (2013a/b) and DFPNI (2012c))

Table 20: Minimum whole building ventilation for dwellings

	Number of bedrooms in dwelling				
	1	2	3	4	5
Whole dwelling ventilation rate 1.2 (l/s)	13	17	21	25	29

Notes: (1) In addition, the minimum ventilation rate should be not less than 0.3 L/s per m^2 of internal floor area. This includes all floors, e.g. for a two-storey building, add the ground and first areas. (2) This is based on two occupants in the main bedroom and single occupant in all other bedrooms. This should be used as the default value. If a greater level of occupancy is expected add 4 l/s per occupant.

Table 21: Ventilation rates for other building types

Building type	Ventilation strategies	Recommended ventilation rate
Broadcasting studios	Mechanical ventilation Cooling comfort	6-10 ACH
Clean room	Mechanical ventilation	10-120 ACH for non-laminar-flow clean room depending on type of work 500-600 ACH for laminar-flow clean room
Computer room/data centre	Mechanical ventilation Air conditioning	Typical 1 ACH or minimum fresh air to suit occupancy
Hospitals and health care	Mechanical ventilation in areas such as operating theatre Natural ventilation areas such as ward areas	6-15 ACH depending on the building's functionality of the room
Laboratories	Mechanical ventilation	6-15 ACH
Museums, libraries, and art galleries	Mechanical ventilation	Depends on nature of exhibits
Schools and educational buildings	Mechanical ventilation Natural ventilation	Classrooms capable of 3 l/s per person for design occupancy when unoccupied Capable of 8 l/s per person when occupied Minimum 6 ACH in washing area.
Shops and retail premises	Mechanical ventilation	5-8 l/s per person maximum design occupancy

Building type	Ventilation strategies	Recommended ventilation rate
	Air conditioning	

7.5.9. Solar gain

Heat gains are from solar gains through glazed facades and the fenestrations. Solar gains can be limited by the type of glass, use of blinds, louvres, or overhangs.

The assessment of the solar gain is best done using simulation software since the radiation falling on the surface resulting from the albedo of the surrounding cannot be captured using manual calculation. However, simple calculation as determining the size of an overhang or shading element can be determined using the altitude angle. The overhang projection factor can be calculated by dividing the overhang projection by distance between bottom of overhang and bottom of window.

The monthly average solar altitude angle in degree for Bhutan is given in below **Table 22**.

Table 22: Solar altitude angle in degree for Bhutan

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6	0	0	0	4	9	10	8	5	2	0	0	0
7	1	4	10	17	22	23	21	18	16	12	7	2
8	13	16	23	30	35	36	34	32	29	24	19	14
9	23	28	35	44	48	49	47	45	41	36	29	24
10	32	38	47	56	61	62	61	58	53	46	38	32
11	39	46	56	67	74	75	74	69	62	52	43	38
12	42	49	60	72	81	86	84	76	66	54	44	40
13	40	48	58	67	73	76	76	71	61	50	41	37
14	35	42	50	57	61	63	64	60	52	42	34	31
15	27	33	40	44	47	50	50	47	40	31	25	23
16	16	22	28	31	34	36	37	34	27	19	14	13
17	5	10	15	18	21	23	24	21	14	6	2	1
18	0	0	1	5	8	11	11	8	1	0	0	0

The Solar Heat Gain Coefficient (SHGC) is the percent of solar energy incident on the glass that is transferred indoors both directly and indirectly through the glass. A window with an SHGC of 0.70 captures about 70% of the available solar energy falling on the window. Clear double glazing has an SHGC of about 0.75 versus 0.60 to 0.70 for standard low-E and about 0.40 for spectrally selective low- E. Which type of glazing is optimal for a given project depends on the climate, summer, and winter fuels costs, and how glass is used in the house design.

Low SHGC: Low-solar-gain glass blocks unwanted solar gain and provides significant savings in both peak and annual cooling loads in hot climates.

Moderate SHGC: In climates with more-or-less equal heating and cooling costs, moderate-gain glass is a reasonable choice, balancing moderate solar gains in winter with moderate blocking of solar gains in summer.

High SHGC: High solar-heat-gain glass is a good choice in cold climate homes with enough south glass to take advantage of passive solar gain, called "sun tempering."

7.6. Fans and Blowers – energy performance assessment

7.6.1. Introduction

Fans and blowers provide air for ventilation and industrial process requirements. Fans generate a pressure to move air (or gases) against a resistance caused by ducts, dampers, or other components in a fan system. The fan rotor receives energy from a rotating shaft and transmits it to the air.

Difference between Fans, Blowers and Compressors

Fans, blowers, and compressors are differentiated by the method used to move the air, and by the system pressure they must operate against. As per American Society of Mechanical Engineers (ASME) the specific ratio - the ratio of the discharge pressure over the suction pressure - is used for defining the fans, blowers, and compressors.

Table 23: Difference between Fan, Blowers and Compressor

Equipment	Specific ratio	Pressure rise (mmWg)
Fans	Up to 1.11	1136
Blowers	1.11to 1.20	1136-2066
Compressor	More than 1.20	-

Fan and blower selection depend on the volume flow rate, pressure, type of material handled, space limitations, and efficiency. Fan efficiencies differ from design to design and by types. Typical ranges of fan efficiencies are given in below **Table 24**

Table 24: Fan Efficiencies

Type of Fan	Peak Efficiency Range
Centrifugal Fan	
Air foil, backward curved/inclined	79-83
Modified radial	72-79
Radial	69-75
Pressure blower	58-68
Forward curved	60-65
Axial fan	
Vanaxial	78-85
Tubeaxial	67-72
Propeller	45-50

Fans fall into two general categories: centrifugal flow and axial flow

In **centrifugal flow**, airflow changes direction twice - once when entering and second when leaving (forward curved, backward curved, or inclined, radial).

In **axial flow**, air enters and leaves the fan with no change in direction (propeller, tube axial, vane axial).

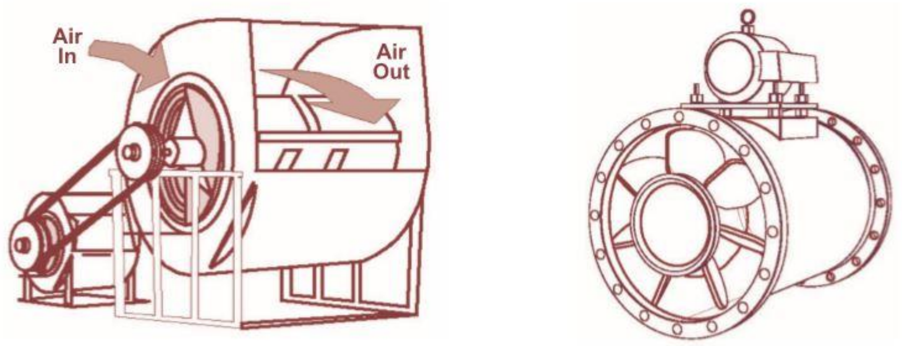


Figure 37: Centrifugal fan (left) and axial fan (right)

Centrifugal Fan types
The major types of centrifugal fan are radial, forward curved and backward curved.

Radial fans are industrial workhorses because of their high static pressures (up to 1400 mm WC) and ability to handle heavily contaminated airstreams. Because of their simple design, radial fans are well suited for high temperatures and medium blade tip speeds.

Forward-curved fans are used in clean environments and operate at lower temperatures. They are well suited for low tip speed and high-airflow work - they are best suited for moving large volumes of air against relatively low pressures.

Backward-inclined fans are more efficient than forward-curved fans. Backward-inclined fans reach their peak power consumption and then power demand drops off well within their useable airflow range. Backward-inclined fans are known as "non-overloading" because changes in static pressure do not overload the motor.

Axial Flow Fan types
The major types of axial flow fans are tube axial, vane axial and propeller.

Tube axial fans have a wheel inside a cylindrical housing, with close clearance between blade and housing to improve airflow efficiency. The wheel turns faster than propeller fans, enabling operation under high-pressures 250 – 400 mm WC. The efficiency is up to 65%.

Vane axial fans are like tube axials, but with addition of guide vanes that improve efficiency by directing and straightening the flow. As a result, they have a higher static pressure with less dependence on the duct static pressure. Such fans are used generally for pressures upto 500 mmWC. Vane axials are typically the most energy-efficient fans available and should be used whenever possible.

Propeller fans usually run at low speeds and moderate temperatures. They experience a large change in airflow with small changes in static pressure. They handle large volumes of air at low pressure or free delivery. Propeller fans are often used indoors as exhaust fans. Outdoor applications include air-cooled condensers and cooling towers. Efficiency is low – approximately 50% or less.

The different types of fans, their characteristics and typical applications are given in following **Table 25**.

Table 25: Types of fan, characteristics, and typical application

Centrifugal Fans			Axial-Flow Fans		
Type	**Characteristics**	**Typical application**	**Type**	**Characteristics**	**Typical application**
Radial	High pressure, medium flow, efficiency close to tube-axial fans, power increases continuously	Various industrial applications, suitable for dust laden, moist air/gases	Propeller	Low pressure, high flow, low efficiency, peak efficiency close to point of free air delivery (zero static pressure)	Air-circulation, ventilation, exhaust
Forward-curved blades	Medium pressure, high flow, dip in pressure curve, efficiency higher than radial fans, power rises continuously	Low pressure HVAC, packaged units, suitable for clean and dust laden air / gases	Tube-axial	Medium pressure, high flow, higher efficiency than propeller type, dip in pressure-flow curve before peak pressure point.	HVAC, drying ovens, exhaust systems
Backward curved blades	High pressure, high flow, high efficiency, power reduces as flow increases beyond point of highest efficiency	HVAC, various industrial applications, forced draft fans, etc.	Vane-axial	High pressure, medium flow, dip in pressure-flow curve, use of guide vanes improves efficiency	High pressure applications including HVAC systems, exhausts
Airfoil type	Same as backward curved type, highest efficiency	Same as backward curved, but for clean air applications			

Common blower types

Blowers can achieve much higher pressures than fans, as high as 1.20 kg/cm^2. They are also used to produce negative pressures for industrial vacuum systems. Major types are centrifugal blower and positive-displacement blower.

Centrifugal blowers look more like centrifugal pumps than fans. The impeller is typically gear-driven and rotates as fast as 15,000 rpm. In multi-stage blowers, air is accelerated as it passes through each impeller. In single-stage blower, air does not take many turns, and hence it is more efficient.

Centrifugal blowers typically operate against pressures of 0.35 to 0.70 kg/cm^2 but can achieve higher pressures. One characteristic is that airflow tends to drop drastically as system pressure increases, which can be a disadvantage in material conveying systems that depend on a steady air volume. Because of this, they are most often used in applications that are not prone to clogging.

Positive-displacement blowers have rotors, which "trap" air and push it through housing. Positive-displacement blowers provide a constant volume of air even if the system pressure varies. They are especially suitable for applications prone to clogging since they can produce enough pressure - typically up to 1.25 kg/cm^2 - to blow clogged materials free. They turn much slower than centrifugal blowers (e.g. 3,600 rpm) and are often belt driven to facilitate speed changes.

7.6.2. Data collection

Following data shall be collected during audit from fan motor name plate and by interviewing the operator or building manager:

- Type of fan
- Application of fan
- Type of speed regulation and flow control
- Type of power transmission (belt driven or direct driven)
- Rated fan power (kW)
- Rated flow
- All other fan motor name plate details

In addition to above, following data shall be collected through measurements:

- Static pressure suctions and discharge side
- Differential velocity pressure
- Air Flow and suction area or area of filters
- Fan input power

7.6.3. Instruments required

- Hand-held clamp meter or three-phase power analyser
- Manometer with pitot tube
- Anemometer
- Measuring tape
- Sling psychrometer or digital thermometer

7.6.4. Performance terms and definitions

Static pressure: The absolute pressure at a point minus the reference atmospheric pressure.
Dynamic pressure: The rise in static pressure which occurs when air moving with specified velocity at a point is bought to rest without loss of mechanical energy. It is also known as velocity pressure.
Total pressure: The sum of static pressures and dynamic pressures at a point.
Fan shaft power: The mechanical power supplied to the fan shaft
Fan motor input power: The electrical power supplied to the terminals of an electric motor drive.

$$\boldsymbol{Static\ fan\ efficiency}, (\%) = \frac{Volume\ in\ m^3/s\ \ X\ \Delta p\ static\ pressure, mmWC}{102\ X\ Fan\ shaft\ power\ (kW)}\ X\ 100$$

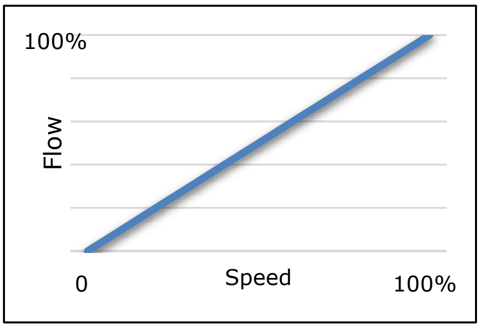
Where,

Δp static pressure, mmWC = Discharge static pressure – Suction static pressure

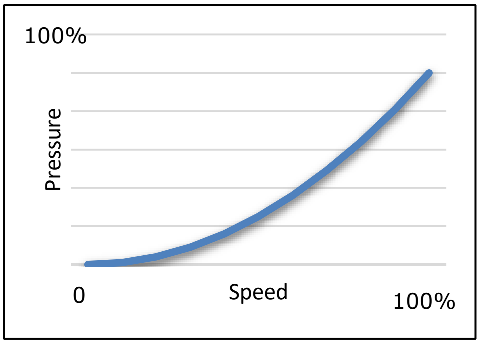
7.6.5. Fan laws

The fans operate under a predictable set of laws concerning speed, power, and pressure. A change in speed (revolutions per minute or RPM) of any fan will predictably change the pressure rise and power necessary to operate it at the new RPM.

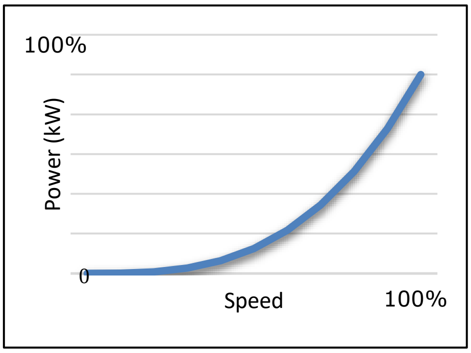
a) Flow ∞ Speed

	$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$ Varying the RPM by 10% decreases or increases air delivery by 10% Q – Flow N- Speed (RPM)

b) Pressure ∞ (Speed)²

	$\frac{SP_1}{SP_2} = \left(\frac{N_1}{N_2}\right)^2$ Reducing the RPM by 10% decreases the static pressure by 19% and an increase in RPM by 10% increases the static pressure by 21%. SP – Static pressure N- Speed (RPM)

c) Power ∞ $(Speed)^3$

	$\frac{kW_1}{kW_2} = \left(\frac{N_1}{N_2}\right)^3$ Reducing the RPM by 10% decreases the power requirement by 27% and an increase in RPM by 10% increases the power requirement by 33%. kW – Power N – Speed (RPM)

7.6.6. Performance evaluation

The fans are tested for field performance by measurement of pressure, flow, temperature, and power.

The fan flow is measured using pitot tube and manometer combination or with an anemometer. Care needs to be taken regarding number of traverse points, straight length section (to avoid turbulent flow regimes of measurement) upstream and downstream of measurement location. The measurements can be on the suction or discharge side of the fan and preferably both where feasible.

1. Static pressure measurement by pitot tube

The **Figure 38** shows how static pressure is measured using a pitot tube and a manometer. Total pressure is measured using the inner tube of pitot tube and static pressure is measured using the outer tube of pitot tube.

Static pressure should be measured on the suction and discharge sides of the fan are taken relative to the atmosphere pressure. This shall be done by using a manometer in combination with the static pressure connection of a pitot tube or a U tube manometer.

When using a pitot tube, it is necessary to carry out a traverse in the pressure measurement plane taking individual point pressure readings in a manner like that for determining flow rate. In general, a smaller number of readings will be found adequate where individual readings do not vary by more than 2% from each other. The average of all the individual readings shall be taken as the static pressure of that section.

2. Air-Velocity measurement

Instrument required: Velocity shall be measured by either pitot tube or a rotating vane anemometer.

a) Velocity measurement by Anemometer

The indicated velocity shall be measured at each traverse point in the cross section by holding the anemometer stationary at each point for a period of not less than 1 minute. Each reading shall be converted to velocity in m/s and individually corrected in accordance with the anemometer calibration. The arithmetic mean of the corrected point velocities gives the average velocity in the air duct and the volume flow rate is obtained by multiplying the area of the air duct by the average velocity. This is the simplest method to measure air velocity.

b) Velocity measurement by Pitot tube

The **Figure 38** shows how velocity pressure is measured using a pitot tube and a manometer. Total pressure is measured using the inner tube of pitot tube and static pressure is measured using the outer tube of pitot tube. When the inner and outer tube ends are connected to a manometer, velocity pressure is obtained. For measuring low velocities, it is preferable to use an inclined tube manometer instead of U tube manometer.

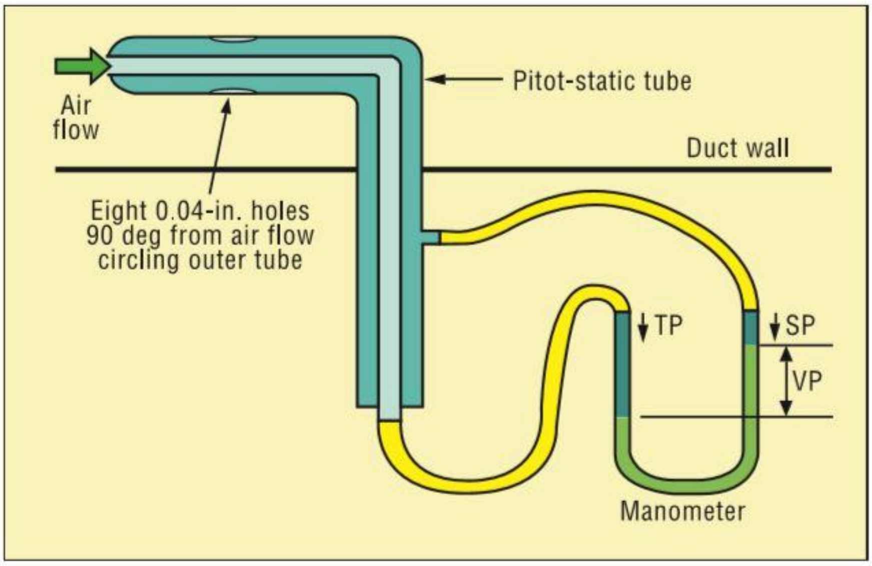


Figure 38: Measurement by pitot tube

To ensure accurate velocity pressure readings, the Pitot tube tip must be pointed directly into (parallel with) the air stream. As the Pitot tube tip is parallel with the static pressure outlet tube, the latter can be used as a pointer to align the tip properly. When the Pitot tube is correctly aligned, the pressure indication will be maximum.

When measuring velocity pressure, the duct diameter (or the circumference from which to calculate the diameter) should be measured as well. This will help in calculating the velocity and volume of air in the duct. In most cases, velocity must be measured at several places in the system.

Traverse readings: In practical situations, the velocity of the air stream is not uniform across the cross section of a duct. Friction slows the air moving close to the walls, so the velocity is greater in the centre of the duct.

To obtain the average total velocity in ducts of 100 mm diameter or larger, a series of velocity pressure readings must be taken at points of equal area. A formal pattern of sensing points across the duct cross section is recommended. These are known as traverse readings. Following **Figure 39** shows recommended Pitot tube locations for traversing round and rectangular ducts.

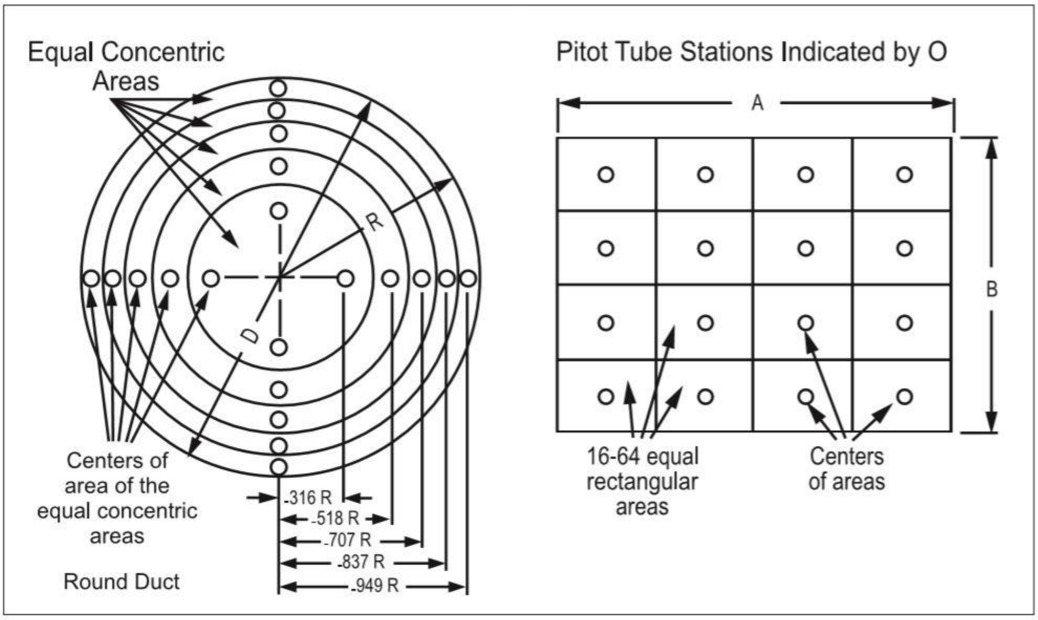


Figure 39: Traverse on round and square duct areas

In round ducts, velocity pressure readings should be taken at centres of equal concentric areas. At least 20 readings should be taken along two diameters. In rectangular ducts, a minimum of 16 and a maximum of 64 readings are taken at centres of equal rectangular areas. Actual velocities for each area are calculated from individual velocity pressure readings. This allows the readings and velocities to be inspected for errors or inconsistencies. The velocities are then averaged.

By taking Pitot tube readings with extreme care, air velocity can be determined within an accuracy of ± 2%.

Calculation of Velocity: After taking velocity pressures readings, at various traverse points, the velocity corresponding to each point is calculated using the following expression.

Velocity (m/s) $= C_p \times \frac{\sqrt{2\times 9.18\times \Delta p\times \gamma}}{\gamma}$

Where,
C_p=The pitot tube coefficient (Take manufacturer's value or assume 0.85)
Δp=The average velocity pressure measured using pitot tube and inclined manometer by taking number of points over the entire cross-section of the duct, mm Water Column
γ =Gas density, kg/m^3 corrected to normal temperature
Corrected gas density is given by= (273×1.29) / (273+ air temperature in °C)

3. Determination of air flow

Once the cross-sectional area of the duct is measured, the flow can be calculated as follows:

Air flow or Volume, (m^3/s) = Area of duct (m^2) x Velocity (m/s)

4. Power measurement

The power measurements can be done using three phase power analyser or a hand-held clamp meter.

Transmission systems: If fan is not connected to motor directly, transmission efficiency should be suitable assumed depending upon the type

Type of transmission	Transmission efficiency
For directly driven fan	100%
Properly lubricated precision spur gears	98% for each step
Flat belt drive	97%
V-belt drive	95%

Therefore,

Fan shaft power = Power input to motor × Efficiency of motor × Transmission system efficiency

Example:

A V-belt centrifugal fan is supplying air to a facility. The performance test on the fan gave the following parameters

Parameters	Values
Density of air at 0°C	1.293 kg/m^3
Ambient air temperature	25°C
Diameter of the circular discharge air duct	0.8 m
Velocity pressure maintained by pitot tube in discharge duct	45 mmWC
Pitot tube coefficient	0.9
Static pressure at fan inlet	-20 mmWC
Static pressure at fan outlet	185 mmWC
Power drawn by the motor coupled with the fan	75 kW
Belt transmission efficiency	97%
Motor efficiency at the operating load	93%

Solution:

Parameters	Calculations
Corrected gas density, γ	(273 X 1.293) / (273 + 25) = 1.18
Velocity	$= C_p \times \frac{\sqrt{2 \times 9.18 \times \Delta p \times \gamma}}{\gamma}$ $= 0.9 \text{ X } \frac{\sqrt{2 \times 9.18 \times 45 \times 1.18}}{1.18}$ = 23.8 m/s
Area of circular discharge duct	= π X (D^2/4) = 3.14 X (0.8^2/4) = 0.5024 m^2

Parameters	Calculations
Flow or volume (m^3/s)	= Area X Velocity = 0.5024 X 23.8 = 11.95 m^3/s
Fan shaft power, (kW)	= 75 X 0.97 X 0.93 = 67.65 kW
Fan static efficiency, (%)	$= \frac{Volume\ in\ m^3/s\ X\ \Delta p\ static\ pressure, mmWC}{102\ X\ Fan\ shaft\ power\ (kW)}\ X\ 100$ $= \frac{11.95\ \ X\ (185-(-20))}{102\ X\ 67.65}\ X\ 100$ **= 35.5%**

7.6.7. Energy saving opportunities

1. Minimizing demand on the fan

- Minimising excess air level in combustion systems to reduce FD fan and ID fan load.
- Minimising air in-leaks in hot flue gas path to reduce ID fan load, especially in case of kilns, boiler plants, furnaces, etc. Cold air in-leaks increase ID fan load tremendously, due to density increase of flue gases and in-fact choke up the capacity of fan, resulting as a bottleneck for boiler / furnace itself.
- In-leaks / out-leaks in air conditioning systems also have a major impact on energy efficiency and fan power consumption and need to be minimized.

2. Adjust the pulley diameter

It is observed at many instances the actual air flow is higher than the rated air flow in the air handling units (AHU) which can be any type of system (chill water, washer, fresh air etc.). Also, when multiple no. of systems is there and overall air changes (ACH) are on the higher side as designed.

After overall study in any of the case the fan volume change is required on a permanent basis, and the existing fan can handle the change in capacity, the volume change can be achieved with a speed change. The simplest way to change the speed is with a pulley change. For this, the fan must be driven by a motor through a v-belt system. The fan speed can be increased or decreased with a change in the drive pulley or the driven pulley or in some cases, both pulleys. As shown in **Figure 40** a higher size fan operating with damper control was downsized by reducing the motor (drive) pulley size from 8” to 6”. The power reduction was 12 kW.

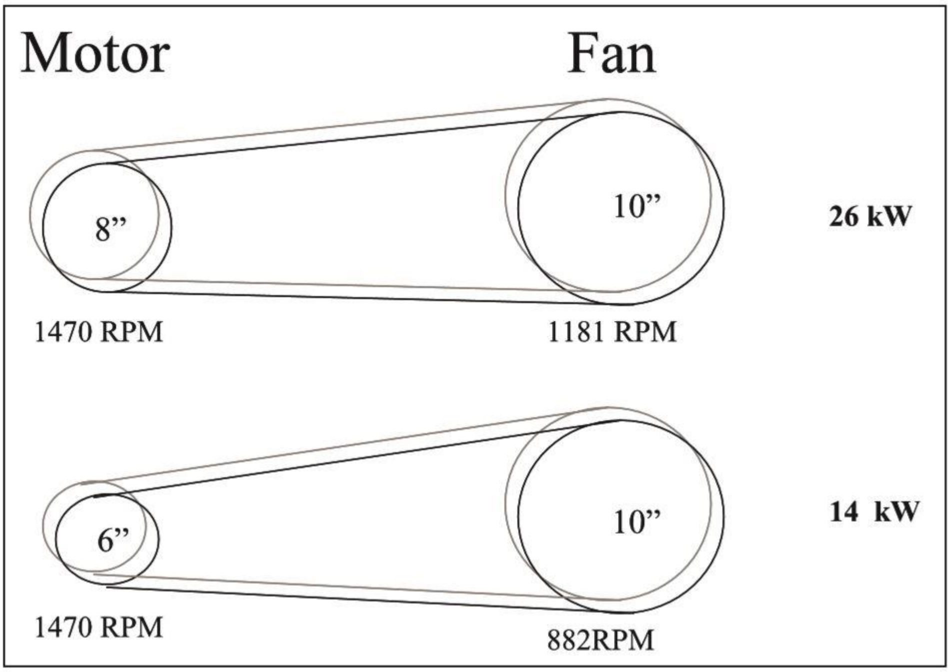


Figure 40: Pulley change

3. Consider replacing damper controls with VFD/VSD

Some fans are designed with damper controls. Dampers can be located at inlet or outlet. Dampers provide a means of changing air volume by adding or removing system resistance. This resistance forces the fan to move up or down along its characteristic curve, generating more or less air without changing fan speed. However, dampers provide a limited amount of adjustment and they are not energy efficient. Consider replacing the dampers control with variable speed drive wherever feasible and payback period is attractive. Since power input to the fan changes as the cube of law, this will usually be the most efficient form of capacity control. However, VSD may not be economical for systems, which have infrequent flow variations.

4. Replace the existing belt driven blower/ fan with new direct driven motors

Old conventional blowers or centrifugal fan with induction motors (see **Figure 41**) installed in air handling unit (AHU) of any type of system (chill water, washer, fresh air, ventilation, etc.) can be replaced with plug fan with BLDC motor (see **Figure 42**)

Multiple combination of plug fan with BLDC motors is also possible (see **Figure 43**) for those blowers which are large in size and are not fully utilised. The brushless direct current motor (BLDC) which are also known electronically commuted motor (ECM) with plug fan. The possible energy savings by replacing the system can be in the range of 25-35% of existing energy consumption.

Figure 41: Centrifugal fan with induction motor

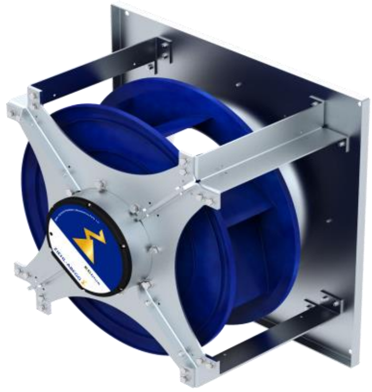


Figure 42: Plug fan with BLDC (single)

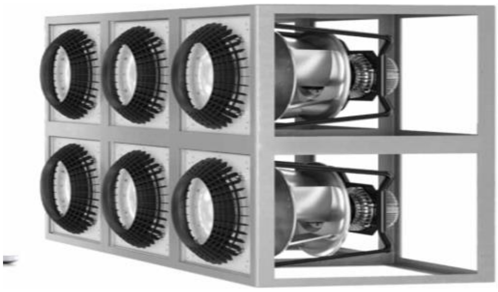


Figure 43: Plug fan with BLDC motors (combination)

5. Others

The findings of performance evaluation will automatically indicate potential areas for improvement, which could be one or more of the following:

- Change of impeller by a high efficiency impeller along with cone.
- Change of fan assembly, by a higher efficiency fan
- Impeller derating (by a smaller diameter impeller) as explained before
- Change of metallic / Glass reinforced Plastic (GRP) impeller by the more energy efficient hollow FRP impeller with aerofoil design, in case of axial flow fans, where significant savings have been reported
- Fan speed reduction by pulley diameter modifications for derating
- Option of two speed motors or variable speed drives for variable duty conditions
- Option of energy efficient flat belts, or, cogged raw edged V belts, in place of conventional V belt systems, for reducing transmission losses.

7.7. Pumps – energy performance assessment

7.7.1. Introduction

Pumping is the process of addition of kinetic and potential energy to a liquid to move from one point to another. Pumps come in a variety of sizes for a wide range of applications. They can be classified according to their basic operating principle as dynamic or displacement pumps. Dynamic pumps can be sub-classified as centrifugal and special effect pumps. Displacement pumps can be sub-classified as rotary or reciprocating pumps.

The centrifugal pump is generally the most economical followed by rotary and reciprocating pumps. Although, positive displacement pumps are generally more efficient than centrifugal pumps, the benefit of higher efficiency tends to be offset by increased maintenance costs.

Since, worldwide, centrifugal pumps account for most of the electricity used by pumps, the focus of this chapter is on centrifugal pump.

7.7.2. System curve and pump curves

A system curve is a graphical representation of the head and flow characteristics of a hydraulic system. **Figure 44** shows system curve with high static head and **Figure 45** shows system curve with low static head.

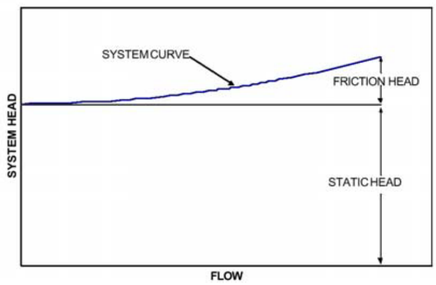


Figure 44: System curve with high static head

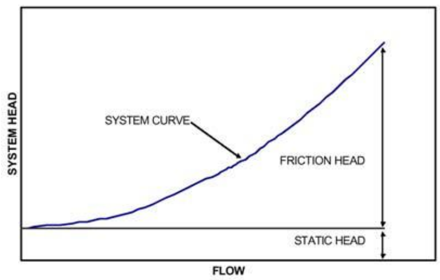


Figure 45: System head with low static head

The performance of a pump can be expressed graphically as head against flow rate. The centrifugal pump has a curve where the head falls gradually with increasing flow. This is called the pump characteristic curve (Head – Flow curve) as shown in the **Figure 46** . Typical pump curve provided by the pump manufactures is the plot the course of the parameters like head(H), power input(P), pump efficiency, Net positive suction head (NPSHr) against flow rate. A typical pump curve is shown in the **Figure 47**

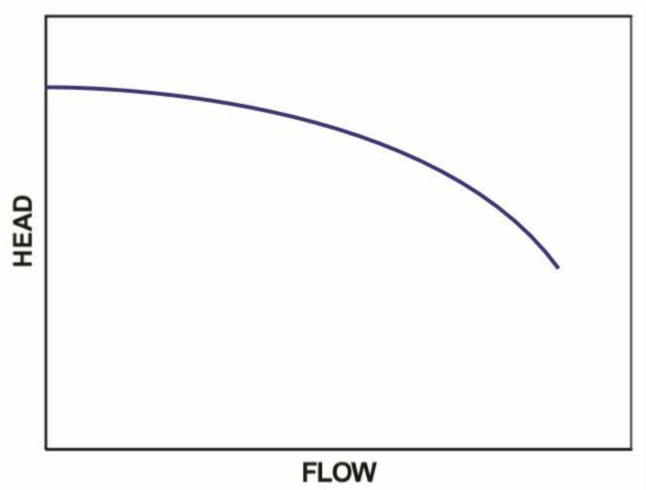


Figure 46: Head-Flow curve

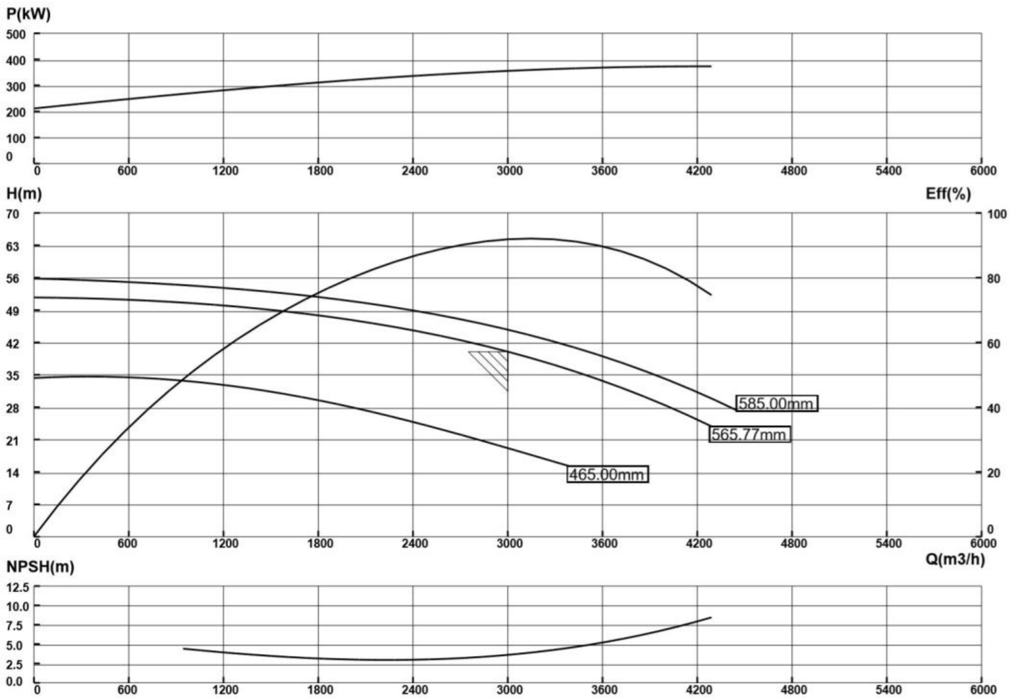


Figure 47: Typical pump curve provided by manufacturer

When a pump is installed in a system the effect can be illustrated graphically by superimposing pump and system curves. The operating point will always be where the two curves intersect as shown in **Figure 48**. If the actual system curve is different to that calculated, the pump will operate at a flow and head different to that expected.

An increasing system resistance will reduce the flow, eventually to zero, but the maximum head is limited as shown. Even so, this condition is only acceptable for a short period without causing problems. An error in the system curve calculation is also likely to lead to a centrifugal pump selection, which is less than optimal for the actual system head losses. Adding safety margins to the calculated system curve to ensure that a sufficiently large pump is selected will generally result in installing an oversized pump, which will operate at an excessive flow rate or in a throttled condition, which increases energy usage and reduces pump life.

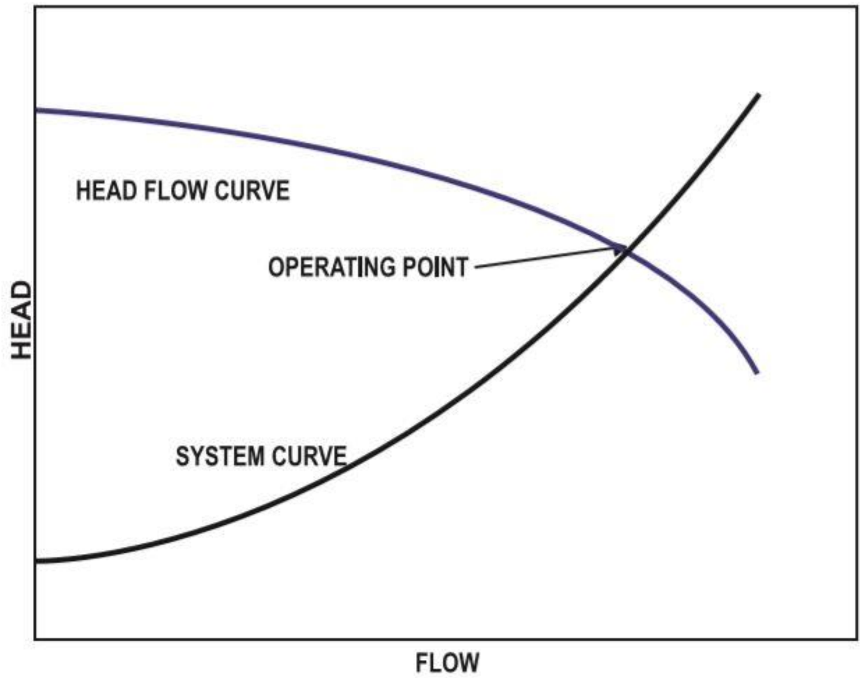


Figure 48: Pump operating point

7.7.3. Data collection

Following data shall be collected during audit from pump name plate and by interviewing the operator or building manager:

- Specification of pump and motors
- Diagram of water distribution network
- Water pressure required for the system
- Number of pumps in operation
- Pump curves
- Details on existing flow control method
- All pumps and motors name plate details

In addition to above following data shall be collected through measurements on field:

- Flow
- Head
- Power
- Motor efficiency

7.7.4. Instruments required

- Ultrasonic water flow meter
- Pressure gauges
- Hand-held clamp meter
- Three-phase power analyser
- Measuring tape

7.7.5. Performance terms and definitions

Pump capacity, Q = Volume of liquid delivered by pump per unit time, m^3/s

Total developed head, H = The difference of discharge pressure and suction pressure

$$\textit{Pump efficiency} = \frac{\textit{Hydraulic power}}{\textit{Power input to the pump shaft}} X\ 100$$

Hydraulic power (kW) = $Q \times (h_d - h_s) \times P \times g / 1000$

Q = volume flow rate (m^3/s), P = density of fluid (kg/m^3), g = acceleration due to gravity (m/s^2), (Discharge head, h_d- Suction head, h_s) = Total head (m)

7.7.6. Performance assessment of pumps

Flow measurement is the most crucial parameter as normally online flow meters are hardly available, in most of the pumping system. The following methods outlined below can be adopted to measure the flow depending on the availability and site conditions.

Motor efficiency can be obtained as described in the **section 7.3.9**

1. Flow measurement

The following are the method for flow measurement:

a) Ultrasonic flow measurement

Operating under Doppler effect principle these meters are non-invasive, meaning measurements can be taken without disturbing the system. Scales and rust in the pipes are likely to impact the accuracy.

- Ensure measurements are taken in a sufficiently long length of pipe free from flow disturbance due to bends, tees, and other fittings.
- The pipe section where measurement is to be taken should be hammered gently to enable scales and rusts to fall out.
- For better accuracy, a section of the pipe can be replaced with new pipe for flow measurements.

b) On-line flow meter

If the application to be measured is going to be critical and periodic then the best option would be to install an on-line flow meter which can get rid of the major problems encountered with other types.

c) Tank filling method

In open flow systems such as water getting pumped to an overhead tank or a sump, the flow can be measured by noting the difference in tank levels for a specified period during which the outlet flow from the tank is stopped. The internal tank dimensions should be preferably taken from the design drawings, in the absence of which direct measurements may be resorted to.

2. Head measurement

Suction head (hs)

This is taken from the pump inlet pressure gauge readings and the value to be converted into meters ($1 kg/cm^2 = 10$ m). If not the level difference between sump water level to the centreline of the pump is to be measured. This gives the suction head in meters.

Discharge head (hd)

This is taken from the pump discharge side pressure gauge. Installation of the pressure gauge in the discharge side is a must, if not already available.

3. Power

Pump motor power should be measured from three phase power analyser. Power can also be measured by hand-held clamp meter. On measuring power from clamp on meter, readings should be taken on regular intervals and numbers of readings should be taken.

4. Operating efficiency and performance evaluation of pumps:

Determination of hydraulic power (Liquid horsepower):

Hydraulic power, P_h (kW) = Q x (hd - hs) x ρ x g / 1000

Where,

Q= Volume flow rate(m^3/sec)

ρ =density of the fluid(kg/m^3)

g= acceleration due to gravity(m/s^2)

(hd - hs) = Total head in metres

Pump shaft power

The pump shaft power P_s is calculated by multiplying the motor input power by motor efficiency at the existing loading.

$P_s = P_m \times \eta_{Motor}$

Pump efficiency

This is arrived at by dividing the hydraulic power by pump shaft power

$\eta_{Pump} = P_h / P_S$

Example:

A facility operates a cooling water pump for process cooling and refrigeration applications. During the performance testing the following operating parameters were obtained, determine the pump efficiency?

Parameter	Value
Pump water flow, Q	0.40 m^3/s
Power consumption, P	325 kW
Suction head, Tower basin level, h_1	+1 m
Delivery head, h_2	55 m
Motor efficiency	88%
Density of water	996 Kg/m^3
Type of drive	Direct

Solution:

Parameter	Calculations
Hydraulic power, P_h	= Q x (hd - hs) x ρ x g / 1000 =0.40 x (55-1) x 996 x 9.81/1000 = 211 kW
Actual power consumption, P_m	= 325 kW
Overall system efficiency, $\eta_{Overall}$	= P_h / P_m = (211 x 100) / 325 = 65 %
Pump efficiency, η_{Pump}	= 65/0.88 = **74 %**

7.7.7. Energy savings opportunities in pumping system

The first step to achieve energy efficiency in pumping system is to target the end-use. A plant water balance would establish usage pattern and highlight areas where water consumption can be reduced or optimized. Good water conservation measures, alone, may eliminate the need for some pumps.

Once flow requirements are optimized, then the pumping system can be analysed for energy conservation opportunities. Basically, this means matching the pump to requirements by adopting proper flow control strategies. Common symptoms that indicate opportunities for energy efficiency in pumps are given in the below **Table 26**

Table 26: Symptoms that indicate opportunity for energy saving

Symptoms that Indicate Opportunity for Energy Saving		
Symptom	**Likely Reason**	**Best Solutions**
Throttle valve-controlled system	Oversized pump	Variable speed drive, trim impeller, small impeller, two speed drive, lower rpm

Symptoms that Indicate Opportunity for Energy Saving		
Symptom	**Likely Reason**	**Best Solutions**
Bypass line (partially or completely) open	Oversized pump	Variable speed drive, trim impeller, small impeller, two speed drive, lower rpm
Multiple parallel pump system with the same number of pumps always operating	Pump use not monitored or controlled	Install controls
Constant pump operation in a batch environment	Wrong system design	On-off controls
High maintenance cost (seals, bearings)	Pump operated far away from Best efficiency point	Match pump capacity with system requirement

1. Flow control by speed variation

Flow control by speed regulation is always more efficient than by control valve. At various speed of rotation, a centrifugal pump has different characteristic curves, which are related to each other by the affinity laws.

The affinity laws are a set of formulas that predict the impact of a change in rotational speed or impeller diameter on the head and flow produced by a pump and power demanded by a pump.

$Q_1/Q_2 = (N_1/N_2)$

$H_1/H_2 = (N_1/N_2)^2$

$P_1/P_2 = (N_1/N_2)^3$

Where:

Q = Flow rate, H = Head, P = Power absorbed, N = Rotating speed

For example, if speed of pump is reduced from 3500 rpm to 1750 rpm, its effect on flow head and power is calculated below.

Flow is proportional to the speed

$Q_1/Q_2 = (N1/N2)$, where $Q_1 = 100\ m^3/hr$

$100/Q_2 = 1750/3500$

$Q_2 = 200\ m^3/hr$

Head is proportional to the square of speed

$H_1/H_2= (N_1/N_2)^2$, where H_1=100m

Example: $100/H_2 = 1750^2/3500^2$

H_2= 400m

Power is proportional to the cube of speed

$P_1/P_2= (N_1/N_2)^3$, Where P_1= 5kW

Example: $5/P_2 = 1750^3/3500^3$

P_2= 40kW

As can be seen from the above laws, doubling the speed of the centrifugal pump will increase the power consumption by 8 times. Conversely a small reduction in speed will result in drastic reduction in power consumption. This forms the basis for energy conservation in centrifugal pumps with varying flow requirements.

2. Fixed flow reduction by impeller trimming

Impeller trimming refers to the process of machining the diameter of an impeller to reduce the energy added to the system fluid.

Impeller trimming offers a useful correction to pumps that, through overly conservative design practices or changes in system loads are oversized for their application.

Trimming an impeller provides a level of correction below buying a smaller impeller from the pump manufacturer. But in many cases, the next smaller size impeller is too small for the pump load. Also, smaller impellers may not be available for the pump size in question and impeller trimming is the only practical alternative short of replacing the entire pump/motor assembly. (see **Figure 49 & Figure 50**) for before and after impeller trimming).

Impeller trimming reduces tip speed, which in turn directly lowers the amount of energy imparted to the system fluid and lowers both the flow and pressure generated by the pump.

The Affinity Laws, which describe centrifugal pump performance, provide a theoretical relationship between impeller size and pump output (assuming constant pump speed):

Changing the impeller diameter follows that there are equations, like the affinity laws, for the variation of performance with impeller diameter D:

$Q_1/Q_2= (D_1/D_2)$

$H_1/H_2= (D_1/D_2)^2$

$P_1/P_2= (D_1/D_2)^3$

Efficiency varies when the diameter is changed within a casing. Diameter changes are generally limited to reducing the diameter to about 75% of the maximum, i.e. a head reduction to about 50%. Beyond this, efficiency and NPSH are severely affected. However, speed change can be used over a wider range without seriously reducing efficiency. For example, reducing the speed by 50% typically results in a reduction of efficiency by 1 or 2 percentage points. The reason for the small loss of efficiency with the lower speed is that mechanical losses in seals and bearings, which generally represent <5% of total power, are proportional to speed, rather than speed cubed. It should be noted that if the change in diameter is more than about 5%, the accuracy of the squared and cubic relationships can fall off and for precise calculations, the pump manufacturer’s performance curves should be referred to.

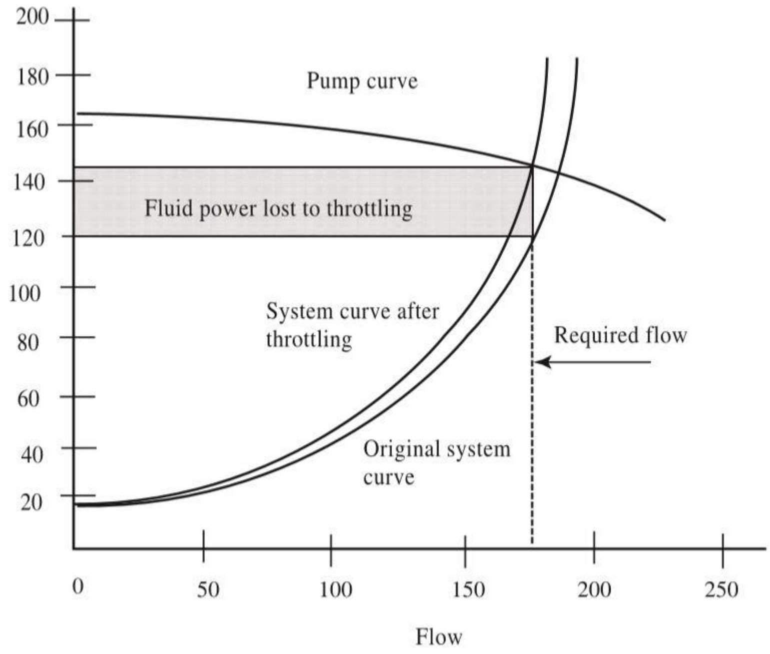


Figure 49: Before impeller trimming

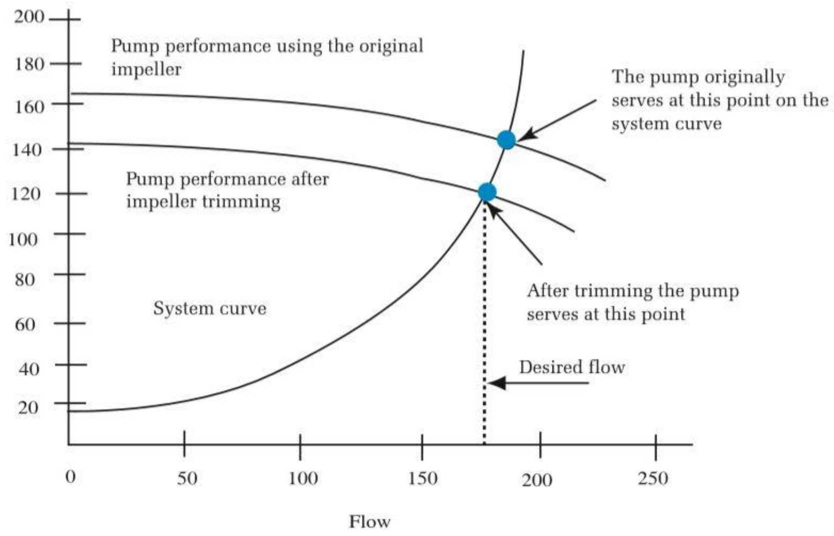


Figure 50: After impeller trimming

3. Flow control by varying speed

Benefits of speed change are different in the system where no or extremely low static head and system with a high static head. In **Figure 51** reducing speed in the friction loss system moves the intersection point on the system curve along a line of constant efficiency.

- The operating point of the pump, 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 that there is a substantial reduction in power absorbed accompanying the reduction in flow and head, making variable speed the ideal control method for systems with friction loss.

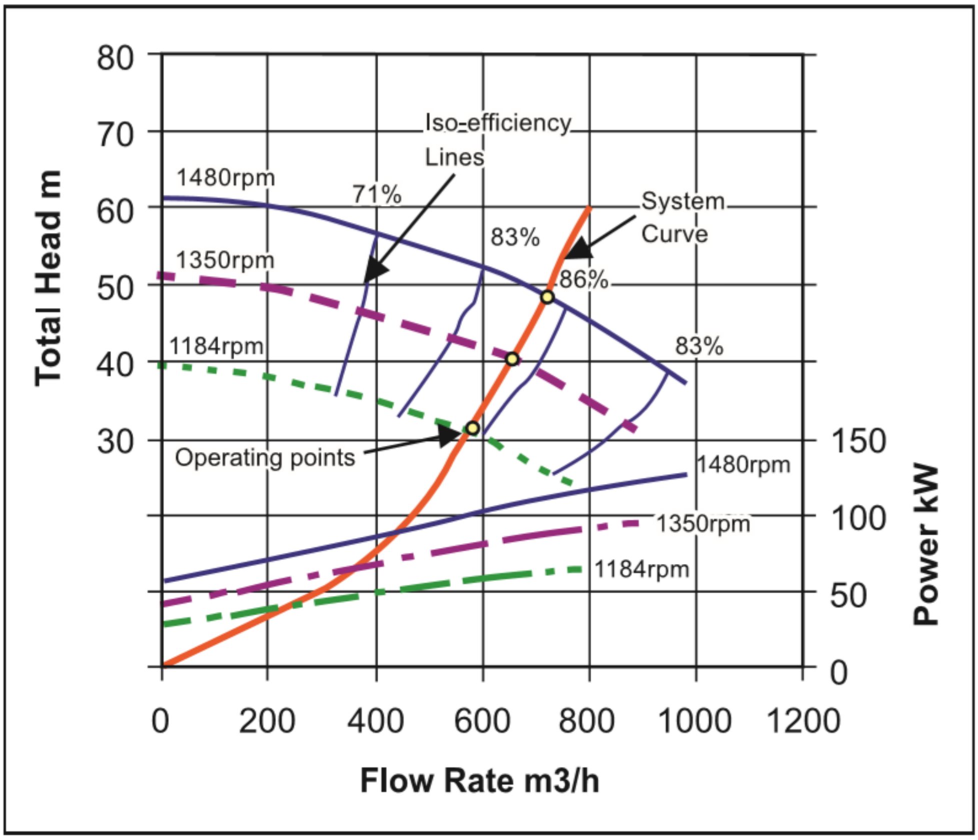


Figure 51: Effect of speed change in a system with no static head

In a system where static head is high, as illustrated in **Figure 52**

- Operating point for the pump moves relative to the lines of constant pump efficiency when the speed is changed.
- The reduction in flow is no longer proportional to speed.

A small turn down in speed could give a big reduction in flow rate and pump efficiency, which could result in the pump operating in a region where it could be damaged if it ran for an extended period of time even at the lower speed. At the lowest speed illustrated at 1184 rpm in **Figure 52**, the pump does not generate sufficient head to pump any liquid into the system, i.e. pump efficiency and flow rate are zero and with energy still being input to the liquid, the pump becomes a water heater and damaging temperatures can quickly be reached. The drop in pump efficiency during speed reduction in a system with static head, reduces the economic benefits of variable speed control. There may still be overall benefits, but economics should be examined on a case-by-case basis.

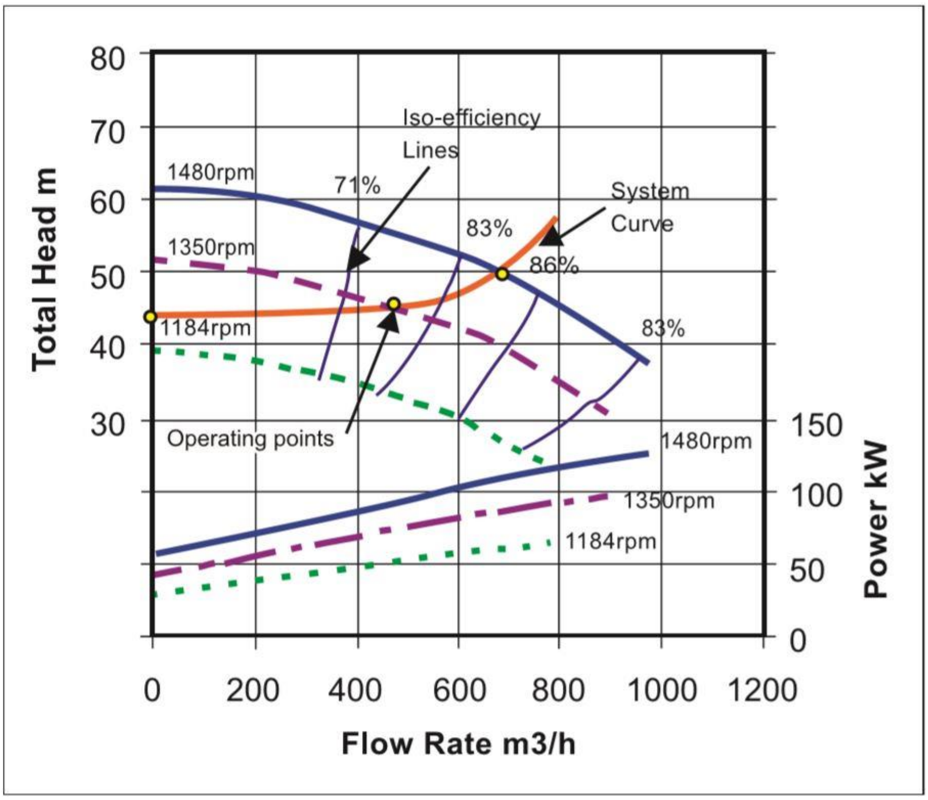


Figure 52: Effect of speed change in a system with high static head

4. Pump speed control by Variable Speed Drives (VSDs)

In contrast, pump speed adjustments provide the most efficient means of controlling pump flow. By reducing pump speed, less energy is imparted to the fluid and less energy needs to be throttled or bypassed. There are two primary methods of reducing pump speed: multiple-speed pump motors and variable speed drives (VSDs).

Although both directly control pump output, multiple-speed motors and VSDs serve entirely separate applications. Multiple-speed motors contain a different set of windings for each motor speed; consequently, they are more expensive and less efficient than single speed motors. Multiple speed motors also lack subtle speed changing capabilities within discrete speeds.

VSDs allow pump speed adjustments over a continuous range, avoiding the need to jump from speed to speed as with multiple-speed pumps. VSDs control pump speeds using several different types of mechanical and electrical systems. Mechanical VSDs include hydraulic clutches, fluid couplings, and adjustable belts and pulleys. Electrical VSDs include eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs). VFDs adjust the electrical frequency of the power supplied to a motor to change the motor's rotational speed. VFDs are by far the most popular type of VSD.

However, pump speed adjustment is not appropriate for all systems. In applications with high static head, slowing a pump risks inducing vibrations and creating performance problems that are like those found when a pump operates against its shutoff head. For systems in which the static head represents a large portion of the total head, caution should be used in deciding whether to use VFDs. Operators should review the performance of VFDs in similar applications and consult VFD manufacturers to avoid the damage that can result when a pump operates too slowly against high static head.

For many systems, VFDs offer a means to improve pump operating efficiency despite changes in operating conditions. The effect of slowing pump speed on pump operation is illustrated by the three curves in **Figure 53.** When a VFD slows a pump, its head/flow and brake horsepower (BHP) curves drop down and to the left and its efficiency curve shifts to the left. This efficiency response provides an essential cost advantage; by keeping the operating efficiency as high as possible across variations in the system's flow demand, the energy and maintenance costs of the pump can be significantly reduced.

VFDs may offer operating cost reductions by allowing higher pump operating efficiency, but the principal savings derive from the reduction in frictional or bypass flow losses. Using a system perspective to identify areas in which fluid energy is dissipated in non-useful work often reveals opportunities for operating cost reductions.

For example, in many systems, increasing flow through bypass lines does not noticeably impact the backpressure on a pump. Consequently, in these applications pump efficiency does not necessarily decline during periods of low flow demand. By analysing the entire system, however, the energy lost in pushing fluid through bypass lines and across throttle valves can be identified.

Another system benefit of VFDs is a soft start capability. During start-up, most motors experience in-rush currents that are 5 - 6 times higher than normal operating currents. These high current fades when the motor spins up to normal speed. VFDs allow the motor to be started with a lower start up current.

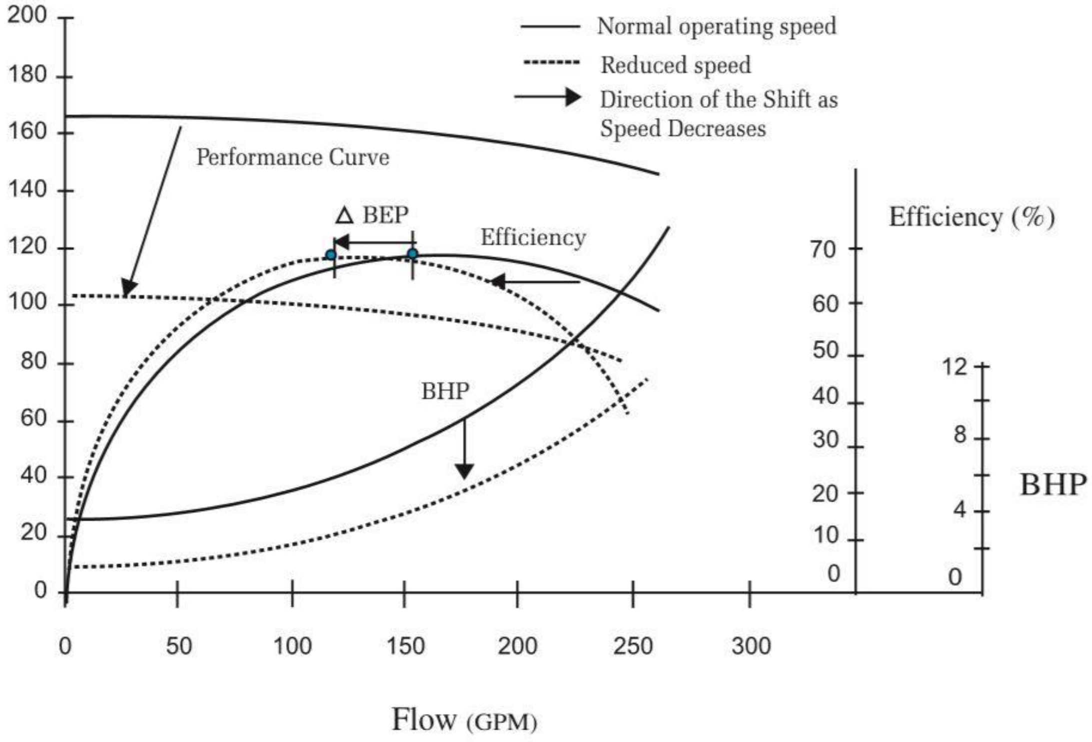


Figure 53: Effect of VFD

5. Flow control valve/Throttling

This is a simplest and commonly used method. It is a most inefficient for flow control. While auditing always look for opportunity to replace throttling by energy efficient methods describe above.

6. Bypass control

With this control approach, the pump runs continuously at the maximum process demand duty, with a permanent by-pass line attached to the outlet. When a lower flow is required the surplus liquid is bypassed and returned to the supply source. This is even less energy efficient than a control valve because there is no reduction in power consumption with reduced process demand.

7. Pumps in parallel switched to meet demand

Another energy efficient method of flow control, particularly for systems where static head is a high proportion of the total, is to install two or more pumps to operate in parallel. Variation of flow rate is achieved by switching on and off additional pumps to meet demand. The combined pump curve is obtained by adding the flow rates at a specific head. The head/flow rate curves for two and three pumps are shown in **Figure 54.**

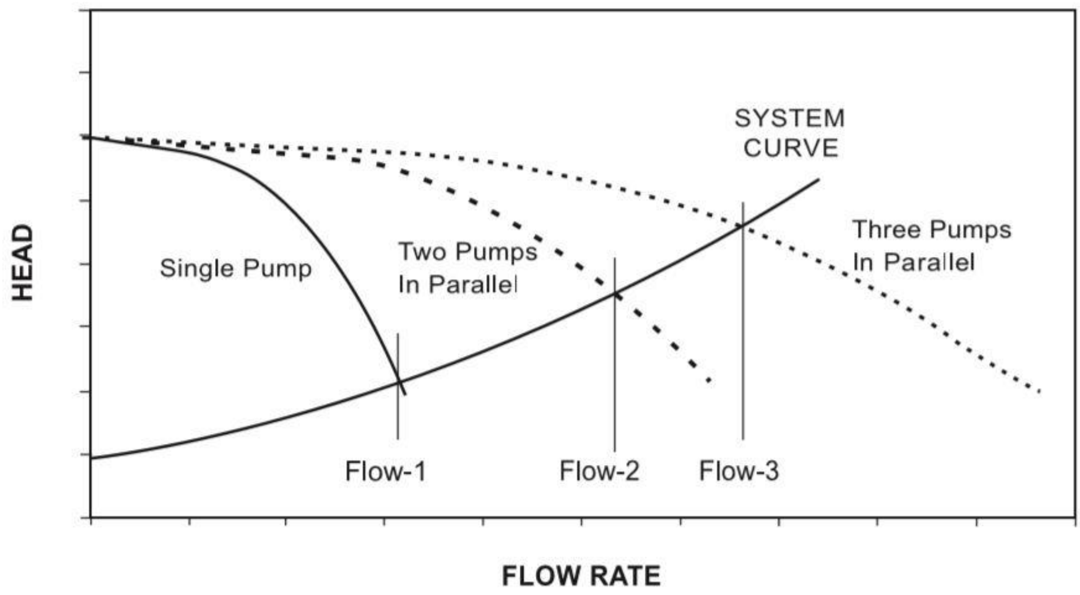


Figure 54: Typical head-flow curve for pumps in parallel operation

8. Other energy savings opportunities

- Use booster pumps for small loads requiring higher pressures.
- Repair seals and packing to minimise flows and reduce pump power requirements.
- Avoid unnecessary cooling water recirculation in DG sets, compressors, refrigeration systems, cooling towers feed water pumps, condenser pumps and process pumps.
- In multiple pump operations, carefully combine the operation of pumps to avoid throttling.
- Replace old pumps by new energy efficient pumps

7.8. Cooling towers – energy performance assessment

7.8.1. Introduction

Cooling towers are an important part of many facilities. The primary task of a cooling tower is to reject heat into the atmosphere. They represent a relatively inexpensive and dependable means of removing low-grade heat from cooling water. The make-up water source is used to replenish water lost to evaporation. Hot water from heat exchangers is sent to the cooling tower. The water exits the cooling tower and is sent back to the exchangers or to other units for further cooling. Typical closed loop cooling tower system is shown in following **Figure 55**

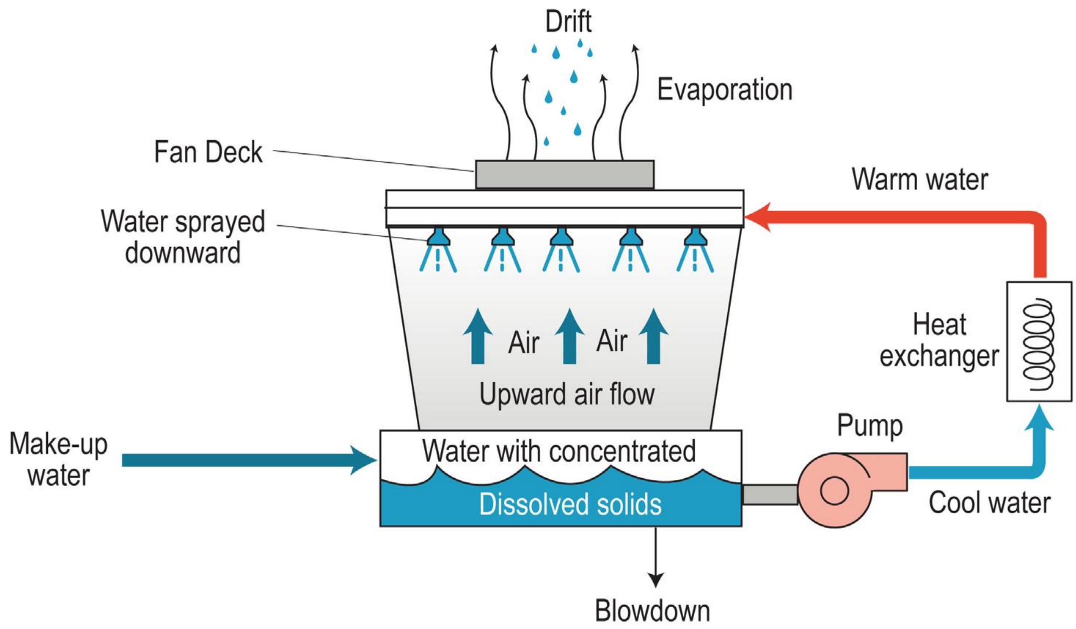


Figure 55: Cooling tower with closed loop

Cooling towers fall into two main categories:

Natural draft: Natural draft towers use large concrete chimneys to introduce air through the media. Due to the large size of these towers, they are generally used for water flow rates above 45,000 m^3/hr. These types of towers are used only by utility power stations.

Mechanical draft: Mechanical draft towers utilize large fans to force or suck air through circulated water. The water falls downward over fill surfaces, which help increase the contact time between the water and the air - this helps maximise heat transfer between the two. Cooling rates of Mechanical draft towers depend upon their fan diameter and speed of operation. Since, the mechanical draft cooling towers are much more widely used, the focus is on them in this chapter. Mechanical draft towers are available in a large range of capacities. Normal capacities range from approximately 10 tons, 2.5 m^3/hr flow to several thousand tons and m^3/hr. Towers can be either factory built or field erected – for example concrete towers are only field erected. The following **Figure 56** illustrates various cooling tower types.

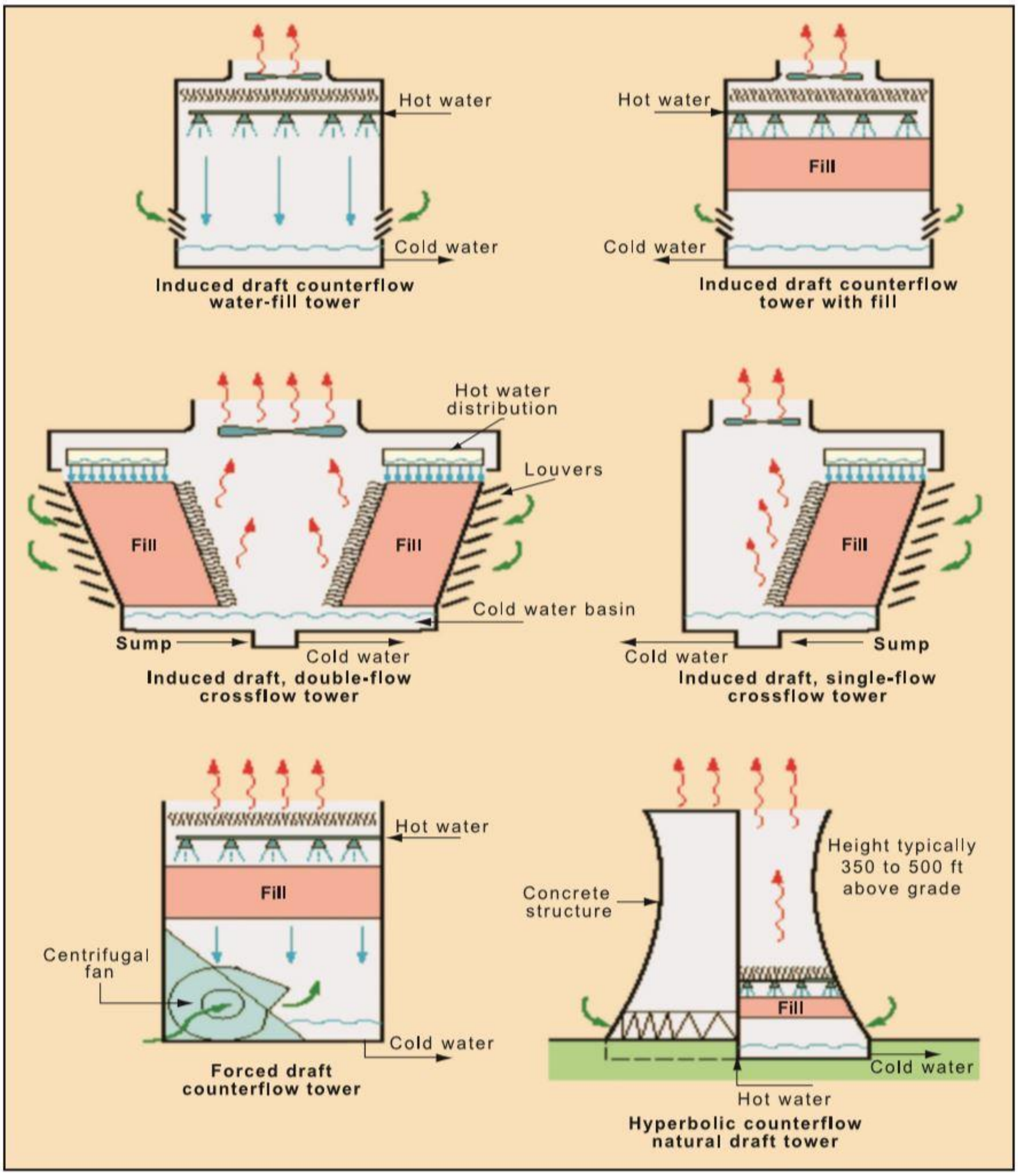


Figure 56: Types of cooling tower (Source: BEE)

Mechanical draft towers are available in the following airflow arrangements:

1. **Counter flows induced draft**

In the counter flow induced draft design, hot water enters at the top, while the air is introduced at the bottom and exits at the top. Both forced and induced draft fans are used.

2. **Cross flow induced draft**

In cross flow induced draft towers, the water enters at the top and passes over the fill. The air, however, is introduced at the side either on one side (single-flow tower) or opposite sides (double-flow tower). An induced draft fan draws the air across the wetted fill and expels it through the top of the structure.

7.8.2. Data collection

Following data from shall be collected during audit from cooling tower motor and fan nameplate and by interviewing the operator or building manager:

- Rated capacity (TR)
- Rated fan, pump, motor, specifications
- Design parameters of cooling tower

In addition to above, following data shall be collected through measurements:

- Cooling water inlet temperature °C
- Cooling water outlet temperature °C
- Ambient air wet bulb and dry bulb temperature °C
- Cooling water flow ($m^{3/}hr$)
- Fan power (kW)
- Air flow (m^3/hr)
- Cooling water TDS

7.8.3. Instruments required

- Ultrasonic water flow meter
- Hand -held clamp meter or three phase power analyser
- Sling psychrometer
- pen-type thermometer
- Anemometer
- TDS-conductivity meter
- Measuring tape

7.8.4. Performance terms and definitions

1. Range and Approach

Range is the difference between the cooling tower water inlet and outlet temperature.

Approach is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature.

Although, both range and approach should be monitored, the `Approach' is a better indicator of cooling tower performance.

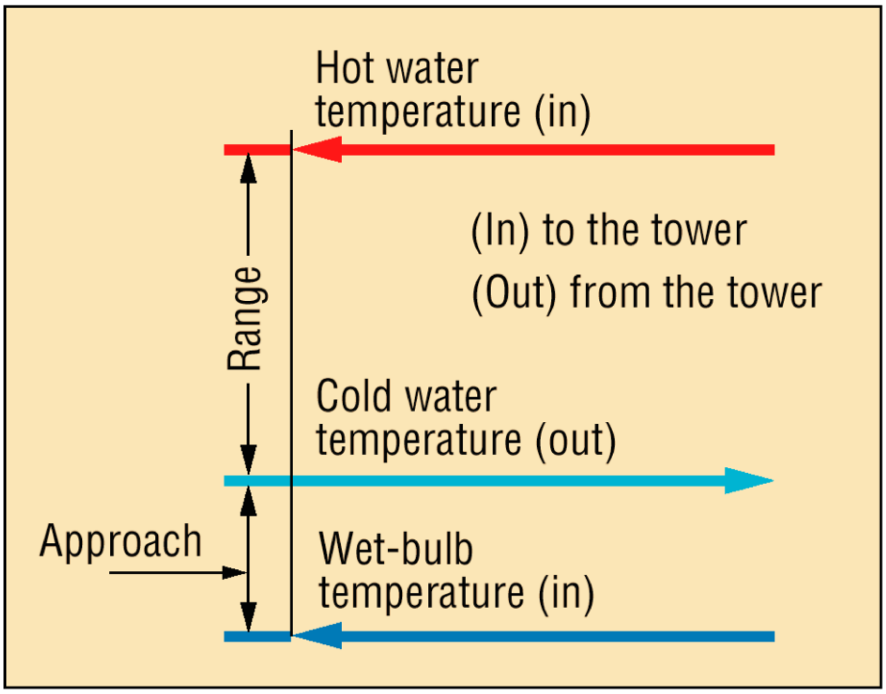


Figure 57: Range and Approach

Range is determined not by the cooling tower, but by the process it is serving. The range at the exchanger is determined entirely by the heat load and the water circulation rate through the exchanger and on to the cooling water.

Range = Heat Load in kcals/hour / Water Circulation Rate in l/hr

Thus, Range is a function of the heat load and the flow circulated through the system.

Cooling towers are usually specified to cool a certain flow rate from one temperature to another temperature at a certain wet bulb temperature. For example, the cooling tower might be specified to cool 4540 m^3/hr from 48.9°C to 32.2°C at 26.7°C wet bulb temperature.

Cold Water Temperature 32.2°C – Wet Bulb Temperature (26.7°C) = Approach (5.5°C)

As a generalization, the closer the approach to the wet bulb, the more expensive the cooling tower due to increased size. Usually a 2.8°C approach to the design wet bulb is the coldest water temperature that cooling tower manufacturers will guarantee. If flow rate, range, approach, and wet bulb had to be ranked in the order of their importance in sizing a tower, approach would be first with flow rate closely following the range and wet bulb would be of lesser importance.

2. Approach and flow

Suppose a cooling tower is installed that is 21.65 m wide × 36.9 m long × 15.24 m high, has three 7.32 m diameter fans and each powered by 25 kW motors. The cooling tower cools from 3632 m^3/hr water from 46.1°C to 29.4°C at 26.7°C wet bulb temperature (WBT) dissipating 60.69 million kcal/hr. The **Table 27** shows what would happen with additional flow but with the range remaining constant at 16.67°C. The heat dissipated varies from 60.69 million kcal/hr to 271.3 million kcal/hr.

Table 27: Flow and approach for given tower

Flow m^3/hr	Approach °C	Cold Water °C	Hot Water °C	Million kcal/hr
3,632	2.78	29.40	46.11	60.691
4,086	3.33	29.95	46.67	68.318
4,563	3.89	30.51	47.22	76.25
5,039	4.45	31.07	47.78	84.05
5,516	5.00	31.62	48.33	92.17
6,060.9	5.56	32.18	48.89	101.28
7,150.5	6.67	33.29	50.00	119.48
8,736	8.33	35.00	51.67	145.63
11,590	11.1	37.80	54.45	191.64
13,620	13.9	40.56	57.22	226.91
16,276	16.7	43.33	60.00	271.32

For meeting the increased heat load, few modifications would be needed to increase the water flow through the tower. However, at higher capacities, the approach would increase.

3. Heat load

The heat load imposed on a cooling tower is determined by the process being served. The degree of cooling required is controlled by the desired operating temperature level of the process. In most cases, a low operating temperature is desirable to increase process efficiency or to improve the quality or quantity of the product. In some applications (e.g. internal combustion engines), however, high operating temperatures are desirable. The size and cost of the cooling tower is proportional to the heat load. If heat load calculations are low undersized equipment will be purchased. If the calculated load is high, oversize and more costly, equipment will result.

Process heat loads may vary considerably depending upon the process involved. Determination of accurate process heat loads can become complex but proper consideration can produce satisfactory results. On the other hand, air conditioning and refrigeration heat loads can be determined with greater accuracy.

4. Range, flow and heat load

Range is a direct function of the quantity of water circulated and the heat load. Increasing the range because of added heat load does require an increase in the tower size. If the cold water temperature is not changed and the range is increased with higher hot water temperature, the driving force between the wet bulb temperature of the air entering the tower and the hot water temperature is increased, the higher level heat is economical to dissipate.

If the hot water temperature is left constant and the range is increased by specifying a lower cold-water temperature, the tower size would have to be increased considerably. Not only would the range be increased, but the lower cold-water temperature would lower

5. Approach & wet bulb temperature

The design wet bulb temperature is determined by the geographical location. Usually the design wet bulb temperature selected is not exceeded over 5 percent of the time in that area. Wet bulb temperature is a factor in cooling tower selection; the higher the wet bulb temperature, the smaller the tower required to give a specified approach to the wet bulb at a constant range and flow rate.

A 4540 m^3/hr cooling tower selected for a 16.67°C range and a 4.45°C approach to 21.11°C wet bulb would be larger than a 4540 m^3/hr tower for same range and approach selected to a 26.67°C wet bulb. Air at the higher wet bulb temperature can pick up more heat. Assume that the wet bulb temperature of the air is increased by approximately 11.1°C. As air removes heat from the water in the tower, each kg of air entering the tower at 21.1°C wet bulb would contain 18.86 kcal and if it were to leave the tower at 32.2°C wet bulb it would contain 24.17 kcal per kg of air.

In the second case, each kg of air entering the tower at 26.67°C wet bulb would contain 24.17 kcals and were to leave at 37.8°C wet bulb it would contain 39.67 kcal per kg of air.

In going from 21.1°C to 32.2°C, 12.1 kcal per kg of air is picked up, while 15.5 kcal/kg of air is picked up in going from 26.67°C to 37.8°C.

6. Effectiveness

Cooling tower effectiveness (in percentage) is the ratio of range, to the ideal range, i.e., difference between cooling water inlet temperature and ambient wet bulb temperature,

Effectiveness= Range / (Range + Approach).

7. Cooling capacity

Cooling capacity is the heat rejected in kcal/hr or TR, given as product of mass flow rate of water, specific heat, and temperature difference.

8. Evaporation loss

Evaporation loss is the water quantity evaporated for cooling duty and, theoretically, for every 1,000,000 kcal heat rejected, evaporation quantity works out to 1.8 m^3.

An empirical relation used often is:
Evaporation Loss (m^3/hr) = 0.00085 x 1.8 x circulation rate (m^3/hr) x (T_1-T_2)

T_1-T_2 = Temp. difference between inlet and outlet water.

9. Cycles of concentration (C.O.C)

Cycles of concentration (C.O.C) is the ratio of dissolved solids in circulating water to the dissolved solids in makeup water. The COC specifies, how often a fresh water added into the loop, can be used or pumped around, before the water has to blow down or bleed off from the cooling tower

10. Blow down

Blow down losses depend upon cycles of concentration and the evaporation losses and is given by relation:

Blow Down = Evaporation Loss / (C.O.C. – 1)

11. Liquid to Gas ratio

Liquid/Gas (L/G) ratio, of a cooling tower is the ratio between the water and the air mass flow rates. Against design values, seasonal variations require adjustment and tuning of water and air flow rates to get the best cooling tower effectiveness through measures like water box loading changes, blade angle adjustments.

Thermodynamics also dictate that the heat removed from the water must be equal to the heat absorbed by the surrounding air:

$L(T_1-T_2) = G(h_2-h_1)$

$L/G = (h_2-h_1)/(T_1-T_2)$

L/G=liquid to gas mass flow ratio (kg/kg)
T_1= hot water temperature (°C)
T_2= cold water temperature (°C)
h_2 = enthalpy of air-water vapor mixture at exhaust wet-bulb temperature
h_1 = enthalpy of air-water vapor mixture at inlet wet-bulb temperature

12. Fill media effect

In a cooling tower, hot water is distributed above fill media which flows down and is cooled due to evaporation with the intermixing air. Air draft is achieved with use of fans. Thus, some power is consumed in pumping the water to a height above the fill and also by fans creating the draft.

An energy efficient or low power consuming cooling tower is to have efficient designs of fill media with appropriate water distribution, drift eliminator, fan, gearbox, and motor. Power savings in a cooling tower, with use of efficient fill design, is directly reflected as savings in fan power consumption and pumping head requirement.

Function of fill media in a cooling tower

Heat exchange between air and water is influenced by surface area of heat exchange, time of heat exchange (interaction) and turbulence in water affecting thoroughness of intermixing. Fill media in a cooling tower is responsible to achieve all the above.

Splash and film fill media

As the name indicates, splash fill media generates the required heat exchange area by splashing action of water over fill media and hence breaking into smaller water droplets. Thus, surface of heat exchange is the surface area of the water droplets, which is in contact with air.

Film fill and its advantages
In a film fill, water forms a thin film on either side of fill sheets. Thus, area of heat exchange is the surface area of the fill sheets, which is in contact with air.

Table 28: Typical comparison between various fill media

Parameter	Splash Fill	Film Fill	Low Clog Film Fill
Possible L/G ratio	1.1-1.5	1.5-2.0	1.4-1.8
Effective Heat Exchange Area	3.-45 m^2/m^3	150 m^2/m^3	85-100 m^2/m^3
Fill Height Required	5-10 m	1.2-1.5 m	1.5-1.8 m
Pumping Head Requirement	9-12 m	5-8 m	6-9 m
Quantity of air Requirement	High	Much low	Low

Due to fewer requirements of air and pumping head, there is a tremendous saving in power with the invention of film fill.

Recently, low-clog film fills with higher flute sizes have been developed to handle high turbid waters. For sea water, low clog film fills are considered as the best choice in terms of power saving and performance compared to conventional splash type fills.

7.8.5. Efficient system operation

1. Cooling water treatment

Cooling water treatment is mandatory for any cooling tower whether with splash fill or with film type fill for controlling suspended solids, algae growth, etc. With increasing costs of water, efforts to increase Cycles of Concentration (COC), by Cooling Water Treatment would help to reduce make up water requirements significantly. In large facilities, COC improvement is often considered as a key area for water conservation. Assumed the feed water has 100 TDS and the cooling water in the loop has 400 TDS, the COC will be 4. As higher the COC as less water is needed for replacement. At the same time the higher cycle of concentration increases the dissolved solids concentration in circulating cooling water which results in scaling and fouling of process heat transfer equipment.

2. Water side problems

Usually the typical problems that any (Open) cooling system meets with are:

- Corrosion and/or Scale formation
- Biologica1/Micro-biological fouling

Corrosion:
Corrosion is a function of various factors such as high salinity of the water, low PH, low Alkalinity, presence of corrosive gases (mainly oxygen and CO_2, dissimilarity of the metals

etc. Corrosion can either lead to failure of the metallurgy (leakages in the heat exchangers) and/or deposit formation of corrosion products.

3. Scale formation

The main sources for the scale formation in the Open Evaporative Condenser circuit are:
Hard water containing, high levels of Calcium and Magnesium, high level of PH and Alkalinity. An open evaporative cooling system (condenser water systems) operated on softened water can meet with severe scaling problems when

- PH of the circulating water is above 9.0
- The total Alkalinity as CaC03 is above 550 ppm
- Temporary hardness in the sources of make-up is above 200 ppm

To control corrosion and scale formation depending upon the severity of each of the problem, either or both chemicals should be used and the selection of the chemicals should be made in accordance with the quality of the make-up water available for plant operation.

4. Bio dispersants and Biocides

To combat problems arising due to the growth of biological and micro biological species, such as algae, fungi, slime, bacteria etc. It is very essential to select a combination of oxidizing and non-oxidizing biocides. Bio-dispersants are used to remove the upper layer of the biological masses and allow better penetration of biocides in the lower layers of biomasses.

5. Chlorination

Chlorination is the most effective and most economical oxidizing biocide. Chlorination for the smaller systems may be done with hypo chlorite-based products and for the larger systems having hold-up volume in excess of $100m^3$ be done with suitable gas chlorinators. The safest gas chlorination equipment are vacuum gravity feed type which can be easily installed on either 50 kg or 100 kg chlorine cylinders.

6. Drift loss

It is difficult to ignore drift problem in cooling towers. Now-a-days most of the end user specification calls for 0.02% drift loss.

With technological development and processing of PVC, manufacturers have brought large change in the drift eliminator shapes and the possibility of making efficient designs of drift eliminators that enable end user to specify the drift loss requirement to as low as 0.003 – 0.001%.

7. Cooling tower fan

The purpose of a cooling tower fan is to move a specified quantity of air through the system, overcoming the system resistance which is defined as the pressure loss. The product of air flow and the pressure loss is air power developed/work done by the fan; this may be also termed as fan output and input kW depends on fan efficiency.

Metallic fans are manufactured by adopting either extrusion or casting process it is always difficult to generate the ideal aerodynamic profiles. The FRP blades are normally hand moulded which facilitates the generation of optimum aerodynamic profile to meet specific duty condition more efficiently. Cases reported where replacement of metallic or Glass fibre reinforced plastic fan blades have been replaced by efficient hollow FRP blades, with resultant fan energy savings of the order of 20-30% and with simple payback period of 6 to 7 months.

Also, due to lightweight, FRP fans need low starting torque resulting in use of lower HP motors. The lightweight of the fans also increases the life of the gear box, motor and bearing is and allows for easy handling and maintenance

7.8.6. Performance assessment of cooling towers

On field performance assessment, the typical measurements and observations involved are:

1. Using a pen-type digital thermometer, measure cooling water (CW) inlet temperature at risers or top of tower
2. Using a pen-type digital thermometer, measure cooling water (CW) outlet temperature at full bottom
3. Using a sling psychrometer, measure intake (ambient) air wet-bulb temperature (WBT) and dry-bulb temperature at each cell at ground level
4. Using an ultrasonic water flow meter, measure cooling water flow measurements,
5. Using a hand-held clamp meter, measure cooling tower fan (CT fan) power (kW) consumption.
6. Using an anemometer, measure the air flow rate of cooling tower fan.
7. Using TDS (total dissolved solids) meter, measure TDS of cooling water
8. Make observations on nozzle flows, drift eliminators, condition of fills, splash bars, etc.

An example has given below to illustrate the performance assessment of cooling towers

Example:

The findings of one typical trial pertaining to the Cooling Towers of a facility is given below:

Parameter	Measured Value	Rated Value
Inlet Cooling Water Temperature, T_1	44°C	43°C
Outlet Cooling Water Temperature, T_2	37.6 °C	33°C
Air Wet Bulb Temperature near cooling tower	29.3 °C	27.5°C
Air Dry Bulb Temperature near cooling tower	40.8 °C	-
Cooling Water flow	1565 m^3/hr	1875 m^3/hr
Measured cooling tower fan flow	989,544 m^3/hr	997,200 m^3/hr
L/G ratio	Calculated below	1.74

Solution:

Parameter	Calculations
Cooling tower (CT) range	= 44 – 37.6 = 6.4°C
Cooling tower approach	= 37.6 – 29.3 = 8.3°C
Cooling tower effectiveness	=Range/ (Range+ Approach) × 100 = 6.4/ (6.4+8.3) × 100 **=43.5%**
Cooling water flow	= 1565 m^3/hr = 1,565,000 kg/hr
Cooling tower fan flow	= 989,544 m^3/hr = 1,068,708 kg/hr (@ density of 1.08 kg/m^3)
L/G ratio of cooling tower kg/kg	= 1,565,000/1,068,708 = 1.46
Evaporation losses	=0.00085 x 1.8 x circulation rate (m^3/hr) x (T_1-T_2) =0.0085×1.8×1565×(44-37.6) =15.32 m^3/hr
Evaporation losses in %	=15.32/1565×100 =0.97%

Comments:

- Cooling water flow is much lower, almost by 16.5%, need to investigate cooling water pump and system performance for improvements. Increasing cooling water flow through cell was identified as a key result area for improving performance of cooling towers.

Other findings (example)

- Algae growth identified in cooling tower cells.
- Cooling tower fans are of GRP (glass reinforced polypropylene) type drawing 36.2 kW average. Replacement by efficient hollow FRP (fiber reinforced plastic) fan blades is recommended.

7.8.7. Energy saving opportunities in cooling towers

- Optimise cooling tower fan blade angle on a seasonal and/or load basis and correct excessive and/or uneven fan blade tip clearance and poor fan balance.
- On old counter-flow cooling towers, replace old spray type nozzles with new square spray ABS practically non-clogging nozzles.
- Replace splash bars with self-extinguishing PVC cellular film fill.
- Install new nozzles to obtain a more uniform water pattern
- Periodically clean plugged cooling tower distribution nozzles.
- Balance flow to cooling tower hot water basins.
- Cover hot water basins to minimise algae growth that contributes to fouling.
- Optimise blow down flow rate, as per COC limit.
- Replace slat type drift eliminators with low pressure drop, self-extinguishing, PVC cellular units.
- Segregate high heat loads like furnaces, air compressors, DG sets, and isolate cooling towers for sensitive applications like A/C plants, condensers of captive power plant etc.
- Monitor L/G ratio, CW flow rates w.r.t. design as well as seasonal variations. It would help to increase water load during summer and times when approach is high and increase air flow during monsoon times and when approach is narrow.
- Monitor approach, effectiveness, and cooling capacity for continuous optimisation efforts, as per seasonal variations as well as load side variations.
- Consider COC improvement measures for water savings.
- Consider energy efficient FRP blade adoption for fan energy savings.
- Consider possible improvements on CW pumps w.r.t. efficiency improvement.
- Control cooling tower fans based on leaving water temperatures especially in case of small units.

7.9. Lighting system – energy performance assessment

7.9.1. Introduction

Light is usually described as the type of electromagnetic radiation that has a wavelength visible to the human eye, roughly 400 to 700 nanometres. Light exists as tiny packets called photons and exhibits the properties of both particle and wave. Visible light rep-resents a narrow band between ultraviolet light (UV) and infrared energy (heat). These waves can exit the eye's retina, which results in a visual sensation called sight. Therefore, seeing requires a functioning eye and visible light.

Lighting is provided in hospitals, commercial buildings, indoor and outdoor for providing comfortable working environment. The primary objective is to provide the required lighting effect for the lowest installed load i.e. highest lighting at lowest power consumption.

The purpose of performance test is to calculate the installed efficacy in terms of lux/watt/m² (existing or design) for general lighting installation. The calculated value can be compared with the norms for specific types of interior installations for assessing improvement options. The installed load efficacy of an existing (or design) lighting installation can be assessed by carrying out a survey as indicated in the following pages.

7.9.2. Data collection

Following data to be collected before conducting assessment

- Collect the single line diagram of electrical drawing pertaining to lighting.
- Following fixture details
    - Type of fixtures
    - Number of fixtures
    - Wattage of each fixture
- Department or section wise room dimension Length, width, and Height.
- Standard required lux level

Typical data format is given below.

Department Or section	Fixture type	Wattage of each fixture	No. of fixture	Total wattage	Room dimension	Illuminance required	Power Feeder detail

7.9.3. Instruments required

For lighting assessment following instruments are required:

- Hand-held clamp meter
- Three-phase power analyser
- LUX meter
- Digital distance meter or measuring tape

7.9.4. Performance terms and definition

- **Luminous flux:** The luminous flux describes the quantity of light emitted by a light source. It is a measure of a lamp's economic efficiency. The most common measurement or unit of luminous flux is the lumen (lm). The lumen rating of a lamp is a measure of the total light output of the lamp. Light sources are labelled with an output rating in lumen.
- **Illuminance (E)**: It is the quotient of the luminous flux incident on an element of the surface at a point, by the area of that element.
  The lighting level produced by a lighting installation is usually qualified by the illuminance produced on a specified plan. In most cases, this plan is the major plan of the task carried out in the interior and is common called the working plan. The illuminance provided by an installation affects both the performance of the tasks and the appearance of the space.
- **Lux (lx):** This is the illuminance produced by a luminous flux of one lumen, uniformly distributed over a surface area of one square metre. One lux is equal to one lumen per square meter.
  - Luminous Efficacy (lm/W): This is the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. It reflects efficiency of energy conversion from electricity to light form.
  - Installed Load Efficacy: It is the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior. Unit: lux per watt per square metre (lux/W/m²)
  - Colour Rendering Index (RI): Is a measure of the degree to which the colours of surfaces illuminated by a given light source confirm to those of the same surfaces under a reference illuminate; suitable allowance having been made for the state of Chromatic adaptation.

7.9.5. Steps for conducting lighting audit

Step 1: Calculate minimum number of measurement points with Room index and Lux measurement

Room index used to determine the minimum number and positions of measurement points in a room.

Room Index=L×W/Hm(L+W)

Where L = length of interior; W = width of interior; Hm = the mounting height, which is the height of the lighting fittings above the horizontal working plane. The working plane is usually assumed to be 0.75m above the floor in offices and at 0.85m above floor level in manufacturing areas.

It does not matter whether these dimensions are in metres, yards, or feet if the same unit is used throughout. Ascertain the minimum number of measurement points from **Table 29.**

Table 29: Determination of measurement points

Room Index	Minimum number of measurement points
Below 1	9
1 and below 2	16
2 and below 3	25
3 and above	36

Carry out Lux level measurement on minimum measurement points.

Calculate load efficacy ratio (ILER): follow the steps below to calculate ILER.

Step 2	Measure the floor area of the interior	Area = ----- m^2
Step 3	Determine the total circuit watts of the installation by a power analyser if a separate feeder for lighting is available. If the actual value is not known a rated value can be obtained including the ballasts	Total watts = -------
Step 4	Calculate Watts per square metre, Value of step 3 divided by value of step 2	W/m^2 = --------
Step 5	Divide average lux level maintained measured in step 1 by step 4 to calculate installed load efficacy lux per watt per square metre	$Lux/W/m^2$ = -----
Step 6	Obtain target $Lux/W/m^2$ lux for type of the type of interior/application (given Table 30)	Target $Lux/W/m^2$ =
Step 7	Calculate Installed Load Efficacy Ratio (5 ÷ 6).	ILER =

Below **Table 30** gives the target $lux/W/m^2$ ($W/m^2/100lux$) values for maintained illuminance on horizontal plane for all room indices and applications:

Table 30: Target load efficacy (ILER)

Room Index	Commercial lighting (Offices, Retail stores etc) Colour rendering required Ra-40-85 (Standard or good)
5	53 (1.89)
4	52 (1.92)
3	50 (2.00)
2.5	48 (2.08)
2	46 (2.17)
1.5	43 (2.33)
1.25	40 (2.50)
1	36 (2.78)

ILER assessment

Compare the calculated ILER with the information in below **Table 31**

Table 31: Indicators of performance

Calculated ILER	Assessment
0.75 or above	Satisfactory or good
0.51-0.74	Review suggested
0.5 or less	Urgent action required

Existing installations with ratios of 0.51 - 0.74 certainly merit investigation to see if improvements are possible. Of course there can be good reasons for a low ratio, such as having to use lower efficacy lamps or less efficient luminaires in order to achieve the required lighting result –but it is essential to check whether there is a scope for a more efficient alternative. Existing installations with an ILER of 0.5 or less certainly justify close inspection to identify options for converting the installation to use more efficient lighting equipment.

Estimate the energy potential energy saving. For a given installation:

Annual energy saving potential (in kWh) = (1.0 - ILER) x Total load (kW) x annual operating hours (h)

If the calculated ILE (lux/W/m²) is less than the target value, then it is advisable to ascertain the reasons. It may be that the requirements dictate a type of luminaire that is not as efficient as the best, or the surface reflectance are less than the normal maxima, or the environment is dirty, etc., Whatever the reasons, they should be checked to see if a more efficient solution is possible.

Example of ILER calculation:
The dimensions of an interior are: Length = 9m, Width = 5m, Height of luminaires above working plane (Hm) = 2m

Step 1: Room index = 9x5/2(9+5) = 1.607

From Table 29 the minimum number of measurement points is 16. As it is not possible to approximate a “square array” of 16 points within such a rectangle it is necessary to increase the number of points to say 18, i.e. 6 x 3.

After taking measurement by lux meter on 18 points in the room the average illumination measured was= 700 lux.

Step 2	Measure the floor area of the interior	Area = 45m²
Step 3	Determine the total circuit watts of the installation by a power analyser if a separate feeder for lighting is available. If the actual value is not known a rated value can be obtained including the ballasts	Total watts = 990 W
Step 4	Calculate Watts per square metre, Value of step 3 divided by value of step 2	22 W/m²
Step 5	Divide average lux level maintained measured in step 1 by step 4 to calculate installed load efficacy lux per watt per square metre	31.8 Lux/W/m²
Step 6	Obtain target Lux/W/m² lux for type of the type of interior/application (given Table 30)	Target Lux/W/m² = 46
Step 7	Calculate Installed Load Efficacy Ratio (5 ÷ 6).	ILER = 0.7

Referring to Table 31 ILER of 0.7 means that there is scope for review of the lighting system.

Annual energy saving potential = (1 – ILER) x watts x no. of operating hours

= (1 – 0.7) x 990 x 8 hrs/day x 300 days

= 712 kWh/annum

7.9.6. Alternative method of lighting audit

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

Step 01: Prepare and inventory of the Lighting System elements, & transformers in the facility by recording the type, rating and quantity of each type of light fixture.

Step 02: With the aid of a lux meter, measure and document the lux levels at various facility locations at working level, as daytime lux and night-time lux values alongside the number of lamps "ON" during measurement.

Step 03: With the aid of portable load analyser, measure and document the voltage, current, power factor and power consumption at various input points, namely the distribution boards or the lighting voltage transformers at the same as that of the lighting level audit.

Step 04: Compare the measured lux values with standard values as reference and identify locations as under lit and over lit areas.

Standard lux value as per IS 3646 is given below or for recommended illumination, reader may refer **Illuminating Engineers Society Recommendations Handbook.**

Record summary of lighting measurement as per given **Table 32:**

Table 32: Summary of lighting measurement

Location/Section	Type of lamp	Measured average lux level	Standard Lux level (as per IS 3646)	Measured power

The following **Table 33** gives the recommended illuminance range for different tasks and activities for a facility. The values are related to the visual requirements of the task, to user's satisfaction, to practical experience and to the need for cost effective use of energy. For others sectors please refer source IS 3646 (Part I): 1992

Table 33: Standard Lux level for facility (Source: IS 3646)

Sl. No	Type of Interior or Activity	Range of Service Illuminance in lux
	General	
1	Switch rooms, meter rooms, oil plant room, HV substation (indoor)	100-150-200
2	Control rooms	200-300-500 Localize lighting of control display and the control desk may be appropriate
3	Relay and telecommunication rooms	200-300-500
4	Diesel generator rooms, compressor rooms	100-150-200
5	Pump houses, water treatment plant houses	100-150-200
6	Battery rooms, charges, rectifiers	50-100-150
7	Cable tunnels and basements, circulating water culverts and screen chambers, storage tanks (indoor), operating areas and filling at outdoor tanks	30-50-100
	General Building Area	
1	Entrance halls, lobbies, waiting rooms	150-200-300
2	Enquiry desks	300-500-750 Localised lighting may be appropriate
3	Gatehouses	150-200-300
	Circulation Areas	
1	Lifts	50-100-150
2	Corridors, passageways, stairs	50-100-150
3	Escalators, travellators	100-150-200
	Medical and First Aid Centres	

Sl. No	Type of Interior or Activity	Range of Service Illuminance in lux
1	Consulting rooms, treatment rooms	300-500-750
2	Rest rooms	100-150-200
3	Medical Stores	100-150-200
	Staff rooms	
1	Changing, locker and cleaners' rooms, cloakrooms. Laboratories	50-100-150
2	Rest rooms	100-150-200
	Staff Restaurants	
1	Canteen, cafeterias, dining rooms, mess rooms	150-200-300
2	Server, vegetable preparation, washing up area	200-300-500
3	Food preparation and cooking	300-500-750
4	Food stores and cellars	100-150-200
	Communications	
1	Switchboard rooms	200-300-500
2	Telephone apparatus rooms	100-150-200
3	Telex rooms, post room	300-500-750
4	Reprographic room	200-300-500
	Building services	
1	General	50-100-150
2	Boiler front	100-150-200
3	Boiler control room	200-300-500 Localised lighting may be appropriate
4	Control rooms	200-300-500 Localised lighting may be appropriate
5	Mechanical plant room	100-150-200
6	Electrical power supply and distribution room	100-150-200
7	Store rooms	50-100-150
	Car parks	
a	Floors	5-20
b	Ramps and corners	30
c	Entrance and exits	50-100-150
d	Control booths	150-200-300

Step 05: Based on careful assessment and evaluation, bring out improvement options.

7.9.7. Daylight analysis of building

Daylight is the diffused natural light from the sky. Daylight varies depending on sky condition. The daylight performance of the building can vary with orientation, adjacent space, level of exposure and the time of assessment.

The daylight analysis of the building is to be conducted under the following conditions only

- The lighting load is high
- The assessment of the lux levels indicates poor daylight conditions.

It is not necessary to conduct the daylight analysis of the whole building. If a complete building is to be audited, then each room must be assessed separately. The selection of the spaces/rooms must be supported with rationale based on the experience of the energy auditor and the requirement set by the client.

Data collection for daylight analysis

The following data shall be collected for daylight analysis:

- The orientation and context of the building (or specific location/area of building) should be drafted, this information can be collected based on the site plan.
- The building plan and section or detail of the specific location/area of building to be audited (In the absence of drawing and detail, the as built drawing must be drafted).
- The sky condition of the time or period during which the assessment is being conducted.

Instruments required

- Measuring tape
- Lux meter
- Protractor to measure angle

Performance terms and definition

Daylight is measured in illuminance this is the amount of light reaching a surface and is measured in lumens/m^2 or lux.

Steps to obtain key operating parameters

1. Draw a plan and section of the room. From the centre of the window, calculate the sky angle (θ) as shown in **Figure 58**
2. Measure the room length, width, and height. Measure the window area. Find the total (walls, ceiling, and floor) room surface area (A) including the window area (A_g). Assume the average reflectance (R) to be 0.5.
3. Calculate the light transmission (T) for the window: Measure the Lux level outside the window and measure the Lux level inside. The transmission factor will be $Lux_{inside}/Lux_{outside}$. The answer will be a decimal fraction such as 0.8 or 0.65 depending on the type of glass and when it was last cleaned.
4. Calculate the Average Daylight Factor: $\bar{D} = \frac{A_g \theta T}{A(1 - R^2)}$

5. Find the centre of the room and measure the lux level. Compare this level to the outside level and calculate the average daylight level percentage for the room centre ($D = Lux_{in}/Lux_{out} \times 100$).

Table 34: Calculating Day light factor

Room ID and Date	Outside sky condition	Sky angle Ɵ	Total surface area with window	Window area	Window Transmission	Daylight level at room centre	Average Daylight Factor

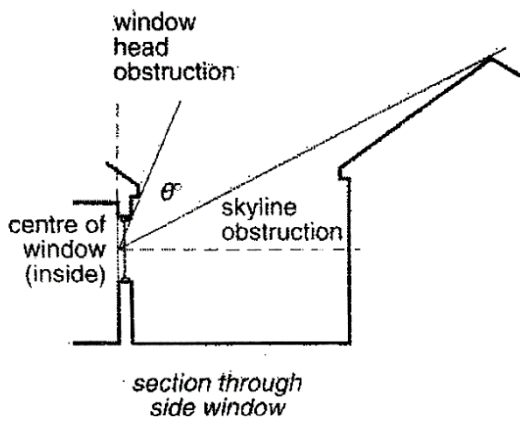


Figure 58: Sky angle

The following can be interpreted from the above calculated results

- If the measured Daylight factor is not with 2<5 % then it indicates opportunity for improvement.
- If it is less than 2% then it could be due to poor transmittance due to dust or because the window area is not enough to achieve the desired daylighting.
- If it is greater than 5% then it could result in glare issues, consider a external or internal shading device.

7.9.8. Energy savings opportunities

While conducting the energy audit various energy savings measures may be explored such as:

- Natural lighting opportunities through windows and other openings. Suggest ways to improve natural lighting during the daytime and maximize sunlight use through use of translucent roof sheets, north light roof, etc.
- Explore the scope for introducing translucent polycarbonate sheets.
- Use of energy efficient lighting methods / products / equipment / retrofits Replace conventional magnetic ballasts by more energy efficient ballasts, with due consideration to life and power factor apart from watt loss.
- Replace energy efficient displays with LEDs in place of lamp type

- Select interior colours for light reflection.
- Assess scope for re-arrangement of lighting fixtures and modify layout for optimum lighting.
- Provide individual / group controls for lighting for improving energy efficiency such as, on / off type voltage regulation type (for illumination control)
- Look for the opportunity to install occupancy sensors and timer operated controls
- Modified switches / electrical circuits

  Install input voltage regulators / controllers for higher energy efficiency as well as longer life expectancy for lamps where high voltages / fluctuations are expected.
- Examine scope for replacements of lamps by more energy efficient lamps, with due consideration to luminaries, colour rendering index, lux level as well as expected life. Performances of luminaries which are commonly used are given in **Table 35**

Table 35: Luminous performance characteristics of commonly used luminaries

Type of Lamp	Lumens/watt		Colour Rendering Index	Typical Application	Typical Life (Hours)
	Range	Average			
Incandescent	8-18	14	Excellent (100)	Homes, restaurants, general lighting, emergency lighting	1000
Fluorescent Lamps	46-60	50	Good (67-77)	Offices, shops, hospitals, homes	5000
Compact fluorescent lamps (CFL)	40-70	60	Very good (85)	Hotels, shops, homes, offices	8000-10000
High pressure mercury (HPMV)	44-57	50	Fair (45)	General lighting in factories, garages, car parking, flood lighting	5000
Halogen lamps	18-24	20	Excellent (100)	Display, flood lighting, stadium exhibition grounds, construction areas	2000-4000
High pressure sodium (HPSV) SON	67-121	90	Fair (22)	General lighting in factories, warehouses, street lighting	6000-12000
Low pressure sodium (LPSV) SOX	101-175	150	Poor (10)	Roadways, tunnels, canals, street lighting	6000-12000
Metal halide lamp	75-125	100	Good (70)	Industrial bays, spot lighting, flood lighting, retail stores	8000

Type of Lamp	Lumens/watt		Colour Rendering Index	Typical Application	Typical Life (Hours)
	Range	**Average**			
LED lamps	50-130	90	Very good (80)	Office, industries, outdoor, retail, hospitality, etc	30,000-60,000
Induction Lamps	65-90	75	Very good (80)	General lighting, factories, warehouse, street lighting, flood lighting, etc	60,000-1,00,000

7.10. Boilers and hot water generator – energy performance assessment

7.10.1. Introduction

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. Boilers are typically used to heat water to feed heating systems or to supply hot water or both. It is commercially available for the hot water requirements at Hotels, Hospitals, Resorts, Swimming pools, residential apartments, Laundries and for various other process. Hot Water Generators are available in both Solid Fuel firing as well as diesel / Gas / Dual Fuel firing variants as per the advantage of economically available fuels.

Water heating in a hotel or residential building is needed for guestrooms, laundry, public restrooms, janitorial work, kitchens, locker room showers, and occasionally swimming pools. Water heating can be a relatively large energy user in a facility, particularly when laundry is done on-site.

The process of heating a liquid until it reaches its gaseous state is called evaporation. Heat is transferred from one body to another by means of (1) radiation, which is the transfer of heat from a hot body to a cold body without a conveying medium, (2) convection, the transfer of heat by a conveying medium, such as air or water and (3) conduction, transfer of heat by actual physical contact, molecule to molecule.

The heating surface is any part of the boiler metal that has hot gases of combustion on one side and water on the other. Any part of the boiler metal that contributes to making steam is heating surface. The amount of heating surface of a boiler is expressed in square meters.

The boiler system comprises of:

- Feed water system,
- Fuel system
- Boiler
- Hot water distribution

The feed water system provides water to the boiler and regulates it automatically to meet the hot water demand. Various valves provide access for maintenance and repair. The fuel system includes all equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used in the system. Boiler is where the fuel is burnt to generate heat and convert water to hot water/steam. The hot water distribution system collects and controls the hot water produced in the boiler. Hot water is directed through a piping system to the point of use.

The water supplied to the boiler that is converted into steam is called feed water. The two sources of feed water are: (1) Condensate or condensed steam returned from the heating system and (2) Makeup water (treated raw water) which must come from outside the boiler room. For higher boiler efficiencies, the feed water is preheated by economizer, using the waste heat in the flue gas.

7.10.2. Data collection

Following data shall be collected during audit from Boiler name plate and by interviewing the Boiler operator or supervisor:

- Type of Boiler
- Make and year of manufacturing
- Rated efficiency of Boiler
- Operating hours
- Operating parameters of Boiler like
  - Operating pressure
  - Operating load or steam required
  - Operating temperature
- Average fuel consumption from operator logbook
- Gross calorific vale (GCV) of fuel
- Feed water and inlet air temperature
- Amount and temperature of Condensate recovery if applicable
- Details of equipment/process where steam is used

While collecting information, it should also be checked, whether the Boiler are installed with Economiser, Air preheater, variable speed drive on FD or ID fan, Condensate recovery, excess air controller and any other energy saving retrofits.

In addition to above collect the following data through measurements:

- Thermal images of Boiler surface and steam pipeline (with focus on potential heat losses)
- Flue gas analysis data (applicable for fuel fired boiler only)
- Electricity consumption of FD and ID fan
- Flow measurement of Feed water
- Temperature measurement of feed water to Boiler, Air inlet and condensate recovered

7.10.3. Instruments required

For fuel fired boiler:

- Flue gas analyser
- Thermal imaging camera
- IR thermometer
- Sling psychrometer or digital thermometer
- TDS-Conductivity meter

For ID & FD fan of fuel fired boiler:

- Three-phase power analyser
- Manometer with pitot tube
- Anemometer

- Measuring tape

For Electric Boiler:

- Three-phase power analyser
- Thermal imaging camera
- IR thermometer

7.10.4. Performance terms and definitions

The performance parameters of boiler, like efficiency and evaporation ratio reduces with time due to poor combustion, heat transfer surface fouling and poor operation and maintenance. Even for a new boiler, reasons such as deteriorating fuel quality, water quality etc. can result in poor boiler performance. Boiler efficiency tests help us to find out the deviation of boiler efficiency from the best efficiency and target problem area for corrective action.

Boiler evaporation ratio, also known as steam to fuel ratio is a common and simple indicator for boiler performance. Evaporation ratio monitoring is best suited for any boiler when its own performance is compared on day to day basis as a performance indicator, given that enthalpy gain in steam and fuel calorific value remain constant. A drop in evaporation ratio indicates a drop in Boiler efficiency.

Boiler efficiency: Thermal efficiency of boiler is defined as the percentage of heat input that is effectively utilised to generate steam.

7.10.5. Performance evaluation of Boilers

There are two methods of assessing boiler efficiency.

Boiler Efficiency

Thermal efficiency of boiler is defined as the percentage of heat input that is effectively utilised to generate steam.

There are two methods of assessing boiler efficiency.

1. Direct Method

This is also known as 'input-output method' since it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. This efficiency can be evaluated using the formula:

$$Boiler\ efficiency\ (\eta) = \frac{Heat\ output}{Heat\ input} \times 100$$

Measurement required for direct method testing

Both heat input and heat output must be measured.

Heat input

The measurement of heat input requires knowledge of the calorific value of the fuel and its flow rate in terms of mass or volume, according to the nature of the fuel.

- **For gaseous fuel**: A gas meter of the approved type can be used, and measured volume should be corrected for temperature and pressure.
- **For liquid fuel**: Heavy fuel oil is very viscous, and this property varies sharply with temperature. A calibrated meter for the particular oil is to be used and over realistic range of temperature should be installed. Even better is the use of an accurately calibrated day tank.
- **For solid fuel**: The accurate measurement of the flow of coal or other solid fuel is difficult. The measurement must be based on mass, which means that bulky apparatus must be set up on the boiler house floor.
- **For electricity**: Using a hand-held clamp meter or three-phase power analyser measure the power consumption of the boiler at full load and convert the kWh into kcal (1 kWh = 860 kcal). Measure the power consumption of boiler at full load.

Heat output
Following parameters required to measure for calculating heat output of Boiler.

Water flow measurement: Measurement of water flow can be done by previously calibrating the feed tank and noting down the levels of water during the beginning and end of trial. Care should be taken not to pump water during this period. An installed water meter can be used for measuring flow rate, but this must be corrected for temperature and pressure.

Temperature: In case of hot water generator, temperature of water can be measured by the thermometer (pen type or relevant type of thermometer).

$$Boiler\ efficiency(\eta) = \frac{Q \times (h_g - h_f)}{q \times GCV\ of\ fuel} \times 100$$

or,

$$Boiler\ efficiency\ for\ electrical\ boiler\ (\eta) = \frac{Q \times (h_g - h_f)}{Electricity\ consumed\ in\ kcal} \times 100$$

1 kWh = 860 kcal

Where,
Q= Quantity of steam generated per hour in kg/hr
q= Quantity of fuel used per hour in kg/hr
h_g=Enthalpy of hot water or steam in kcal/kg
h_f=Enthalpy of feed water in kcal/kg

Example:

- Type of boiler: Electric
- Quantity of hot water generated: 2 TPH
- Power consumption: 190 kWh
- Feed water temperature: 25° C
- Hot water temperature: 95° C

$$Boiler\ efficiency(\eta) = \frac{2 \times (95 - 25) \times 1000}{190 \times 860} \times 100 = 85.6\%$$

7.10.6. Boiler Blowdown

When water is boiled and steam is generated, any dissolved solids contained in the water remain in the boiler. If more solids are put in with the feed water, they will concentrate and may eventually reach a level where their solubility in the water is exceeded and they deposit from the solution. Above a certain level of concentration, these solids encourage foaming and cause carryover of water into the steam. The deposits also lead to scale formation inside the boiler, resulting in localized overheating and finally causing boiler tube failure.

It is, therefore, necessary to control the level of concentration of the solids and this is achieved by the process of 'blowing down', where a certain volume of water is blown off and is automatically replaced by feed water - thus maintaining the optimum level of total dissolved solids (TDS) in the boiler water. Blow down is necessary to protect the surfaces of the heat exchanger in the boiler. However, blow down can be a significant source of heat loss, if improperly carried out. Please refer guidelines specified by manufacturer for recommended TDS level in boiler.

Conductivity as Indicator of Boiler Water Quality

Since it is tedious and time consuming to measure total dissolved solids (TDS) in boiler water system, conductivity measurement is used for monitoring the overall TDS present in the boiler. A rise in conductivity indicates a rise in the "contamination" of the boiler water.

Conventional methods for blowing down the boiler depend on two kinds of blowdown - intermittent and continuous.

Intermittent Blowdown

The intermittent blown down is given by manually operating a valve fitted to discharge pipe at the lowest point of boiler shell to reduce parameters (TDS or conductivity, pH, Silica and Phosphates concentration) within prescribed limits so that steam quality is not likely to be affected. In intermittent blowdown, a large diameter line is opened for a short period of time, the time being based on a thumb rule such as “once in a shift for 2 minutes”.

Intermittent blowdown requires large short-term increases in the amount of feed water put into the boiler, and hence may necessitate larger feed water pumps than if continuous blow down is used. Also, TDS level will be varying, thereby causing fluctuations of the water level in the boiler due to changes in steam bubble size and distribution which accompany changes in concentration of solids. Also, substantial amount of heat energy is lost with intermittent blowdown.

Continuous Blowdown

There is a steady and constant dispatch of small stream of concentrated boiler water, and replacement by steady and constant inflow of feed water. This ensures constant TDS and steam purity at given steam load. Once blow down valve is set for a given conditions, there is no need for regular operator intervention.

Even though large quantities of heat are wasted, opportunity exists for recovering this heat by blowing into a flash tank and generating flash steam. This flash steam can be used for pre-heating boiler feed water or for any other purpose. This type of blow down is common in high-pressure boilers.

Blowdown calculations

The quantity of blowdown required to control boiler water solids concentration is calculated by using the following formula:

$$\text{Blow down (\%)} = \frac{\text{Feed water TDS x \% Make up water}}{\text{Maximum Permissible TDS in Boiler water}}$$

If maximum permissible limit of TDS as in a package boiler is 3000 ppm, percentage make up water is 10% and TDS in feed water is 300 ppm, then the percentage blow down is given as:

$=300\times1/3000= 1\%$

If boiler evaporation rate is 3000 kg/hr then required blow down rate is:

3000 x 1 /100= 30 kg/hr

Benefits of Blowdown

Good boilers blow down control can significantly reduce treatment and operational costs that include:

- Lower pre-treatment costs
- Less make-up water consumption
- Reduced maintenance downtime
- Increased boiler life
- Lower consumption of treatment chemicals

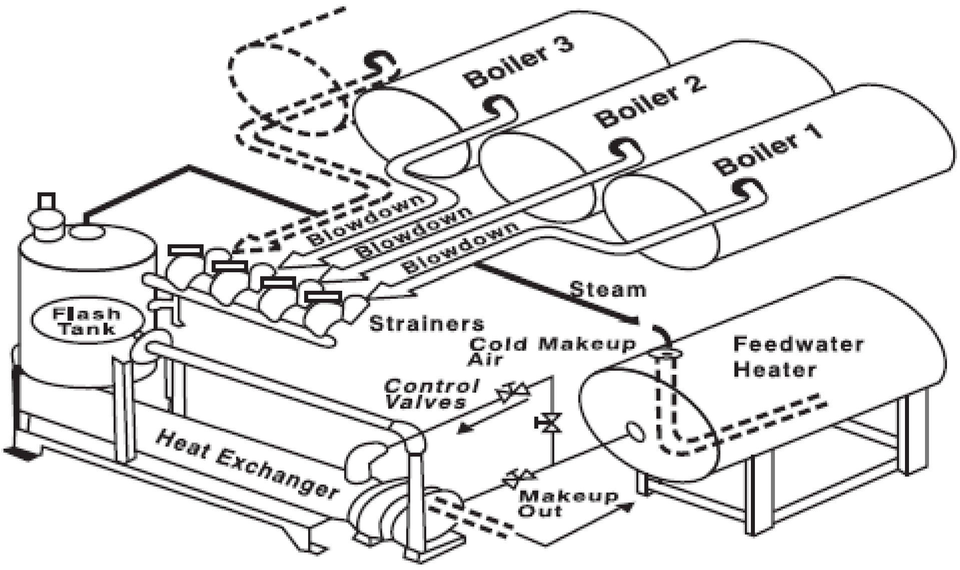


Figure 59: Blowdown heat recovery system

7.10.7. Energy saving opportunities

The various energy efficiency opportunities in boiler system can be related to combustion, heat transfer, avoidable losses, high auxiliary power consumption, water quality and blowdown.

Examining the following factors can indicate if a boiler is being run to maximize its efficiency:

1. Stack temperature

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 sulphur as low temperature can lead to sulphur dew point corrosion. Stack temperatures greater than 200°C indicates potential for recovery of waste heat. It also indicate the scaling of heat transfer/recovery equipment and hence the urgency of taking an early shut down for water / flue side cleaning.

2. Feed water preheating using economiser

Typically, the flue gases leaving a modern 3-pass shell boiler are at temperatures of 200 to 300°C. Thus, there is a potential to recover heat from these gases. The flue gas exit temperature from a boiler is usually maintained at a minimum of 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, LPG or gas oil is used, the economy of heat recovery must be worked out, as the flue gas temperature may be well below 200°C.

The potential for energy saving depends on the type of boiler installed and the fuel used. For a typically older model shell boiler, with a flue gas exit temperature of 260°C, an economizer could be used to reduce it to 200°C, increasing the feed water temperature by 15°C. Increase in overall thermal efficiency would be in the order of 3%. For a modern 3-pass shell boiler firing natural gas with a flue gas exit temperature of 140°C. A condensing economizer would reduce the exit temperature to 65°C increasing thermal efficiency by 5%.

3. Combustion air preheat

Combustion air preheating is an alternative to feedwater heating. In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20°C. 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 units as heat exchangers in the exit flue as an alternative to an economizer, when either space or a high feed water return temperature make it viable.

4. Incomplete combustion

Incomplete combustion can arise from a shortage of air or surplus of fuel or poor distribution of fuel. It is usually obvious from the colour or smoke and must be corrected immediately.

In the case of oil and gas fired systems, CO or smoke (for oil fired systems only) with normal or high excess air indicates burner system problems. A more frequent cause of incomplete combustion is the poor mixing of fuel and air at the burner. Poor oil fires can result from improper viscosity, worn tips, carbonization on tips and deterioration of diffusers or spinner plates.

With coal firing, unburned carbon can comprise a big loss. It occurs as grit carry-over or carbon-in-ash and may amount to more than 2% of the heat supplied to the boiler. Non uniform fuel size could be one of the reasons for incomplete combustion. In chain grate stokers, large lumps will not burn out completely, while small pieces and fines may block the air passage, thus causing poor air distribution. In sprinkler stokers, stoker grate condition, fuel distributors, wind box air regulation and over-fire systems can affect carbon loss. Increase in the fines in pulverized coal also increases carbon loss.

5. Excess air control

The **Table 36** gives the theoretical amount of air required for combustion of various types of fuel.

Table 36: Theoretical combustion data - common Boiler fuel

Fuel	kg of air required/kg of fuel	kg of flue gas/kg of fuel	m^3 of flue/kg of fuel	Theoretical CO_2 % in dry flue gas	CO_2 % in flue gas achieved in practice
Bagasse	3.2	3.43	2.61	20.65	10-12
Coal (bituminous)	10.8	11.7	9.40	18.70	10-13
Lignite	8.4	9.10	6.97	19.40	9-13
Paddy Husk	4.6	5.63	4.58	19.8	14-15
Wood	5.8	6.4	4.79	20.3	11.13
Furnace Oil	13.90	14.30	11.50	15.0	9-14
LSHS	14.04	14.63	10.79	15.5	9-14

Excess air is required in all practical cases to ensure complete combustion, to allow for the normal variations in combustion and to ensure satisfactory stack conditions for some fuels. The optimum excess air level for maximum boiler efficiency occurs when the sum of the losses due to incomplete combustion and loss due to heat in flue gases is minimum. This level varies with furnace design, type of burner, fuel and process variables. It can be determined by conducting tests with different air fuel ratios. Typical values of excess air supplied for various fuels are given in **Table 37**

Table 37: Excess air levels for different fuels

Fuel	Type of Furnace or Burners	Excess Air (% by weight)
Pulverized coal	Completely water-cooled furnace for slag tap or dry ash removal	15-20
Coal	Partially water-cooled furnace for dry-ash removal	15-40
	Spreader stoker	30-60
	Water-cooler vibrating-grate stokers	30-60
	Chain-grate and traveling-gate stokers	15-50
	Underfeed stoker	20-50
Fuel oil	Oil burners register type	15-20
Fuel oil	Multi-fuel burners and flat flame	20-30
Natural gas	High pressure burner	5-7
Wood	Dutch over (10-23%through grates) and Hofft type	20-25
Bagasse	All furnaces	25-35
Black liquor	Recovery furnaces for draft and soda-pulping processes	30-40

Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximately 0.6% rise in efficiency.

Various methods are available to control the excess air:

• Portable oxygen analysers and draft gauges can be used to make periodic readings to guide the operator to manually adjust the flow of air for optimum operation. Excess air reduction up to 20% is feasible.

• The most common method is the continuous oxygen analyser with a local readout mounted draft gauge, by which the operator can adjust air flow. A further reduction of 10-15% can be achieved over the previous system.

• The same continuous oxygen analyser can have a remote controlled pneumatic damper positioner, by which the readouts are available in a control room. This enables an operator to remotely control a number of firing systems simultaneously.

The most sophisticated system is the automatic stack damper control, whose cost is really justified only for large systems.

6. Radiation and convection heat loss

The external surfaces of a shell boiler are hotter than the surroundings. The surfaces thus lose heat to the surroundings depending on the surface area and the difference in temperature between the surface and the surroundings.

The heat loss from the boiler shell is normally a fixed energy loss, irrespective of the boiler output. With modern boiler designs, this may represent only 1.5% on the gross calorific value at full rating, but will increase to around 6%, if the boiler operates at only 25 percent output.

Repairing or augmenting insulation can reduce heat loss through boiler walls and piping.

7. Automatic blowdown control

Uncontrolled continuous blowdown is very wasteful. Automatic blowdown controls can be installed that sense and respond to boiler water conductivity and pH. A 10% blow down in a 15 kg/cm^2 boiler results in 3% efficiency loss.

8. Reduction of scaling and soot losses

In oil and coal-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. Also, same result will occur due to scaling on the water side. 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 1% 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 about 20°C above the temperature for a newly cleaned boiler, it is time to remove the soot deposits. It is, therefore, recommended to install a dial type thermometer at the base of the stack to monitor the exhaust flue gas temperature.

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

9. Reduction of Boiler steam pressure

This is an effective means of reducing fuel consumption, if permissible, by as much as 1 to 2%. Lower steam pressure gives a lower saturated steam temperature and without stack heat recovery, a similar reduction in the temperature of the flue gas temperature results.

Steam is generated at pressures normally dictated by the highest pressure / temperature requirements for a particular process. In some cases, the process does not operate all the time, and there are periods when the boiler pressure could be reduced. The energy manager should consider pressure reduction carefully, before recommending it. Adverse effects, such as an increase in water carryover from the boiler owing to pressure reduction, may negate any potential saving. Pressure should be reduced in stages, and no more than a 20 percent reduction should be considered.

10. Variable speed control for Fans, Blowers and Pumps
Variable speed control is an important means of achieving energy savings. Generally, combustion air control is affected by throttling dampers fitted at forced and induced draft fans. Though dampers are simple means of control, they lack accuracy, giving poor control characteristics at the top and bottom of the operating range. In general, if the load characteristic of the boiler is variable, the possibility of replacing the dampers by a VSD should be evaluated.

11. Effect of Boiler loading on efficiency
The maximum efficiency of the boiler does not occur at full load, but at about two-thirds of the full load. If the load on the boiler decreases further, efficiency also tends to decrease. At zero output, the efficiency of the boiler is zero, and any fuel fired is used only to supply the losses. The factors affecting boiler efficiency are:

- As the load falls, so does the value of the mass flow rate of the flue gases through the tubes. This reduction in flow rate for the same heat transfer area, reduced the exit flue gas temperatures by a small extent, reducing the sensible heat loss.
- Below half load, most combustion appliances need more excess air to burn the fuel completely. This increases the sensible heat loss.

In general, efficiency of the boiler reduces significantly below 25% of the rated load and as far as possible, operation of boilers below this level should be avoided.

12. Proper Boiler scheduling
Since, the optimum efficiency of boilers occurs at 65-85% of full load, it is usually more efficient, overall, to operate a fewer number of boilers at higher loads, than to operate a large number at low loads.

13. Boiler replacement
The potential savings from replacing a boiler depend on the anticipated change in overall efficiency. A change in a boiler can be financially attractive if the existing boiler is:

- Old and inefficient
- Not capable of firing cheaper substitution fuel
- Over or under-sized for present requirements
- Not designed for ideal loading conditions

The feasibility study should examine all implications of long-term fuel availability and company growth plans. All financial and engineering factors should be considered. Since boiler plants traditionally have a useful life of well over 25 years, replacement must be carefully studied.

Lower water temperature settings: All too often water heater settings are much higher than they need to be and turning them down is one of the easiest ways to reduce energy waste. Before this, ensure the tank and piping have adequate insulation, and then measure the temperature of the water at some points of use. The maximum recommended water temperature for hand washing and showering is 40°C.

Reduce hot water Use: Install flow restrictors and aerators in sink faucets. Do not install them in areas like janitor's closets where they are used for filling buckets where filling speed is important. Install low-flow showerheads to reduce hot water usage. Some showerheads, particularly older ones, have flow rates of more than 18 l per minute, while low-flow models are half that amount. Check the flow rates in the showers by turning on the shower to a normal flow rate and timing how long it takes to fill a 4-litre bucket. Install self-closing faucets in public restrooms.

Reduce heat loss: If the hot water storage tank is warm to the touch, it is losing valuable heat to the surroundings 24 hours a day and needs a tank wrap or blanket. Blankets are inexpensive and easy to install and are readily available at hardware stores. Also insulate the exposed hot water piping, and repair or replace any existing insulation.

Label faucets: Posting labels such as "Please turn off the water." to remind user. If continuously running water is a problem, install self-closing faucets where you push down on a lever for 10 to 15 seconds of water flow. Also, occupancy sensing controls typically consisting of a photocell and solenoids can be installed above sinks to control water flow.

Reduce the amount of time the system operates: It may pay to turn the hot water generators off during times the facility is closed, or during peak electric demand hours. Time clocks are available for this purpose. Circulating pumps can be turned off in unoccupied wings of the hotel or facility when hot water is not necessary instantaneously.

7.11. Kitchen & Laundry equipment – energy performance assessment

Food preparation in hotel restaurants is a factor in the energy budget, with cooking using about 6% and refrigeration (not including guest icemakers) using about 2% of the total energy consumed in the hotel.

7.11.1. Data collection

Following data shall be collected during audit of kitchen and laundry from equipment nameplate and by interviewing the operator or manager.

- General operating parameters
- Rated parameters
- Operating hours
- User operational behaviour
- Age of the equipment

7.11.2. Instruments required

- IR thermometer
- Thermal imaging camera
- Hand-held clamp meter

7.11.3. Performance terms

Usually, different types of equipment are used in kitchen and laundry as per the user convenience, hence defining a standard performance term is difficult. However, an energy auditor shall rely on principle of energy balance i.e. energy in = energy out + energy stored.

7.11.4. Performance evaluation

There are no standard testing procedures or steps for performance evaluation of different types of equipment used in kitchen and laundry due to wide variation of equipment use. However, an energy auditor shall follow below steps to identify energy savings opportunities.

- Measure the energy consumption of the equipment per hour per day or per batch.
- Find the operating hours per day and annual operating hours of the equipment.
- Conduct visual inspection of equipment to identify noticeable losses including user behaviour.
- Find whether the audited equipment is the best available technology available in the market or the most energy efficient equipment.
- Develop energy savings opportunities, first with no/low cost options and then with medium and high investments.

7.11.5. Energy savings opportunities - Cooking

- Turn individual pieces of cooking equipment off or down to an idling temperature during slack production times or when not needed.
- Operate at the proper temperature, (e.g., fryers at 325˚F to 350˚F.) Excessive temperature wastes energy and often results in improperly cooked food.

- Do not increase temperature during rush hours to increase production. Excessive temperature could destroy the quality of the product and energy consumption will increase.
- On gas units, make sure each gas flame burns blue and adjust the gas to-air ratio when necessary. Keep burner parts clean. Poorly adjusted flames waste gas and may also deposit soot and carbon on the food.
- Do not load the units beyond the manufacturer's recommended capacity. Overloading results in poor food quality.
- Keep all units clean and properly maintained.
- Establish and implement a regular schedule of preventive maintenance tasks.

7.11.6. Specific measures for energy intensive equipment

A. **Fryers:** Drain and strain the oil and check fat levels frequently. This saves oil and preserves food quality. Low fat levels can cause premature oil breakdown.

B. **Griddles**: Pre-heat only until the griddle surface has achieved the correct cooking temperature required to cook the food, and heat only the sections necessary. Clean the griddle frequently and always re-season. Scrape the cooking surface between production intervals. Cleaning some types of griddle surfaces requires special tools - use them. Inspect each griddle section periodically for hot or cold spots.

C. **Broilers:** Preheating a broiler for an extended period of time or at an excessively high temperature wastes energy and could alter the food quality and taste. Load the broiler to maximum capacity to gain maximum efficiency. Clean grates frequently – carbonized grease hinders heat transfer, lowers cooking efficiency, and mars food quality. Adjust broiler section power; for example, use one section to full heat for rare meats, and lower another section for well-done meats, to save energy while also improving cooking consistency. Consider infrared broilers whenever possible as they may be turned off when not in use and then quickly reheated when needed.

D. **Ovens:** Energy efficiency of ovens depends upon how well they are constructed and used. Insulation levels and quality are two of the most significant factors in oven design. Some inexpensive ovens have little-to no insulation in the oven door. In addition, ovens consume considerable amounts of energy when they are left on, even when no food is being cooked. If your kitchen production requirement does not call for a full-sized oven, consider a half-size oven; it will operate at much better economies.

E. **Steamers:** Steamer ovens are well insulated to reduce heat loss to the kitchen. They are quick to preheat because of the high heat transfer characteristics of steam. Therefore, they require less energy to stay up to temperature during slow times. Keep the unit fully loaded when possible as a steamer operates at peak efficiency and productivity at full capacity. Control the water quality to the steamer. If the water in your area is hard or contains chemicals at any significant levels, these can coat and corrode the steaming components. This scale and possible chemical carryover can deteriorate steamer performance, food quality, and almost always results in premature steamer component failures. Check with a professional water treatment company about proper water softening.

7.11.7. Cold storage system

A Refrigerated storage which includes cold storage and frozen food storage is the best-known method of preservation of food to retain its value and flavour. The refrigeration system in a cold storage is usually a vapour compression system comprising the compressor, condenser, receiver, air cooling units and associate piping and controls.

In smaller cold rooms and walk-ins, the practice is to use air cooled condensing units with sealed, semi-sealed or open type compressors. In the light of the CFC phased out, the trend now is to use HCFC-22, HFC-134a or other substitute refrigerants. In the medium and large sized units, the practice is to use a central plant with ammonia as the refrigerant. In some present day medium and large sized units with prefabricated (insulated) panel construction the trend is to use modular HCFC-22/HFC units which are compact, lightweight, and easy to maintain.

7.11.8. Energy savings opportunities in kitchen refrigeration

Refrigeration is a vital tool for almost every food service operator, but refrigeration systems have two strikes against them, they are “On” all the time and they consume electricity. The hotel has a number of deep freezers and cold storage rooms. This means that even small amounts of energy wasted by poorly maintained refrigeration will add up to substantial costs over time. Here are some practical recommendations to keep refrigeration systems running efficiently:

- Use strip curtains or plastic swing doors on cold stores. These “infiltration barriers” block warm moist air from getting into the boxes while the door is open. Strip curtains used in busy kitchens can reduce compressor runtime significantly and that saves lot of energy. Remember, strip curtains have to cover the entire door opening.
- Make sure that the doors of the cold stores are shut all the time. Repair or replace broken auto-closers on the doors, lubricate door hinges, and realign sagging doors. Also, don’t allow employees to prop open walk-in doors.
- Check all the door gaskets every fortnightly on all refrigerators and replace any gaskets that are torn, cracked, worn out, or only plain missing. (Always use the manufacturer’s specified replacement). A refrigerator door must seal completely to be effective. Remember, that the proper sealing of doors is not for keeping the cold air in – it is to keep hot and humid kitchen air out.
- Airflow is an important part of refrigeration. When the coils are clogged and dirty, the compressor works harder and will fail sooner. Thus it is recommended to clean the evaporator coil (the cold one inside the refrigerator) and condenser coil (the hot one outside the refrigerator or on the roof) at least quarterly. If the aluminum fins are frozen or bent/damaged, then call a qualified service person for the cleaning. Remember – never use a caustic cleaner on these coils.
- Find the time clocks that control the freezer defrost and set them properly. Time clocks might be located on top of or underneath the freezers, on the wall, or on the roof. There is a clock for each freezer. With the help of these clocks, the number of daily defrost cycles can be reduced from four to three and sometimes even two. Each cycle should be about 15 minutes long. Also, make sure that the evaporator drain line is heated and

insulated so that the defrost condensate has some place to go. Improper defrosting can waste a lot of electricity and compromise safe freezer temperatures.

- Use only Compact fluorescent lamps (CFL) in cold storages. A regular CFL will work fine in the cold storage but for freezer a low temperature rated CFL or LED light is required. LED's would be the ideal solutions for both applications.

7.11.9. Energy savings opportunities in kitchen ventilation

An unbalanced or poorly designed kitchen exhaust system can spell trouble both for restaurant's air quality and for utility bills.

- Catch all that is possible – Cut down on spillage by adding inexpensive side panels to hoods that are failing to capture, and push each appliance as far back against the wall as possible to maximize hood overhang and close the air gap between the appliance and the wall.
- Rebalance the act – If an air balance has not been performed recently, it's time to do so. Time, maintenance, broken belts, and poor commissioning all lead to kitchen exhaust systems that are out of balance, potentially moving too much or too little air, spilling and costing money. This also applies to dining room heating, ventilation, and air conditioning (HVAC) system; outside doors that are hard to open because of suction or that blow open by themselves are a sure sign that it's time to order an air balance.
- Use variable-speed exhaust– Typically, kitchen exhaust hoods have two settings: "off" and "on". Naturally, "off" is ideal for when the kitchen is empty, and "on" may be great for the frenzied lunch and dinner rush—but neither is quite right for the afternoon lull, the post-dinner wind down, or any other situation when the kitchen isn't operating at full capacity. Variable-speed, demand-based exhaust controls get around this problem by using sensors to monitor the cooking and varying the exhaust fan speed to match the ventilation needs. Demand ventilation controls typically reduce the cost to operate an exhaust system by anywhere from 30 to 50 % and can be installed on either new installations or retrofitted to existing hoods.
- Maximize hood size – A 4-foot deep hood is somewhat typical for restaurant exhaust, but more smoke and heat can be captured if a 5 or 6-foot-deep hood is used.

7.11.10. Energy savings opportunities - Laundry

One of the large consumers of water and heat in the hotel, laundry is an outlet that can significantly reduce energy consumption with no effect on guest comfort or satisfaction. Some of the important points to achieve desired results are listed below:

- Shift the lights – different switches operating for different corners of the laundry. This will help in switching off the lights when not required.
- Clean lamps and lights fixture every month to maintain the lighting levels.
- Clean and wash walls, floors and ceiling to allow better reflection of lights.
- Check and record the water consumption. Compare water consumption daily to find wastages, if any.
- Consider using cold water detergents. It will greatly reduce energy consumption.

- Reduce hot water temperature to 48°C.
- Repair or replace all hot water piping insulation.
- All steam line values should be checked for leaks. That is, you should be able to shut off steam to any machine not in use keeping steam supply main open.
- If possible, use final rinse water for 1st wash while washing uniforms and hotel cloths.
- Reduce time between loads to prevent tumblers from cooling down.
- Air line should be checked for leaks.
- Periodically clean exhaust duct and blower of lint and dust.
- Keep steam pressure at lowest possible level.
- Shut off steam valve whenever machine is not being utilized.
- Keep radiator coils and fins free from dirt all the times.
- Ensure all steam traps in perfect working order.
- Keep an eye on the preventive maintenance schedule of all laundry equipment by Engineering Department to ensure timely compliance.
- Ensure that drying tumblers and washing machines are always kept clean and free from scale.
- Switch off laundry exhaust fans when laundry is closed.
- Ensure that extractors are working properly. Incomplete extraction increases load on dryer and consumes more energy for drying.
- Inform boiler room when hot water is not required so that boilers can be shut down to save fuel.

7.12. DG Sets - energy performance assessment

7.12.1. Introduction

Reciprocating engines produce electricity using a combustible fuel and generator. In addition to producing electricity, useful heat can be recovered from the exhaust gas using a heat recovery steam generator (HRSG), or heat recovery system for hot water **Figure 60**. Heat can also be recovered from the lubricating oil cooler, the jacket water cooler and/or the charge air cooler, and this recovered "waste" heat can be provided to a heating load. In this case, the reciprocating engine power plant would be operating in a Combined Heat & Power (CHP) or cogeneration mode. The energy performance of a reciprocating engine is influenced by several factors such as the type of fuel, the reciprocating engine power capacity, minimum capacity, availability, heat rate and heat recovery efficiency.

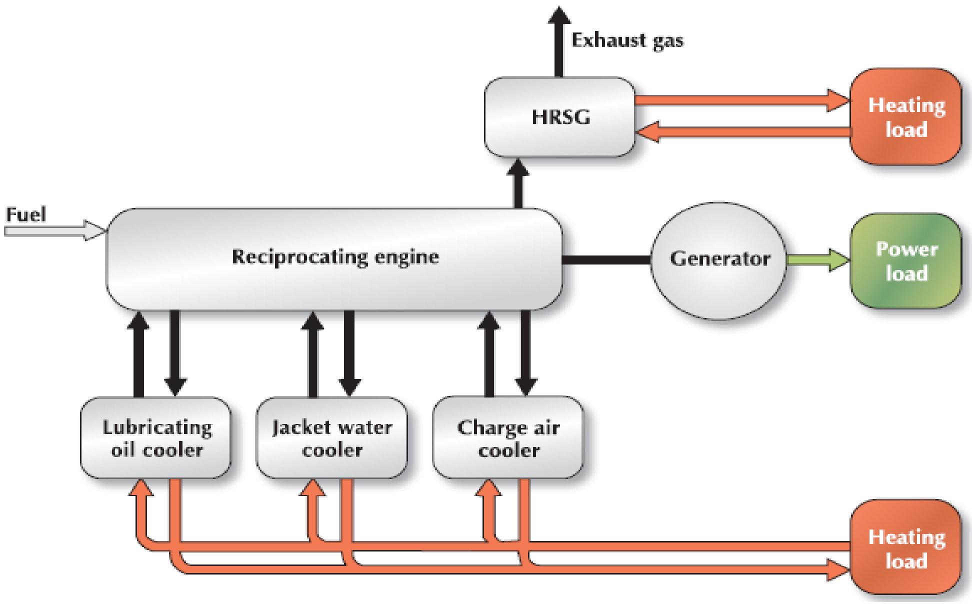


Figure 60: Reciprocating engine cogeneration

A diesel generating set **Figure 61** should be considered as a system since its successful operation depends on the well-matched performance of the components, namely:

a) The diesel engine and its accessories.
b) The AC Generator.
c) The control systems and switchgear.
d) The foundation and powerhouse civil works.
e) The connected load with its own components like heating, motor drives, lighting etc.

It is necessary to select the components with highest efficiency and operate them at their optimum efficiency levels to conserve energy in this system.

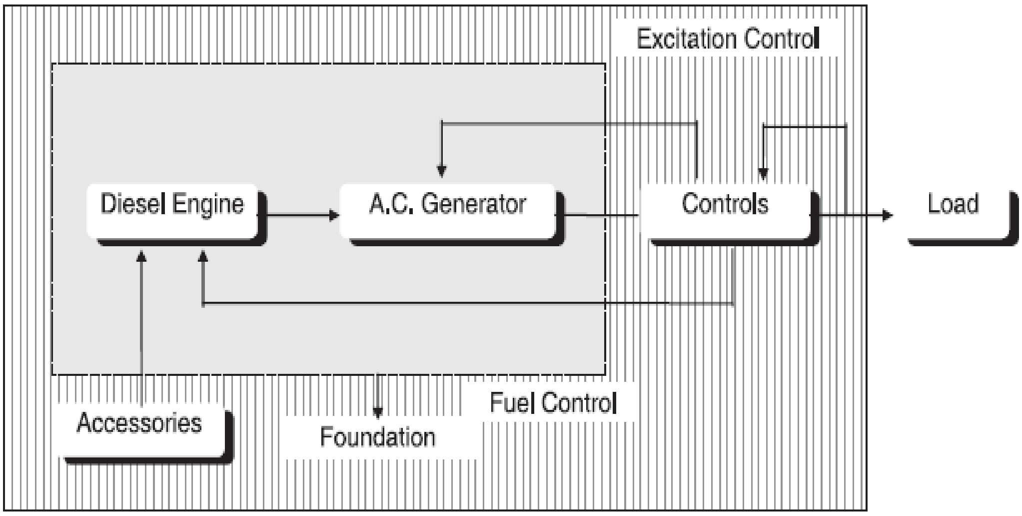


Figure 61: DG set system

7.12.2. Selection considerations

To decide on the type of engine, which is most suitable for a specific application, several factors need to be considered. The two most important factors are: power and speed of the engine. The power requirement is determined by the maximum load. The engine power rating should be 10-20% more than the power demand by the end use. This prevents overloading the machine by absorbing extra load during starting of motors or switching of some types of lighting systems or when wear and tear on the equipment pushes up its power consumption. Speed is measured at the output shaft and given in revolutions per minute (RPM). An engine will operate over a range of speeds, with diesel engines typically running at lower speeds (1300- 3000 RPM). There will be an optimum speed at which fuel efficiency will be greatest. Engines should be run as closely as possible to their rated speed to avoid poor efficiency and to prevent build-up of engine deposits due to incomplete combustion - which will lead to higher maintenance and running costs. To determine the speed requirement of an engine, one has to again look at the requirement of the load.

For some applications, the speed of the engine is not critical, but for other applications such as a generator, it is important to get a good speed match. If a good match can be obtained, direct coupling of engine and generator is possible; if not, then some form of gearing will be necessary - a gearbox or belt system, which will add to the cost and reduce the efficiency.

There are various other factors that have to be considered, when choosing an engine for a given application. These include the following: cooling system, abnormal environmental conditions (dust, dirt, etc.), fuel quality, speed governing (fixed or variable speed), poor maintenance, control system, starting equipment, drive type, ambient temperature, altitude, humidity, etc.

Suppliers or manufacturers literature will specify the required information when purchasing an engine. The efficiency of an engine depends on various factors, for example, load factor (percentage of full load), engine size, and engine type.

7.12.3. Selection and installation factors

Sizing of a Genset:

a) If the DG set is required for 100% standby, then the entire connected load in HP / kVA should be added. After finding out the diversity factor, the correct capacity of a DG set can be found out.

   Example: Connected Load = 650 kW
   Diversity Factor = 0.54 (Demand / Connected load)
   Max. Demand = 650 x 0.54 = 350 kW
   % Loading = 70
   DG Set rating = 350/0.7 = 500 kW
   At 0.8 PF, rating = 625 kVA

b) For a new installation, an approximate method of estimating the capacity of a DG set is to add full load currents of all the proposed loads to be run in DG set. Then, applying a diversity factor depending on the facility, process involved, and guidelines obtained from other similar units, correct capacity can be arrived at.

   High Speed Engine or Slow/Medium Speed Engine. The normal accepted definition of high-speed engine is 1500 rpm. The other features and comparison between high and medium / slow speed engines are mentioned below **Table 38**:

Table 38: Comparison of high & slow speed engine

Factor	Slow speed engine	High speed engine
Break mean effective pressure - therefore wear and tear and consumption of spares	Low	High
Weight to power ratio- therefore sturdiness and life	More	Less
Space	High	Less
Type of use	Continuous use	Intermittent use
Period between overhauls[5]	8000 hours	3200 hours
Direct operating cost (includes lubricating oils, filters etc.	Less	High

[5] Typical recommendations from manufacturer

Keeping the above factors and available capacities of DG set in mind, the cost of economics for both the engines should be worked out before arriving at a decision

Capacity combinations
From the point of view of space, operation, maintenance, and initial capital investment, it is certainly economical to go in for one large DG set than two or more DG sets in parallel.

Two or more DG sets running in parallel can be a advantage as only the short-fall in power – depending upon the extent of power cut prevailing - needs to filled up. Also, flexibility of operation is increased since one DG set can be stopped, while the other DG set is generating at least 50% of the power requirement. Another advantage is that one DG set can become 100% standby during lean and low power-cut periods.

Air cooling versus water cooling
The general feeling has been that a water-cooled DG set is better than an air-cooled set, as most users are worried about the overheating of engines during summer months. This is to some extent is true and precautions have to be taken to ensure that the cooling water temperature does not exceed the prescribed limits. However, from performance and maintenance point of view, water and air cooled sets are equally good except that proper care should be taken to ensure cross ventilation so that as much cool air as possible is circulated through the radiator to keep its cooling water temperature within limits.

While, it may be possible to have air cooled engines in the lower capacities, it will be necessary to go in for water cooled engines in larger capacities to ensure that the engine does not get over-heated during summer months.

Safety features
It is advisable to have short circuit, overload and earth fault protection on all the DG sets. However, in case of smaller capacity DG sets, this may become uneconomical. Hence, it is strongly recommended to install a circuit protection. Other safety equipment like high temperature, low lube oil pressure cut-outs should be provided, so that in the event of any of these abnormalities, the engine would stop and prevent damage. It is also essential to provide reverse power relay when DG sets are to run in parallel to avoid back feeding from one alternator to another.

Parallel operation with grid
Running the DG set in parallel with the mains from the supply undertakings can be done in consultation with concerned electricity authorities. However, some supply undertakings ask the consumer to give an undertaking that the DG set will not be run in parallel with their supply. The reasons stated are that the grid is an infinite bus and paralleling a small capacity DG set would involve operational risks despite normal protections like reverse power relay, voltage and frequency relays.

Maximum single load on DG set
The starting current of squirrel cage induction motors is as much as six times the rated current for a few seconds with direct-on-line starters. In practice, it has been found that the starting

current value should not exceed 200 % of the full load capacity of the alternator. The voltage and frequency throughout the motor starting interval recovers and reaches rated values usually much before the motor has picked up full speed.

In general, the HP of the largest motor that can be started with direct online starting is about 50 % of the kVA rating of the generating set. On the other hand, the capacity of the induction motor can be increased, if the type of starting is changed over to star delta or to auto transformer starter, and with this starting the HP of the largest motor can be up to 75 % of the kVA of Genset.

Unbalanced load effects

It is always recommended to have the load as much balanced as possible, since unbalanced loads can cause heating of the alternator, which may result in unbalanced output voltages. The maximum unbalanced load between phases should not exceed 10 % of the capacity of the generating sets.

Neutral earthing

The electricity rules clearly specify that two independent earths to the body and neutral should be provided to give adequate protection to the equipment in case of an earth fault, and also to drain away any leakage of potential from the equipment to the earth for safe working.

7.12.4. Waste heat recovery in DG sets

A typical energy balance in a DG set indicates following break-up:

Table 39: Energy balance in DG set

Input	Output
100% Thermal Energy	35% Electrical Output
	4% Alternator Losses
	33% Stack Loss through Flue Gases
	24% Coolant Losses
	4% Radiation Losses

Among these, stack losses through flue gases or the exhaust flue gas losses on account of existing flue gas temperature of 350°C to 550°C, constitute the major area of concern towards operational economy. It would be realistic to assess the Waste Heat Recovery (WHR) potential in relation to quantity, temperature margin, in kcals/Hour as:

Potential WHR = (kWh Output/Hour) × (8 kg Gases / kWh Output) × 0.25 kcal/kg°C × (t_g– 180°C)

Where, t_g is the gas temperature after Turbocharger, (the criteria being that limiting exit gas temperature cannot be less than 180°C, to avoid acid dew point corrosion), 0.25 being the specific heat of flue gases and kWh output being the actual average unit generation from the set per hour. For a 1100 KVA set, at 800 KW loading, and with 480°C exhaust gas temperature, the waste heat potential works out to: 800 kWh × 8 kg gas generation / kWh output × 0.25 kCal/kg°C × (480 – 180), i.e., 4,80,000 kCal/hr

While the above method yields only the potential for heat recovery, the actual realisable potential depends upon various factors and if applied judiciously, a well configured waste heat recovery system can tremendously boost the economics of captive DG power generation.

The factors affecting Waste Heat Recovery from flue Gases are:
a) DG Set loading, temperature of exhaust gases
b) Hours of operation and
c) Back pressure on the DG set

Consistent DG set loading (to over 60% of rating) would ensure a reasonable exit flue gas quantity and temperature. Fluctuations and gross under loading of DG set results in erratic flue gas quantity and temperature profile at entry to heat recovery unit, thereby leading to possible cold end corrosion and other problems.

Number of hours of operation of the DG Set has an influence on the thermal performance of waste heat Recovery unit. With continuous DG Set operations, cost benefits are favourable.

Back pressure in the gas path caused by additional pressure drop-in waste heat recovery unit is another key factor. Generally, the maximum back pressure allowed is around 250-300 mmWC and the heat recovery unit should have a pressure drop lower than that. Choice of convective waste heat recovery systems with adequate heat transfer area are known to provide reliable service.
The configuration of heat recovery system and the choice of steam parameters can be judiciously selected with reference to the specific facility (site) requirements. One interesting configuration of waste heat recovery deployed is installation of waste heat boiler in flue gas path along with a vapour absorption chiller, to produce 8°C chilled water working on steam from waste heat.

7.12.5. Data collection

Following data shall be collected by interviewing the DG set operator or supervisor:

- Annual running hours
- Annual electricity produced
- Annual Diesel consumption
- All other rated and operational parameters of DG Set

In addition to above, the following data shall be collected through observations & measurements:

- Electricity consumption during trial period
- Diesel consumption during trial period
- Flue gas analysis data

7.12.6. Instruments required

- Three-phase power analyser
- Flue gas analyser
- Measuring tape

7.12.7. Performance terms

$$Specific\ Fuel\ Consumption = \frac{Fuel\ consumption\ by\ DG\ set}{Electricity\ generated\ (kWh)}$$

7.12.8. Performance assessment

Routine energy efficiency assessment of DG sets on shop floor involves following typical steps:

Conduct a 2-hour trial on the DG set, ensuring a steady load, wherein the following parameters to be measurements.

1. Power logging to measure current, voltage, Power factor, average loading, and kWh generation.
2. Fuel consumption by measuring difference in diesel level of fuel tank before and after the trial. This diesel level can be measured by the dipping the stick in the diesel tank. Or the diesel consumption can be noted from diesel flow meter if installed and calibrated.
3. Stack gas temperature.

A format as shown in the below **Table 40** is useful for monitoring the performance.

Table 40: Typical format for DG set monitoring

DG Set No.	Electricity Generating Capacity (Site), kW	Average loading during trial, kW	Type of Fuel used	Average Load	Specific Fuel Consumption (l/kWh)

Example: A 200 kVA DG set produces 650 kWh unit while consuming 200 litres of diesel calculate its specific fuel consumption.

Solution:

Specific Fuel consumption= Fuel consumption by DG set / Electricity generated (kWh)
Specific fuel consumption= 200/650 =**0.30 litres/kWh**

7.12.9. Energy saving opportunities in DG sets

- Ensure steady load conditions on the DG set, and provide cold, dust free air at intake (use of air washers for large sets, in case of dry, hot weather, can be considered).
- Improve air filtration.
- Ensure fuel oil storage, handling, and preparation as per manufacturers' guidelines/oil company data.
- Consider fuel oil additives in case they benefit fuel oil properties for DG set usage.
- Calibrate fuel injection pumps frequently.
- Ensure compliance with maintenance checklist.
- Ensure steady load conditions, avoiding fluctuations, imbalance in phases, harmonic loads.
- In case of a base load operation, consider waste heat recovery system adoption for steam generation or refrigeration chiller unit incorporation. Even the Jacket Cooling Water is amenable for heat recovery, vapour absorption system adoption.
- In terms of fuel cost economy, consider partial use of biomass gas for generation. Ensure tar removal from the gas for improving availability of the engine in the long run.
- Consider parallel operation among the DG sets for improved loading and fuel economy thereof.
- Carryout regular field trials to monitor DG set performance, and maintenance planning as per requirements.

7.13. Renewable energy systems

7.13.1. Scope in energy audit

The inclusion of Renewable energy in energy audits depends upon the focus of the audit and the objectives of the client organization management team. If the organisational goal is to reduce the overall carbon footprint, then it will come under renewable energy focused areas. Whereas if the organisation's goal is to reduce the energy, this will come under the scope of energy audit. Also, it should be noted that low-cost or no-cost opportunities should be of prime focus. Principle which focusses on reducing the size of the renewable system required or to save the energy wastage should be followed under renewable energy audits.

The solar systems are available in various sizes depending upon the application. Over the years as the technology has improved the efficiency of these solar energy collector has improved and there are a lot of varieties available. The amount of electricity generated is dependent on several factors: the size and arrangement of the system, module type, the available sunlight, and the efficiency of the electrical components used to covert solar energy into electricity.

7.13.2. Stand-alone PV system

A free standing or Stand-alone PV System is made up of a number of individual photovoltaic modules (or panels) usually of 12 volts with power outputs of between 50 and 100+ watts each. These PV modules are then combined into a single array to give the desired power output. A simple *standalone PV system* is an automatic solar system that produces electrical power to charge banks of batteries during the day for use at night when the suns energy is unavailable. A stand-alone small-scale PV system employs rechargeable batteries to store the electrical energy supplied by a PV panels or array.

Stand-alone PV systems are ideal for remote rural areas and applications where other power sources are either impractical or are unavailable to provide power for lighting, appliances, and other uses. In these cases, it is more cost effective to install a single stand-alone PV system than pay the costs of having the local electricity company extend their power lines and cables directly to the home.

A stand-alone photovoltaic (PV) system is an electrical system consisting of and array of one or more PV modules, conductors, electrical components, and one or more loads. But a small-scale PV system does not have to be attached to a roof top or building structures for domestic applications, they can be used for camper vans, RV's, boats, tents, camping and any other remote location. Many companies now offer portable solar kits that allow you to provide your own reliable and free solar electricity anywhere you go even in hard to reach locations.

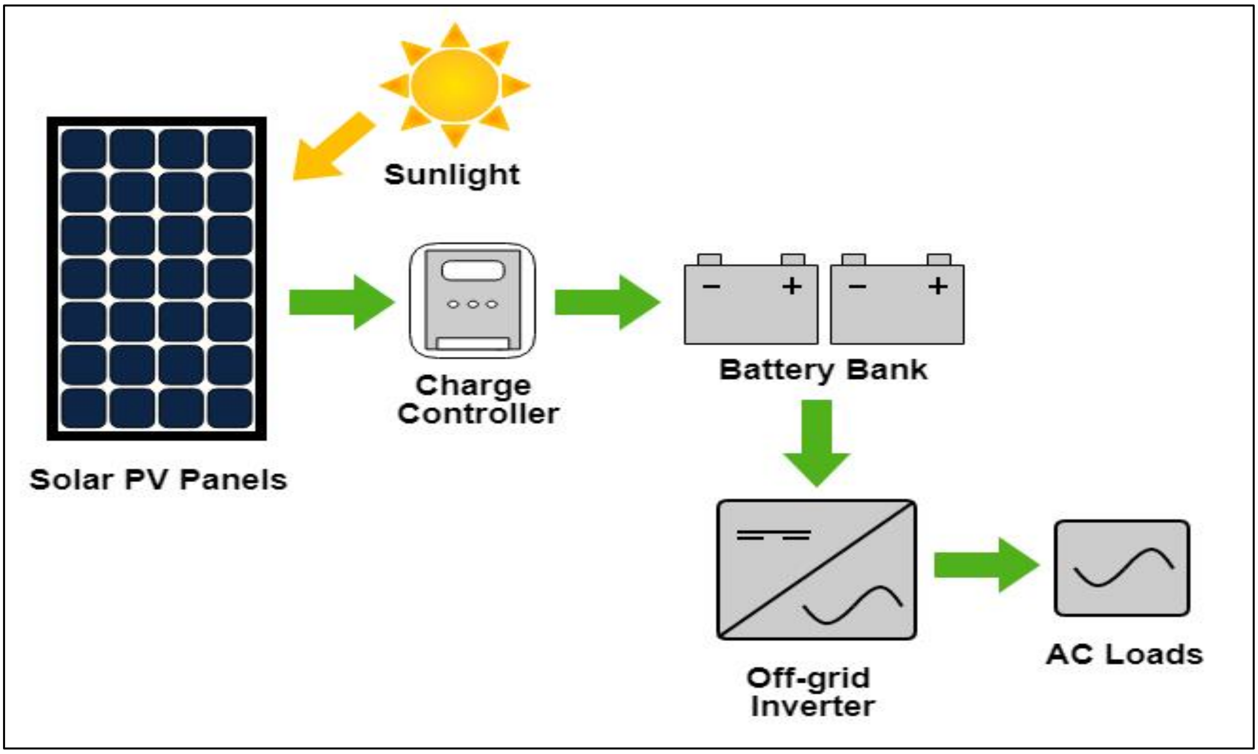


Figure 62: Stand-alone PV system (Source: Apricus solar)

7.13.3. Solar potential in Bhutan

According to International Renewable Energy Agency (IRENA), Bhutan has the potential of 12 GW of solar generation capacity. The solar resource data show that Bhutan has an adequate resource for flat-plate collectors, with annual average values of global horizontal solar radiation ranging from 4.0 to 5.5 kWh/m^2 per day (4.0 to 5.5 peak sun hours per day). Various other parameters related to the solar energy are mentioned below.

Direct Normal Solar Radiation: **Figure 63** shows the annual average direct normal radiation which are important for solar thermal system. The DNI varies between 2.5 and 5.0 kWh/m^2 per day. The best DNI resource is in some of the high-altitude areas in the far north of the country. Average DNI estimate of less than 6.0 or 7.0 kWh/m^2 per day is insufficient for concentrating solar power systems.

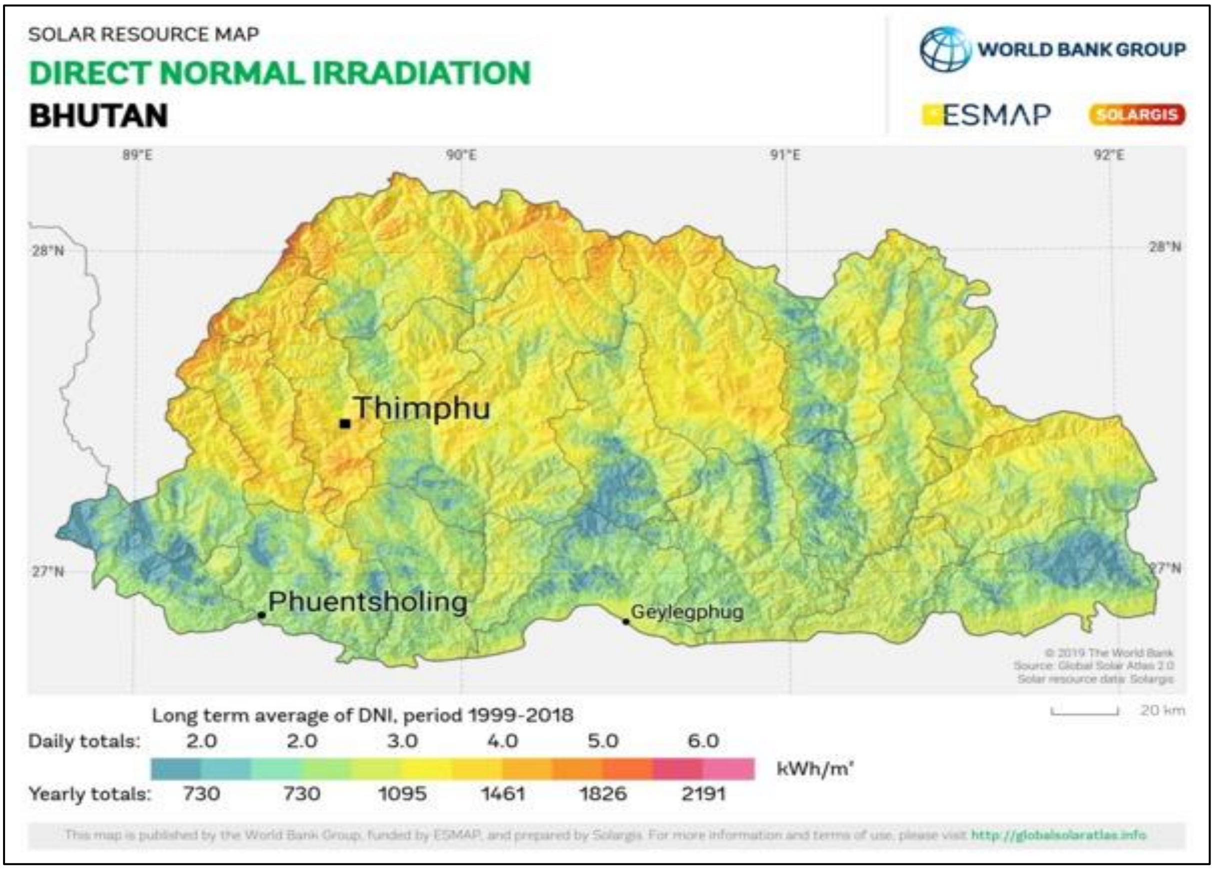


Figure 63: Direct Normal Irradiation map of Bhutan (Source: World bank group)

Global Horizontal Solar Radiation: **Figure 64** shows the annual average GHI, which is considered for flat plate solar collector applications. The values range from 4.0 to 5.5 kWh/m^2 per day. From the figure it is clear that the solar resource for flat-plate collectors is available for Bhutan. The best resource is in the northern part of the country with a few in the central-west portion near Paro and just north of Wangdue. In Bhutan's rural electrification program, estimations of solar home system production use an annual average GHI value of 4.4 kWh/m^2 per day (NREL).

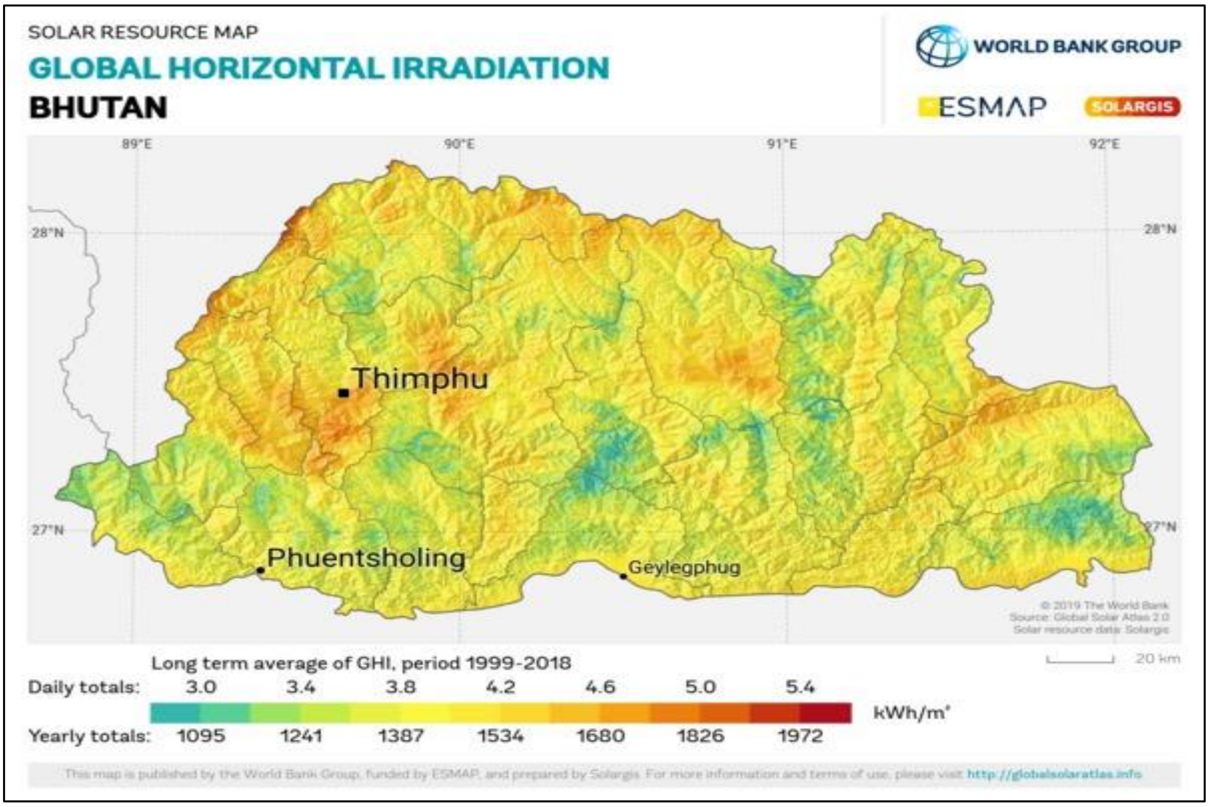


Figure 64: Global Horizontal Irradiation (Source: World bank group)

7.13.4. Data collection to estimate solar PV potential

If a solar PV is not installed, following data shall be collected from site for solar potential estimate

- Connected load (kW)
- Actual average load (kW)
- Average monthly electricity consumption (kWh)
- Critical load (needs to ON most of the time)
- Annual working days
- Available area, rooftop or ground in m^2
- If available area is rooftop than find type of rooftop (tiles/corrugated metals/others)

7.13.5. Data collection for solar PV audit

If a solar PV is already installed, following data shall be collected during audit:

- Average electricity generation by solar plant per month and year (kWh/month, kWh/year)
- DC power output from PV module (kW) or DC power input to inverter (kW)
- AC power input from inverter (kW)
- Array area (m^2)
- GPS location of solar plant

7.13.6. Instruments required

- Measuring tape or Distance meter
- Hand-held clamp meter
- Compass

7.13.7. Performance terms

- Performance ratio
- Solar PV module efficiency
- Inverter efficiency
- System efficiency
- Capacity utilisation factor

7.13.8. Performance assessment of the PV system

The performance of solar photovoltaic power plant work can be done manually as well as automatically using various software's or tools. The tools imports meteorological data from many different sources and help to predict the performance of the system. Software can evaluate the performance of grid-connected, stand-alone and pumping systems based on the specified module selection. The program accurately predicts the system yields computed using detailed hourly simulation data. Solar GIS is a geographic information system designed to meet the needs of the solar energy industry. The application combines solar resource data and meteorological data with a web-based application system to support planning, development, and operation of solar energy systems.

While in order to evaluate the performance of SPV plant manually, it required to understand various parameters. These parameters are the indicators of the performance of the plant and can be used by the auditor for evaluating the plant performance.

Performance Ratio (PR)

The performance ratio (PR) indicates the overall effect of losses on a PV array's normal power output depending on array temperature and incomplete utilization of incident solar radiation and system component inefficiencies or failures. Also defined as a ratio of the final yield divided by the reference yield and it represents the total losses in the PV system when converting from DC to AC. It indicates how close it approaches ideal performance during real operation and allows comparison of PV systems independent of location, tilt angle, orientation, and their nominal rated power capacity. Performance ratio will also consider the availability of the grid, minimum level of irradiation needed to generate electrical energy.

Performance ratio is defined by the following equations as

$$PR\ (\%) = \frac{Total\ AC\ Energy\ Output(kWh)}{Global\ Irradiation, (kWh/m^2)\ X\ Array\ Plane\ Area(m^2)\ X\ Panel\ Efficiency}\ X\ 100$$

7.13.9. Solar PV module efficiency

Solar panel efficiency is a measurement of a solar panel's ability to convert sunlight into usable electricity. The efficiency is the most used parameter to compare the performance of one solar cell to another. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Different types of materials used in manufacturing of solar panel yields possess different efficiencies. Today, most solar panels have efficiencies between 15% and 20%. The instantaneous PV module conversion efficiency is calculated in the equation:

$$P_{max} = V_{OC} \, X \, I_{SC}$$

Where,
Voc is the open-circuit voltage
Isc is the short-circuit current

$$\eta_{PV} = \frac{DC\ power\ output\ from\ the\ PV\ module\ (kW)}{Global\ Irradiation\ kW/m^2\ \ X\ Array\ area(m^2)}\ X\ 100$$

7.13.10. Inverter efficiency

It is the comparison of the amount of the total AC power obtained after the inverter with the DC power generated by the solar panel. In order to maintain a good overall system efficiency, it is required that an appropriate inverter is selected for the system. The instantaneous PV module conversion efficiency is calculated in the equation.

$$\eta_{inv} = \frac{AC\ power\ output\ from\ the\ inverter\ (kW)}{DC\ power\ input\ to\ the\ inverter\ (kW)}\ X\ 100$$

7.13.11. System efficiency

System efficiency is a collective term that include efficiencies of various electrical equipment present in the system along with various other efficiencies that affects the system. The instantaneous PV module conversion efficiency is calculated in the equation.

$$\eta_{PV} = \frac{AC\ power\ output\ from\ the\ system\ (kW)}{Global\ Irradiation\ kW/m^2\ \ X\ Array\ area(m^2)}\ X\ 100$$

7.13.12. Capacity Utilisation Factor (CUF)

It is the ratio of the actual output from a solar plant over the year to the maximum possible output from it for a year under ideal conditions. If the system delivers full rated power continuously, its CF would be unity. It is dependent on the location, orientation, tilt angle unlike the Performance ratio.

$$CUF(\%) = \frac{Energy\ output\ (kWh)}{Total\ Installed\ Capacity\ (kW)\ X\ time\ period\ (hrs)}\ X\ 100$$

7.13.13. Specific plant losses

Energy losses occur in various components in a SPV Power plant under real operating conditions. These losses are evaluated using the monitored data.

There exist a variety of sources through which energy losses occur in PV systems. These losses affect the performance of PV systems thereby justifying why, it is necessary to evaluate these losses using detailed performance monitoring data. Prominent among these losses are array capture losses, shading losses, system losses, cell temperature losses, soiling and degradation. Soiling and degradation losses are more difficult to evaluate because they are small effects that occur over large fluctuations in operating conditions.

The International Electrotechnical Commission (IEC) prepares and publishes international standards for photovoltaic systems that convert solar energy into electrical energy, as well as for all the elements in the entire photovoltaic energy system. In case of detail specific or performance monitoring these testing, procedures needs to be followed. The standards are used for testing and monitoring the module performance. Some of them are mentioned below:

IEC 60891 Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics
IEC 61853-2: Scope of work in progress includes spectral response, incidence angle and module operating temperature measurements for PV module performance testing and energy rating.
IEC 61683 Power conditioners – Procedure for measuring efficiency

7.13.14. Effect of temperature on Solar efficiency

The power generation from the PV plant is greatly affected by the temperature. If the temperature of the module goes beyond the rated module temperature, the power generated is much less when compared to the power generated when the temperature equals or is marginally greater than the rated temperature. This effect appears on the output voltage of the cell, where the voltage is indirectly proportional to the temperature, i.e. the decrease in voltage is caused by an increase in the cell temperature.

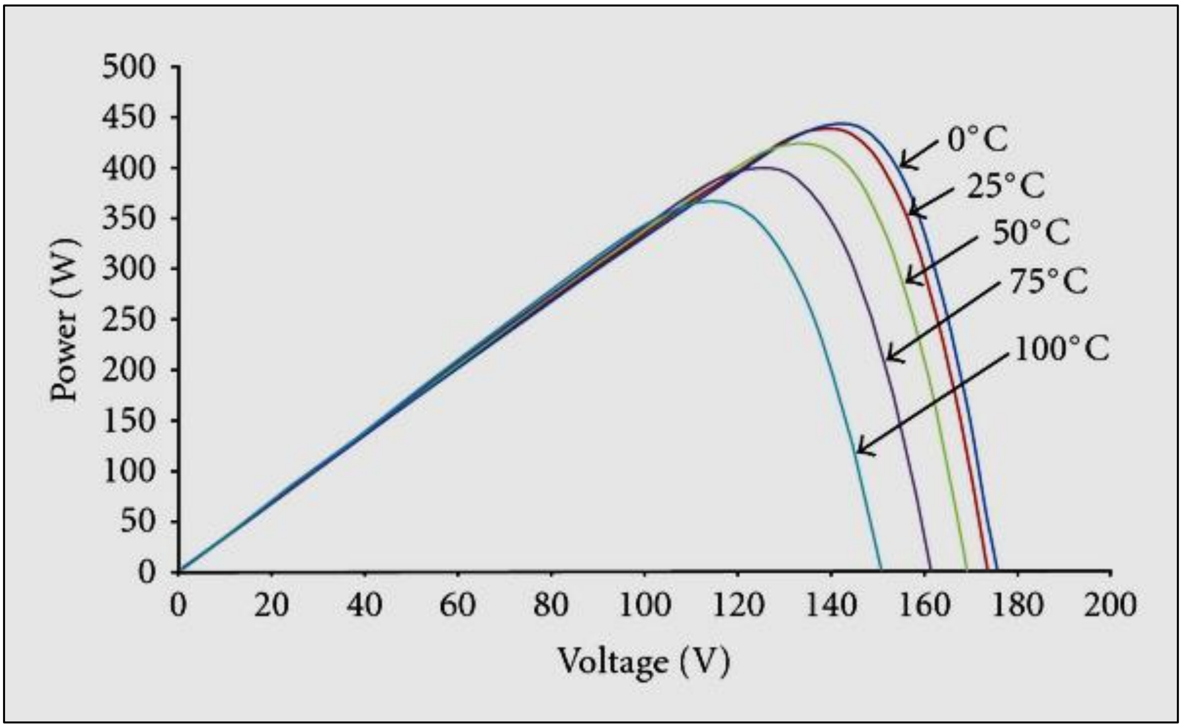


Figure 65: Effect of temperature change on power and voltage

7.13.15. Solar PV facts

- The area required to install 1 kWp capacity solar PV system is approx. 8 to 10 m^2.
- Solar panels produce approx. 10 kWh of electricity per square foot.
- It is possible to install a solar PV system without battery to reduce installation cost.
- The orientation of solar panels (solar angles) are best aligned according to the latitude of location.
- Solar PV also produces electricity during cloudy days, but in lesser amount.
- Most solar panels come with a 25-year warranty. Solar energy is a completely free source of energy and is found in abundance. Solar energy can also be used to generate hot water or steam for process applications in industries.

7.13.16. Solar water heating system

Solar water heating system is a device that uses solar energy to heat water for domestic, commercial, and industrial needs. Water is heated during the daytime and is stored in a tank which makes it available throughout the day as well night due to insulation provided over the tank. The system is generally installed on the roof or open ground, with the collector facing the sun and connected to a continuous water supply. The sun rays have heats up the water up to 55°C to 70°C which is more than enough for various applications. The water remains at required temperature for a duration of approximately two days.

For use in cloudy days, as a backup the system consists of an electrical heating system. The estimated life of a solar water heater is 15 to 20 years. A typical solar water heating system roughly can save up to 1500 units of electricity every year, for every 100 litres per day of solar water heating capacity.

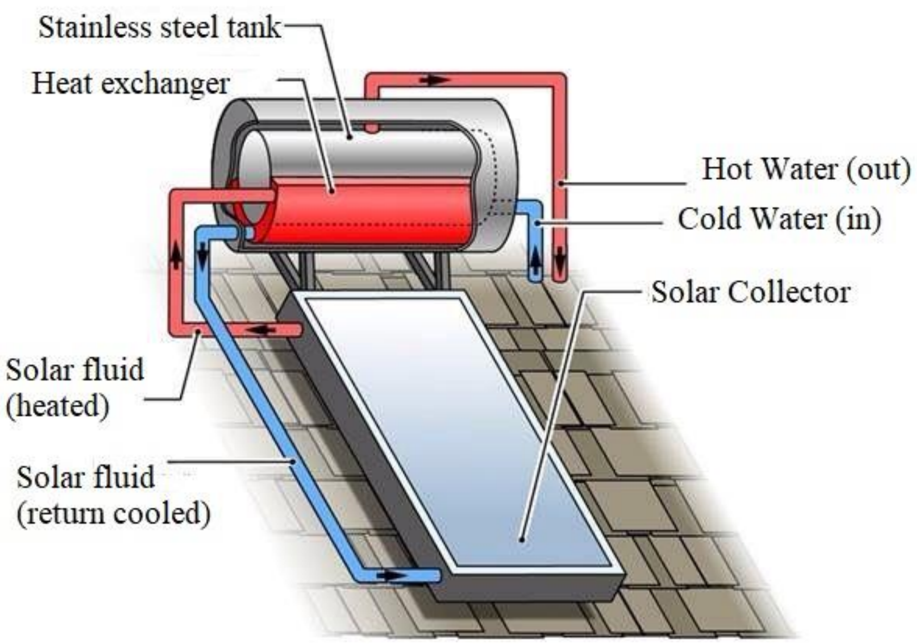


Figure 66: Solar water heater

7.13.17. Data collection to estimate solar water heating potential

If a solar thermal system is not installed, following data shall be collected to estimate solar water heating potential:

- Amount of hot water required per day (kl/day)
- Available roof top or ground area (m^2)
- Existing system of water heating
- Existing energy usage for water heating
- Type of process and other relevant details

7.13.18. Selection of a solar water system

The following factors are considered while selecting an appropriate solar water heating system for any facility.

1. **Types of panels**

There are basically two types of solar panel commonly available are:

Flat plate collector

Flat plate solar panels are commonly used collectors that has a metal plate with a dark-coloured coating to absorb heat. Pipes under the plate contain water or some other fluid such as glycol, which absorbs heat and carries it to the water in the storage cylinder. A transparent cover, usually glass, admits solar radiation but stops it from escaping. The construction is simple, with no moving parts, which means they are easily repaired. They are relatively low cost and can supply water at temperatures up to 95ºC, though efficiency diminishes rapidly above 70ºC, so systems should be sized to avoid these sorts of temperatures.

Evacuated glass tube collector

Evacuated glass tube solar panels are made up of several glass tubes, typically 20 or more. Each tube has a vacuum to reduce convection and conduction heat losses. Evacuated tubes may contain an absorber plate connected to pipes through which a heat-absorbing fluid circulates or a heat pipe that contains an evaporating/condensing fluid to transfer heat.
Individual tubes sometimes fail but can be replaced at relatively low cost.

2. **Sizing the panels**

The size of the panel depends on the water storage capacity available and is typically based on a ratio of about 1 square meter of panel for each 50–70 litres of cylinder volume. Most panels commercially available are in the 3–8 m² range.

3. **Positioning to maximize solar heat absorption**

The heating capacity of a solar water heating system is directly proportional to the amount of solar radiation absorbed, which depends on the following factors:

- Solar intensity: That is the available solar radiation energy (kWh/m²) at a location.
- Solar panel area: The larger the area, the more heat can be produced.
- Solar panel tilt angle: The optimum installed angle for solar absorption is perpendicular to the sun. But due to the continuous change in sun's position an optimal angle is chosen to maximize the utilization.
- Solar panel orientation: The positioning of the panel to maximize the solar energy considering the suns movement.

7.13.19. Efficiency of collector

The efficiency and effectiveness of a solar water heating system depends on the size, type of panels used, and on positioning them to maximize absorption of solar radiation. Although for basic evaluation of performance of solar water heater, the efficiency of the system needs to be monitored. Collector efficiency can be given as the ratio between the solar energy incident on the panel to the available thermal energy at the application site. Efficiency can be shown in the equation as follows:

$$\eta = \frac{Heat\ energy\ available}{Incident\ Solar\ energy} = \frac{Q_{out}}{Q_{in}}$$

Where,

$$Q_{in} = A_c X G_t$$

$$Q_{out} = m X C_p X (T_{out} - T_{in})$$

$$\eta = \frac{m X C_p X F_R X (T_{out} - T_a)}{A_c X G_t}$$

Where,

Q_{out} = the energy absorbed by the collector (W/m^2)
m = mass of water going into the collector (kg/s)
C_p = specific heat capacity of water
A_C = the size of the collector (m^2)
F_R = collector heat loss factor
G_t = total solar radiation intensity (W/m^2)
T_{in} = temperature of incoming water
T_{out} = temperature of the outgoing water
T_a = ambient temperature

8 Energy Performance Index (EPI)

8.1. Introduction

The Energy Performance Index (EPI) of a building is its annual energy consumption in kilowatt-hours per square meter of the building. While calculating the EPI of a building, the area of unconditioned basements shall not be included. EPI can be determined by:

$$EPI = \frac{annual\ energy\ consumption\ in\ kWh}{Total\ build\ up\ area\ (excluding\ unconditioned\ basement)}$$

Energy Performance Index (EPI) in kWh/m^2/year will be consider for rating the building on energy performance. Bandwidths for Energy Performance Index for different climatic zones have been developed based on percentage air-conditioned spaces. For example, a building in composite climatic zone having greater than 50% of their build up area, the bandwidths of EPI range between 190-90 kWh/m^2/year.

8.2. Determining Energy Performance Index (EPI)

The different sources of energy used in the building have to be identified with the help of facility people and walkthrough survey of the facilities.

Step 1- Data collection

The following data needs to be collected for calculating EPI.

- The total electrical energy consumption of the facility both grid and captive[6] are to be collected month wise over a one-year period.
- The total builds up area of the building needs to be collected. The buildup area is the carpet area plus area covered by thickness of walls plus balconies etc. and would exclude parking areas.
- The operating hours per day and working days per year have to be collected.

Step 2- Analysis

Energy performance Index (EPI): Energy Performance Index is a measuring tool to evaluate the performance of the building in terms of the total energy consumption and the total built up area.

$$\text{Energy Performance Index (EPI), kWh/annum}/m^2 = \frac{(EB^7\ energy + DG\ energy),\ \ kWh/annum}{Total\ builtup\ area,\ m^2}$$

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[6] In case diesel generator set (DG) is also installed then monthly energy generated by DG must be collected for a year

[7] EB- Electricity Bill

Table 41: EPI Comparison

Parameter	Actual EPI	EPI recommended by Building code
EPI (kWh/annum/m^2)		

8.3. Determining Average Annual Hourly EPI (AAHEPI)

The number of operating hours of a building may vary depending on the nature of operation. The AAHEPI enables the performance assessment taking into account the actual operating hours which will be more meaningful. AAHEPI is defined as follows.

$$\text{AAHEPI, Wh/h}/m^2 = \frac{EPI,\ (kWh\ per\ annum\ per\ m^2)}{Operating\ hours\ per\ annum}\ X\ 1000$$

Example: A commercial building located in warm and humid climatic region, has built up area of 17,814 m^2 excluding basements. The annual energy consumption of the building is 3,735,640 kWh from the Grid and 2,964,758 kWh from captive DG sets. The facility operates 12 hrs a day and 250 days per year. Calculate the EPI and AAHEPI.

Solution:

$$\text{Energy Performance Index (EPI), kWh/annum/}\ m^2$$
$$= \frac{(3{,}735{,}640 + 2{,}964{,}758),\ kWh/annum}{17{,}814\ \ m^2}$$

Energy Performance Index (EPI), kWh/annum/m^2= 376

$$\text{AAHEPI, Wh/h}/m^2 = \frac{376,\ kWh\ per\ annum\ per\ m^2}{12 \times 250}\ \ X\ 1000$$

AAHEPI, Wh/h/m^2= 125

9 Cost Benefit Analysis

After identifying the list of energy-efficiency measures applicable to the facility, the auditor shall also conduct cost benefit analysis for the measures and make recommendations for their implementation. Step-by-step guidance for energy auditors on payback period, return of investment, net present value, and internal rate of return, in order to conduct the common economic analysis for the assessment of financial viability of the energy efficiency measures is presented below.

9.1. Payback period

Payback period refers to the amount of time (number of years) it takes to recover the capital cost of an investment. Shorter payback period means more attractive investments while longer paybacks are less desirable. It is a simple term to determine whether to go through with an investment or not.

Simply put, the payback period is the cost of the investment divided by the annual cash flow or annual net savings and can be calculated using the following equation:

$$Simple\ payback\ period = \frac{Capital\ cost}{Annual\ net\ savings}$$

Annual net savings is the cost savings achieved after all the operational costs have been met. The word 'Simple' is used as a prefix to the term 'payback period' to denote that time value of money is not considered in its calculation.

Example: A new waste heat recovery system (WHR) installed in a facility is expected to reduced energy bill by Nu. 400,000. If the capital cost of investment of the new WHR is Nu. 500,000. What will be the expected payback period for the project?

$$Simple\ payback\ period = \frac{500{,}000}{400{,}000} = 1.25\ years, or\ 15\ months$$

9.2. Return on investment (ROI)

Return on Investment (ROI) is a performance measure used to evaluate the efficiency of an investment or compare the efficiency of a number of different investments. ROI tries to directly measure the amount of return on a particular investment, relative to the investment's cost. To calculate ROI, the benefit (or return) of an investment is divided by the cost of the investment. The result is expressed as a percentage or a ratio.

$$ROI = \frac{Annual\ net\ cash\ flow}{Capital\ cost}\ X\ 100$$

Example: An investment of Nu. 100,000 for equipment is expected to provide an after-tax cash flow of Nu. 25,000 over a period of six years, without significant annual fluctuations. What is the return of investment?

$$ROI = \frac{25,000}{100,000} X\ 100 = 25\%$$

9.3. Net present value (NPV)

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyse the profitability of a projected investment or project.

The net present value method considers the time value of money. This is done by equating future cash flow to its current value today, or in other words by determining the present value of any future cash flow. The present value is determined by using an assumed interest rate, usually referred to as a discount rate. Discounting is the opposite process to compounding. Compounding determines the future value of present cash flows, whereas discounting determines the present value of future cash flows.

The net present value method calculates the present value of all the yearly cash flows (i.e. capital costs and net savings) incurred or accrued throughout the life of a project and summates them. As a matter of convention, costs are represented as negative values and savings as positive values. The sum of all the present values is known as the net present value (NPV). The higher the net present value, the more attractive is the proposed project.

The following formula is used to calculate NPV:

$$NPV = -\frac{CF_0}{(1+i)^0} + \frac{CF_1}{(1+i)^1} + \dots\dots\dots + \frac{CF_n}{(1+i)^n} = \sum_{t=0}^{n} \frac{CF_t}{(1+i)^t}$$

Where,

CF_t = Cash flow occurring at the end of year 't' (t =0,1…n) (As per our convention, net savings or inflows are represented by (+) sign and net costs or outflow are represented by (-) sign. Since capital investment is an outflow, it will be treated as negative (-) as per our convention)
i = Discount rate
n = Life of the project

The discount rate (i) employed for evaluating the present value of the expected future cash flows should reflect the risk of the project. Hence the decision rule associated with the net present value criterion is: "Accept the project if the net present values is positive and reject the project if the net present value is negative". A negative net present value indicates that the project is not achieving the return standard and thus will cause an economic loss if implemented. A zero NPV is value neutral.

The net present value takes into account the time value of money and it considers the cash flow stream in entire project life.

Example: Using the net present value analysis technique, evaluate the financial merits of the two proposed projects shown in the table. The annual discount rate is 8% for each of the project.

Projects	Project 1	Project2
Capital Cost (Nu.)	30,000	30,000
Year	**Net annual savings (Nu.)**	**Net annual savings (Nu.)**
1	+6,000	+6,600
2	+6,000	+6,600
3	+6,000	+6,300
4	+6,000	+6,300
5	+6,000	+6,000
6	+6,000	+6,000
7	+6,000	+5,700
8	+6,000	+5,700
9	+6,000	+5,400
10	+6,000	+5,400
Total net savings at the end of 10^{th} year	**+60,000**	**+60,000**

For Project 1:

$$NPV = -\frac{30000}{(1+0.08)^0} + \frac{6000}{(1+0.08)^1} + \frac{6000}{(1+0.08)^2} + \frac{6000}{(1+0.08)^3} + \frac{6000}{(1+0.08)^4} + \frac{6000}{(1+0.08)^5} + \frac{6000}{(1+0.08)^6} + \frac{6000}{(1+0.08)^7} + \frac{6000}{(1+0.08)^8} + \frac{6000}{(1+0.08)^9} + \frac{6000}{(1+0.08)^{10}}$$

NPV = +10,254

For Project 2:

$$NPV = -\frac{30000}{(1+0.08)^0} + \frac{6600}{(1+0.08)^1} + \frac{6600}{(1+0.08)^2} + \frac{6300}{(1+0.08)^3} + \frac{6300}{(1+0.08)^4} + \frac{6000}{(1+0.08)^5} + \frac{6000}{(1+0.08)^6} + \frac{5700}{(1+0.08)^7} + \frac{5700}{(1+0.08)^8} + \frac{5400}{(1+0.08)^9} + \frac{5400}{(1+0.08)^{10}}$$

NPV = +10,867

For a 10-year lifespan, the net present value for project 1 is Nu. 10,254, while for project 2 it is Nu. 10,867. Therefore project 2 is preferred.

The whole credibility of the net present value depends on a realistic prediction of discount rate which could often be unpredictable. prudent to set the discount rate slightly above the interest rate at which the capital for the project is borrowed.

9.4. Internal rate of return

By setting the net present value of an investment to zero (the minimum value that would make the investment worthwhile), the discount rate can be computed. The internal rate of return (IRR) of a project is the discount rate, which makes its net present value (NPV) equal to zero. It is the discount rate of equation:

$$0 = -\frac{CF_0}{(1+i)^0} + \frac{CF_1}{(1+i)^1} + \dots\dots\dots + \frac{CF_n}{(1+i)^n} = \sum_{t=0}^{n} \frac{CF_t}{(1+i)^t}$$

Where,

CF_t = Cash flow occurring at the end of year 't'
i = Discount rate
n = Life of the project

CF_t value will be negative if it is expenditure and positive if it is savings.

If this discount rate is greater than current interest rate, the investment is sound.

This procedure, like net present value, can also be used to compare alternatives. The criterion for selection among alternatives is to choose the investment with the highest rate of return. The calculation procedure for determining IRR is tedious and usually requires a computer spreadsheet. The IRR function formula is available in Excel and can be used in practice. However, it is important to get acquainted with the fundamental procedure of determining the IRR. Determining IRR is an iterative process requiring guesses and approximations until a satisfactory answer is derived.

9.5. Capital investment considerations

To judge the attractiveness of any investment, we must consider the following four elements involved in the decision:

- Initial capital cost or net investment
- Net operating cash inflows (the potential benefits)
- Economic life (time span of benefits)
- Salvage value (any final recovery of capital)

9.5.1. Initial capital cost or net investment

When companies spend money, the outlay of cash can be broadly categorized into one of two classifications: expenses or capital investments. Expenses are generally those cash expenditures that are routine, ongoing, and necessary for the ordinary operation of the business. Capital investments, on the other hand, are generally more strategic and have long term effects. Decisions made regarding capital investments are usually made by senior management and carry with them additional tax consequences as compared to expenses.

The capital investments usually require a relatively large initial cost. The initial cost may occur as a single expenditure or occur over a period of several years. Generally, the funds available for capital investments projects are limited.

Initial capital costs include all costs associated with preparing the investment for service. This includes purchase cost as well as installation and preparation costs. Initial costs are usually non-recurring during the life of an investment.

9.5.2. Net operating cash inflows

The benefits (revenues or savings) resulting from the initial cost for a capital investment occur in the future, normally over a period of years. As a rule, the cash flows which occur during a year are generally summed and regarded as a single end-of-year cash flow. Annual expenses and revenues are the recurring costs and benefits generated throughout the life of the investment after adjusting for applicable taxes and effects of depreciation. Periodic replacement and maintenance costs are similar to annual expenses except that they do not occur annually.

9.5.3. Economic life

The period between the initial cost and the last future cash flow is the life cycle or life of the investment.

9.5.4. Salvage value

The salvage (or terminal) value of an investment is the revenue (or expense) attributed to disposing of the investment at the end of its useful life. If substantial recovery of capital from eventual disposal of assets at the end of the economic life, these estimated amounts must be made part of the analysis. Such recoveries can be proceeds from the sale of facilities and equipment (beyond the minor scrap value), as well as the release of any working capital associated with the investment.

10 Detailed Energy Audit Reporting

After finishing the energy audit, the audit team should write an energy audit report. In the report, the auditors should explain their work and the results in a well-structured format. The energy audit report should be concise and precise and should be written in a way that is easy for the target audience to comprehend. Some key issues that should be kept in mind while writing an audit report are:

- The audit report should be written in a way that provides suitable information to the potential readers of the report which could be the building owner or facility manager, the supervisor of engineering or maintenance.
- The audit report should be concise and precise and use direct language that is easy to understand.
- Use more graphs rather than tables for the presentation of data, results, and trends.
- The recommendation section should be specific, clear and with adequate detail.
- Assumptions made in the analysis should be explained clearly (If any). How changes in the key assumptions can influence the results should also be explained.
- The auditors should do their best to avoid mistakes and errors in the report, especially in the results. Even a few errors could damage the credibility of the audit.
- The energy audit report should be consistent in structure and terminology used.
- The calculations made in the analysis work should be explained clearly.

Typical energy audit report contents and format are shown below. The following format is applicable for detailed energy audit of a facility in most industries and buildings. However, the format can also be modified for targeted energy audit.

10.1. Typical contents of the report

1. Title page
2. Table of contents
3. Acknowledgements
4. Auditor firm and audit team details and declaration
5. Executive summary
6. Audit objectives, scope, and methodology
7. Facility overview
8. Energy and utility system description
9. Energy performance assessment
    - Summary of recommendations and action plan
10. List of suppliers of retrofits / vendors
11. Annexures / references, software tools used

The details pertaining to each content are given in the following sections.

10.1.1. Title page of the report

The title page of the report may contain:

Audit report title, for example if the detailed energy audit is carried out for building "XYZ", then the title could be "Energy Audit Report of XYZ".

Similarly, if the audit covers one system or equipment (e.g. Boiler) of building "XYZ" then the title can be "Energy Audit Report of Boiler of XYZ".

Name of the building/facility and location: The title sheet may also include the name along with and identification code (if there is any identification code for buildings issued by government) and category. The location of building/facility shall also be mentioned.

Date of report (month and year)

Auditor name: The name of the auditor may be written on the title sheet.

Mandatory audit details: If the energy audit is carried out as a part of mandatory requirement, it may be mentioned.

10.1.2. Table of contents

A table of contents sometimes also refer as simply "Contents". The contents usually include the titles or descriptions such as chapter titles and in longer reports second level (section level) and third level (subsections level) as applicable.

Like any engineering report, table of contents should be very comprehensive and include:

- Sections and subsections along with page numbers in main content sheet
- List of tables along with the table number and corresponding page number
- List of figures and graphs including diagrams and flow charts along with number and corresponding page number
- Abbreviations used in the report

All chapters, sections and subsections of the chapters, tables, figures, graphs, flow charts and diagrams should be numbered for easy identification and references.

10.1.3. Acknowledgement

The basic purpose to include acknowledgement page is just to give a thankful note for all those facility personnel who have supported you in carrying out your audit. It is advisable to include people in the proper order according to the importance of their provided support. However, acknowledgment should be concise not more than 1 or 2 paragraphs.

10.1.4. Audit firm and team details and declaration

The report shall contain the energy auditor details (such as name, address, phone, fax, e-mail address etc.). The details shall also include energy auditor registration number as and when such a registration system is instituted by DRE in Bhutan. A declaration such as shown here may be used:

The data collection has been carried out diligently and truthfully. All data measuring devices used by the auditor are in good working condition, have been calibrated and have valid certificate from the authorized approved agencies and no tampering of such devices has occurred. All reasonable professional skill, care and diligence had been taken in preparing the energy audit report and the contents thereof are a true representation of the facts. The energy audit has been carried out in accordance with the Energy Auditing and Reporting Guidelines issued by the Department of Renewable Energy, Ministry of Economic Affairs, Royal Government of Bhutan, 2020".

The energy auditor shall sign the energy audit report under the seal of the firm below the declaration.

10.1.5. Executive Summary

An executive summary provides management of the audited facility with brief overview of the total savings and highlight of each energy saving measure. The purpose of an executive summary is to summarize the key points of the energy audit study such as energy saving potential, recommendations, cost savings, investment requirement etc, for each sub system for which energy audit done. Executive summary should be tailored to non-technical personnel.

The executive summary shall draw the entire information from the main report. The executive summary shall contain:

- Summary of energy savings potentials
- Recommended energy-efficiency measures (with a brief explanation of each)
- Implementation costs, savings, and payback period for the recommended measures, A typical format is shown in **Table 42**

Table 42: Summary of energy savings recommendation format

Sl. No.	Brief description of Energy saving recommendation	Annual energy savings (kWh/year)	Annual fuel savings (kl/year)	Annual cost savings (Nu.)	Investment (Nu.)	Simple Payback period in months

- Highlight the impact of implementation of energy savings measures in energy savings and cost savings,
- Summary list of energy saving measures along with classification shall be given. A typical format is shown in **Table 43**

Table 43: Types and priority for energy savings measure format

Sl. No.	Type of energy savings recommendations	Annual electricity (kWh) or fuel savings (kl/kg)	Annual Savings (Nu.)	Priority
A	No/low cost measure • Operational improvement Housekeeping			
B	Medium term measure • Controls • Equipment Process change			
C	Long term measure • Energy efficiency devices • Product modification Technology change			

10.1.6. Audit objective, scope, and methodology

- Audit objectives and purpose of energy audit.
- Scope of work: Brief description of scope of work can be given in this section while detailed scope can be enclosed as annexure.
- Methodology and approach followed for the audit (i.e. inspection, measurements, calculations, analysis, and assumptions).
- Time schedule for conducting the energy audit – field study and report preparation.
- Instruments used: Details of portable energy audit instruments and specific online instruments used during the audit (such as make, model, type, parameters measured, calibration details, etc.)

Facility overview

Under the overview of the facility, energy audit report shall include the information pertaining to:

- General details and description
- Process description – brief description of facility process with layout

10.1.7. Energy consumption profile

The section shall include the following:

- Energy consumption pattern: The audit report shall contain data for one year preceding the year for which energy audit report is being prepared giving details of energy consumed and specific energy consumption of facility.
- Desegregations of the energy consumption data and identification of major energy consuming equipment /section /process
- Mention unit cost (Nu./kWh) for electricity and Nu./kl or Nu./kg for fuel considered for techno-economic evaluation.

10.1.8. Equipment and utility system description

This section shall include all major energy consumer of facility (any or all of the following that are applicable):

- Motors
- Boilers and Hot water generator
- HVAC
- Lighting
- Water pumping systems

10.1.9. Energy performance assessment

There may be some other sections /equipment in addition to those mentioned above which may need to be added. Each item of the above list shall be treated in a separate chapter while preparing the report. Under each equipment/ section the following may be given (refer relevant sections pertaining to the equipment)

- Introduction and description of the equipment and process
- Specifications / design parameter / PG test values
- Energy consumption pattern and specific energy consumption
- Observations, analysis, and findings:
    - General condition of the facility and equipment
    - Operation and operating parameters
    - Surveys conducted
    - Test and trial runs
    - Performance analysis / efficiency evaluation
- Energy saving recommendations
- Summary list of energy saving measures and classification as per suggested implementation schedule (short term, medium term and long term)
- Impact of implementation of energy saving recommendations (pre and post scenario) in terms of specific energy consumption /specific energy cost.

Energy savings recommendations

All energy conservation measures suggested during the audit study shall include:

1. A suitable title of recommendation (for easy identification)
2. A brief description of present practice/ system/ equipment shall be given, its background and its impact on energy efficiency or energy consumption should be provided. The technical estimations on energy loss/wastage due to the present system can be included. A brief process flow / line diagram can help in easy explanation of present system
3. Description of recommendation: Details pertaining to the recommendation regarding its technical and operational features, benefits expected and any known risk, etc
4. If the recommendation pertains to replacement, retrofitting, or resizing, the auditor shall give the key technical specifications along with energy performance parameters (efficiency / specific energy consumption, etc).

5. Detailed estimation of energy savings and energy cost reduction over a reasonable technical or economic life of the measure
6. Detailed techno-economic evaluation
7. Preliminary assessment of the financial attractiveness or assessment of maximum investment based on the estimated energy cost and saving potential over the life of the measure
8. Where different alternatives are available, all options may be compared, and better options suggested.
9. Where the installation or implementation of any recommended energy saving measure affects the procedure of operation and maintenance, staff deployment and the budget, the recommendation shall include discussion of such impacts including their solution.
10. List of Suppliers / vendors /contractors details for implementation

Table 44: Energy savings recommendation format

Reporting format for energy savings recommendation	
Title of recommendation	Replace high wattage 40 W fluorescent tube lights with energy efficient 18 W LED tube light
Description of existing system	150 High wattage fluorescent tube lights (40 W each) are installed for lighting the shop floor, electrical control room and office. (Average use 12 hours per day)
Description of proposed system	• Replace fluorescent tube lights with energy efficient LED tube lights • The replacement of tube lights may be done in phase wise manner. Such as if any or couple of lights are fused or damaged replace those with LED lights
Energy savings Calculations	
Existing system	
No. of fluorescent tube lights	= 150
Power consumption of each fluorescent tube lights	= 40 W = 0.04 kW
Average use per day	= 12 hours
Annual running of facility	= 250 days
Annual energy consumption of tube lights	= 150 X 0.04 X 12 X 250 = 18,000 kWh
Proposed system	
No. of LED tube lights	= 150
Power consumption of each LED tube lights	= 18 W = 0.018 kW
Average use per day	= 12 hours

Annual running of facility	= 250 days
Annual energy consumption of tube lights	= 150 X 0.018 X 12 X 250 = 8,100 kWh
Net energy savings	= 18,000 – 8,100 = **9,900 kWh**
Cost benefits	
Annual monetary savings (@ 3 Nu./kWh)	= **Nu. 29,700**
Investment (@ Nu. 330 per LED tube light)	= 150 X 330 = Nu. 49,500
Payback	= 49,500 / 29,700 = **20 months**

10.1.10. Action plan

The auditor shall summarise all recommendations and provide action plan for implementation in which the recommendations are prioritised. This shall be discussed with the energy manager / concerned facility personnel.

The action plan shall include:

- Preparation of detailed techno-economics of the selected measures in consultation with energy manager / facility personnel
- A monitoring and verification protocol to quantify on annual basis the impact of each measure with respect to energy conservation and cost reduction for reporting to top management of the buiding.
- A time schedule agreed upon by the facility management of selected measures taking into consideration constraints such as availability of finance, resources, and availability of proposed equipment.

10.1.11. List of suppliers, vendors, and contractors

The energy audit report shall provide the information for supporting the facility to implement proposed recommendations. Such information may include list of suppliers / vendors and local contractors who would be able to provide the technology or services to the facility for effective implementation of recommended measures. The details shall include name and address, contact person, contact details such as phone, fax, email etc.

The energy auditor’s role is not to promote specific supplier / vendor and hence it is important to provide details of various options and to let the Facility choose the vendor of their choice using their own criteria. It strongly recommended that the list of vendors may be accompanied by a disclaimer, that the energy auditor does not recommend or endorse any supplier.

10.1.12. Appendices

Appendices shall include background material that is essential for understanding the calculations and recommendations and may include:

- Facility layout diagrams
- HVAC layout diagrams
- Reference graphs used in calculations, such as motor efficiency curves, pump performance curves etc.
- Data sets that are large enough to clutter the text of the report.
- Detailed specifications, design details, test certificates, performance covers.

10.1.13. References, software used

The audit report shall include the references utilized for technical inputs such as papers, journals, handbooks, publications etc. In addition, if the auditor used any software for the analysis, the details of such software shall be given in the report.

11 Post Audit Activities

In practice there are often barriers that prevent the successful implementation of energy efficiency measures recommended in an energy audit report. Therefore, it is helpful to establish a clear procedure to ensure the successful realization of recommended improvements. An implementation action plan should be described in a simple way with clear goals, saving targets, and definitions of roles and responsibilities for its execution

A detailed action plan helps to ensure a systematic process to implement energy-efficiency measures. The action plan can be updated regularly, most often on an annual basis, to reflect recent achievements, changes in performance, and shifting priorities. While the scope and scale of the action plan is often dependent on the organization, the steps below outline a basic starting point for creating a plan:

1. Define technical steps and targets
2. Determine roles and resources

Before finalizing the action plan, it is better to consult with facility managers and key engineers to get their input on the action plan.

11.1. Define technical steps and targets

The energy audit results can provide an indication of the technical performance of the facility and its gap with the efficient performance. Based on this, opportunities for energy-efficiency improvement can be identified and prioritized.

Three key steps are:

1. Create performance targets for each facility process, department, and operation of the organization to track progress towards achieving the goals.
2. Set timelines for actions, including regular meetings among key personnel to evaluate progress, completion dates, milestones and expected outcomes.
3. Establish a monitoring system to track and monitor the progress of actions taken. This system should track and measure energy use and project/program activities.

11.2. Determine roles and resources

11.2.1. Identify internal roles

The action plan should determine who is involved in the energy-efficiency program and what their responsibilities are. Depending on the organization and action plan, this might include departments such as:

- Facility and operations management
- Financial management - capital investments, budget planning
- Human resources - staffing, training, and performance standards
- Maintenance

- Supply management - procurement procedures, energy purchasing and equipment and materials
- Building design
- Engineering
- Communications Marketing
- Environmental, Health, and Safety

11.2.2. Identify external roles

The action plan should determine the degree to which consultants, service providers, vendors, and other product providers will be used. Some organizations may choose to outsource entire aspects of their action plan while others may only want to contract with specific vendors for limited projects. If contractors will be used, the action plan should determine what standards will be used to evaluate bids and incorporated these metrics into agreements with contractors.

11.2.3. Determine resources

For each project or program in the action plan, estimate the cost for each item in terms of both human resources and capital/expense. Then, develop the business case for justifying and gaining funding approval for action plan projects and resources need.

11.2.4. Implement the action plan

To successfully implement the action plan, it is vital to gain support from the personnel within the facility involved in the energy-efficiency improvement programs. To implement the action plan, the following steps should be considered:

1. Create a communication plan: Develop targeted information for key audiences about the energy efficiency action plan

2. Raise awareness: Build support for all levels of the organization for energy efficiency initiatives and goals.

3. Build capacity: Through training, access to information, and transfer of successful practices, and procedures to expand the capacity of the staff.

4. Motivate: Create incentives that encourage staff to improve energy performance to achieve goals.

5. Track and monitor: Use the tracking system developed as part of the action plan to track and monitor progress regularly.

11.2.5. Evaluate progress:

Facility managers can evaluate the progress of their activities using energy data and a review of the activities taken as part of the action plan, comparing them to the established goals. This review can be used to revise the action plan and see the lessons learned. Regular evaluation of energy performance and the effectiveness of energy-efficiency initiatives also allows energy managers to:

- Measure the effectiveness of projects and programs implemented
- Make informed decisions about future energy projects
- Reward individuals and teams for accomplishments
- Document additional savings opportunities as well as non-quantifiable benefits that can be leveraged for future initiatives

It is worth highlighting the fact that a company needs to have an energy management program to be able to fully benefit from the energy audit results and to have sustainable energy efficiency improvement. If it does not have an energy management program, the audit will likely be a one-time event, and the implementation rate of the audit recommendations will be low.

12 Energy Audit Instruments

Description of instruments	Image representation (for visual purpose only)
Hand-held Clamp meter Used for measurement of voltage, current, power factor and power without interrupting the connections or routine operation of facility for quick and instantaneous measurements.	
Three-phase power analyser Used for measurement of various parameters such as voltage, current, power factor, power, harmonics, frequency, reactive power, and all other electrical parameters. This instrument is applied online without interrupting the routine operation of the facility and can measure and record all electrical parameters for long duration (more than 24 hours). The recorded data can easily be transported in computer/laptop for further analysis and identification of energy savings opportunity.	
Thermal imaging camera This is a non-contact type infra-red thermal monitoring and imaging device for measuring thermal energy radiation from hot or cold surfaces of an object. The thermal camera unit converts electromagnetic thermal energy (IR) radiated from an object into electronic video signals. These signals are amplified and transmitted via interconnected cable to a display monitor where the resulting image is analysed and interpreted for hot/cold spots	

Description of instruments	Image representation (for visual purpose only)
Infra-red (IR) thermometer This is a non-contact device, used for measuring temperatures from a distance using infrared technology – helpful in determining heat loss. This is also helpful in determination of temperature of objects placed in hazardous or hard-to-reach places.	
Sling Psychrometer A type of hygrometer used to measure the relative humidity in the atmosphere with the help a dry bulb and a wet bulb thermometer mounted on it. A dry bulb thermometer measured the dry air temperature while the wet bulb thermometer dipped in a wet cloth measure the wet bulb temperature.	
Pen-type thermometer This is a contact-type device used for measurement of surface or water temperatures. This is helpful in HVAC system to measure the temperatures of chilled water and cooling water.	
Hygrometer This is used to measure dry bulb temperatures, wet bulb temperatures, humidity, and dew point of ambient air. This is an especially useful device in assessing HVAC system. (Image source: Extech)	

Description of instruments	Image representation (for visual purpose only)
Flue gas analyser This instrument has in-built chemical cells which measure various gases such as O_2, CO_2, CO, NO_x, SO_x, etc. This is mainly used to monitor the exhaust flue gases coming out of boiler or fuel fired furnace stacks. It is portable, lighter, and easier to operate. (Image source: Testo)	
Ultrasonic water flow meter Used for measurement of flow of liquids through pipelines of various sizes through ultrasonic sensors mounted on the pipelines – helpful in determining pumping and cooling system efficiencies. This is a non-invasive technique to measure the water flow. This is mainly used to assess performance of pumps by measuring water flow.	
Lux meter Used for measurement of illumination level – helpful in optimising lighting loads. This is also known as light meter. (Image source: Extech)	

Description of instruments	Image representation (for visual purpose only)
Anemometer Used for measurement of air flow, this is useful is assessing the performance of cooling tower and air handling unit fans. (Image source: Extech)	
Manometer with pitot tube Used for measurement of pressures in air duct carrying exhaust gases or air from fans and blowers. To measure pressure in air pipe, manometers must be used in combination with a pitot tube. (Image source: Extech)	
Tachometer Used for measurement of motor speed in RPM (revolutions per minutes). This can be used either in contact type method or non-contact method to measure the rotation of motor shaft and determine the belt slip.	

Description of instruments	Image representation (for visual purpose only)
Smart energy meters Used for measurement of voltage, current and power in single phase. This is mainly used to measure and monitor the single-phase electronic equipment’s energy consumption. This can also record the energy consumption data.	
Ultrasonic leak detector Used for detection of gas and compressed air leakages in HVAC facility. This detects almost any leaks because short distance/access and high air pressure is not needed, sensitive to sound and filters background noises. This instrument does not measure the size of leak that energy auditor has to assess.	
TDS Conductivity meter Used for spot measurement of TDS (total dissolved solids) and conductivity of water especially in boiler blowdown. This is also useful during performance assessment of cooling tower.	

13 List of Simulation Software

Software Name	Software application and brief description
Building Simulation Software (ESim)	ESim is a building energy simulation tool used for design, commissioning, and retrofit analysis. Building energy simulation is performed using a computer to virtually represent a building design and perform physics based calculations. The simulations can range from a building component to a cluster of buildings. For energy simulation, the building model along with the usage pattern and weather of the location are required to determine various outputs, such as peak loads, system sizing, and energy consumption for any given period. This information can be used for estimating the utility bills, for evaluating cost–benefit analysis of various design strategies.
Pump System Improvement Modeling tool (PSIM)	PSIM 2 is a free educational tool that allows engineers to build models of pump systems and simulate hydraulic behaviour. PSIM 2 will model pump system behaviour and demonstrate the impact of operational and design trade-offs on system performance and energy usage for centrifugal and positive displacement pumping systems.
Pump system assessment tool (PSAT)	The **Pumping System Assessment Tool (PSAT)** is a free online software tool to help industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.
TRNSYS	It is an extremely flexible graphically based software environment used to simulate the behaviour of transient systems. The vast majority of simulations are focused on assessing the performance of thermal and electrical energy systems TRNSYS is made up of two parts. The first part is an engine (called the kernel) that reads and processes the input file, iteratively solves, determines convergence, and plots system variables. The kernel also provides utilities that determine thermo-physical properties, invert

Software Name	Software application and brief description
	matrices, perform linear regressions, and interpolate external data files. The second part of TRNSYS is an extensive library of components, each of which models the performance of one part of the system. The standard library includes approximately 150 models ranging from pumps to multi-zone buildings, wind turbines to electrolyzers, weather data processors to economics routines, and basic HVAC equipment to cutting edge emerging technologies. Models are constructed in such a way that users can modify existing components or write their own, extending the capabilities of the environment. Applications • Central plant modeling • Building simulation (including LEED Energy Modeling) • Solar thermal processes • Ground coupled heat transfer • High temperature solar applications • Geothermal heat pump systems • Coupled multi-zone thermal/airflow modeling Optimization • Energy system research • Emerging technology assessment • Power plants (Biomass, Cogeneration) • Hydrogen fuel cell systems • Wind and Photovoltaic Systems • Data and simulation calibration Reference website for purchase: http://www.trnsys.com/
Thermal comfort tool	Thermal comfort can also be calculated using on freely available tool such as the https://comfort.cbe.berkeley.edu/ The tool helps calculate thermal comfort under both adaptive as well as using PMV for ASHRAE as well as EN thermal comfort conditions.

Software Name	Software application and brief description
LightSim	This software uses TMY (Typical Meteorological Year) or EPW (Energy Plus weather data) weather files as input. The hourly illuminance incident on windows and skylights is computed assuming that natural daylight has luminous efficacy of 110 lm/W. The hourly illuminance on the work plane of an interior space is computed using the IES method. The fraction of time that daylighting meets a target illuminance, and hence the fraction of time that electric lights can be turned off, is computed. These results support the design and economic evaluation of daylighting projects. After each simulation, LightSim reports input data and annual simulation results. It reports the fraction of hours that illumination from daylighting meets or exceeds the target illumination on a monthly basis. LightSim also reports the “fraction electrical power reduction” if sophisticated controls were able to turn off or dim a portion of the lights, to meet the target illumination. Reference website for purchase: https://syngient.in

14 Annexures

14.1. Compilation of audit checklist and energy savings tips for Building

These are generic checklists and improvement options for guidance of energy auditors. This list is not a substitute for a detail assessment carried out by an energy auditor. Care must be exercised in matching an improvement option for Buildings from this list based on the actual situation on the ground.

14.1.1. Building Envelope

1. **Improper alignment and operation of windows and doors allows excessive infiltration**
    - Resize exterior doors, i.e., delivery doors, making them smaller to reduce excessive infiltration
    - Add expandable separate enclosures, where practical
    - Install self-closing doors on openings to unconditioned spaces
    - Install a switch on overhead doors that prevents activation of heating and cooling units when doors are open.
    - Install vestibule doors at major entrances
    - Realign or re-hang windows or doors that do not close properly. In extreme cases, consider permanent sealing of windows. Make sure automatic door closing mechanisms work properly.
    - Replace or repair faulty gaskets in garage or on other overhead doors.
2. **Weather-stripping and caulking around windows, doors, conduits, piping, exterior joints, or other areas of infiltration where it is worn, broken, or missing**
    - Where practical, cover all windows and through the wall cooling units when not in use. Specially designed covers can be obtained at relatively low cost
    - In areas with constant strong winds, install wind screens to protect exterior doors from direct blast of prevailing winds. Screens can be opaque, constructed of metal framing with armored glass. Careful positioning is necessary for infiltration control.
    - Replace worn and/or broken weather-stripping and caulking
    - Replace broken or cracked windows. (Air leakage is most evident when wind is blowing against the side of the building)
3. **Doors and /or windows separating conditioned from non-conditioned areas (including outdoors) are left open**
    - Post instructions to raise awareness amongst the people
    - Assure that automatic door closers function properly
4. **Excessive expanses of glass exist on exterior walls.**
    - Totally or partially insulate non-operable windows. Consider replacing non-operable window with walls.

- Install double-pane windows consider adding reflective or heat absorbing film to minimize solar gain in summer and heat loss in winter. (Note: Any window film reduces natural lighting and winter solar gain)
- Install adjustable outdoor shading devices
- Attach storm glazing to moveable sash of operable windows
- When replacing windows, replace with thermopiles, utilizing the same casings
- Keep curtains and drapes closed in unoccupied spaces

5. **There is no insulation between conditioned and unconditioned spaces.**
   - Insulate between heated/cooled spaces and unconditioned or outside areas such as parking garages, porticos, storage, basements, and attics.
6. **Ceiling/roof insulation is inadequate or has been water damaged**
   - Add new insulation to meet recommended standard. (check the cost effectiveness of this measure particularly if your facility is over their stories.)
   - Before replacing water damaged insulation, repair roof where required.
   - Verify that vapor barrier faces the conditioned space and is intact
7. **Blinds and curtains are not used to help insulate the building**
   - Add reflective or heat absorbing films to reduce solar heat gain in summer. Caution: Natural lighting and solar heat gain in winter will be reduced. Also, unless protected by an additional layer of glass, these films are subject to damage
   - Install outdoor shading devices
   - Instruct personnel to close interior shading devices to reduce night heat loss in winter and to reduce solar heat gain during the summer
   - Place reminders where appropriate
   - Repair or replace damaged or missing shading devices

14.1.2. HVAC

1. **Space temperatures are higher or lower than thermostat settings**
   - For electric control system, install pre-set solid-state thermostats which do not require calibration
   - Recalibrate thermostat
   - Blow out moisture, oil and dirt form pneumatic lines (for pneumatic systems), clean contacts if electrical control system
   - Recalibrate controllers
   - Ensure that control valves and dampers are modulated properly
   - Ensure that heat generating device is producing heat and that heat distribution to the space is unobstructed
   - Make sure that air intake volume is not excessive
2. **Thermostat settings have not been adjusted for change in seasons**
   - Replace existing thermostat with a thermostat which has a separate setting for cooling and a separate setting for heating or use one thermostat to control heating and one thermostat to control cooling
   - Change the location of thermostats from areas subject to extreme temperature fluctuations, such as next to window, or over a heating or cooling unit

3. **Unoccupied or little used areas are heated or cooled unnecessarily**
   - Install system controls to reduce heating/cooling of unoccupied spaces
   - Shut down air conditioning units at night, on weekends and holidays
   - Do not heat/cool in low traffic areas, hallways, or unoccupied rooms/floors
   - Plan occupancy so guest is assigned in same area of hotel
   - Have housekeeping close draperies and adjust thermostat to acceptable level in unoccupied area or room
   - Consider regrouping activities into smaller areas which can be conditioned separately form remainder of building
4. **Heating/cooling equipment is started before occupants arrive and/or is operating during last hour of occupancy**
   - Install a time clock or an automated energy management system that will reduce heating and /or cooling. Maintain ventilation rates
   - Experiment with star-up times and duration of operation to determine satisfactory comfort levels for occupants. Reduce or turn off heating and cooling during the last hour of occupancy, allowing the building to "coast."
5. **Heating/cooling equipment is operating in lobbies, corridors, vestibules, and /or other public areas**
   - Properly adjust and balance air/water systems and controls.
   - Lower heating set points in the above areas if there is no possibility of freeze-up. Disconnect electrical heating units (or switch off at breaker box). Maintain ventilation.
   - Close HVAC supply ducts serving the above areas.
6. **Ventilation systems are not utilized for natural cooling capability**
   - Install an economizer cycle with enthalpy control to optimize use of outside air for cooling
   - Whenever possible, use outside air for cooling rather than using refrigeration. (use economizer cycle, if available)
7. **Exhaust system operation is not programmed**
   - Install time clocks or other controls to shutoff exhaust system when not needed
   - Install a rheostat in series with exhaust fan to modulate fan speed so that no more than the necessary amount of air will be exhausted
   - Install controlled or gravity dampers on all exhaust ducts to close ducts when fan is not operating
   - Discontinue use of unnecessary exhaust fans
   - Re-wire restrooms' exhaust fans to operate only when lights are on
   - Establish schedules so that exhaust fans run only when needed
   - Group smoking and other areas with similar exhaust requirements so that they may be served by one exhaust system. Reduce ventilation in remaining non-contaminated areas

14.1.3. Water Heating system

1. **Water in heating system is heated when there is no need**
   - Install control to automatically shut down heat generating device when outside air temperature reaches set temperature
   - Turn off boiler, pumps, or heat source
2. **Condensate from street stream is being discharged to sewer drain**
   - Install pump to return condensate to boiler or return condensate by gravity, if possible. Condensate can also be used to heat domestic water or boiler combustion air prior to its return to the boiler feedwater system
3. **Steam, condensate, and heating water piping insulation is in disrepair or missing**
   - Install additional pipe insulation in accordance with design specifications
   - Inspect pipes for broken or missing insulation. Repair or replace as needed
4. **Evidence indicated faulty or inefficient boilers or furnaces**
   - Replace dangerous or ineffective units with more efficient modular type units. (Note: Do not install oversize unit.)
   - If applicable, install baffle-type devices in the tubes to improve efficiency.
   - Remove scale deposits, accumulation of sediment and boiler compounds on water side surfaces. Examine and treat rear portion of boiler (the area most susceptible to scale formation)
   - Remove soot from tubes
   - Observe the fire when the unit shuts down. If the fire does not cut off immediately, it could indicate a faulty solenoid valve. Repair or replace, as necessary
   - Inspect all boiler insulation, refractory, brick work and boiler casing for hot spots and air leaks. Repair and seal as necessary
5. **Waste heat from flue gas is not recovered**
   - Utilize heat from flue gas to preheat combustion air by means of a heat recovery device
   - Consider economizer to transfer heat form flue gas to feed water
   - Consider heat recovery from continuous blowdown
6. **Electric water heater has no time restrictions on heating cycle**
   - Limit the duty cycle with a time clock or other control devices to avoid adding the water heating load to the building during peak electrical demand periods. (additional hot water storage capacity may be required.)
   - Utilize "vacation cycle" on water heater when not needed during extended periods. (Note: Complete deactivation could cause leaks.)
7. **Devices to conserve heated water have not been utilized where practical**
   - Replace standard faucets with self-closing, flow restrictor valves. (Note: Highly mineralized water or water containing sediment can cause blockages.)
   - Install a solar water heater to assist in meeting building hot water demand. This will significantly reduce consumption of traditional energy fuels in facilities which are large users of hot water

8. **Storage tanks, piping and water heaters are utilized inefficiently**
    - Install a small domestic hot water heater to maintain desired temperature in water storage tank. This could eliminate the need for operating one of the large spaces heating boilers during summer months
    - Install de-centralized water heating

14.1.4. Lighting

1. **Inefficient lamps are used in offices, workrooms, hallways, and gymnasiums**
    - Replace inefficient and old lighting fixtures with more energy conserving types such as LEDs
2. **Lamps and fixtures are not clean**
    - Establish a regular inspection and cleaning schedule for lamps and luminaires (fixtures). Dust build-up reduces effectiveness
    - Replace lens shielding that has turned yellow or hazy with new acrylic lenses which do not discolor
    - Replace outdated or damaged luminaires with modern typed that are easy to clean
3. **Ceilings and other room surfaces have reduced reflectivity due to dirt**
    - When repainting or recovering, use coatings or coverings with good reflectance and clear surfaces
4. **Daylight is not used effectively**
    - Install light sensors and dimming equipment which automatically compensate for varying natural lighting conditions
    - Locate workstations requiring high illumination adjacent to windows
    - Switch off lights when daylight is sufficient
    - Clean windows and skylights
5. **Lighting is on in unoccupied areas**
    - Rewire switches so that one switch does not control all fixtures in multiple workspaces
    - Provide timer switches in remote or seldom used areas where there will be brief occupancy periods
    - Post instruction to turn off lights when leaving area
    - Identify areas being controlled by ganged switches
    - Assure wall switch timers function properly
6. **Security/outdoor lighting is not automatically controlled and /or lighting levels are excessive**
    - Replace exterior incandescent lamps with more efficient types such as LEDs
    - Replace burned out lamps with lower wattage lamps
    - Establish manual operation schedule considering change in daylight with season
    - Control lighting with existing photoelectric or time-clock controls if practical
    - Eliminate outdoor lighting where practical
    - Replace burned out lamps with lower wattage lamps

14.2. List of excel forms

These forms are available in "soft" format (MS excel files) for the reader of the EARG. Some of these sheets are reproduced as tables in **section 14.3** of these guidelines as a reference. The data collection sheet has been prepared for the following equipment and utilities.

1. Electricity bills
2. Transformer
3. Motor
4. Evaporator
5. Condenser
6. Cooling towers
7. Air handling units (AHU)
8. Pumps
9. Boiler (Electric)
10. Lighting
11. Solar PV

14.3. Sample excel forms

Electricity Bill									
Months	Contract Demand (kVA)	Actual Maximum Demand (kVA)	Power Factor (PF)	Energy Consumption (kWh)	Demand charges	Energy charges	PF Penalty/incentive	Total Bill	Effective Rate (Nu./kWh)

Cooling Tower										
S.No.	Identification	Rated Capacity (TR)	Cooling water inlet temperature °C	Cooling water outlet temperature °C	Ambient air wet bulb temp. °C	Ambient air dry bulb temp. °C	Measured cooling water flow (m^3/hr)	Measured Fan Power (kW)	Measured Air flow (m^3/hr)	Cooling water (TDS)

15 References

- Guidebook for energy auditors and energy managers by Bureau of Energy Efficiency (BEE), India
- Energy Audit handbook by Sustainable energy authority of Ireland (SEAI)
- Industrial energy audit guidebook by Ali Hasanbeigi, Lynn Price, Berkeley National Laboratory
- Energy Audit manual and tool by Canadian industry Program for Energy conservation (CIPEC)
- Descriptive Manual on Energy Efficiency by STENUM Asia and ACMA supported by UNIDO, Vienna.
- International standard on energy management system, ISO 50001.
- International standard on energy audits, ISO 50002.