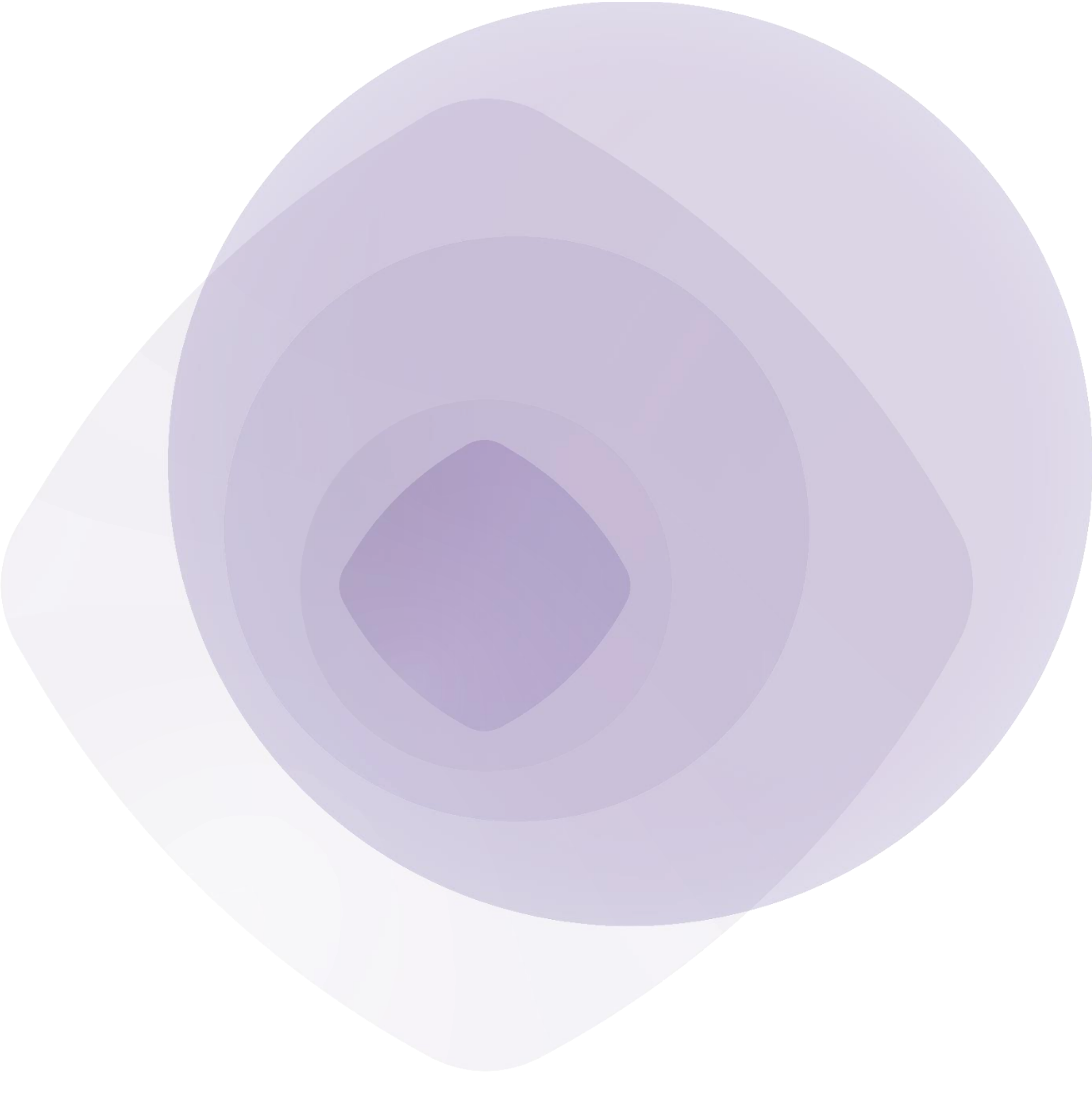
Republic of Mauritius

Energy Efficiency Management Office

Energy Efficiency and Energy Conservation Guidelines for Manufacturing Sector

June 2025



Energy Efficiency and Energy Conservation Guidelines for the Manufacturing Sector in Mauritius

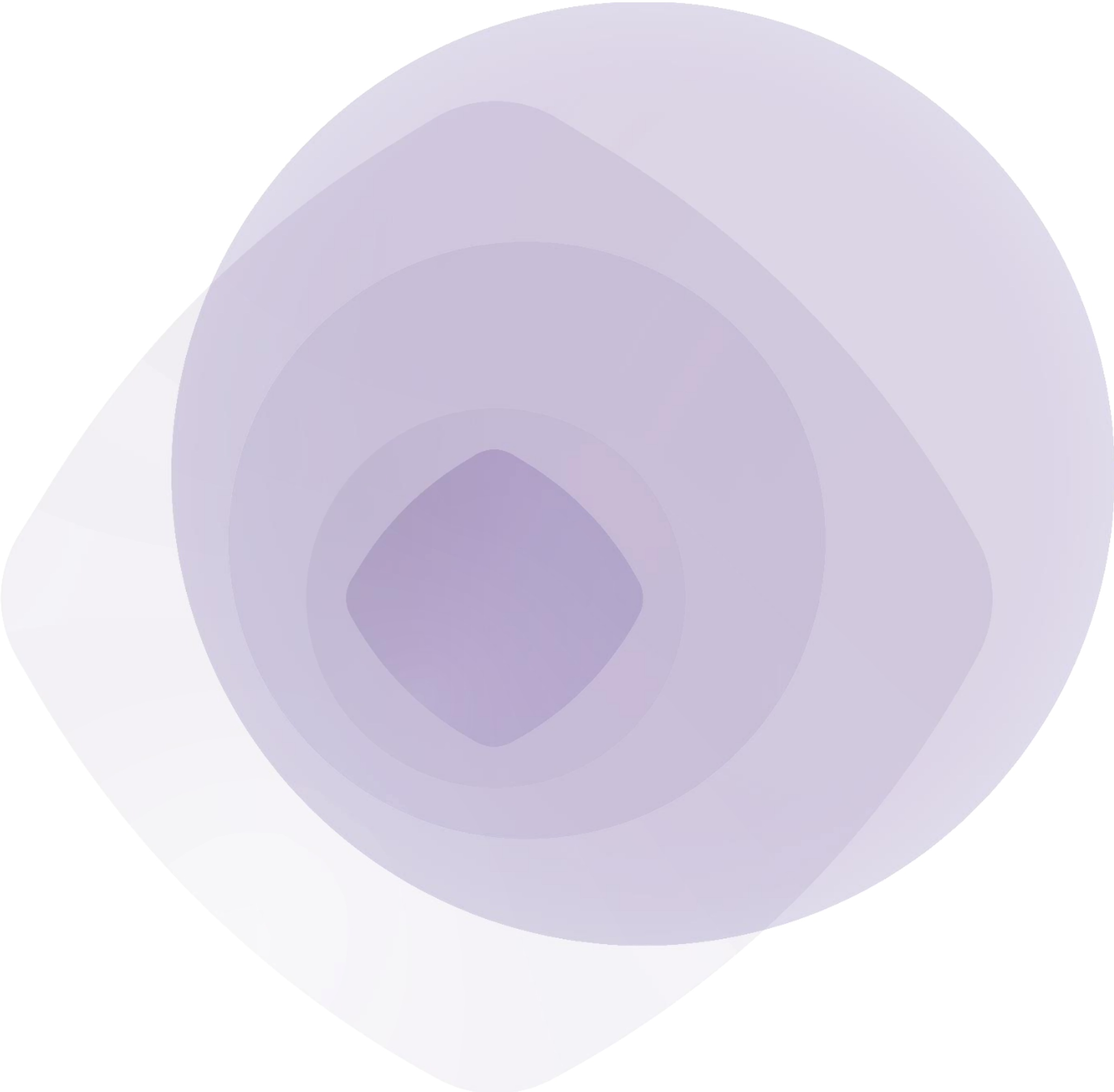
Commissioned on behalf of:
Energy Efficiency Management Office (EEMO)
Ministry of Energy and Public Utilities
Level 4, The Celicourt Tower
Sir Celicourt Antelme Street
Port Louis

Email: eemo@govmu.org
Website: https://eemo.govmu.org/

Study by:
Grant Thornton Bharat LLP
L 41, Connaught Circus, Outer Circle,
New Delhi - 110 001
Delhi, India

Email: contact@in.gt.com
Website: https://www.grantthornton.in/

Last modified on:
June 6, 2025



Foreword

The manufacturing sector stands as a pillar of our economy, accounting for 13.2% of Mauritius' Gross Value Added while consuming 190.8 ktoe of energy annually - representing 19.7% of our nation's total final energy consumption and 24.5% of all electricity generated. As our third-largest electricity consumer and second-largest energy-consuming sector, its efficient operation is crucial to our national development.

Energy audits conducted across the sector reveal significant potential for energy savings—opportunities that, if harnessed, can strengthen both the financial position of individual enterprises and the competitiveness of our industries on the global stage.

Improving energy efficiency is not merely an environmental imperative; it is a strategic necessity. By adopting the measures outlined in these guidelines, manufacturers can reduce operational costs, decrease reliance on imported energy, and curb the growth in peak electricity demand—all while contributing to national energy security and sustainability goals. However, realizing these benefits requires building the capacity of organizations to implement the right measures effectively.

These guidelines have been developed to equip the manufacturing sector with clear, actionable strategies for optimizing energy performance. They provide standardized benchmarks for key equipment, best practices for energy management, and pathways to achieve certifications such as ISO 50001. We urge all stakeholders to actively apply these recommendations, adapt them to their specific contexts, and share feedback to ensure continuous improvement of the guidelines.

The Ministry of Energy and Public Utilities wishes to extend its appreciation to the consultant, Grant Thornton, for their dedication in delivering this invaluable resource. We believe these guidelines will be instrumental to transform energy efficiency from a challenge into an opportunity— driving Mauritius toward a more resilient, competitive, and sustainable industrial future.

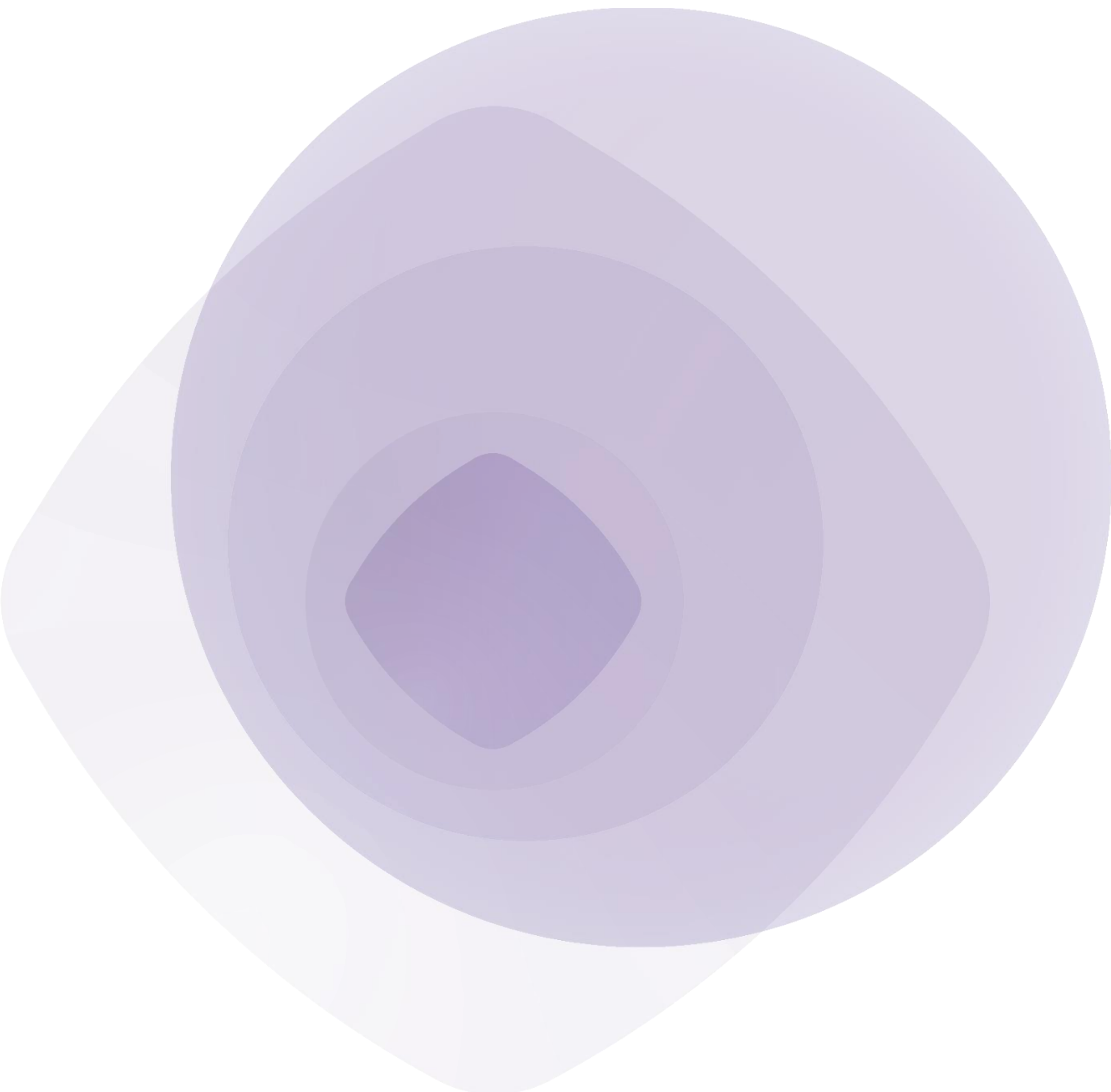


Table of Contents

Contents

List of Tables

Terms and definitions

Term	Definition
Action plan	A projection of potential improvement opportunities, detailing the timeline and assigned responsibilities, along with a verification method to assess whether energy performance has improved.
Air ratio	Air ratio is defined as the ratio of actual air supplied (AAS) to theoretical air requirement. The air ratio is considered based on a steady state operation at constant load conditions and can be measured and verified at specific measurement points, while maintaining maximum permissible limit for carbon monoxide (CO) level to 200 ppm.
Audit team	Group of professionals who assess and analyse the energy consumption of a facility or organization. The team typically includes energy auditors, engineers, and other specialists who conduct detailed evaluations, recommend energy-saving measures, and help implement improvements.
Bill of Quantity (BoQ)	Detailed document used in the construction industry to itemize all the materials, parts, and labour required for a project, along with their associated costs
Boundary	Boundaries can be physical or organizational limits. They help in distinguishing what operations (energy systems, processes, equipment, people/functions) will be included when tracking energy production and energy consumption
Carbon emissions	Release of carbon dioxide (CO_2) and other carbon compounds into the atmosphere, primarily as a result of human activities such as burning fossil fuels (coal, oil, and natural gas), deforestation, and industrial processes contributing to the greenhouse effect, leading to global warming and climate change
Clean Development Mechanism	United Nations-run carbon offset scheme established under the Kyoto Protocol. It allows countries with emission-reduction or emission-limitation commitments to implement emission-reduction projects in developing countries. These projects can earn Certified Emission Reduction (CER) credits, each equivalent to one tonne of CO_2
Derating	Process of reducing a motor's rated capacity (power output) to ensure safe and efficient operation under non-standard or harsh environmental conditions.
Energy audit	Systematic process of evaluating how energy is used in a building, facility, or organization to identify opportunities for energy savings and efficiency improvements which involves analyzing energy consumption patterns, assessing the performance of energy-using systems and equipment, and recommending measures to reduce energy use and costs.
Energy baseline	Quantitative reference providing a basis for comparison of energy performance
Energy efficiency	Energy efficiency refers to the practice of using less energy to perform the same task or produce the same outcome which involves optimizing processes, equipment, and systems to reduce energy consumption while maintaining or improving performance leading to cost savings, reduced environmental impact, and enhanced sustainability.
Energy efficiency act (2011)	Legal act to promote the efficient use of energy and reduce carbon emissions in Mauritius. Key components of the act include the establishment of the Energy Efficiency Management Office, which is responsible for developing and implementing strategies, programs, and action plans for energy efficiency
Energy intensity	Energy intensity is a measure of the energy efficiency within the industry's scope of energy management. A typical measure can be the amount of energy it takes to produce a specific output unit, the specific energy consumption.

Term	Definition
Energy management system (EnMS)	Energy management system can be defined as management system to establish an energy policy, objectives, energy targets, action plans and process(es) to achieve the objectives and energy targets
Energy management team	Staff or workers who have the responsibility and authority for accomplishing the agenda of facilities energy management scope
Energy performance	Measurable result(s) related to energy efficiency, energy use and energy consumption
Energy performance improvement	Improvement in measurable results of energy efficiency, or energy consumption related to energy use, after comparing to the energy baseline
Energy Performance Indicator (EnPI)	Measure or unit of energy performance, as defined by the organization. Quantification of the (EnPI) at a point in or over a specified period is EnPI value
Energy policy	Statement by the organization of its overall intention(s), direction(s), and commitment(s) related to its energy performance. This is usually expressed by the top management of the facility.
Energy review	Analysis of energy efficiency, energy use and energy consumption based on data and other information, leading to identification of improvement measures
Energy-saving certificates	Tradable certificates that represent a specific amount of energy savings achieved through efficiency projects
Energy target	Quantifiable objective of energy performance improvement
Gate to gate concept	Impact of a product from the start of its production process until it leaves the factory gate
ISO 50001:2011	A document that specifies requirements an organizations energy management system should meet, to align with a standard of energy management that is recognized as acceptable in international territories.
ISO 50002:2014	A document that specifies the requirements for conducting energy audits to identify opportunities for improving energy performance. It applies to all types of organizations and energy uses. The standard outlines the principles, processes, and deliverables of energy audits, providing guidance on how to carry them out effectively
Measurement	Process to determine a value
Monitoring	Monitoring is assessing the status of a system, a process, or an activity
Specific Energy Consumption (SEC)	Refers to the amount of energy required to produce a unit of output or perform a specific task. It's often used to measure the energy efficiency of various processes, machines, or systems.
Stakeholder validation	Process of engaging with and obtaining feedback from stakeholders to ensure that their needs, expectations, and concerns are accurately understood and addressed in a project or initiative
Subsidies	Financial assistance provided by the government to individuals, businesses, or institutions to support economic activities and promote public objectives
Tax credits	Energy tax credits are government incentives that reduce the amount of tax owed by individuals or businesses when they invest in low carbon technologies
Waste heat recovery	Process of capturing and reusing heat that is generated as a byproduct of industrial processes, power generation, or other activities

Abbreviations

AAS	Actual Air Supplied
ABMA	American Boiler Manufacturers Association
AC	Air Conditioners
AHU	Air Handling Unit
ANSI	American National Standards Institute
APFC	Automatic Power Factor Control
ASEAN	Association of Southeast Asian Nations
ASME	American Society of Mechanical Engineers
BLDC	Brushless Direct Current
BOP	Best Operating Point
BOQ	Bill of Quantity
BTU	British Thermal Unit
CFM	Cubic Feet per Minute
CNC	Computerised Numerical Control
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COC	Cycle of Concentration
COP	Coefficient of Performance
CPVC	Chlorinated Polyvinyl Chloride
CSPF	Cooling Seasonal Performance Factor
DR	Demand Response
EC	Energy Conservation
EC	Electronically Commutated
ECM	Energy Conservation Measures
EE	Energy Efficiency
EEMO	Energy Efficiency Management Office
EER	Energy Efficiency Ratio
EM	Energy Management
EnB	Energy Baseline
EnMS	Energy Management System
EnPI	Energy Performance Indicator
FAD	Free Air Delivery
FRP	Fiber Reinforced Plastic
GCV	Gross Calorific Value
GDP	Gross Domestic Product
Gg	Gigagrams
GSM	Grams per square meter
HID	High Intensity Discharge
hp	Horsepower
HT	High Tension
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency

IEC	International Electrotechnical Commission
IRR	Internal Rate of Return
ISO	International Organization for Standardization
kg	Kilogram
KPI	Key Performance Indicator
kVA	Kilo Volt Ampere
kVAr	Kilo Volt Ampere reactive
kW	Kilowatt
kWh	Kilowatt-hour
LED	Light Emitting Diode
LPD	Lighting Power Density
LT	Low Tension
m^3	Cubic meter
MEPS	Minimum Energy Performance Standards
mmWC	Millimeter Water Column
MUR	Mauritian Rupee
NDC	Nationally Determined Contribution
NIST	National Institute of Standards and Technology
NPSH	Net Positive Suction Head
NPV	Net Present Value
O_2	Oxygen
OEM	Original Equipment Manufacturer
PF	Power Factor
PID	Proportional–integral–derivative
PNEE	Programme National d’Efficacité Energétique
PVC	Poly Vinyl Chloride
RH	Relative Humidity
ROI	Return on Investment
RPM	Revolutions Per Minute
SCM	Standard Cubic Meter
SEC	Specific Energy Consumption
SEGR	Specific Electricity Generation Ratio
SIDS	Small Island Developing States
SME	Small and Medium Enterprises
SOP	Standard Operating Procedure
SPC	Specific Power Consumption
TR	Tonnes of Refrigeration
UNCTAD	United Nations Conference on Trade and Development
USA	United States of America
VFD	Variable Frequency Drive
VRF	Variable Refrigerant Flow
VSD	Variable Speed Drive
WHR	Waste Heat Recovery

1. Introduction

1.1. Background

Enhancing energy efficiency within the industrial sector plays a key role in reducing the link between economic growth and environmental degradation. It lowers industrial energy intensity while boosting competitiveness. Currently, the industrial sector accounts for nearly one-third of global primary energy use and its associated energy-related emissions. As consumer demand continues to rise, this sector is expected to grow at an even faster pace. In developing nations and economies in transition, industry can require as much as 50% of the total energy supply (excluding transport), often leading to a conflict between the pursuit of economic development and the challenges of limited energy resources.

Worldwide, industries possess considerable but underutilized opportunities to enhance energy efficiency. According to the International Energy Agency (IEA), improving energy efficiency has the potential to contribute over 40% of the global reduction required in energy-related emissions. It has been estimated that industry in particular, has the technical potential to decrease its energy intensity and emissions by up to 26 per cent and 32 per cent providing a striking 8 per cent and 12.4 per cent reduction in total global energy use and CO_2 emissions.[1] Improving energy efficiency in industry is one of the most cost-effective measures to help supply-constrained developing and emerging countries meet their increasing energy demand and loosen the link between economic growth and environmental degradation, such as climate change.

Efforts are underway worldwide to assist industries in adopting low-carbon technologies and high-efficiency equipment. Key pathways through which energy efficiency is being integrated into the industrial sector include:

Industrial Energy Efficiency

01 Energy Management
- Comprehensive and holistic energy and climate strategy to manage industrial energy consumption across business verticals and improve the Industry's green profile.
- International Standards- Corporate EnMS (ISO 50001)

02 Audits and measurement and verification
- Field data collection and investment grade audits.
- Develop model M&V plans, reports to demonstrate energy savings.
- M&V audits as per the compliance requirements

03 Process and Energy Optimization
- Integrate energy efficient designs of process and supply facilities.
- Find the right solution for balancing costs and energy consumption.

04 Decarbonization Strategy
- Integrate EE and cleaner production.
- Transform production process, minimize resource & energy use, environmental impact and waste while ensuring resilient and competitive operations.

05 Diversification and Market Strategy
- Techno commercial assessmentto analyze emerging energy efficiencyopportunities.
- Developbusiness, market and sustainability strategies.
- Develop robust business and financial models to capture emerging market value.

The Republic of Mauritius is among the top five African countries in the UNCTAD Productive Capacities Index.[2] Mauritius has developed a diversified manufacturing sector that focuses on labour-intensive processes, particularly in textiles and food processing. The government supports innovation through various initiatives, including strong intellectual property protection and technology transfer programs. This approach has positioned Mauritius as a competitive player in global markets, with ongoing efforts to diversify into more advanced manufacturing sectors.

[1] *International Energy Agency - How energy efficiency will power net zero climate goals*
[2] *Economic Development Board, Mauritius*

The manufacturing industries in Mauritius is dominated by the following sectors[3]:

Textile and Apparel
A major contributor to the economy, known for high-quality and sustainable practices primarily targeting European and U.S.A markets. The industry focuses on products such as knitwear, denim, and high-end fashion items. Contributing to MUR 18,858 million market share.

31% market share

Seafood Processing
A leading exporter regional hub for seafood processing, trading, warehousing, and re-export of fresh, chilled, frozen, or value-added seafood products. Contributing to MUR 12,345 million market share

20% market share

Cane Sugar Processing
Sugarcane cultivation occupies a significant portion of the island's arable land, and the industry has evolved into a diversified sector producing not only sugar but also by-products such as ethanol, rum, and electricity from bagasse. Contributing to MUR 10,443 million market share.

17% market share

Agro Processed and Drinks
A major exporter of refined sugars, alcohol, rum, and high-value horticulture such as fruits and vegetables. Contributing to MUR 2,749 million market share

4.5% market share

Medical Devices and Pharma
Medical device manufacturers producing items such as needles, catheters, implants, and surgical instruments with robust growth of 252% shown over the last decade. Contributing to MUR 2,000 million market share.

3.3% market share

Jewellery and Precious metal
Mauritius is known for its skilled artisans who create intricate jewellery pieces, major companies play a significant role in refining and supplying gold and silver to local jewellers. Contributing to MUR 1,937 million market share.

3.2% market share

Watches, Optical Lenses, Photographic instruments
The watches and photographic instruments industry is rapidly growing in Mauritius showing 125% growth over the last decade, contributing to MUR 1,809 million market share

3.0% market share

Wood and Wood Products
Hardwood is used in furniture, joinery, and ship model manufacturing, while softwood is used for construction purposes such as scaffolding and shuttering. Contributing to MUR 957 million market share

1.6% market share

The Republic of Mauritius aims to improve energy efficiency to achieve a 10% reduction in energy consumption by 2030 as compared with 2019 levels[4], focusing on implementing measures like energy

[3] *Market share as of 2023*
[4] *Mauritius NDC 2021*

audits, Minimum Energy Performance Standards (MEPS), and energy performance contracting. The government of Mauritius is actively working towards these goals through various initiatives.

The Republic of Mauritius introduced the Energy Efficiency Act (EE Act) in 2011 which provides for the efficient use of energy and its conservation in Mauritius. The Energy Efficiency Management Office (EEMO) was set up under the EE Act in 2011 with the objective of promoting the efficient use of energy and promoting national awareness for the efficient use of energy to reduce carbon emissions and protect the environment.

One of the functions of the EEMO is to issue guidelines for energy efficiency and conservation in all sectors of the economy. Mauritius herewith presents its Energy Efficiency and Energy Conservation (EE & EC) Guidelines for Manufacturing sector.

1.2. Objective of the EE & EC guidelines

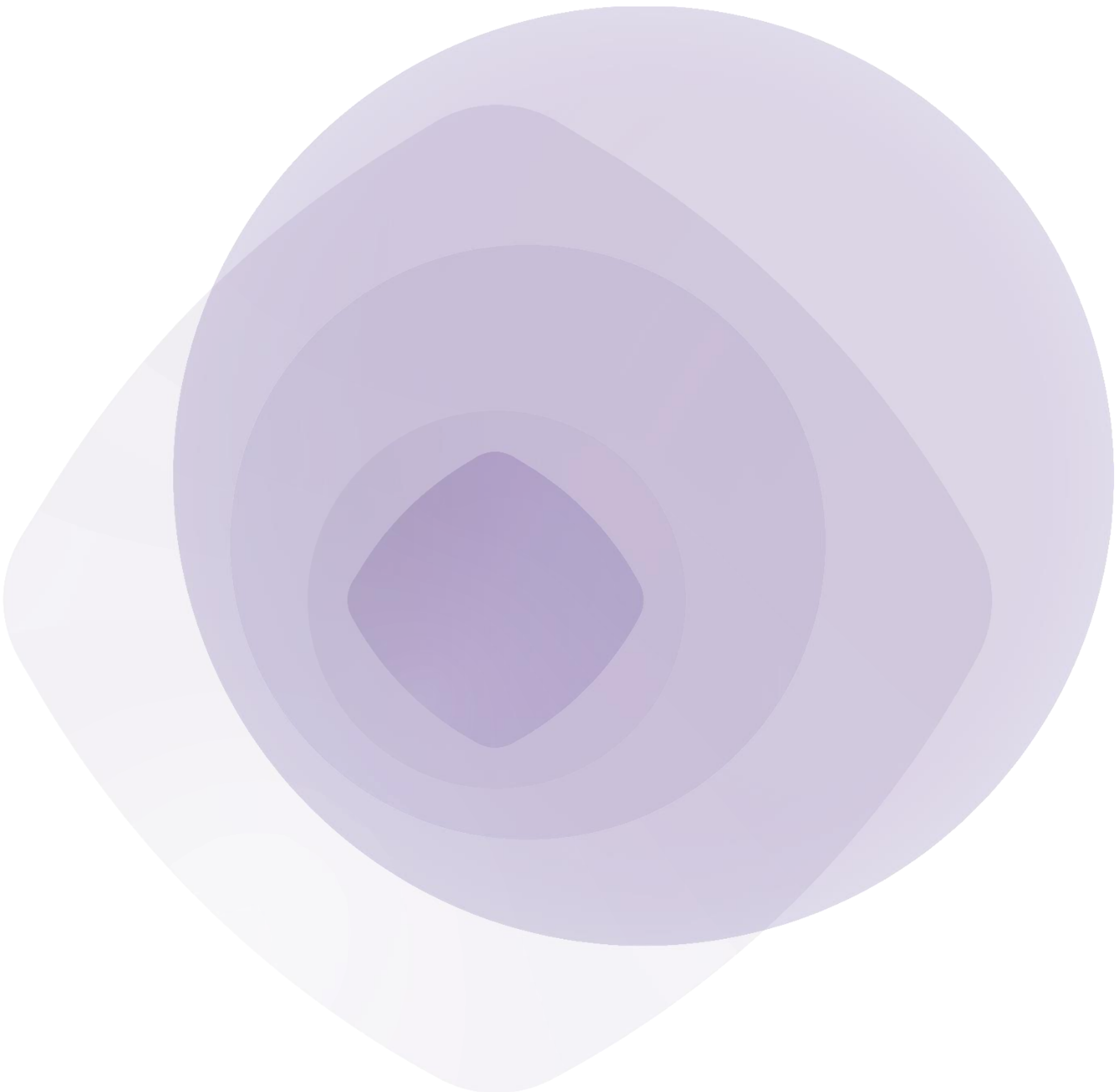
The industrial sector in Mauritius plays a vital role in the country's economic diversification and growth. It contributes approximately 18.2% to the GDP (as of 2023) and provides employment to nearly 21% of total employment.[5] The industrial sector in Mauritius is accounts for 7.5% (334 Gg CO_{2e}) of the total emissions from energy sector of Mauritius in 2022.[6] The manufacturing sub sectors such as textiles, food processing and sugar production plays a vital role in Mauritian economy. In 2023, the industrial production index rose by 2.1%, driven by growth in electricity, gas, steam, and air conditioning supply (+5.4%) and manufacturing (+2.1%), along with others such as water supply, sewerage, waste management, and remediation activities (+2.6%).[7]

The main objective of this assignment is to provide guidelines for manufacturing enterprises, to guide the management and operators in these enterprises to manage energy consumption by standardizing the energy performance values of various energy consuming equipment and systems deployed in the manufacturing processes. These energy efficiency guidelines aim to empower industrial entities to adopt practices that optimize energy use while minimizing environmental impact. By following these guidelines, Mauritian industries can advance their goals of reducing greenhouse gas emissions, enhancing energy security, and promoting innovative technologies that benefit current and future generations.

One important component to be considered under this assignment is the development of benchmarking of standard energy performance values and procedures for establishing target energy performance values for major energy-consuming equipment and systems, such as boiler, air compressor, furnace, thermic fluid heater, Waste Heat Recovery (WHR) equipment, motor, etc. in the manufacturing enterprises. This is imperative to provide a pathway to key decision makers and those responsible for maintenance and energy management in these sectors towards improvement of energy performance.

The standards would be the optimum performance values achieved by an energy consuming equipment while targets may be considered equal to the best values that may be achieved by the same energy consuming systems in daily operation

[5] *Mauritius Trade Easy, Mauritius: Economic and Political Overview, November 2024*
[6] *UNFCCC, First Biennial, 2024 Biennial Transparency Report (BTR). BTR1.; Publication date. 26 Dec 2024*
[7] *Mauritius Trade Easy, Mauritius: Economic Outline, November 2024*



2. Methodology

The Industrial EE& EC guidelines were developed on an iterative data-oriented methodology to achieve the industrial Energy Efficiency and Conservation objectives of the Government of Mauritius. The following international EE & EC guidelines, policies and standards were reviewed and drawn insights towards defining the structure of the guidelines:

Table 1: Reviewed Global Guidelines on EE & EC

Country	Guidelines
India	Energy efficiency and energy conservation guidelines for large industries
	Energy efficiency and energy conservation guidelines for micro, small and medium enterprises
United States of America (USA)	Energy Star Guidelines for energy management
Rwanda	Guidelines promoting energy efficient measure
Eswatini	Energy efficiency and energy conservation policy
Lao People's Democratic Republic	Industrial energy efficiency and energy conservation guidelines
Association of Southeast Asian Nations (ASEAN)	Technical guidelines for energy efficiency and energy conservation
European Union	Energy efficiency guidelines
Japan	Energy efficiency improvement and conservation guidelines

EE Strategies and Policies of multiple African nations including South Africa, Kenya, Tanzania, Nigeria, Egypt, and The Gambia were also reviewed for drawing insights on energy conservation and energy efficiency during the development of the EE & EC guidelines. The review aimed to analyse how each country addresses energy challenges, the specific guidelines they have developed, and the mechanisms they use to promote energy efficiency. Key areas of comparison included the regulatory frameworks, energy-saving strategies, implementation methods, and monitoring tools. Additionally, the policies regarding energy consumption, emission reductions, and sustainability initiatives were examined in detail. The objective was to understand the various approaches taken by these countries in managing energy efficiency and conservation, focusing on their scope, methodologies, and policies.

2.1. Steps followed for preparation of Industrial EE & EC guidelines

The preparation of guidelines followed a step wise methodology as shown below. The approach was undertaken in six key steps – review of international guidelines, review and leverage past energy efficiency work in Mauritius, data collection, benchmarking, recommendations for improving EE &EC, and stakeholder validation.

The steps followed for preparation of EE & EC guidelines are showcased below:

1. **Review of EE & EC guidelines in other countries**

   The initial steps focused on reviewing the international guidelines, policies, and standards on energy efficiency and energy conservation followed across the globe in various countries, such as India, USA, Rwanda, Lao PDR, Eswatini, European Union, Japan, ASEAN, etc. with a target to define the structure of the guidelines by understanding key challenges in EE & EC and how these countries tackled these challenges along with energy-saving strategies, implementation methods, and monitoring tools.

2. **Review and leverage past work done in EE in the manufacturing sector**

   Past energy efficiency initiatives and work done in energy efficiency in Mauritius was reviewed to draw insights on EE & EC challenges and strategies for reducing energy consumption. Past energy efficiency and conservation efforts in Mauritius across manufacturing and other sectors, utilizing data from energy audits, sectoral studies, and public sources were studied. Projects such as the Programme National d'Efficacité Energétique (PNEE) and additional studies such as "Energy Use and Energy Efficiency in Industry and SME Sectors" and SIDS DOCK program were reviewed. The documents such as "Removal of Barriers to Energy Efficiency and Energy Conservation in Buildings" initiative, which developed energy regulations, a building code, and compliance mechanisms, extending efficiency efforts to the industrial sector.

3. **Data collection from industries, industry associations and technology vendors**

   Stakeholder consultation was carried out to collect data related to energy efficiency of industrial equipment along with challenges faced in improving energy efficiency and energy conservation.

Associations with industrial connect, such as Economic Development Board, Business Mauritius and Association of Mauritian Manufacturers were consulted. Data was also collected from 20 manufacturing industries across various sectors such as textile, food processing, Poultry, sugar cane industry, packaging industry, etc. Technology vendors for equipment such as chillers, air conditioners, air compressors, cold rooms, boilers, and pumps were consulted for getting energy performance metrics and their values for the equipment supplied in Mauritius.

4. **Perform benchmarking of KPI for energy consuming equipment**

   Data was collated from various sources such as industries, industrial associations, technology vendors in Mauritius and data gaps were filled with insights from international standards and global guidelines followed across the globe.

   Data was analysed for all leading energy consuming equipment present in manufacturing industries were assessed such as boilers, HVAC equipment (chillers, AC), cold rooms, Air Compressors, Motors, Fans and Blowers, Pumps, Lighting systems, Diesel Generators, AHU, etc. Energy Performance Indicators (EnPIs) related to the energy consuming equipment were analysed e.g., Specific power consumption (kW per CFM) for air compressors, Chiller performance metric such as kW per TR. The detailed analysis was used to benchmark the ‘standard values’ and ‘target values’ for parameters such as air ratio, specific energy consumption, waste heat recovery level, equipment efficiency, luminous efficacy, energy efficiency ratio, target power factor.

5. **Identifying EE & EC measures for various equipment**

   Measures related to energy conservation and improving energy efficiency for all equipment were identified and listed considering the technical feasibility of the measures. The technology readiness level of the measures was considered with the availability of technology providers who can provide them and ease of serviceability such as maintenance aspects.

6. **Stakeholder Validation**

   The stakeholder validation with key industry organizations and technology vendors to validate the synthesized and benchmarked data. The stakeholder learnings were also used as feedback into the overall process to refine the final outcome.

The section below defines the scope, individual structural components and performance indicators of the EE & EC guidelines

2.2. Scope of Industrial Energy Conservation Guidelines

The Industrial EE & EC guidelines classify primary utilities and equipment into two distinct categories: common energy-consuming equipment and process equipment. Common equipment refers to auxiliary devices that are widely utilized across various industries, with their types and capacities varying based on the specific processes and operational scale. On the other hand, process equipment consists of specialized devices primarily designed for specific sub-sectors or production processes, and these typically represent a substantial share of the industry's energy usage.

Mauritius' domestic industrial sector plays a significant role in the country's GDP. Most Mauritian industries need support in enhancing their knowledge and capabilities, as well as upgrading their technology. Additionally, the industrial sector must be made aware of the environmental impacts caused by inefficient production processes.

The utilities/equipment under the purview of the Industrial EE & EC guidelines have been selected to maximize the energy savings potential by selecting most widely used equipment across the industries. Some of the key industries operating in Mauritius are as shown in Table 2.

Table 2: Utilities/equipment under the scope of the Industrial EE & EC guidelines

Sector	Process Specific	Utilities (across sectors)
Textile	Clutch motor/ Servo Motor in sewing machine	Air compressor
	Stenter	Boiler
	Fabric testing machines	Chiller
Food and Beverage	Agitators (motors)	Fan and blower
	Cold Rooms	Lighting system
	Dough Mixers (motors)	Boiler
Cane Sugar	Sugarcane crushers (motors)	Pump
	Evaporators	Boiler
Agro Processed and Drinks	Boilers	Fan
	Husking/hulling machines (motors)	Chiller
Medical Devices and Pharma	Capsule filling machines (motors)	Electrical system
	Roller (motors)	Motor

2.3. Performance metrics – Standard and Target Values

The Industrial EE & EC guidelines classify energy efficiency performance and measurement metrics for industries into two main categories: standard values and target values. These metrics cover various common and process-specific energy-consuming equipment used across industries.

The primary focus of these values is to establish standards that help improve the performance of existing facilities, new installations, and retrofits. An empirical equation, based on the average and standard deviation of data samples, is used to determine the standard and target values, which are detailed in the following sections.

Standard Values

The Standards are typical performance values achieved by an energy consuming utility or equipment throughout daily operation.

A. Evaluation

The following equation is used to calculate the standard values:

Standard value = Average value of the data samples

Upper limit = Standard value + 2.5% of the standard value

Lower limit = Standard value – 2.5% of the standard value

To allow variations in equipment performance within the range of standard values, a nominal tolerance of (+) 2.5 percent to (-) 2.5 percent of the standard value is considered.

B. Components

The standard component is divided into four segments, each of which focuses on the relevant instructions for the utility/equipment's standard operations.

Table 3: Categorisation of the standard values

Component	Focus Areas
Management and control	This section outlines how to manage and regulate important operational parameters of various energy-consuming devices in the industry. In a multi-equipment environment, it also covers load sharing under part load situations.
Measurement and recording	This section specifies the frequency at which operating parameters are measured and recorded.
Maintenance and inspection	This section outlines preventive maintenance and the overhauling plan for various equipment. It also includes a plan for frequent instrument calibration to preserve data measurement accuracy.
Installation of new facility	This section outlines instructions for installing energy-efficient equipment in existing utilities and upgrading existing systems.

Target Values

Target values are equal to the best achievable values of an energy consuming utility throughout daily operation.

A. Evaluation

The following equation is used to calculate the target values:

Target value = Average value of the data samples – standard deviation of the data series

Upper limit = Target value + 2.5% of the target value

Lower limit = Target value – 2.5% of the target value

To allow variations in equipment performance within the range of target values, a nominal tolerance of (+) 2.5 percent to (-) 2.5 percent of the target value is considered.

Target values are equal to the best achievable values of an energy consuming equipment in daily operations

B. Components

The target components include a set of guidelines for the efficient use of energy-consuming equipment and energy management practices. These guidelines are essential for ensuring that the equipment operates at its optimal performance. They should align with current practices and offer insights for choosing new equipment with improved features.

3. Energy Management System

The energy management system outlines an organization's commitment and action plan for implementing energy efficiency and conservation initiatives within its operations. It is a crucial element in the success of the EE & EC program, as it defines how the organization structures its program and engages partners and stakeholders in activities aimed at overcoming energy efficiency barriers.

As part of their overall energy strategy, many organisations are actively pursuing energy efficiency measures in industrial production and consumption by developing detailed energy management systems. Promoting energy efficiency as a strategy is often highlighted as the most cost-effective tool for managing energy demand and reducing costs for industries. Implementing wide-scale energy-saving measures is considered the most reliable, technically feasible, economically viable, and environmentally sound method for mitigating the negative impacts of industrial production and consumption.

Both designated and non-designated industries can greatly benefit from deploying energy management systems (EnMS) in their operations. An EnMS will define the firm's vision, objectives, and targets for energy efficiency and conservation, aligning with the Government of Mauritius' policies, decrees, and guidelines on EE & EC. Additionally, the organization's energy management system will serve as a guiding document to align management, partners, and employees in adopting and implementing EE & EC initiatives.

3.1. Energy Management Policy

Energy management policy refers to a structured framework of regulations, strategies, and practices designed to optimize energy production, distribution, and consumption while ensuring sustainability, efficiency, and cost-effectiveness. These policies are implemented by organizations and industries to reduce energy waste, lower greenhouse gas emissions, and promote the use of renewable energy sources. Key components include energy audits, efficiency standards, incentives for clean energy adoption, and long-term planning to balance economic growth with environmental protection. Effective energy management policies are essential for achieving energy security, mitigating climate change, and fostering sustainable development in both developed and emerging economies.

3.2. ISO 50001: Energy management systems

The energy management system of the organizations operating in Mauritius shall be governed by the key principles of the ISO 50001. The organizations can also assess their readiness for an ISO 50001 Energy Management System certification by evaluating the ISO 50001 readiness assessment. The guidelines for ISO 50001 energy management systems are given in Table 4.

Table 4: ISO 50001 to be adopted

Guidelines from ISO 50001 – Energy Management Systems
The organizations should establish an energy system that takes into consideration the following components: ▪ **Alignment with Organizational Purpose:** Ensuring the policy is relevant to the organization's goals. ▪ **Framework for Objectives:** Providing a structure for setting and reviewing energy objectives and targets. ▪ **Commitment to Resources:** Ensuring the availability of information and resources to achieve energy goals.

Guidelines from ISO 50001 – Energy Management Systems

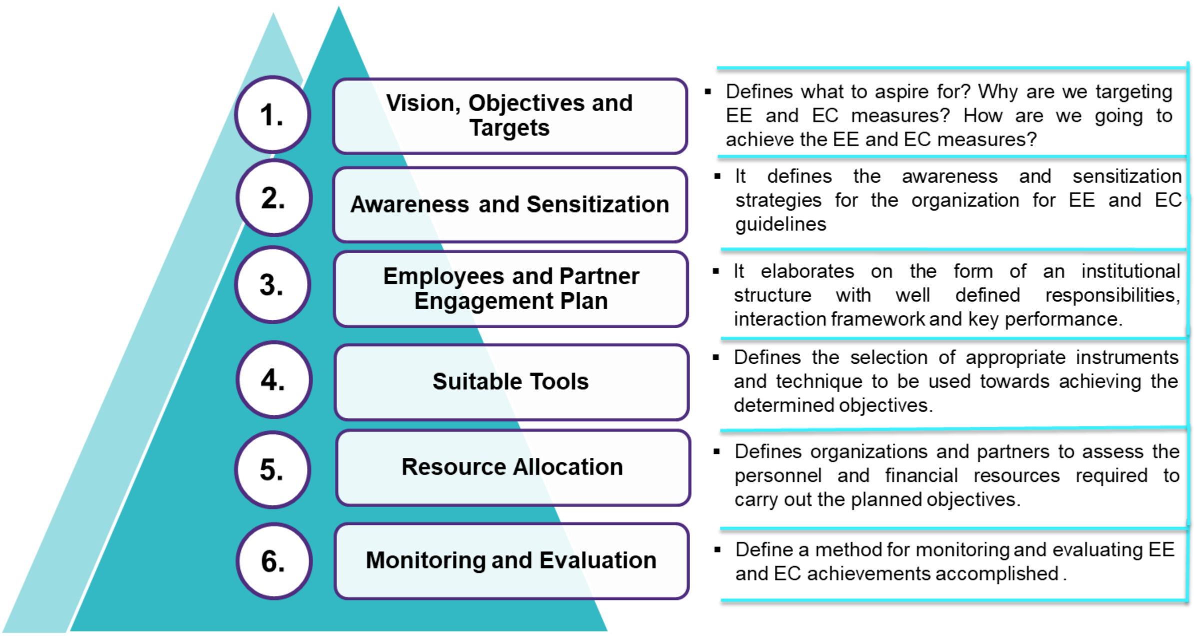
- **Legal Compliance:** Committing to meet legal and other requirements related to energy efficiency.
- **Continual Improvement:** Focusing on ongoing improvement of energy performance and the EnMS.
- **Energy-Efficient Procurement:** Supporting the purchase of energy-efficient products and services.
- **Design Considerations:** Encouraging design activities that improve energy performance.

The energy management system shall:

- be available as documented information
- be communicated within the organization
- be available to interested parties, as appropriate
- be periodically reviewed and updated as necessary

3.3. Components of Energy Management Systems

The energy management system should include the following key steps (but not limited to):



Vision, objectives and targets

The first step will define the organization's vision (*what to aspire for?*), objectives (*why are we targeting EE & EC measures?*) and targets (*how are we going to achieve the EE & EC vision?*). If the organization is in the initial stages of EE & EC, it will be important to limit the objectives and targets to major or most critical energy components so that it is easier to focus on a smaller group which has the potential to save a sizeable amount of energy savings.

Key activities for defining the organization's vision, objectives and targets are:

- Develop a suitable Energy Policy Statement within the EE & EC policy framework, regularly review it, and update as necessary.

- Determine the energy consumption per unit of products or services by conducting Preliminary Energy Audits (Walk-through audits).
- Set goals and create a plan to reduce energy usage, specifying the target reduction percentage relative to total energy consumption.
- Assess the results of the implemented plans through detailed Energy Audits (Diagnostic Energy Audits).

Awareness and sensitization

The second component of the Energy Management System will outline strategies for raising awareness and sensitizing the organization to EE & EC initiatives. This involves identifying target groups and developing communication methods to introduce stakeholders to the organization's EE & EC efforts.

Organizations should recognize that an awareness campaign will be ineffective if it does not emphasize the benefits for the beneficiaries, such as lower energy bills or enhanced industrial competitiveness. Therefore, it is crucial to adopt the right communication strategy to address questions such as, *"What energy efficiency options do I have to reduce my office's energy bill?"* or *"How can I lower production costs in my factory/department?".* The following key activities should be carried out in defining awareness and sensitization plan:

- Create your EE & EC communication strategy around three key principles: accuracy, simplicity, and moderation. Tailor the messages to the target audience, explaining how the organization's EE & EC initiatives will benefit or incentivize them.
- Identify various communication methods and consider using a mix of approaches such as one-on-one conversations, brochures with EE & EC statistics, exhibitions, presentations, and workshops.

Engage employees and partners

The organizations in their energy management system should highlight the key implementation employees and partners in the form of an institutional structure with well-defined responsibilities, interaction framework and key performance indicators. This step should typically answer – *who are the people responsible in my organization to implement EE & EC initiatives, what are the functions/responsibilities the assigned people have for implementing and managing EE & EC initiatives of the organization?* Organizations should cover diverse competencies including technical, finance and marketing across factory operations to business management while developing an institutional structure for EE & EC initiatives.

The following key activities shall be carried out to engage employees and partners:

- Identify and categorize stakeholders involved in the organization's EE & EC initiatives, including top management, middle managers, and factory workers.
- Form a cross-functional task force for EE & EC, comprising members from technical, finance, marketing, and other relevant departments.
- Define the responsibilities and key performance indicators for the task force.
- Create an action-based interaction framework to integrate the task force with other operations and divisions. For example, the task force might facilitate budget approvals from the finance division for purchasing new energy-efficient machinery.

Select suitable tools

Once the engagement plan has been established, the organizations or the selected task force should determine a selection of appropriate instruments and techniques to be used towards achieving the determined vision, objectives and goals. This step should typically answer – *How are we going to achieve the targets set as per the energy management system, what will be the tools and key methodologies for implementation?* These technologies and methodologies must be thoroughly tested/piloted and established before the organization should deploy them on a scale. The following activities shall be carried out:

- Analyse the key gaps in organization's EE & EC efforts and compile the main pain points. These gaps may relate to industrial processes and equipment, human resources, finance, and budget.
- Identify solutions or requirements to address these challenges and compile recommendations from the energy audits. Solutions may include increasing the maintenance schedule for machinery, purchasing new equipment, creating training programs, and applying for grants and subsidies.

Allocate Resources

The organizations must conduct discussions with selected partners and task force to assess the personnel and financial resources needed to carry out the planned activities from previous step. If the resources are discovered to be insufficient for any reason, it may be necessary to reconsider the energy saving target and the targeted energy users. This process can be an iterative process till there is a consensus that the resources available can indeed help to achieve the set target. The key activities for allocating resources are:

- Create a roadmap with short-, medium-, and long-term timelines for implementing EE & EC initiatives, prioritizing quick wins (high-impact actions with low effort or cost).
- Gain consensus on the organization's EE & EC plans with relevant stakeholders and partners and present the necessary tools and methodologies for implementing these initiatives.
- Estimate and allocate the personnel and financial resources needed for the EE & EC initiatives and distribute these resources across the planned roadmap.

Monitoring & Evaluation

Finally, it is critical to implement a method for monitoring and evaluating EE & EC achievements accomplished during the developed roadmap. It will be important to construct quantitative indications that can be used to evaluate performance more easily in terms of its success as well as shortcomings and bottlenecks encountered. By expanding or strengthening effective measures and changing or removing badly performing programmes, monitoring and evaluation will help organizations to draw lessons and fine-tune the implementation process for the next cycle or phase of programme implementation. It also aids the organization's credibility with the government, as concrete results demonstrate the effectiveness of the funds mobilized for this purpose, increasing the chances of persuading the government to allocate more resources.

Defining key measurement and performance indicators against set of planned activities is an important task. Indicators can be categorized into:

- **Delivery and mainstreaming**: Tracking the progress of fundamental and structural aspects of implementation. Including - vision, objectives and targets ratified, actions and implementation timelines ratified, institutional and collaboration framework mobilized, funds mobilized, etc.

- **Institutional readiness**: Tracking progress in improving institutional capacities including capacity needs of departments analysed and upgraded as per the institutional framework, integrating EE & EC in organization budgets, etc.
- **Action outputs**: Assessing the results of actions. For e.g., Number of people trained, new machinery integrated, maintenance improved, etc.
- **Impact indicators (outcomes)**: Assessing the progress towards the implementation of goals and strategic objectives, including units of electricity saved from baseline estimates, units of emissions saved from baseline estimates.

The organizations shall *form an independent monitoring and reporting team.*

3.4. Guidelines for conducting energy audits

This section details the overview of energy audits and guidelines for conducting energy audits in industries.

Energy Audits

An energy audit involves inspecting, surveying, and analyzing energy flows within a facility to identify alternatives that can reduce energy costs. The audit aims to pinpoint the most efficient and cost-effective Energy Conservation Measures (ECMs). These opportunities or measures may involve more efficient usage or partial to complete replacement of existing installations. The survey includes:

- Organizing electricity data, such as online metering, billing data, load profiles, load factor, power factor, and baseline consumption.
- Understanding utility rates and structures, including the costs associated with energy and power usage (energy vs. demand charges).
- Identifying all electrical power-consuming equipment, their operating hours, procedures, and potential areas for savings.

In industries where multiple forms of energy are used, these activities should be conducted for all energy types.

Types of Energy Audits

There are three common types of energy audits namely: Preliminary, Detailed and Investment-grade.

Preliminary energy audit	The preliminary audit (alternatively called a simple audit, screening audit or walk-through audit) is the simplest and quickest type of audit. This inspection is based on visual verifications, study of installed equipment and operating data to identify any glaring areas of energy waste or inefficiency. Typically, only major problem areas will be uncovered during this type of audit. Corrective measures are briefly described, and quick estimates of implementation cost, potential operating cost savings, and simple payback periods are provided. This level of detail, while not sufficient for reaching a final decision on implementing proposed measures, is adequate to prioritize energy-efficiency projects and to determine the need for a more detailed audit.
Detailed (General) energy audit	The detailed audit (alternatively general energy audit) expands on the preliminary audit described above by collecting more detailed information about facility operations and by performing a more detailed evaluation of

	energy conservation measures. It provides a breakdown of the energy use, and a quantitative evaluation of the energy conservation opportunities and measures selected to correct the defects or improve the existing installations. This level of analysis can involve advanced on-site measurements and sophisticated computer-based simulation tools to evaluate precisely the selected energy retrofits. A detailed financial analysis is performed for each measure based on detailed implementation cost estimated, site specific operating cost savings, and the customer's investment criteria. Sufficient details are provided to justify project implementation
Investment-grade energy audit	The investment grade energy audit is the most sophisticated of all the types of energy audit. It requires detailed energy modelling, analysis of the facility, and energy meter data for several years. It provides a detailed analysis of capital- intensive modifications focusing on potential costly energy conservation opportunities requiring rigorous engineering study.

Portable instruments for conducting measurement and trials during energy audit

Listed below are some instruments used to measure data needed in carrying out an energy audit.

Electrical

- **Power Analyzer –** specialized instrument used to measure and analyse electrical power in various systems, including both AC and DC circuits. It provides detailed insights into power consumption, energy efficiency, and the quality of electrical systems. Power analyzers are essential tools for monitoring parameters such as voltage, current, frequency, power factor, and harmonics.
- **Multimeter –** A versatile instrument used to measure voltage, current, and resistance in electrical circuits. It helps diagnose faults, verify performance, and ensure safe operation of electrical equipment.
- **Smart energy meters –** Advanced meters that track real-time electricity consumption, enabling end-users to monitor usage patterns. They support demand-side management and help identify energy-saving opportunities.

Thermal

- **Thermometers and thermocouples –** Tools used to measure temperatures of machinery, process fluids, and workspaces. They ensure optimal operating conditions and prevent overheating-related inefficiencies.
- **Infrared temperature gun –** A handheld tool that measures surface temperatures remotely via thermal radiation. Ideal for checking steam lines, motors, and other hard-to-access equipment.
- **Ultrasonic leak detector** – to detect leaks in steam and compressed air distribution systems.
- **Thermal imager -** Device that detects and visualizes infrared radiation emitted by objects. This radiation is converted into an image that displays temperature variations, allowing users to see heat patterns and differences that are invisible to the naked eye
- **Bomb calorimeter –** A scientific instrument used to measure the heat of combustion of a substance. It operates under constant volume conditions and is commonly used in thermodynamic studies, food science, and fuel analysis

- **Combustion/flue gas analyzer –** Measures flue gases (O_2, CO_2, temperature) to evaluate the efficiency of fossil fuel systems. Ensures optimal combustion, reducing fuel waste & emissions.

Others

- **Ultrasonic flow meter –** A device that measures the volumetric flow rate of a fluid by detecting how the fluid's flow affects an ultrasonic beam. Ultrasonic flow meter is non-intrusive, meaning that it can be installed without shutting down the system or interrupting the flow, making them suitable for situations where downtime is undesirable.
- **Lux meter –** A device that measures illuminance levels (in lux) to assess lighting adequacy in workspaces. It ensures compliance with energy efficiency standards and helps optimize artificial and natural lighting
- **Measuring tape –** Used to record dimensions of walls, windows, and equipment layouts for energy audits. Helps assess insulation needs, space planning, and compliance with efficiency standards.
- **Vane Anemometer –** A device used to measure wind speed and volumetric flow. It typically consists of a small turbine or propeller connected to a digital display. As the wind blows, it causes the turbine to spin, and the device calculates the wind speed based on the rotation rate
- **Hygrometer –** An instrument used to measure the humidity, or the amount of moisture, in the air or a gas.
- **Manometer and Pressure gauge –** An instrument used to measure the pressure of a fluid (liquid or gas) within a system.
- **Vernier Caliper –** A precision measuring instrument used to measure dimensions with high accuracy. It consists of a main scale and a sliding vernier scale, which allows for precise readings. Vernier Calipers can measure internal and external dimensions, as well as depths.
- **Stopwatch –** Handheld timekeeping device used to measure the amount of time elapsed from a specific start point to a stop point. It typically features start, stop, and reset functions, allowing users to precisely track time intervals.
- **Tachometer –** An instrument used to measure the rotation speed of a shaft or disk, typically in engines or other machinery. It displays the speed in Revolutions Per Minute (RPM)

Audit Instrument Calibration

Calibration is the process of comparing a measuring instrument's readings against a known standard to ensure accuracy and reliability. Over time, sensors and meters can drift due to wear, environmental factors, or aging components, leading to incorrect measurements. Regular calibration corrects these deviations, maintaining precision in energy audits, equipment monitoring, and compliance with industry standards.

Calibration procedures:

- **Preparation –** Ensure the instrument is clean and free from damage. Gather reference standards with traceable certification (e.g., NIST, ISO).
- **Comparison Testing –** Expose the instrument to a known input (e.g., fixed voltage, temperature) and record its readings.
- **Adjustment (if needed) –** If deviations exceed acceptable limits, recalibrate using manufacturer-specified methods (e.g., trim pots, software correction).
- **Documentation –** Record calibration results, including pre- and post-adjustment values, date, and technician details.
- **Labelling & Certification –** Attach a calibration sticker indicating the next due date and issue a compliance certificate.

Calibration Standards:

- **ISO/IEC 17025 –** International standard for testing and calibration laboratories.
- **ANSI/NCSL Z540.3 –** U.S. guideline for metrological traceability.
- **NIST Traceability –** Ensures reference standards align with the U.S. National Institute of Standards and Technology.
- **Manufacturer Specifications –** Equipment-specific tolerances and intervals (e.g., annual calibration for thermal sensors).

Energy Accounting

Before energy costs can be managed, they first have to be known. Energy accounting provides feedback (from the energy audit analysis) on how much energy an organization uses and how much it costs. It also provides a means to effectively communicate energy data that staff, industry management can use to improve cost management.

Specifically, energy accounting assists with:

- Recording and attributing energy consumption and costs – this requires a full understanding of the electricity tariffs/utility bills
- Troubleshooting energy problems and billing errors
- Providing a basis for prioritizing energy capital investments
- Evaluating energy programs success and communicating results
- Creating incentives for energy management
- Budgeting more accurately

An owner or occupier of an industry or facility may investigate the inclusion of the relevant components of an energy investment plan into a project. Such projects can be registered under various clean energy programs such as the clean development mechanism or any other carbon finance mechanism in place**.**

The simple steps for energy accounting in a manufacturing industry are:

1. **Set objectives:** Set objectives of energy accounting such as reducing costs or identifying inefficiencies.

2. **Identifying energy sources:** Identifying energy inputs and listing all energy sources (e.g., electricity, gas, steam, diesel, etc.). Note the points of supply (meters, utility, bills, generators)

3. **Map energy flow:** Create a flow diagram showing how energy moves through the facility (e.g., electricity to machines, lighting, HVAC, etc.). Use submeters for key areas or equipment to track consumption more accurately.

4. **Data collection:** Record energy consumption over time (daily, weekly, monthly) from meter/submeter readings or bills.

5. **Data analysis and normalization:** Adjust for production volume, weather, or operating hours to make data comparable. Identify where and when most energy is used and look for patterns, peaks, and inefficiencies.

6. **Set targets:** Calculate energy performance indicators (e.g., kWh per unit produced) and compare with industry standards and set realistic goals for improvement.

7. **Act and monitor:** Implement energy saving measures and track results and refine actions based on feedback.

Use of software tools can be utilized for energy accounting which would help in automating data collection, analysis, reporting, and visualization. Various software tools are utilized across the globe such as EnergyCAP, eSight Energy, and Dexma Energy Intelligence Platform. Energy management systems such ABB ability energy manager and EcoStruxure by Schneider Electric are utilized in industries. Other SCADA/IoT integration tools can be used by plants with sensors and control systems which can create SCADA platform with energy modules and custom dashboards or collect and analyse real time operational data for energy (e.g., Ignition by Inductive Automation).

Demand-Side Management

The demand side management consist of planning, implementation, and monitoring of utility activities designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand. The demand side management covers the complete range of load-shape objectives, including strategic conservation and load management, as well as strategic load growth.

The load management programs seek to lower peak demand during specific, limited time periods by temporarily curtailing electricity usage or shifting usage to other time periods. Peak demand management does not necessarily decrease total energy consumption but could be expected to reduce the need for investments in networks and/or power plants.

An example of demand side management is presented below:

Demand Response (DR) in frozen foods processing plant – plant operating large refrigeration and blast freezing units that run continuously. The power utilities require large users to temporarily reduce demand during grid stress or peak demand events. If the utility runs any Demand Response programs, then the industry can avail any benefits of offered by the utility. During a DR event (e.g., hot summer day with high grid load), the industry can:

- Pre-cool storage areas before the DR event
- Reduce or delay non-critical processes (like packaging or washing lines)
- Temporarily cycle or throttle compressors in refrigeration systems without affecting food safety

Tariffs are often higher during critical hours. These above demand side management measures would help industry in reducing consumption during critical hours which would lead to reduced electricity costs. This will help in maintaining production schedules and product standards. This would result in improved relationship with utility and positive contribution to grid reliability.

The industry can achieve the DSM measures through:

- Advanced control systems for refrigeration
- Real time alerts and scheduling from DR aggregator or utility
- Energy management dashboards for tracking DR events and performance

The Steps for conducting energy audit

The audit activities shall be carried out as per ISO 50002:2014 Guidelines. The steps in the audit execution will include establishment of baseline, performance assessment of equipment, estimation of operating specific energy consumption/operating efficiency, specific water consumption and identifying energy and water conservation measures.

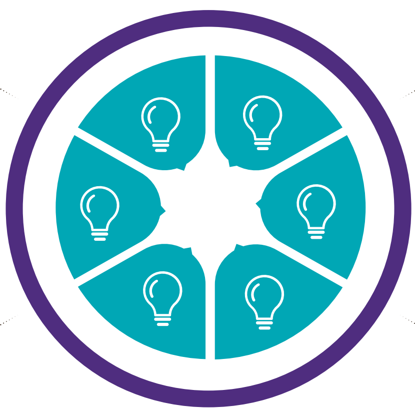
The methodology for the audit depicting various tasks, activities and outcomes is presented in figure below**.**

Preparation

- Schedule of activities
- Interactions with industry management
- Identifying primary data required

Reporting

- Investment grade audit report preparation
- Presentation of findings to industry



Data Collection

- Collection of time series data
- Establish energy and water baseline
- Inventory of equipment and operational data

Implementation and M&E

- Action plan for implementation of improvement measures
- Financial Support Information

Field Visit

- Performance assessment of major equipment•
- Review of operational manuals and procedures
- Implementing no cost measures to realize savings

Data Analysis

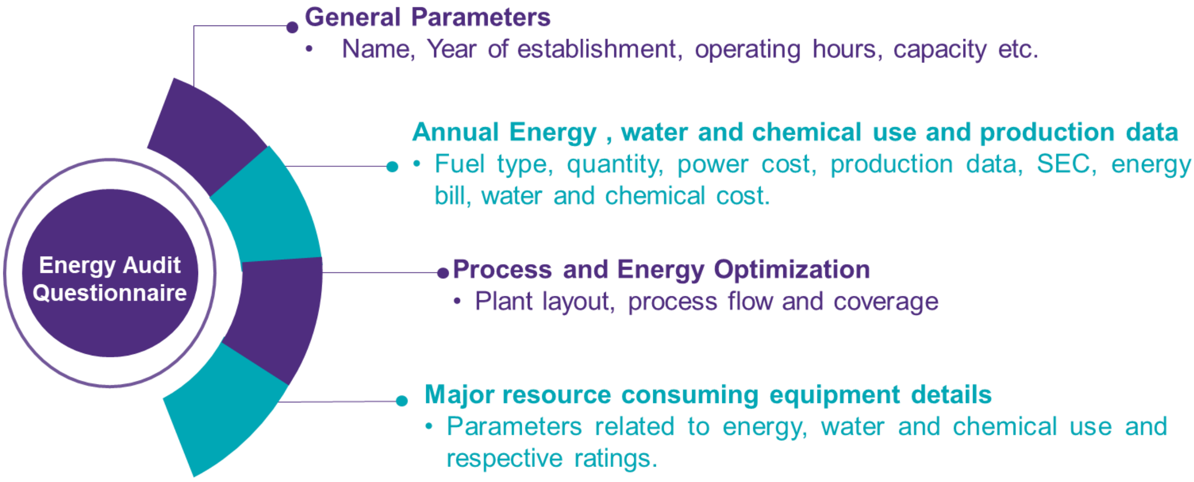
- Review and analysis of data
- Identification of energy and water conservation measures
- Financial feasibility of the opportunities
- Analysis of Energy and Environmental Impact

1. Initial preparatory work & inception meeting

This step is crucial in the execution of the assignment as it establishes the blueprint for all subsequent activities, including the overall scope, pace of activities, and availability of existing information. The project team organizes an inception meeting with the management representative from the industry and various department heads. Discussion points during the inception meeting include:

- Strategy for executing the assignment
- Field movement plans for the proposed team
- Appointment of nodal officer(s) for each identified industry
- Availability of historical time series data
- Assistance required from company officials during the audit

Data collection is very important to know the historical trend of electricity and fuel consumption in the plants as well as collection of data required for estimation of EnPIs and energy saving potential.



2. Collection and analysis of time series data

The audit team circulates a data collection questionnaire for energy audit to the industry. The questionnaire consists of:

a. Basic information about the plant facility like production process, product and production capacity.

b. Resource profile of the plant set-up: historical energy and water data - monthly as well as yearly, key sub-process/ equipment,

c. Major resource consuming equipment: installed equipment inventory (design), its operating parameters such as operating hours, actual load and any operational restrictions. Maintenance plans and procedures, and

d. Process flow and boundaries of the plant (see figure below). The questionnaire has provisions for industry to provide any other relevant information, if necessary.

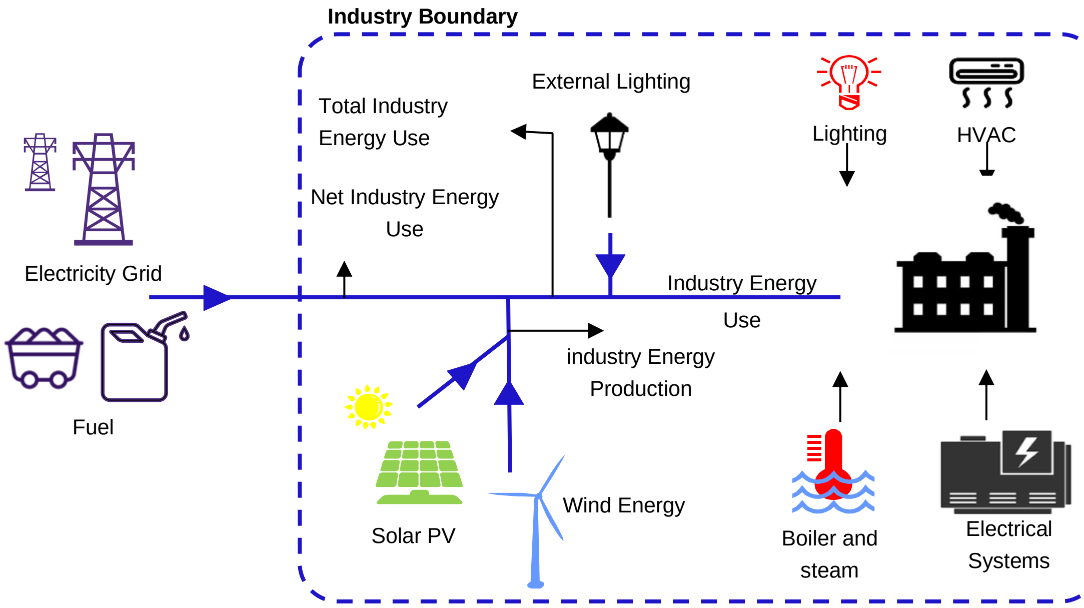
The audit team analyses questionnaire data to establish energy and water consumption baselines of the industry as a whole and important sub-processes/equipment. These baselines will be depicted in the form of energy and water performance indicators (EnPIs/Water KPIs) and these EnPIs & KPIs are compared to industry benchmarks within country and internationally. This will enable the team to identify thrust areas where significant potential for energy and water conservation exists. The project team provides guidance to the industry representative to fill in the questionnaire. If gaps exist, they are filled during the field visit by a project team for detailed measurement and performance assessment.

3. Field visit

Based on preliminary data submission and analysis, site visit should be scheduled to conduct an energy assessment. The objective of the site visit will be, measurement and observe the major energy consuming equipment and the identification of energy conservation opportunities.

The energy assessment will be conducted the following stages.

- **Measurement and Critical Analysis of Existing Situation**: In this stage, there will be a comprehensive evaluation of the current conditions of the manufacturing industry. This includes assessing process energy usage, identifying areas of inefficiency and the efficiency of equipment and installations (pumps, cooling, ventilation, etc.). Identifying weaknesses in these areas is crucial for understanding the baseline energy performance.
- **Site Energy Balance:** This step involves a detailed examination of the energy consumption of the industry. Actual energy consumption data will be compared to theoretical consumption levels.



- **Feasibility Study for energy efficiency and renewable energy**: This step focuses on the feasibility of identifying energy efficiency measures and setting up renewable energy electricity production system. The assessment will include an examination of the potential for renewable energy sources (e.g., solar, wind) at the industry. It will also explore the economic viability and environmental benefits of energy efficiency measures and renewable energy options.
- **Feasibility Study for Sustainable Water Use**: This component evaluates the feasibility of implementing more sustainable water management practices on the sites. It encompasses water treatment and recycling solutions. The study will assess the availability of water resources, current water usage, and the potential for recycling and sustainable water practices to reduce environmental impact and costs.

This energy assessment phase of the project is integral to the decision-making process, as it provides a comprehensive understanding of the existing conditions, identifies potential improvements, and evaluates their feasibility and impact. It lays the groundwork for informed and sustainable decisions regarding energy and resource management within the project.

The audit team scrutinizes the filled-in questionnaire. A field movement plan for the team should be developed. This plan shall comprise detailed schedule of the teams based on availability of the nodal persons of the factories and geographical locations. The team shall then visit the units as per the field movement plan for conducting comprehensive assessment.

The audit team shall take a walk-through of the industry to know exact locations along with energy consuming equipment/process and plan arrangements for the Energy Audit schedule.

In case, there are any important data/facts regarding electricity and fuel consumption of the plant equipment, the audit team should visit the different sections of the respective factory to take measurements of various operating parameters. The audit team shall utilize the measuring instruments (as shown in previous sub-sections) and use standard measurement techniques.

4. Data analysis and measures for improvement

At the conclusion of the field measurements, the audit team shall discuss the initial findings and potential energy savings opportunities with the relevant officials of the respective companies. The project team shall conduct a detailed review and analysis of the collected time series data and actual measurements to assess the performance of equipment and systems. Energy performance indicators (EnPIs) should be established for all sub-processes and the entire plant. Based on these steps, energy conservation opportunities will be identified and categorized as 'No cost', 'Low cost', and 'Capital intensive measures'.

During the field study, wherever possible the audit team should try to implement the no cost measures to realize the energy and water savings by the plant immediately.

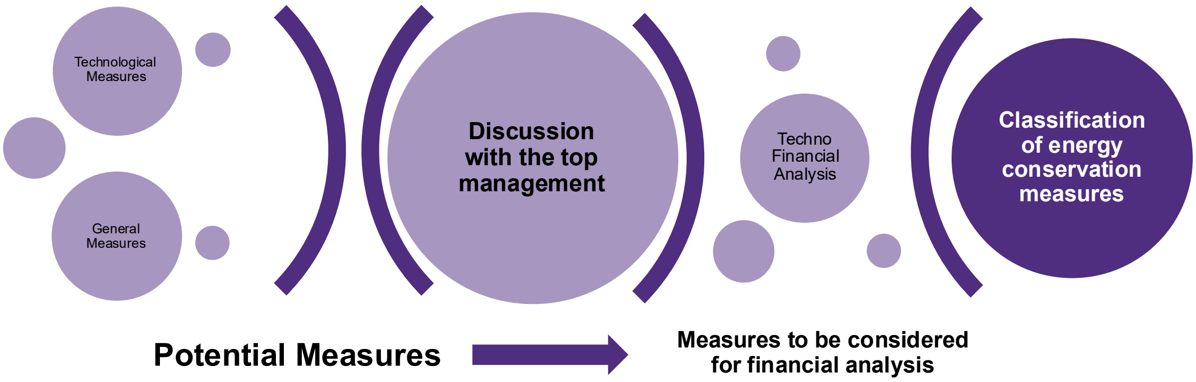
The team should use proven tools for identification of EnPIs and performance assessment such as *energy balance*. The audit team should identify suitable tools for the assignment depending on the equipment and process studied. The team should make use of open-source software tools such as RETScreen, PVsyst, etc. for renewable energy potential assessment.

- Review of the Connected Load, layout and production process
- Review of annual electricity bills, fuel consumption and any other energy consumption data
- Review of preliminary data and energy performance
- Denfine Energy Baseline (EnB), Energy Performance Indicator (EnPI)
- Study and observe any energy saving options implemented within the industry
- Establish the baseline SEC for monitoring reduction in energy consumption as per Gate-to-Gate concept.
- Assess possible energy saving options & recommend various technically sound and economically viable measures to improve the energy performance indicators

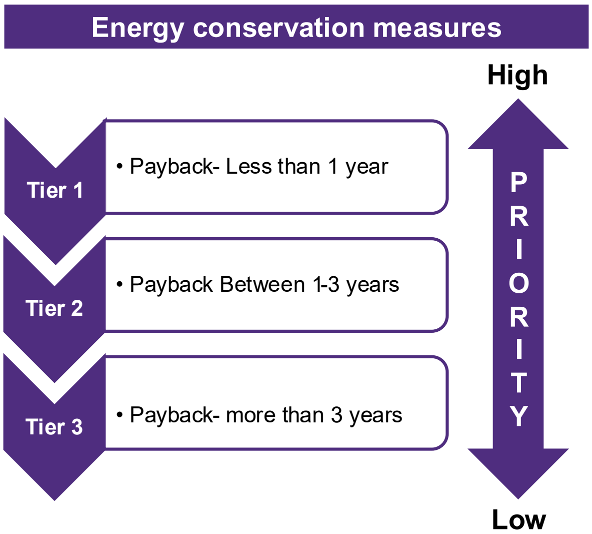
5 – Coherent Implementation Roadmap

This energy saving measures shall be distinguished between two categories:

- **Corrective Measures**: These focus on improvements that do not require substantial investments but rather revolve around optimizing regulations, equipment management, and user behaviour. They aim to maximize energy efficiency through existing resources.
- **Significant Improvement Measures**: These are more resource-intensive and time-consuming but promise a substantial enhancement in the site's overall energy efficiency.



For each planned operation, the following details should be provided.



- **Energy Saving Recommendation**: Recommendation will consist of proposed technology details/ proposed capacity and suggested operational pattern. Detailed design engineering will not be a part of this activity.
- **Cost Estimates**: Detailed breakdowns of costs, including unit prices and quantities, with reference to the sources of price information.
- **Profitability Analysis**: A calculation of the expected return on investment. This will include the gross payback time in relation to the estimated lifespan of materials or equipment and overall cost calculation. It will also incorporate projections of energy prices over the material's lifespan.
- **Financial Support Information**: The service provider should outline any financial support mechanisms or incentives applicable to the industry, such as energy-saving certificates, tax credits, and national or local subsidies. Based on these steps, energy conservation opportunities should be identified and categorized as short term, medium term, and long term.
- **Bill of quantity**: Service provider should provide the bill of quantity for devices, equipment and other requirements for installation at sites to enhance EE and energy conservation.
- Above information shall facilitate decision-making. Additionally, an energy accounting system for industries should be established to enable industry team to monitor consumption & technical operating data. It may rely on metering & data collection, allowing for remote data transmission, storage, and presentation. The emphasis is on creating a simple and effective system.
- **Action Plan –** All corrective measures and significant improvement measures should be categorized into a priority list and shall have a timeline for implementation mentioned within an action plan.

The assessment includes considerations for necessary tools, associated costs, and timelines. Detailed descriptions of energy policies, performance targets, and continuous improvement opportunities will be included to guide and enhance energy management practices.

6. Reporting

After conducting all the activities, the audit team will prepare a final energy audit report in a standard format comprising of the following:

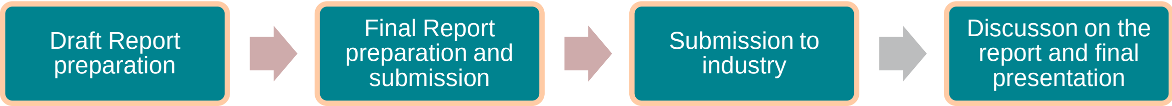


Table of contents

Executive summary

- Facility overview
- Utility use and tariff analysis
- Condition assessment of targeted energy systems
- Energy baseline and balance of the factory.
- Digitalization options
- Energy performance indicators
- Performance assessment of key equipment and areas/sections
- Observations and findings of the study
- Comprehensive benefit / cost analysis (NPV, IRR, ROI)
- Payback period calculation keeping in view the energy cost.
- Summary cost and savings presentation
- Implementation strategy
- List of instruments and devices used during audit with accuracy level and traceability of calibration status.

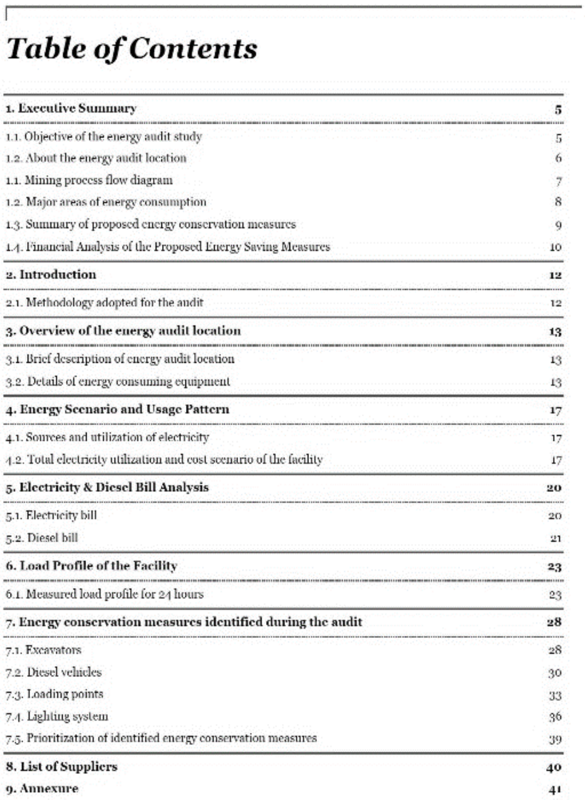
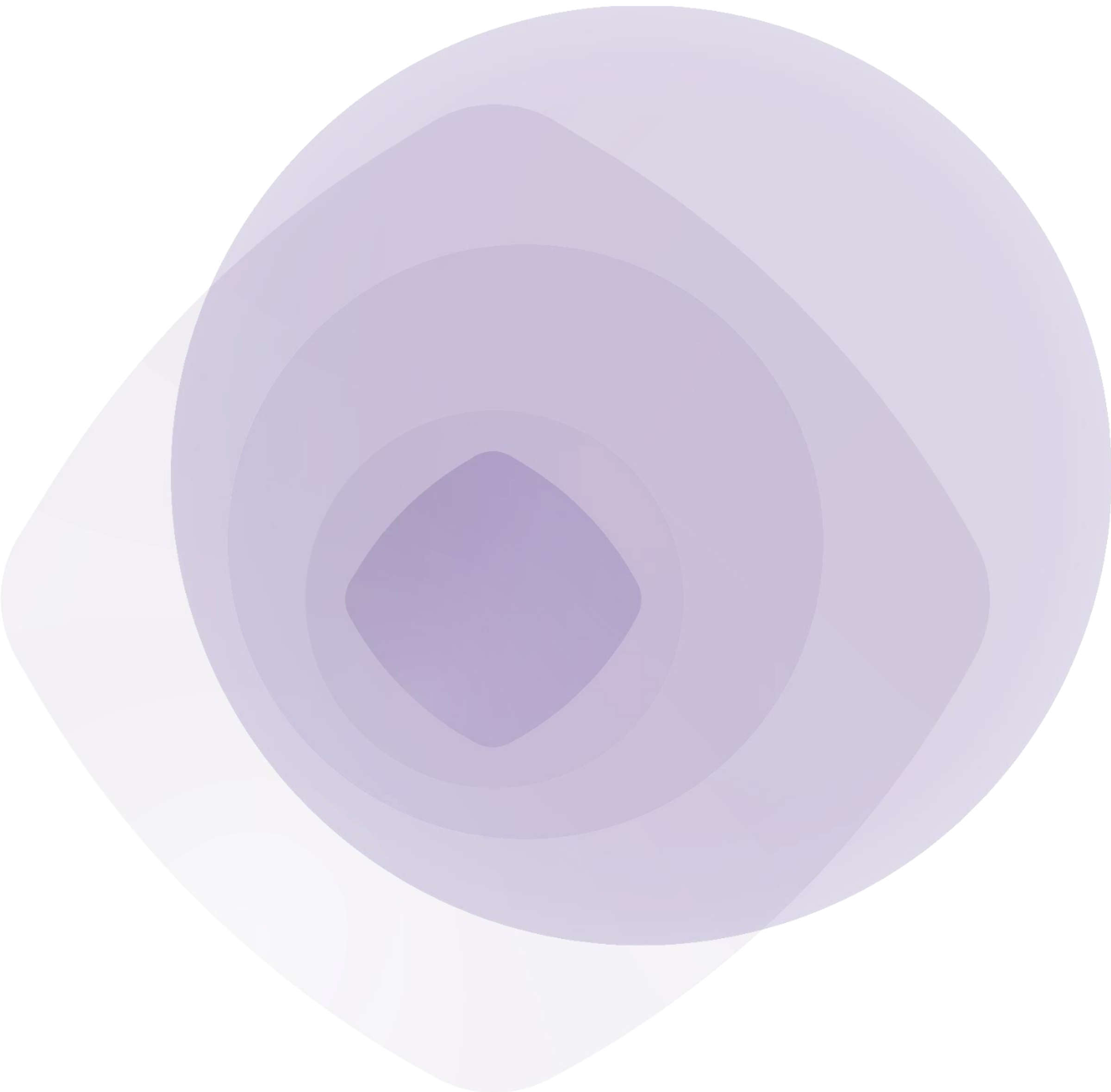


Table of Contents



4. Industrial Energy Efficiency and Conservation Guideline for common equipment

4.1. Air Compressors and Compressed Air Network

Air compressors are utilized across various industries to meet process requirements, operate pneumatic tools and equipment, and fulfil instrumentation needs. They consume a significant amount of electricity in industrial settings. However, only 10-30% of the energy reaches the point of end use, while the remaining 70-90% is lost as unusable heat energy, with smaller losses due to friction and noise.

Air compressors are generally classified into two types: Positive Displacement Compressors and Dynamic Compressors. Positive Displacement Compressors increase gas pressure by reducing its volume and are categorized into screw, reciprocating, and rotary compressors. Dynamic Compressors, on the other hand, increase air velocity, which is then converted to higher air pressure at the outlet. These are typically centrifugal compressors and are further categorized into radial and axial flow types.

Different industries have varying requirements based on their scale and operations. Small and medium-sized industrial enterprises usually use reciprocating and screw-type compressors, while large industrial enterprises typically deploy screw or centrifugal-type compressors.

Air compressors in major industrial sectors in Mauritius – **Textile, Food Processing, Agro processing and beverages, Sugar Cane industry, Pharmaceutical, Light engineering and electronics, Packaging industry.**

Performance assessment

The efficiency of air compressors is calculated using capacity assessment and leakage assessment which subsequently define the specific power consumption of the air compressor.

Capacity assessment

The capacity of a compressor is defined as the full rated volume of gas flow compressed and delivered under conditions of total temperature, total pressure, and composition prevailing at the compressor inlet. It is also called free air delivery (FAD) i.e. air at atmospheric conditions at any specific location. Ageing of compressor along with inherent efficiencies may cause the free air delivery rate to be less than the design value. To assess the capacity of the air compressor we use the capacity assessment test.

Free air delivery is calculated using:

$$\boldsymbol{Q} = \frac{(\boldsymbol{P_2} - \boldsymbol{P_1})}{\boldsymbol{P_0}} \times \frac{\boldsymbol{V}}{\boldsymbol{t}}$$

In case of high suction air temperature as compared to ambient air temperature, use correction factor:

$$\boldsymbol{Q_{corrected}} = \frac{(\mathbf{273} + \boldsymbol{T_{ambient}})}{(\mathbf{273} + \boldsymbol{T_{suction}})}$$

Where:
Q - Free air delivery (m^3/min)
P_2 - Final pressure after filling(kg/cm^2a)
P_1 - Initial pressure after bleeding (kg/cm^2a)
P_0 - Atmospheric pressure (kg/cm^2a)
V - Storage volume (m^3)
t - Time taken to build up pressure to P_2 (minutes)

Equipment required for capacity assessment test: Stopwatch, Distance meter, Vernier Caliper

Leakage Assessment

Air leakages can be a significant source of wasted energy in an industrial compressed air system. They may account for as much as 20 to 30 percent of a compressor's output. Industries which proactively undertake leak assessments can detect, and repair can reduce leaks to less than 10 percent of compressor output. These air leakages can be anywhere in the areas such as

- Couplings, hoses, tubes, and fittings
- Pressure regulators
- Open condensate traps and shut-off valves
- Pipe joints, disconnects, and thread sealants.

Leakage Quantity can be calculated using:

$$Q_L = \frac{Q \times t_{on}}{(t_{on} + t_{off})}$$

Where:
Q - Free Air Delivery of Compressor
Q_L - Leakage quantity
t_{on} - On load time i.e., loading period (seconds)
t_{off} - Off load time i.e., unloading period (seconds)

Equipment required for leakage assessment test: Stopwatch

Specific Power Consumption

The Specific Power Consumption (SPC) of air compressors serves as an effective guide in comparing air compressor efficiencies of different air compressors.

The specific power consumption of air compressor can be calculated by following formula

$$SPC = \frac{P\ (kW)}{Q\ (cfm)}$$

Where:
P - Power of input is in kW
Q - FAD of compressor is in cfm

Equipment required for calculating specific power consumption: 3 phase power analyser, Stopwatch

The specific power consumption of reciprocating and screw compressor vary depending upon their use and area of installation. An indicative list of specific power consumption of the air compressors is as shown in Table 7.

Common monitorable parameters

The following common parameters can be monitored by industry to assess the performance of air compressors.

Table 5: Common monitorable parameters – air compressor

Parameter	Unit	Instrument	Frequency
Air pressure	kg/cm^2	Pressure gauge	Daily
Air inlet temperature	°C	Thermocouple	Daily
Loading duration	hours	Electronic timer	Daily
Unloading duration	hours	Electronic timer	Daily
Energy consumption	kWh	Energy meter	Daily

The air compressor selection criteria based on pressure requirement & capacity of air delivery required is presented in the Table 6. The specific power consumption targets are shown in Table 8.

Table 6: General Selection Criteria for Air Compressors[8]

Type of Compressor	Capacity (m^3 /h)		Pressure (bar)	
	From	To	From	To
Roots blower compressor single stage	100	30000	0.1	1
Reciprocating Single / Two stage	100	12000	0.8	12
Reciprocating Multistage	100	12000	12	700
Screw Single stage	100	2400	0.8	13
Screw Two stage	100	2200	0.8	24
Screw Centrifugal	600	300000	0.1	450

Table 7: Specific Power Consumption of air compressor[9]

Type	FAD range cfm	Pressure range (bar)	SPC range(kW/cfm)
Reciprocating	20 – 7000	0.8 – 12	0.2 – 0.35
Screw	50 – 1500	0.8 – 24	0.14 – 0.35
Centrifugal	500 - 5000	0.8 – 20	0.14 – 0.35

Table 8: SPC standard and target - air compressor

Specific Power Consumption (kW/CFM)	Reciprocating air compressor	Centrifugal air compressor	Screw air compressor
Standard	0.29	0.20	0.18
Target	0.22	0.14	0.14

[8] *Source: Energy Efficiency in Electrical Utilities – Book 3 (Bureau of Energy Efficiency, India)*
[9] *Source: Energy Efficiency in Electrical Utilities – Book 3 (Bureau of Energy Efficiency, India)*

Procedures for rational use of energy

Management

- The industry shall ensure the drawing of clean, cool, and dry air by compressors for optimum performance and follow the operational controls provided in the Energy Management (EM) manual for the air compressor.
- The industry shall use a suitable size of air compressors to meet the plant demands.
- Ensure air intake to compressor is not warm and humid by locating compressors in well-ventilated area or by drawing cold air from outside. Every 4°C rise in air inlet temperature will increase power consumption by 1 percent
- Install manometers across the filter and monitor the pressure drop as a guide to replacement of element.
- Minimize low-load compressor operation; if air demand is less than 50 percent of compressor capacity, consider changing over to a smaller compressor or reduce compressor speed appropriately (by reducing motor pulley size) in case of belt driven compressors.
- If more than one compressor is feeding to a common header, compressors must be operated in such a way that only one small compressor should handle the load variations whereas other compressors will operate at full load
- If pressure requirements for processes are widely different (e.g., 3 bar to 7 bar), it is advisable to have two separate compressed air systems.
- Reduce compressor delivery pressure, wherever possible, to save energy.
- Provide extra air receivers at points of high cyclic-air demand which permits operation without extra compressor capacity.
- Retrofit with variable speed drives in big compressors, say over 100 kW, to eliminate the `unloaded' running condition altogether.
- Keep the minimum possible range between load and unload pressure settings
- Automatic timer-controlled drain traps waste compressed air every time the valve opens. So, frequency of drainage should be optimized
- Install equipment interlocked solenoid cut-off valves in the air system so that air supply to a machine can be switched off when not in use.
- Present energy prices justify liberal designs of pipeline sizes to reduce pressure drops.
- Compressed air piping layout should be made preferably as a ring main to provide desired pressures for all users.
- A smaller dedicated compressor can be installed at load point, located far off from the central compressor house, instead of supplying air through lengthy pipelines.
- Misuse of compressed air such as for body cleaning, agitation, general floor cleaning, and other similar applications must be discouraged to save compressed air and energy.
- Pneumatic equipment should not be operated above the recommended operating pressure as this not only wastes energy but can also lead to excessive wear of equipment's components which leads to further energy wastage.
- Pneumatic transport can be replaced by mechanical system as the former consumed about 8 times more energy. The highest possibility of energy savings is by reducing compressed air use.
- Because of high pressure drop, ball or plug or gate valves are preferable over globe valves in compressed air lines.

Monitoring and Evaluation

- The industry shall undertake an on-line monitoring of pressure and air flow at the downstream of compressors and the power consumption of individual compressors to assess the performance, i.e. Specific Power Consumption which shall be described in the EM Manual

Maintenance and inspection

Procedures for rational use of energy
▪ Clean air-inlet filters regularly. Compressor efficiency will be reduced by 2 percent for every 250 mm WC pressure drop across the filter. ▪ Keep compressor valves in good condition by removing and inspecting once every six months. Worn-out valves can reduce compressor efficiency by as much as 50 percent. ▪ Fouled inter-coolers reduce compressor efficiency & cause more water condensation in air receivers & distribution lines resulting in increased corrosion. Periodic cleaning of intercoolers must be ensured. ▪ Compressor free air delivery test (FAD) must be done periodically to check the present operating capacity against its design capacity and corrective steps must be taken if required. ▪ The possibility of heat recovery from hot compressed air to generate hot air or water for process application must be economically analysed in case of large compressors ▪ Check air compressor logs regularly for abnormal readings, especially motor current cooling water flow and temperature, inter-stage and discharge pressures and temperatures and compressor load-cycle. ▪ Compressed air leakage of 40 – 50 percent is not uncommon. Carry out periodic leak tests to estimate the quantity of leakage. ▪ All pneumatic equipment should be properly lubricated, which will reduce friction, prevent wear of seals and other rubber parts thus preventing energy wastage due to excessive air consumption or leakage. ▪ Pneumatic tools such as drill and grinders consume about 20 times more energy than motor driven tools. Hence, they have to be used efficiently. Wherever possible, they should be replaced with electrically operated tools. ▪ Where possible welding is good practice and should be preferred over threaded connections

New Installations

- The industry shall undertake demand assessments of compressed air to select a suitable compressed air system based on the existing requirements as well as considering the immediate expansion plans. This includes energy-efficient systems, such as an inbuilt VFD, motor with permanent magnet, inverter type air compressor, etc.
- The industry shall select and install air compressors with the lowest SPC while meeting the compressed air demands.
- The industry shall install air compressors in a direction that a hermetically closed room or intake of contaminated air (oil, gas, etc.) is avoided.
- The industry shall design and install a compressed air network with a minimum pressure drop. It shall use seamless metallic pipes or 'Fiber Reinforced Plastic' (FRP) pipe for compressed air lines, which shall be described in the EM Manual.
- The industry should install intelligent electronic control systems to minimize energy consumption and reduce loss of compressed air. It shall also include an auto-drain system for moisture removal.
- The industry shall locate air compressors in such a way that it reduces the piping length and minimizes line-pressure losses.
- The industry shall meet fluctuations in compressed air demands using VFD-enabled screw air compressors. In case of a multiple air compressors system, the industry shall use one-inverter type air compressor with a suitable pressure setting to meet the variable load conditions while the other air compressors shall be used in continuous operation to cater to the base load.
- The industry shall use centrifugal compressors for meeting a high volume with low pressure applications, wherever feasible.
- The industry shall install air dryers in the distribution line which supplies to dry air usage points only, e.g., instrumentation air.
- The industry shall ensure the proper location of air compressors and the quality of suction air as per the recommendation of the manufacturers, which shall be described in the EM Manual.

4.2. Pump and pumping system

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 on further bifurcation are sub-classified as centrifugal and special effects pumps whereas displacement pumps are sub-classified as rotary or reciprocating pumps Centrifugal pumps account for major share of electrical consumption in the industrial sector.

A centrifugal pump is of a simple design. The two main parts of the pump are impeller and the diffuser. Impellers are usually made up of bronze, polycarbonate, cast iron or stainless steel. The impeller resides in the diffuser which captures and directs the water of the impeller.

Pumps and pumping system in major industrial sectors in Mauritius – **All Industrial sectors**

Performance assessment

The most critical aspect involving any pumping system is the matching of the pumps to the loads. Even an efficient pump if so, selected will operate at poor efficiencies if there is a mismatch to the pumping system. Further pump efficiencies drop can also be expected over time due to deposits in the impellers. Performance assessment of pumps would reveal the existing operating efficiencies in order to take corrective actions by the industries.

The performance of pumps can be assessed using following formula

$$\eta = \frac{P_h}{P_s} = \frac{\left({[Q \times (h_d - h_s) \times \rho \times g]}/{1000} \right)}{P_s}$$

Where:
Q - fluid flow rate (m^3/s)
h_d - discharge head (m)
h_s - suction head (m)
ρ - density of fluid (kg/m^3)
g - acceleration due to gravity
P_h- Hydraulic power
P_s - Shaft power
η - Efficiency

Equipment required for pump efficiency: Ultrasonic flow meter, Pressure gauge, power analyzer

Common monitorable parameters

The following common parameters can be monitored to assess the performance of pump and pumping system.

Table 9: Common monitorable parameters – pump and pumping systems

Parameter	Unit	Instrument	Frequency
Electricity Consumption	kWh	Energy meter	Daily
Suction head	m	Pressure gauge	Daily

Parameter	Unit	Instrument	Frequency
Delivery head	m	Pressure gauge	Daily
Flow rate	m^3/h	Flow meter	Daily
Fluid temperature	°C	Thermocouple	Daily

The standard practice in the industry is to use mono-block centrifugal pumps or submersible pumps. These pumps and their impellers are made of cast iron and hence has a higher efficiency degradation rate. Often the industry installs the pumps on basis of kW or hp rating of motor, which is not a correct practice.

The target in case of pumps for industries can be:

- Go for steel impeller and steel body pumps for better life and lower efficiency degradation
- Prefer higher efficiency end-suction centrifugal or vertical design pumps
- Match the requirement on basic of best efficiency available to deliver required discharge water flow at the necessary differential head rather than the hp or kW rating of the motor.

The efficiency of pumps depends on discharge flow rate and delivery head, however, typical range of efficiencies as per standard and targets can be as shown in Table 10.

Table 10: Standard and target efficiencies of pumps

Efficiency of Pumps[10]	
Standard value	30%
Target value	60%

The procedures to be followed for rational use of energy are:

Procedures for rational use of energy
Management

- The industry shall use 'characteristic curves' provided by the manufacturer for the monitoring and control of pump operation. The pump(s) shall be operated close to 'Best Operating Point' (BOP) as specified by the pump manufacturer.
- The industry shall use pumps with highest efficiency to meet the base load when multiple pumps are in operation.
- While using multi-pumps, the industry shall manage and control the loading of pump in such a way that it achieves the highest possible loading near the BOP in respective characteristic curve.
- The industry shall ensure optimum loading of pumps during the entire range of operation both during full load and part load while operating multiple pumps in parallel, which shall be provided in the EM Manual.
- The industry shall manage the piping network of the pumping system and the control operating parameters, such as flow rate, pressure, and temperature, which shall be provided in the EM Manual.
- The industry shall maintain a minimum Net Positive Suction Head (NPSH) of pumps as prescribed by the manufacturer.

Monitoring and Evaluation

[10] *Varies based on discharge flow, delivery head and type on construction*

Procedures for rational use of energy

- The industry shall measure and record key operating parameters such as the total differential head, flow rate and power consumption to evaluate efficiency of pumps which shall be described in EM Manual. It shall use on-line monitoring for centralized large system and periodical measurement for decentralized smaller pumps.

Maintenance and inspection

- The industry shall undertake routine/scheduled overhauling of pumps according to the instructions provided by the manufacturers, which shall be described in the EM Manual.
- The industry shall maintain and inspect parameters, such as speed of motor, body temperature in pump ends, and vibration on a periodical basis, which shall be described in the EM Manual.
- Industry shall undertake corrective maintenance in case of a significant drop in the total differential head observed in the pumping system.
- Industry shall ensure a dynamic balancing of pump assembly after each overhauling

New Installations

- The industry shall select correct capacity of pump with energy efficient systems such as IE3/ IE4 motor or permanent magnet synchronous motor, variable frequency drives (VFD), cogged v-belts for belt driven systems, etc., while considering existing demand and immediate future expansion plans.
- The industry shall undertake water balance of the plant to assess the total pumping capacity.
- Industry shall undertake dynamic balancing of pump assembly during installation.
- The industry shall optimize the number of stages available in a multi-stage pump (e.g., boiler feedwater pump) in case of availability of the head margins.
- The industry shall design and install a pumping network with minimum system resistance using seamless pipes, which shall be described in the EM Manual.
- The industry shall use a booster for small loads requiring higher pressures.

Typical characteristics of an inefficient oversized pump and its description is presented in Table 11.

Table 11: Oversized pump and its description

Characteristics of Oversized Pump	Description
Excessive flow noise	Oversized pumps cause flow-induced pipe vibrations, resulting in excessive noise and increased damage to pipework (including flanged connections, welds and piping supports)
Highly throttled flow control valves	Pumps tend to remain in more restrictive positions with oversized pumps; this increases backpressure, decreasing efficiency
Frequent replacement of bearings and seals	Increased backpressures from increased flow rates creates high radial and thrust bearing loads as well as high pressures on packing glands and mechanical seals
Heavy use of bypass lines	A system that heavily uses bypass lines indicates that the system has either oversized pumps, is not balancing properly, or both
Intermittent pump operation	Pumps being used for purposes such as filling or emptying tanks that run very intermittently indicate oversizing and hence suffer increased start/stop inefficiencies and wear, as well as increased piping friction

Pump wear and maintenance

Effective, regular pump maintenance keeps pumps operating efficiently and allows for early detection of problems in time to schedule repairs and to avoid early pump failures. Regular maintenance avoids losses in efficiency and capacity, which can occur long before a pump fails. The main cause of wear and corrosion is high concentrations of particulates and low pH values. Wear can create a drop in wire to water efficiency of unmaintained pumps by around 10–12.5%. Much of the wear occurs in the first few years, until clearances become similar in magnitude to the abrading particulates.

Studies indicate that the average pumping efficiency in manufacturing plants can be less than 40%, with 10% of pumps operating below 10% efficiency. Oversized pumps and the use of throttled valves were identified as the two major contributors to the loss of efficiency. Energy savings in pumping systems of between 30% and 50% could be realized through equipment or control system changes. A pump's efficiency can also degrade during normal operation due to wear by as much as 10% to 25% before it is replaced. Table 12 presents common problems and solutions in pumping system.

Table 12: Pumping - Problems and solutions

Common Problem	Potential Measures to Improve Efficiency
Unnecessary demand on pumping system	Reduce demand on system
Oversized pumps	Select pump that operates near to BOP Change impeller Trim impeller Fit multiple-speed pump Use multiple-pump arrangements Fit lower speed pump/motor
Pump wear	Pump maintenance
Less efficient impeller	Change impeller
Inefficient pump throttling controls	As for oversized pumps Fit adjustable or variable-speed drive
Inefficient piping configuration	Change piping inefficiencies
Oversized motor	Change motor
Inefficient motor	Change to high-efficiency motor
Lack of monitoring and/or documentation	Install monitoring and conduct survey

4.3. Heating Ventilation and Air Conditioning system

The heating, ventilating, and air conditioning (HVAC) system for an industrial facility is the system of motors, ducts, fans, controls, and heat exchange units responsible for delivering heated or cooled air to different parts of the industrial facility. The purpose of the HVAC system is to add or remove heat and moisture to maintain the desired environmental conditions for people, products or equipment.

A lot of manufacturing plants are fully air conditioned, and almost all industrial facilities have office areas that are cooled. The HVAC system is responsible for a significant portion of the energy use and energy cost in building areas of the industry.

Some of the prominent types of HVAC systems installed in industrial facilities range from Water cooled chillers, Air cooled chillers, Split fixed AC, Variable Refrigerant Volume/flow units, Cassette fixed speed AC, etc.

HVAC equipment in major industrial sectors in Mauritius – **Textile, Food Processing, Agro processing and beverages, Sugar Cane industry, medical devices and Pharmaceuticals, Light engineering and electronics, High Precision Engineering Products, Watches and photographic instruments, Packaging industry, Jewelry.**

Performance assessment

The performance assessment test for HVAC systems will verify the performance of the refrigeration system based on values as assessed through field measurements. The performance assessment will measure net cooling capacity along with the energy requirements at operating conditions. The objective of the test is to estimate the energy consumption at actual load vis-à-vis design conditions.

The cooling capacity be estimated by following relation:

$$\boldsymbol{Tonnes\ of\ Refrigeration\ (TR)} = \frac{\boldsymbol{Q \times c_p \times (T_i - T_o)}}{\boldsymbol{3024}}$$

Alternatively, British Thermal Unit (BTU)[11] could also be used to measure refrigeration capacity of equipment:

$$\boldsymbol{BTU = Q \times c_p \times (T_i - T_o)\ \times 3.968}$$

Where:
TR - cooling TR duty
BTU - British thermal unit
Q - mass flow rate of coolant (kg/hour)
C_p - coolant specific heat (Kcal /kg °C)
T_i - inlet Temperature of coolant to evaporator (chiller) (°C)
T_o - outlet temperature of coolant from evaporator (chiller) (°C)

Equipment required for HVAC TR: Hygrometer, Power analyzer, Vane anemometer, Vernier Caliper

Air Conditioners

The efficiencies of air conditioners are usually measured in terms of their Energy Efficiency Ratios (EER).

EER of air conditioner:

$$\boldsymbol{EER\ = \frac{Btu\ of\ cooling}{watt\ hours\ of\ electric\ energy\ input}}$$

Where:
EER - Energy Efficiency Ratios
BTU - British thermal unit
Electric energy is denoted as watt-hour (Wh)

[11] *One TR is equivalent to 12,000 BTU*

Equipment required air conditioner performance: Hygrometer, Power analyzer, Anemometer, Vernier Caliper

Alternatively, **The Cooling Season Performance Factor (CSPF)** is a metric used to evaluate the seasonal energy efficiency of HVAC systems, particularly refrigeration and air conditioning units. Unlike a single-point efficiency measurement (such as EER or COP), CSPF accounts for varying load conditions and ambient temperatures over an entire cooling season, providing a more accurate representation of real-world performance

The Cooling Season Performance Factor (CSPF) is particularly valuable because it addresses a common flaw in traditional efficiency metrics—**the assumption of constant full-load operation**. HVAC systems frequently run at partial capacity due to fluctuating temperatures and cooling demands. By incorporating **real-world operating profiles**, CSPF captures efficiency degradation at lower loads, standby losses, and cycling effects, offering a **more holistic view of energy consumption**.

CSPF is the ratio of total cooling output (in BTU or kWh) to total energy input (in kWh) over a cooling season.

$$\boldsymbol{CSPF} = \frac{\boldsymbol{Total\ Seasonal\ Cooling\ output}(\boldsymbol{kWh\ or\ BTU})}{\boldsymbol{Total\ Seasonal\ Energy\ Output}\ (\boldsymbol{kWh\ or\ BTU})}$$

CSPF provides a realistic assessment of HVAC energy efficiency by considering seasonal variations in load and temperature. The Energy Efficiency (Minimum energy Performance Standards for Regulated Machinery) Regulations is in operation since March 01, 2025. The Regulations enforces a Minimum Energy Performance Standard (MEPS) for air conditioners having capacity <12kW. Tests according to ISO 5151 and ISO 16358 have to be conducted on each model that is imported.

Steps to calculate CSPF:

(a) Define the Cooling Season
- Determine the temperature bins (e.g., hours spent at 24°C, 29°C, 35°C, etc.).
- Use historical weather data for the region.

(b) Measure/Estimate Cooling Load at Each Bin
- Cooling load varies with outdoor temperature (higher temps = higher load).
- May use load profiles or standardized test conditions.

(c) Determine System Efficiency at Each Bin
- Measure/estimate EER (Energy Efficiency Ratio) or COP at different loads.
- Part-load efficiency is often lower than full-load efficiency.

(d) Compute Cooling Output & Energy Input for Each Bin
- Cooling Output= Load (tons or BTU/hr) × Hours in bin
- Energy Input= Cooling Output / EER (or COP)

(e) Sum Up Seasonal Values
- Total Cooling Output = Sum of cooling output across all bins
- Total Energy Input = Sum of energy input across all bins

(f) Calculate CSPF

Chillers

Chiller efficiency is usually measured in terms of specific power consumption.

Specific power consumption of chiller:

$$SPC = \frac{Electrical\ Power\ (kW)}{Cooling\ Capacity\ (TR\ or\ BTU)}$$

Where:
SPC - Specific Power Consumption
kW - Kilowatt
Cooling Capacity - Tonnes of Refrigeration or British thermal Unit

Equipment required chiller performance: Hygrometer, Power analyzer, Anemometer, Vernier Caliper, Ultrasonic flow meter

Chiller efficiencies depend on what type of compressor is used in the chiller, and whether air or water cooling is used. Water cooled magnet bearing centrifugal compressors can achieve SPC of 0.5 kW/TR.

Common monitorable parameters

The HVAC system essentially comprises of fans, pumps, cooling tower, cooling and heating. The common monitorable parameters are shown below.

Procedures for rational use of energy
Management ▪ The management shall use energy management manuals as provided by the equipment manufacturer for optimal performance of the air conditioning unit ▪ Operating under best practices to reduce air conditioning load by using blinds, etc., adjusting the temperature of the room and frequency of the ventilation, operational time of equipment's and humidity values of the facilities as per the energy management manual ▪ The industries should incorporate the impacts of seasonal changes in weather to obtain best efficiency from the heating and cooling equipment so installed in the industry ▪ Multiple air conditioning equipment or facilities using same or different types of facilities shall be managed in a way that the total facilities and equipment efficiency will be collectively improved based on load conditions ▪ The heating source facilities shall be controlled and optimized in a way that auxiliary equipment shall also be considered to improve facilities overall efficiency
Monitoring and Evaluation ▪ The industry should facilitate development of energy operations manual for monitoring and evaluation of energy consumption by heating and air conditioning facilities ▪ The temperature and humidity levels should be regularly monitored and recorded for the operational areas
Maintenance and inspection ▪ Properly inspect and monitor the operations of air conditioners to ensure energy efficient heating or cooling operation of the industry ▪ The automatic temperature devices that are installed in the air conditioners should be regularly inspected and monitored
New Installations ▪ The new equipment being installed in the industries should comply with the standards and regulations promulgated by the Energy Efficiency Management Office. ▪ Each air conditioner to be independently controlled by each operational area as per demand ▪ Highly efficient operation of the HVAC system to be introduced by controlling the number of operational air conditioners ▪ Systems enabling wind rotation and current rotation to be introduced

The standard and target values for HVAC equipment depends on the Energy efficiency ratios or specific power consumptions as shown in below tables.

Table 13: Standard and Target Values of EER of Air Conditioners

EER of Air Conditioners[12]	
Standard value	3.0
Target value	4.0

Table 14: Standard and Target Values for specific power consumption of Chillers

Specific power consumption of Chillers	kW/TR	
	up to 200 TR	> 200 TR
Standard Values		
Efficient water-cooled chiller	1.59	1.01
Air cooled chiller	1.17	-
Target Values		
Efficient water-cooled chiller	0.8	0.5
Air cooled chiller	1.02	-

The purposes of HVAC systems are to supply enough air of the right temperature to keep people comfortable and to exhaust harmful or unpleasant air contaminants. Table 15 gives a list of some of the common problems which may occur in industries and their initial maintenance actions.

Table 15: HVAC system - Problems and solutions

System Component	Problem	Initial Maintenance Action
Filter	Excessively dirty	Replace or clean
Damper	Blocked open/ linkage disconnected	Check damper controls
	Leaks badly	Clean and overhaul
Ductwork	Open joints	Repair
	Loose insulation in duct work	Replace and attach firmly
	Water leakage or rust spots	Repair
	Crushed	Replace
Grillwork	Air flow impossible due to dirt	Remove and clean
	Blocked by equipment	Remove equipment
Fan	Motor not hooked up to fan	Disconnect motor or install fan belts

[12] *Varies based on cooling capacity of air conditioner (TR)*

System Component	Problem	Initial Maintenance Action
	Excess noise	Check bearings, belt tension mountings, dirty blades
	Insufficient ventilation	Check fan and surrounding duct work and grill work
	Belt too tight or too loose	Adjust motor mount
	Pulleys misaligned	Correct alignment
Pump	Hot-water pump is cold (or vice versa)	Inspect valving; check direction of flow
Blower	Air flow problem, air not moving	Check direction of rotation and change wiring if needed;
Chiller	Leaks	Repair
Cooling tower	Scaling on spray nozzles	Remove by chipping or chemical means
	Leaks	Repair
	Cold water too warm	Check pumps, fans, fill; clean louvers
	Excessive water drift	Check drift elimination, metering orifices, basins; over-pumping check
Compressor thermostat	Temperature reading not accurate	Calibrate
	Leaks water or oil from mounting	Check pneumatic control lines

4.4. Fans and blowers

Fans and blowers provide air for ventilation and industrial process requirements. Fans generate pressure to move air (or gases) against a resistance caused by ducts, dampers, or other components in a fan system. Fan selection depends on the volume flow rate, pressure, type of material handled, space limitations, and efficiency.

Fans, blowers, and compressors are differentiated by the method they use to move the air, and by system pressure they must operate against. American Society of Mechanical Engineers (ASME) uses the specific ratio (the ratio of discharge pressure over suction pressure) to differentiate amongst fans, blower, and compressors.

Based on operating principle, fans are grouped in two categories, namely, (1) centrifugal & (2) axial flow fans. Similarly, industrial blowers and air handling units are grouped into (1) centrifugal and (2) positive displacement blowers. The selection of a fan or blower depends on the various process requirements, such as air volume, system resistance, output pressure, and working environment.

Fans and blowers in major industrial sectors in Mauritius – **All Industrial Sectors**

Performance assessment

Performance assessment of fans and blowers in industries defines the volume flow rate, the power input and the total pressure rise across the fan under actual operating conditions. These test results provide actual value for the flow resistance of the air duct system, which can then be compared with the design values. [13]

Fan efficiencies vary for different designs & types of fans. Industrial fans fall under two categories: centrifugal and axial flow fans. In centrifugal fans the airflow changes its direction twice, once while entering and second while leaving. In case of axial flow fans, the airflow changes no direction. Fans can be selected by industries based on their requirements and area to be covered. Typical efficiencies of centrifugal fans range from 65-70% whereas Electronically Commutated (EC+) allow for 90% efficiency. EC+ fans integrate a brushless DC motor with an integrated driver, allowing for precise control of the fan's speed and torque.

Efficiency of fan:

$$\eta_m = \frac{Q \times \Delta p}{102 \times P_s} \times 100$$

$$\eta_s = \frac{Q \times \Delta p_s}{102 \times P_s} \times 100$$

Where:
Δp - Total pressure (mmWC)
Δp_s - Static pressure (mmWC)
P_s - Shaft power (kW)
Q - fluid flow rate (m^3/s)
η_m - Mechanical Efficiency
η_s - Static Efficiency

Equipment required for fan efficiency: Manometer, Vane anemometer, Power analyzer

Common monitorable parameters

The following common parameters can be monitored by industry to assess the performance of fans and blowers.

Table 16: Common monitorable parameters – fans and blowers

Parameter	Unit	Instrument	Frequency
Electricity Consumption	kWh	Energy meter	Monthly
Suction head	mm WC	Pitot tube	Monthly
Delivery head	mm WC	Pitot tube	Monthly
Fluid temperature	^oC	Thermocouple	Monthly

The procedures for rational use of energy in fans and blowers are shown below.

[13] *Source: Energy Efficiency Guidelines for Industries, Bureau of Energy Efficiency, India*

Procedures for rational use of energy

Management

- The industry should ensure that the quality of suction air being passed to fan or blower is clean
- The industry should ensure no blockage or restrictions at inlet or suction of fan or blower.
- Manage and operate fans and blowers close to best operating point of the characteristic curve, as provided by the manufacturer.
- Use blowers in series for high resistance, and in parallel connection for low resistance system in case of multiple blower operation.
- Use multiple blowers in parallel to generate higher volume instead of single large pumping system.
- Undertake pressure holding test to detect and plug-off for leakages in distribution system.
- Replace over-sized fans/ blowers with optimum size system to meet the process requirements for high-load conditions.
- Retrofit existing fan or blower with a VFD in case of fluctuating load conditions in place of damper control.
- Use on-line monitoring for centralized large system and periodical measurement for decentralized smaller blowers

Monitoring and Evaluation

- The industry should measure and record the following: Key operating parameters, such as pressure head, temperature, and electricity consumption, on a daily basis to assess specific energy consumption (SEC) of fan or blower.

Maintenance and inspection

- Ensure allowable impeller inlet seal clearances per design. These clearances include axial overlap, radial clearance, back plate clearance, labyrinth seal clearance, etc., as per instructions provided by OEM.
- Undertake corrective maintenance in case of a significant drop in pressure head observed in the system.
- Undertake overhauling of fans and blowers according to the instructions provided by the manufacturers.
- Inspect the blower and fan for vibration and noise levels on a quarterly basis.
- Ensure dynamic balancing of fans/ blower’s assembly after each overhauling.
- Calibrate instruments and gauges as per the recommendations of the suppliers to ensure reliability and maintain accuracy of data

New Installations

- Undertake demand assessment of air to select suitable fan or blower as applicable, while considering the dust type, its concentration, etc., while handling dust-laden gases.
- Select and install correct capacity of fan/ blower with highest efficiency, considering existing requirements, immediate expansion plans, plant layout, and routing of pipes.
- Avoid unnecessary bends and turns while installing air ducts.
- Install direct coupled motor drives wherever possible.
- Provide sufficient straight length of duct (at least 3 times the duct diameter) and shall avoid bends close to fan inlet to avoid uneven air flow and vibrations

4.5. Cooling towers

Cooling towers are among the most effective systems for evaporative cooling of hot water in industrial settings. They provide a dependable and cost-efficient method for removing low-grade heat from cooling water by lowering its temperature close to the wet bulb temperature of air through evaporation.

There are mainly two types of cooling towers used in industries: Natural Draft Systems and Mechanical Draft Systems. Natural draft systems typically utilize large concrete chimneys to draw air through the media, with water flow rates above 45,000 m^3/hr. and commonly found in utility power stations. Mechanical draft systems typically employ large fans to push air through circulated water, with water descending over fill surfaces, increasing contact time with air and enhancing heat transfer.

Cooling Towers equipment in major industrial sectors in Mauritius – **Textile, Food Processing, Agro processing and beverages, Packaging industry.**

Performance assessment

Cooling tower performance is defined by the cooling tower efficiency, which is the ratio of range to the ideal range of cooling tower. The range of the cooling tower is the difference between cooling tower water inlet to outlet temperature. The approach of the cooling tower is difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature.

Efficiency of Cooling tower:

$$\boldsymbol{Effectiveness} = \frac{\boldsymbol{Range}}{(\boldsymbol{Range} + \boldsymbol{Approach})}$$

Where range is

$$\boldsymbol{Range} = \boldsymbol{A} - \boldsymbol{B}$$

And approach is

$$\boldsymbol{Approach} = \boldsymbol{B} - \boldsymbol{C}$$

Where:
A - Entering water temperature (return from process)
B - Cold water temperature (supply to process)
C - Ambient wet bulb temperature

Equipment required for cooling tower effectiveness: Thermocouple, digital or infrared thermometer

The effectiveness of cooling towers varies greatly depending on various parameters; however, an efficient cooling tower will give an efficiency of 70% – 75%

Common monitorable parameters

The following common parameters can be monitored to assess the performance of cooling towers.

Table 17: Common monitorable parameters – cooling towers

Parameter	Unit	Instrument	Frequency
Ambient dry bulb temperature	^{o}C	Thermometer	Daily
Ambient wet bulb temperature	^{o}C	Thermometer	Daily
Cooling water inlet temperature	^{o}C	Thermometer	Daily
Cooling water outlet temperature	^{o}C	Thermometer	Daily
Cooling duty water flow rate	m^3/hr	Flowmeter	Daily
Makeup water	m^3/day	Flowmeter	Daily

The target value for cooling tower performance are as follows:

Table 18: Performance parameters of Cooling towers[14]

Parameter	Unit	Target value
Approach	°C	4.0 – 5.0
Cycle of concentration	-	8 – 10
Drift loss	%	0.001 – 0.005% of circulating flow rate
Effectiveness	%	70 – 75%

The procedures for rational use of energy is shown below for cooling towers.

Procedures for rational use of energy

Management

- Install thermostatic controller to switch off cooling tower fans automatically when the temperatures of return water and supply water are almost same.
- Install VFD for varying cooling demands in the process.
- Use cellular PVC (poly vinyl chloride) drift eliminators in place of wooden blade drift eliminators.
- Using PVC fills in place of wooden bars.
- Ensure proper functioning of drift eliminators to control drift losses within limits. Maintain cycle of concentration (COC) within the limits to minimize make-up water in cooling water.
- Use on-line monitoring for centralized large system and periodical measurement for decentralized smaller cooling tower

Monitoring and Evaluation

- Quantity of make-up water addition used towards compensation of water losses, such as evaporation loss, drift loss, blowdown loss, etc., on daily basis.
- Electricity consumption of the cooling tower (includes associated fans and pumps) with dedicated energy meter in place.
- Inlet & outlet temperatures of water, water flow rate & its pressure on daily basis.
- Ambient conditions that include dry bulb, wet bulb temperature, and RH.

Maintenance and inspection

- Undertake visual inspection of fills in the cooling tower once in three months to ensure proper distribution of water.
- Carry out chemical disinfection sump to avoid micro-organism growth

New Installations

- Undertake load assessment for selection of suitable cooling tower system.
- Install cooling tower with moulded FRP fans of aerofoil design.
- Install multiple cooling tower systems in parallel in place of a single large system to meet higher volume requirements of cooling water.

4.6. Electrical utilities

Transformers are integral components in manufacturing industries, playing a crucial role in the efficient distribution and utilization of electrical power. These devices are used to step up or step-down voltage levels, ensuring that machinery and equipment receive the appropriate voltage for optimal performance. In manufacturing settings, transformers help in reducing energy losses during transmission and distribution, thereby enhancing overall energy efficiency.

[14] *Source: Energy efficiency guidelines for MSME in India (Bureau of Energy Efficiency)*

Industrial transformers are designed to handle high power loads and are built to withstand harsh operating conditions, such as high temperatures, dust, and vibrations. They are essential for powering heavy machinery, lighting systems, and other electrical equipment used in production processes. Additionally, transformers contribute to the safety of manufacturing operations by providing stable and reliable power, minimizing the risk of electrical faults and downtime.

The use of advanced transformer technologies, such as dry-type and oil-immersed transformers, allows for better performance and longevity. Dry-type transformers are preferred in environments where fire safety is a concern, as they do not use flammable liquids. On the other hand, oil-immersed transformers are known for their excellent cooling properties and are used in applications requiring high efficiency and reliability.

Transformers in major industrial sectors in Mauritius – **All Industrial sectors**

Performance assessment

Electrical distribution systems consist of two types of loads: inductive and resistive. Resistive loads include incandescent lighting and resistance heating. Inductive loads encompass AC motors, induction furnaces, transformers, and certain lighting solutions. Inductive power requires both active power (kW) to perform work and reactive power (kVAr) to create and maintain electromagnetic fields. The power factor, which is the ratio of active power to reactive power is always less than or equal to one.

Transformers play a crucial role by accepting electrical energy at one voltage and converting it to another voltage for end use. This allows electrical energy to be generated at relatively low voltages and transmitted at high voltages with low currents, minimizing line losses and voltage drops. Transformers can be classified as core type or shell type based on the placement of the primary and secondary coils around the steel core. Depending on the application, transformers can be step-up or step-down. The performance of a transformer can be assessed using various methods:

Transformer loading

$$\boldsymbol{Transformer\ Loading}\ (\%) = \frac{\boldsymbol{D_m}}{\boldsymbol{D_r}} \times \mathbf{100}$$

Where:
D_m - measured demand (kVA)
D_r - rated demand (kVA)

Power factor

$$\boldsymbol{Power\ factor} = \frac{\boldsymbol{P}}{\boldsymbol{Q}}$$

Where:
Q - active power
P - reactive power

For Transformers, All-day efficiency is a crucial parameter for distribution transformers, which experience varying loads throughout the day. Unlike power transformers, which operate at full load most of the time, distribution transformers often run under light loads for extended periods and face peak loads only for short durations.

All-day efficiency is defined as:

$$\boldsymbol{All\ day\ Efficiency} = \frac{\boldsymbol{Total\ Energy\ Output}\ (\boldsymbol{24\ hours})(\boldsymbol{kWh})}{\boldsymbol{Total\ Energy\ Input}\ (\boldsymbol{24\ hours})\ (\boldsymbol{kWh})} \times \mathbf{100}$$

It considers energy efficiency over a 24-hour period, accounting for both:

1. Iron (core) losses, which are constant regardless of load
2. Copper (I^2R) losses, which vary with the load

Equipment required: Power analyzer: Thermal imager, 3 – phase Power analyzer

Power factor (PF) is the ratio of working power, measured in kilowatts (kW), to apparent power, measured in kilovolt amperes (kVA). **Power factor of more than 95% is considered as efficient with target values above 99%**. The main reason which causes low power factor is inductive load in the system. Inductive loads constitute a major portion of the power consumed in industrial complexes, some of them are:

- Transformers, Induction motors
- Induction generators (windmill generators)
- High intensity discharge (HID) lighting

How does low power factor impact industries?

Low power factor in the electrical system of industries has several disadvantages like:

- High current requirement by the equipment
- Heating and copper losses
- Poor voltage regulation
- Power factor penalty and high demand charges by the utility in the electricity bill.

What can be done to improve power factor?

Power factor of industries can be improved by:

- Inclusion of more resistive load in the system.
- Installation of automatic power factor control (APFC) system using static capacitor. Some of the key areas where capacitors can be installed in the facility are:
  - At HT bus / transformer
  - LT bus of transformer
  - Main sub-plant buses
  - Load points
- Use of synchronous condenser

How can it be done?

Some of the steps an industry can take to improve its power factor are:

- Identification of the sources of low power factor loads in plant
- Locating close to end equipment to reduce I^2R loss
- Release of system capacity(kVA) happens if reactive current is reduced.

Common monitorable parameters

The following common parameters can be monitored by industry to assess the performance of electrical utilities.

Table 19: Common monitorable parameters – electrical utilities

Parameter	Unit	Instrument	Frequency
Voltage	Volt	Voltmeter	Daily
Current	Ampere	Ammeter	Daily
Power	kVA	Power analyzer	Weekly
Oil temperature	°C	Temperature gauge	Daily
Winding temperature	°C	Temperature gauge	Daily
Tap position	-	-	Daily
Harmonics	%	Power analyzer	Monthly

The procedures for rational use of energy related to transformers is given below.

Procedures for rational use of energy

Management

- Operate transformer close to best efficiency loading point to minimize no load losses and load losses.
- Maintain the power factor close to unity at transformer level to reduce the load losses.
- Ensure proper electrical compatibilities while operating two or more transformers in parallel. These include voltage ratio, impedance, polarity, etc.
- Maintain the operating temperature of the transformer within the prescribed limits provided by the manufacturer to achieve full life span services and reduce energy losses.
- Switch off under-loaded transformers put in parallel operation to reduce part load energy losses.
- Make necessary tap adjustment in transformer to compensate output voltage drop due to long cable runs

Monitoring and Evaluation

- Key operating parameters such as voltage, power factor, loading and harmonics on daily basis.
- Temperature of oil and windings of the transformer.
- Room temperature and moisture level wherein the transformer is installed on daily basis.

Maintenance and inspection

- Undertake scheduled preventive maintenance as per manufacturer's instructions to ensure the following: oil and winding temperature, oil level and leakage, oil level in OLTC (on-line tap changer) mechanism, earth resistance, condition of relief diaphragm, sealing arrangement, etc.
- Check and replace silica gel when the colour turns to pink.

New Installations

- Undertake load assessment of the plant to select suitable size and number of transformers, considering best efficiency points for loading and routine/ seasonal operations.

Procedures for rational use of energy

- Select transformers with the minimum eddy losses for non-linear load applications.
- Select the transformer with relatively low no-load losses (for example amorphous core type) to maintain the best efficiency at low loads.
- Install an oil-filled transformer which is more efficient and have long life than a dry-type transformer.
- Install OLTC-enabled transformers for new installations to maintain end-use voltage close to the design level.

4.7. Motors

Motors are essential components in the manufacturing industry, converting electrical energy into mechanical energy to power various machines and processes.

Electric motors are widely used in industries for various loads, such as process machinery, fans, blowers, pumps, compressors, conveyors, etc. A wide range of capacities of motors are used for these applications.

Motors in major industrial sectors in Mauritius – **All Industrial sectors**

Overview of motor use and operational parameters

Type of Load

Motor loads can be classified based on how torque and power requirements change with speed. Here are the main types of motor loads:

- **Constant Torque Load:** Constant torque loads are where applications call for the same amount of driving torque throughout the entire operating speed range. The torque remains constant whereas the power increases linearly with speed. Examples of use cases are conveyors, reciprocating compressors, positive displacement pumps, rotary kilns, etc.
- **Variable Torque Load:** With a variable torque load, the loading is a function of the speed. The torque varies with the square of the speed and varies with the cube of the speed. Examples of use cases are centrifugal pumps, blowers, fans, etc.
- **Constant Power Load:** A constant power load is normal when material is being rolled and the diameter changes during rolling. The power is constant, and the torque is inversely proportional to the speed. Example of use cases are lathe machines, drilling machines, grinding machines, grinders, rolling machines, CNC machines, etc.

Understanding load type is crucial for selecting the most energy-efficient motor and control system. For example, variable torque loads often yield significant energy savings with variable speed drives.

Torque Requirements

The rotational force needed to start, accelerate, and operate the driven equipment. It includes starting torque (must overcome static friction and inertia), accelerating torque (motor accelerates from standstill to full speed), and running torque (torque required to keep the load moving at constant speed).

Proper sizing ensures the motor operates closer to its peak efficiency range. For example, oversizing a motor to handle high starting torque while the running torque remains low can lead to inefficient operation, especially at partial loads. Thus, using a high starting torque motor (like a Design D induction motor) rather than oversizing or installing a soft starter or VFD to manage high inrush current and torque smoothly could be potential solutions.

Speed Requirements

The operational speed(s) at which the driven equipment needs to operate. This can be fixed speed, multiple discrete speeds, or continuously variable speed. Matching motor speed to actual process requirements, especially for variable speed applications, is critical. The application type are shown below:

Table 20: Application types and speed classification of Motors

Application Type	Speed Requirement	Motor Type Suggestion
Constant Speed	Fixed speed	Synchronous or standard induction motor
Variable Speed	Adjustable speed	VFD-controlled induction or BLDC motor
High Speed	>3000 RPM	Universal motors, high-speed induction
Low Speed, High Torque	<1000 RPM	Gear motors, multi-pole motors

Using fixed-speed motors where variable speed is needed often results in wastage of energy through throttling or damping. Incorrect speed can also cause wear or failure in mechanical systems. Thus, running motors at optimal speeds reduces energy consumption. Precise speed control is essential in applications like conveyors, mixers, and CNC machines.

Duty Cycle

The duty cycle of a motor refers to the pattern of operation over time — specifically, how long the motor runs versus how long it rests. It is a critical factor in motor selection and directly impacts energy efficiency, thermal performance, and motor lifespan. Types as per IEC 60034-1 standard are:

Table 21: Various types of duty cycles

Duty Type	Description	Example Applications
S1 – Continuous Duty	Motor runs at constant load for a long time until thermal equilibrium is reached.	Fans, pumps
S2 – Short-Time Duty	Motor runs at constant load for a short time, then rests long enough to cool.	Crane hoists
S3 – Intermittent Periodic Duty	Sequence of identical cycles with on/off periods, no thermal equilibrium.	Presses, elevators
S4 – Intermittent with Starting	Like S3, but includes significant starting.	Machine tools
S5 – Intermittent with Starting and Braking	Like S4, but includes electric braking.	Rolling mills
S6 – Continuous Operation with Intermittent Load	No rest, but load varies cyclically.	Conveyors with variable loads
S7–S10 – Complex Duty Cycles	Include combinations of load, speed, braking, and rest.	Specialized industrial machinery

Oversizing for short duty cycles leads to inefficiency and higher energy use. Motors must be sized for the actual duty cycle, not just peak load. Motors in intermittent duty (S3–S6) can be smaller than continuous-duty motors for the same peak load, saving energy and cost.

Required Power

Amount of mechanical power needed to drive a load efficiently under specific operating conditions which considers both the useful work and losses within the equipment itself. If the motor is too small, it may overheat or fail. If the motor is too large, it will run underloaded, leading to low efficiency and poor power factor. Motors are most efficient at 75–100% of rated load and operating consistently below this range wastes energy. Variable Frequency Drives (VFDs) should be used to adjust power based on real-time load, which would improve efficiency.

Operating Environment

The operating environment of a motor refers to the physical and electrical conditions in which the motor functions. This might include environmental factors such as the presence of dust, moisture, corrosive chemicals, or altitude. Harsh environments can impact motor cooling, insulation integrity, and bearing life, leading to decreased efficiency over time. Some examples of impact of environmental factors are shown below:

Table 22: Different environmental factors and their impact on motor efficiency

Environmental Factor	Description	Impact on Efficiency
Ambient Temperature	Temperature around the motor	High temps increase resistance and losses; may require derating
Altitude	Elevation above sea level	Less air density reduces cooling; motors may overheat and need derating
Humidity & Moisture	Presence of water vapor or condensation	Can cause insulation failure and corrosion
Dust & Contaminants	Particles in the air (e.g., in cement or textile industries)	Can clog cooling systems and reduce heat dissipation
Vibration & Shock	Mechanical disturbances	Can damage bearings and windings, reducing efficiency
Corrosive Atmosphere	Chemicals or salt in the air	Degrades motor materials, especially in coastal or industrial areas
Ventilation	Airflow around the motor	Poor ventilation leads to overheating and reduced efficiency
Power Quality	Voltage fluctuations, harmonics, imbalance	Causes overheating, torque pulsations, and energy losses

Several measures can be taken up for maintaining efficiency in harsh environments such as using totally enclosed fan cooled or explosion-proof motors in dusty or hazardous areas, applying derating factors for high temperature or altitude, installing Install filters or enclosures in dirty or corrosive environments, and ensuring proper ventilation and regular maintenance.

Hazardous Locations

Hazardous locations are environments where flammable gases, vapours, dust, or fibres may be present in sufficient quantities to cause explosions or fires. Motors used in these areas must be specially designed to prevent ignition of the surrounding atmosphere.

Motors in hazardous locations must be flameproof, non-sparking, or encapsulated. These designs often include heavier enclosures, special seals, and cooling limitations, which can impact efficiency. Enclosed motors (such as totally enclosed fan cooled motor) have restricted airflow, which can again impact efficiency negatively. Thus, measure such as high efficiency explosion-proof (IE3 or IE4) motors shall be installed in hazardous locations and should be implemented with VFDs with proper filters to reduce energy use and harmonics. Motors should be maintained using clean tools and cool environments to reduce thermal stress.

Available Power Supply

The characteristics of the electrical power available, including voltage, frequency, and number of phases, as well as power quality issues like voltage sags/swells, harmonics, and unbalance. Voltage imbalances, sags, or excessive harmonics can significantly reduce motor efficiency, increase losses, and shorten motor life. Thus, motors must operate at peak efficiency with stable, balanced, and clean power. Three-phase motors are more efficient, have better starting torque, and have smoother operation compared to single phase motors. Motors with poor power factor draw more current, increasing losses. Power factor correction (e.g., capacitors) improves efficiency in such cases.

Motor Controls

Motor controls are devices or systems used to start, stop, regulate, protect, and monitor electric motors. They ensure motors operate safely, efficiently, and in line with the application's requirements. The different types of motor controls are manual control (simple on/off switch), electromechanical control (uses contractors and relays), electronic control (semiconductors for precise control), and automatic control (based on sensors or logic).

Soft starters reduce inrush current and mechanical stress during startup and improve energy efficiency by minimizing losses during acceleration. Sensors and controllers adjust motor operation based on real-time load, prevents overuse and saves energy. Some motor controllers include capacitors to improve power factor. Variable speed drives are paramount for energy efficiency in variable load applications, allowing the motor speed to precisely match demand, leading to substantial energy savings (e.g., for fans and pumps, power consumed is proportional to the cube of the speed).

Motor Type

There are several types of motors commonly used in manufacturing, each with its unique characteristics and applications.

AC induction motors are widely used due to their high efficiency and reliability. Squirrel cage induction motors, known for their simple design and low maintenance, are cost-effective and suitable for various industrial applications. Wound rotor induction motors, on the other hand, offer greater control over speed and torque, making them ideal for heavy-duty applications where precise control is needed.

DC motors are another important category. Brushed DC motors have a simple design, making them cost-effective and easy to maintain, although their brushes wear out over time and require replacement. Brushless DC motors, offering higher efficiency, longer lifespan, and quieter operation, are commonly used in applications where precision and control are essential, such as robotics and automation systems.

Synchronous motors are also prevalent in manufacturing. Permanent magnet synchronous motors use permanent magnets on the rotor, resulting in high efficiency and power density, suitable for applications requiring precise speed control and constant torque. Reluctance synchronous motors, with their unique rotor design, provide high efficiency and low rotor losses, making them ideal for applications where high torque and energy efficiency are essential.

Motor Efficiency

Motor efficiency is a measure of how effectively an electric motor converts electrical energy (input) into mechanical energy (output). The International Electrotechnical Commission (IEC) has defined several classes of motor efficiency, known as IE (International Efficiency) ratings. These ratings help in distinguishing the energy efficiency of electric motors. Electric motors are categorised into efficiency classes: IE1, IE2, IE3, IE4, and IE5 each representing a step up in energy efficiency. IE1 motors are the least efficient, while IE5 motors are the most efficient. The primary differences among these classes lie in their energy consumption and operational efficiency, with each subsequent class offering improvements in these areas.

Minimum efficiency values of IE motors based on based on test methods specified in IEC 60034-2-1:2014 are presented in Annexure – Table of motor efficiency values. The comparison of motor efficiency of all IE classes is shown below:

Table 23: Comparison of motor efficiency classes

Motor Class	Efficiency
IE 1 (Standard)	Lowest efficiency
IE 2 (High efficiency)	~15% better than IE 1
IE 3 (Premium)	~20% better than IE 1
IE 4 (Super Premium)	~25% better than IE 1
IE 5 (Ultra-Premium)	~30% better than IE 1

Use of manufacturer data and tools

Motor manufacturers provide detailed technical data and digital tools to help engineers, technicians, and energy managers select, size, and optimize motors for specific applications. Using these resources ensures accurate selection, maximum efficiency, and regulatory compliance. Some of the key data provided by manufacturers are:

Table 24: Examples of key data provided by motor manufacturers

Data type	Description	Significance
Efficiency Curves	Efficiency vs. load/speed	Helps identify optimal operating range
Torque-Speed Curves	Shows motor behaviour under load	Crucial for matching motor to application
Power Factor Data	Indicates reactive power	Important for energy billing and system design
Thermal Data	Heat rise, insulation class	Ensures motor longevity in specific environments
Duty Cycle Ratings	IEC/ISO classifications	Helps match motor to load profile
Derating Factors	For altitude, temperature, etc.	Ensures safe and efficient operation
Starting Current & Torque	Inrush current and torque at startup	Important for electrical system design

Some manufacturers also provide tools for motors such as Motor selection tools (Siemens SIMOTICS, ABB Motor Selector, WEG Motor Guide), efficiency calculators, VFD sizing tools, thermal modelling tools (ANSYS Motor-CAD, Siemens Simcenter), real time monitoring (ABB Ability, Siemens Digital Twin), etc.

Using manufacturer data and tools helps in selecting the correct size of motor that operates near peak efficiency and leads to reduced downtime with avoided oversizing. The use of manufacturer data and tools pre-validates the data which helps in speeding up engineering decisions. It also leads to optimised life cycle cost and purchase price.

Performance assessment

Measuring and assessing the Energy Performance Indicator for electric motors involves evaluating efficiency, power consumption, and operational performance. Below is a structured approach to determine and analyse EnPIs for electric motors:

Motor Efficiency (η):

$$\boldsymbol{Motor\ efficiency}\ (\eta) = \frac{\boldsymbol{P_{out}}}{\boldsymbol{P_{in}}} \times \mathbf{100}$$

Where:
Motor efficiency (η) – effectiveness of converting electrical energy into mechanical energy
P_{out} – Rated power, Watts (or horsepower)
P_{in} – electrical power input to the motor, Watts (or horsepower)
However, accurate measurement of hydraulic power is not feasible on site, therefore load factor can be assessed on site to evaluate motor performance. Underloading (<40%) reduces efficiency of motor whereas overloading (>100%) risks overheating and potential damage.

Load Factor:

$$\boldsymbol{Load\ Factor}(\%) = \frac{\boldsymbol{Actual\ load}\ (\boldsymbol{kW\ or\ hp})}{\boldsymbol{Rated\ load}\ (\boldsymbol{kW\ or\ hp})} \times \mathbf{100}$$

Equipment required for the assessment: Clamp meter, power analyzer, Tachometer, Energy meter

Common monitorable parameters

The following common parameters can be monitored by industry to assess the performance of motors.

Table 25: Common monitorable parameters – motors

Parameter	Unit	Instrument	Frequency
Actual Load	kW	Energy meter	Daily
Voltage	V	Power analyzer	Daily
Current	A	Clamp meter	Daily
Power factor	-	Power Analyzer	Weekly

The standard and target values for lighting systems are given below.

Table 26: Standard and target values for motor efficiency

Motor efficiency	
Standard value	IE 2/3
Target value	IE 4/5

The procedures for rational use of energy for motors is given below.

Procedures for rational use of energy

Management

- The industry shall stop motor driven equipment when not in use or during idle operation, which shall be described in the EM Manual. It shall take into account the energy losses during idle run period versus energy consumption during initial start-up.

Procedures for rational use of energy

- Parallel operation of multiple motors shall be managed in a way to achieve high efficiency of the motors as a whole, which shall be described in the EM Manual. Suitable load allocation during parallel operation of multiple motors shall be implemented during partial load conditions to maintain higher efficiency under varying load conditions.
- Industry shall review the current use, end pressure and discharge rate of fluid machines (e.g. pumps, fans, blowers, compressors, etc.), and manage to reduce the load of the connected electric motors according to the instructions which shall be described in the EM Manual. The instructions may include the number of operating units, speed reduction, pipe layout and dimensions, impeller size, etc., to cater to the variable load conditions.
- If the load variations on motor are large, for e.g., as a result of frequent starts and stops of large components like compressors which could be detrimental to other equipment installed in the plant, then the industry shall consider appropriate starter method for motors.
- Industry shall manage use of electricity in different types of electricity-using utilities (e.g. motor driven utilities, electric heating utilities, etc.) with a view to reduce electrical losses (e.g. voltage or current losses), which shall be described in the EM Manual.
- It is recommended that the voltage unbalance (the condition where voltages of the three phases are not equal) at the motor terminals shall not exceed 1% (maximum deviation from mean of voltages / mean value of voltages).
- Direct-on-line starter method where motor connects directly to full line voltage shall be used for small motors (<5 hp) where high inrush current is acceptable
- Star-delta starter method where motor is started in star (wye) configuration then switches to delta for full power shall be used for motors (>5 hp) with light to moderate loads
- Auto-transformer starter method uses transformer to reduce voltage during startup which shall be used to medium to large motors requiring reduced voltage but higher torque
- Soft starter method works by gradually increasing voltage using solid-state electronics which is best for applications needing smooth start such as conveyors or compressors
- VFD shall be used for starting motors in application needing speed control, energy efficiency, and torque management.

Monitoring and Evaluation

- Industry shall measure such parameters of electricity-using equipment and record the results which will be necessary to reduce electrical losses, as described in the EM Manual.

Maintenance and inspection

- The motor-driven equipment shall be periodically inspected and maintained to reduce mechanical losses occurring in electric motors, power transmission units, and machines that apply loads to the motors, which shall be described in the EM Manual.
- Motor-driven system shall be lubricated as described by the equipment manufacturer.
- The motor-driven utility shall be periodically inspected and maintained for different fluid machines (e.g. pumps, fans, blowers, and compressors) to prevent leakages and reduce resistance of pipes and ducts, which shall be described in the EM Manual.

New Installations

- Install and use efficient motors of suitable sizes.
- install motors with compatible configurations to meet applications with large fluctuations of loads.

4.8. Lighting system

Lighting systems in manufacturing industries play a pivotal role in ensuring operational efficiency, safety, and productivity. Modern manufacturing facilities often utilize LED high bay and low bay lights due to their EE, long lifespan, & superior brightness. These lights provide uniform illumination, reducing shadows and glare, which is crucial for precision tasks and minimizing errors. Additionally, task lighting is employed in specific workstations to enhance visibility and accuracy. Emergency and exit lighting are also essential components, ensuring safe evacuation during power outages or emergencies. Implementing smart lighting controls, such as motion sensors and timers, further optimizes energy usage and reduces costs. Overall, well-designed lighting systems contribute significantly to a safe, efficient, and productive manufacturing environment. The industry has lighting components of different illumination levels based on specific requirements at different levels of the industry.

Lighting system equipment in major industrial sectors in Mauritius – **All Industrial sectors**

Performance assessment

Conducting a performance assessment test of the lighting systems will define the installed efficacy of a facility in terms of lux/watt/m² (existing or design) for general lighting installation. The efficacy value can be compared with the norms for specific types of interior installations for assessing improvement options and for the best technology solution. The formulae for performance assessment of lighting systems is as follows.

Lighting Efficiency:

$$LPD\left(\frac{W}{m^2}\right) = \frac{Lux}{Efficacy}$$

$$Lux = \frac{Lm}{m^2}$$

$$Efficacy = \frac{Lm}{W}$$

$$; \; Lumens = Lux \times Area$$

Where:
LPD - Lighting power density (W/m2)
W - Watt
Lm – Lumens

Equipment required for the assessment: Lux meter, Single Phase power analyzer

Common monitorable parameters

The following common parameters can be monitored by industry to assess the performance of lighting systems.

Table 27: Common monitorable parameters – lighting system

Parameter	Unit	Instrument	Frequency
Illumination	Lux	Lux meter	Quarterly

Parameter	Unit	Instrument	Frequency
Electricity consumption	kWh	Energy meter	Daily

The target lux levels based on the type of operation is as follows:

Table 28: Target illumination based on operations[15]

Lighting Area	Average illumination (Lux)	Lighting Glare index
Furnace rooms, bending, annealing lehrs	100	28
Mixing rooms, forming (blowing, drawing, pressing, rolling)	150	28
Cutting to size, grinding, polishing, toughening	200	25
Finishing (beveling, decorating, etching, silvering)	300	22
Brilliant cutting	700	19
General inspection	200	19
Fine inspection	700	19
Storage areas	150	25
Maintenance workshop	150	28
Entrance, corridor, stairs	100	28
Outdoor areas	20	25

Further the industries can refer to the lighting power densities

Table 29: Lighting power densities for industries[16]

Lighting Area	Average illumination (Lux)	Lighting power density (w/m^2)
Administrative building	50 – 400	5.0 – 9.5
Administrative corridor	100	2.3 – 7.1
Shop floor lighting (process)	150 – 300	6.0 – 12.0
Workshop	150 – 300	7.1 – 14.1
Warehouse - storage area	100 – 150	3.5 – 7.08

The standard and target values for lighting systems are given below.

Table 30: Standard and target values for luminous efficacy

Luminous efficacy	
Standard value	80 Lm/W
Target value	120 Lm/W

[15] *Source: Energy Efficiency guidelines in MSME (Bureau of Energy Efficiency, India)*
[16] *Source: Energy Efficiency guidelines in MSME (Bureau of Energy Efficiency, India)*

The procedures for rational use of energy are given below.

Procedures for rational use of energy
Management ▪ Maintain lighting systems in different areas based on standard illumination levels ▪ Install suitable control systems to auto switch off or dimming of lighting system. The control systems include motion sensors, timers, interlocking with security systems to avoid lighting when not required, etc. ▪ Manage dimming or turning off light in a way that eliminates excessive/unnecessary lighting. ▪ Eliminate unwanted lighting within the industrial premises. ▪ Use natural lighting wherever feasible.
Monitoring and Evaluation ▪ Illumination level of lighting installed in various sections on quarterly basis.
Maintenance and inspection ▪ Undertake cleaning of windowpanes to ensure maximum utilization of daylight and lighting systems on quarterly basis. ▪ Clean and replace lighting fixtures and lamps as per requirements.
New Installations ▪ Replace inefficient lighting with energy-efficient lighting facilities (LEDs, induction lamps, etc.) ▪ Maintain standard illumination with minimum lighting power density (LPD). ▪ Select suitable lighting fixtures that can be easily maintained and allow easy cleaning and replacement of light source. ▪ Ensure maximum use of natural day light and reduce electric lighting load, e.g. use of translucent roof, large fibre glass skylight, high opening in the wall, etc. ▪ Provide due consideration to factors affecting the total lighting efficiency while selecting lighting fixtures. The factors include illuminance efficiency of the light sources, efficiency of lighting circuits and lighting fixtures, etc. ▪ Use solar tubes and solar photo voltaic based lighting system wherever feasible.

4.9. Power generator set

Power generating sets produce electricity using a combustible fuel and a generator. In addition to electricity useful heat can be recovered and provided for to heating load.

Power generator equipment in major industrial sectors in Mauritius – **All Industrial Sectors**

Performance assessment

The performance of power generator sets is defined using the Specific Electricity Generation Ratio (SEGR). The SEGR value of the generator set is the amount of electricity generated per unit of fuel.

Power generator efficiency

$$\boldsymbol{SEGR}\left(\frac{\boldsymbol{kWh}}{\boldsymbol{lit}}\right) = \frac{\boldsymbol{Electricity\ generation\ (kWh)}}{\boldsymbol{Fuel\ Consumption\ (lit)}}$$

Where:
SEGR - Specific electricity generation ratio (kWh/lit)

Equipment required for the assessment: Power Analyzer

Common monitorable parameters

The following common parameters can be monitored by industry to assess the performance of electrical utilities.

Table 31: Common monitorable parameters – power generation set

Parameter	Unit	Instrument	Frequency
Electricity generation	kWh	Energy meter	Daily
Diesel consumption	Liter	Flow meter	Daily

The typical standard SEGR of the diesel generation and target SEGR are provided in Table 32.

Table 32: Standard and target SEGR of diesel generators

Parameter	SEGR (kWh/L)
Standard	2.5 – 3.2
Target (<150 kVA)	3.0
Target (>150, <400 kVA)	3.4 – 3.7
Target (>400)	> 3.7

Procedures for rational use of energy

Management

- Ensure efficient operation of captive power generation system to maintain optimum specific energy generation ratio (SEGR)
- Manage operations in such a way to ensure proper load distribution while maintaining SEGR close to design level, in case of multiple power generation system operation.
- Install waste heat recovery (WHR) system in case of continuously operated generation system.

Monitoring and Evaluation

- Electricity generation and fuel consumption on daily basis by installing dedicated energy meter and flow monitoring system

Maintenance and inspection

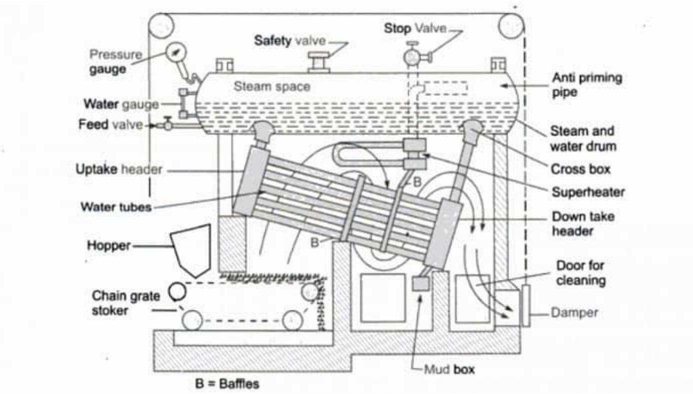
- Maintain proper functioning of injection pump and faulty nozzles to optimize fuel consumption.
- Clean and maintain carbon brushes to ensure proper contacts.
- Replenish lubricating oil as per recommended schedule to maintain the quality of the lubricant.
- Clean the filters once in a month to avoid blockage.
- Inspect for vibration and noise level on quarterly basis.
- Inspect for wear and tear of foundation bolts, and bearings on quarterly basis.
- Undertake periodical maintenance including overhauling as per the instructions by the OEM.
- Ensure dynamic balancing after each overhauling.
- Calibrate instruments and gauges as per the recommendations of the suppliers to ensure reliability and maintain accuracy of data.

New Installations

- Assess critical backup load for installing backup power generation system.

5. Industrial Energy Efficiency and Conservation Guideline for process equipment

5.1. Boiler and boiler systems



Source: https://www.www.linquip.com

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. The key elements of a boiler are burner, combustion chamber, heat exchanger, exhaust stack, and controls. Typically, boilers are classified as fire tube or water tube depending on type of media in the tubes. Boilers form an energy intensive component of industries. They are used to heat or vaporize a fluid which is then used in various processes or heating applications, including water heating, central heating, boiler-based power generation, cooking, and sanitation. Though there are infinite numbers of boiler designs, these can be generally they fit into one of above two categories.

Boiler equipment in major industrial sectors in Mauritius – **Textile, Food Processing, Agro processing and beverages, medical devices and Pharmaceuticals, Sugar cane industry.**

Performance assessment

Performance of boiler reduces with time due to poor combustion, heat transfer fouling and poor operation and maintenance as well as deterioration in fuel and water quality. Efficiency testing for boilers can help us understand how far the boiler efficiency drifts away from the boiler efficiency.

The performance of boilers is expressed in terms of thermal efficiency. The thermal efficiency of boilers can be estimated using the following methods.

Boiler Efficiency:

Direct method

The direct method 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. Efficiency can be evaluated using the formula

Boiler efficiency can be calculated using:

$$\boldsymbol{Boiler\ efficiency} = \frac{\boldsymbol{Heat\ output}}{\boldsymbol{Heat\ Input}} \times \mathbf{100}$$

$$\boldsymbol{Boiler\ Efficiency} = \frac{\boldsymbol{Q} \times (\boldsymbol{h_g} - \boldsymbol{h_f})}{\boldsymbol{q} \times \boldsymbol{GCV}}$$

Where:
h_g – Enthalpy of saturated steam in kcal/kg of steam
h_f - Enthalpy of feed water in kcal/kg of water

Q – Quantity of steam generated per hour
GCV - Gross Calorific Value

Equipment required for the assessment: Pressure Gauge, Ultrasonic flow meter, Temperature sensor, Bomb Calorimeter, Stopwatch.

Parameters to be monitored for the calculation of boiler efficiency by direct method are:

- Quantity of steam generated per hour (Q) in kg/hr.
- Quantity of fuel used per hour (q) in kg/hr.
- The working pressure (in kg/cm^2 (g)) and superheat temperature (°C), if any
- The temperature of feed water (°C)
- Type of fuel and gross calorific value of the fuel (GCV) in kcal/kg of fuel

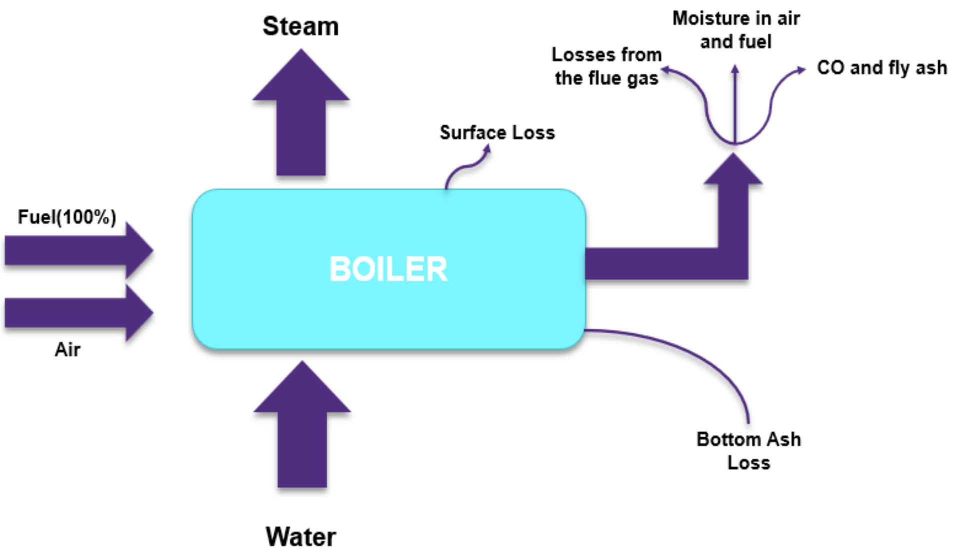
Indirect method

Indirect method is also called as heat loss method. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. The losses that occur in a boiler are:

- Loss of heat due to dry flue gas
- Loss of heat due to moisture in fuel and combustion air
- Loss of heat due to combustion of hydrogen
- Loss of heat due to radiation
- Loss of heat due to unburnt fuel

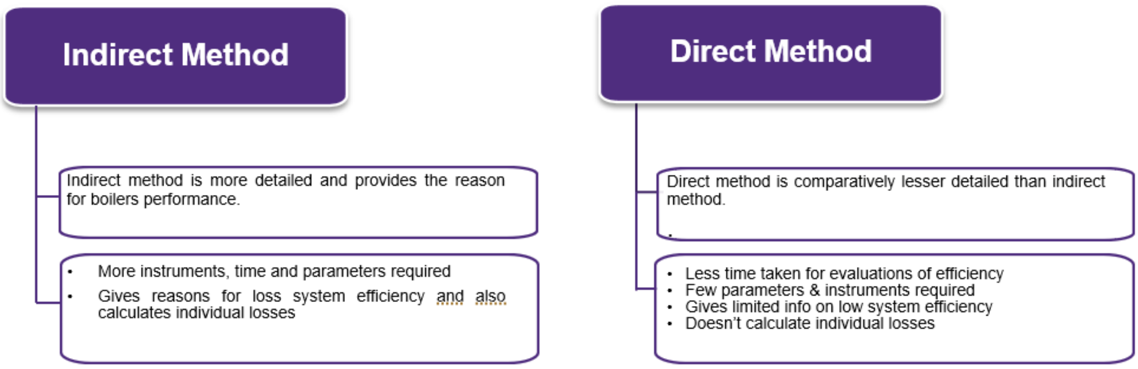
The performance evaluation through indirect method is presented in figure below. The indirect efficiency of the boiler is evaluated using formula.

$$\boldsymbol{Efficiency = 100 - \sum Losses}$$



Equipment required for the assessment: Flue gas analyzer, Pressure gauge, Ultrasonic flow meter, Temperature sensor, Bomb Calorimeter, Stopwatch.

The comparison of direct and indirect methods is presented below:



Evaporation Ratio

Boiler Evaporation Ratio means kilogram of steam generated per kilogram of fuel consumed. However, this figure will depend upon type of boiler, calorific value of the fuel and associated efficiencies. It can be calculated using the following formula.

$$\textit{Evaporation ratio} = \frac{\textit{Heat utilized for steam generation}}{\textit{Heat addition to steam}} = \frac{\textit{kilogram of steam generated}}{\textit{kilogram of fuel consumed}}$$

Evaporation ratio of boilers shall vary depending on the fuel being consumed for the boiler operation. Calculating the evaporation ratio of boilers is crucial for assessing and improving their performance and efficiency. It helps determine how effectively the boiler converts fuel into steam, a key indicator of its fuel economy and overall operation. A higher evaporation ratio indicates a better efficiency, while a lower ratio suggests potential problems like incomplete combustion or heat losses. Higher the calorific value of the fuel, higher will be its evaporation ratio.

Table 33: Typical range of evaporation ratio in boilers

Type of boiler	Range
Coal fired boiler	4 - 6
Oil fired boiler	13 – 14.5
Gas fired boiler	11 – 13

Common monitorable parameters

The following common parameters can be monitored by industry to assess the performance of boiler.

Table 34: Common monitorable parameters – boiler

Parameter	Unit	Instrument	Frequency
Steam pressure	bar	Pressure gauge	Hourly
Steam generation	kg/hr.	Flow meter	Daily
Fuel consumption	Unit*	Weigh balance or flow meter	Daily

Parameter	Unit	Instrument	Frequency
Air ratio	kg/kg fuel	Flue gas analyzer	Daily
Flue gas temperature	°C	Thermocouple	Daily
Feedwater temperature	°C	Thermocouple	Daily
Surface temperature	°C	Thermocouple	Monthly

** Fuel unit: kg for solid fuel, L for liquid fuel and SCM for gas*

The air ratios for boiler are presented in Table 35 and standard and target for the surface temperatures of boiler are presented in Table 36.

Table 35: Standard and target values of air ratios for boiler

Parameter	Load factor (%)	Air Ratio			
		Coal	Biomass	Liquid fuel	Natural Gas
Standard	50 – 100	1.35-1.50	1.49-1.56	1.26-1.33	1.15-1.18
Target	50 – 100	1.32-1.38	1.32-1.39	1.18-1.24	1.12-1.15

Table 36: Surface temperatures of boiler

Parameter	Surface temperature (°C)*
Standard	Ambient temperature + 35
Target	Ambient temperature + 20

** Average skin temperature under steady state operation*

Typical boiler efficiencies range from about 90% for the best solid biomass fuel boilers to close to 95% for oil- and natural gas-fired boilers. The main reason for the poorer performance of biofuels is the high moisture content of the fuel, which increases flue gas losses.

Table 37: Standard and target value of boiler efficiency

Fuel	Standard	Target
HFO	84%	90%
Coal	78%	83%

Electric boilers are known for their high efficiency, often rated between 99% and 100%.[17] This high efficiency is since electric boilers convert nearly all the electrical energy they consume into heat, with minimal losses during operation. Unlike gas or oil boilers, electric boilers do not have combustion losses, which contributes to their high efficiency.

Best Operating practices

A boiler is often the largest consumer of fuel in a factory or building. Any improvements that maintenance can make in its operation are therefore immediately reflected in decreased energy

[17] *https://www.boilerguide.co.uk/electric-boiler/efficiency*

consumption and decreased energy cost. The important operating practice to be followed for boiler are as follows:

- Feed water tank and fuel oil tank should be covered from top
- Implement an effective water treatment program and blow down control
- Conduct regular checks to ensure the boiler efficiency is at optimal level
- Regular analysis of flue gases to identify excess air
- Maintain burners at proper adjustments
- Replace or repair any missing or damaged insulation
- Periodically calibrate measurement equipment and tune the combustion control system
- Maximum efficiency is achieved at about two third of the full load, therefore the load swings should be minimized, and demand should be scheduled properly
- 3 mm of soot, (deposits on the boiler) can cause an increase in fuel consumption by 2.5 percent due to increased flue gas temperature
- For every 1 % reduction in excess air, there is approximately 0.6 % rise in efficiency
- To improve thermal efficiency by 1 %, the combustion air temperature must be raised by 20 °C
- A 10 percent blow down in 15 kg/cm^2 boiler results in 3 percent efficiency loss
- Three to five days before a scheduled shut down, increase the blow down by 50 percent and during the last 24 hours before shutting down, decrease the continuous blow down and increase the manual blow down
- Monitor, evaluate and compare performance data regularly to derive accurate performance standards.

Typical problems in boiler and steam distribution system and their solutions are presented in Table 38[18].

Table 38: Boiler and steam distribution system: Problems and solutions

System Component	Problem	Initial Maintenance Action
Boiler	Inoperable gauges	Overhaul boiler controls as soon as possible
	Most recent boiler adjustment at least two years ago	Have boiler adjusted for most efficient firing
	Scale deposits on water side of shutdown boiler	Remove scale; check water-softening system
	Boiler stack temperature more than 30°C above steam or water temperature	Clean tubes and adjust fuel burner (Ref. 1)
	Fuel valves leak	Repair
	Stack shows black smoke or haze when boiler is operating	Check combustion controls
	Rust in water gauge	Check return line for evidence of corrosion
	Safety valves not checked or tagged	Have inspection performed immediately

[18] *Wayne C Turner, Steve Doty, Energy Management Handbook, Sixth Edition*

System Component	Problem	Initial Maintenance Action
Steam trap	Leaks	Have inspection performed; repair or replace
Steam valve	Leaks	Repair
Steam line	Lines uninsulated	Have insulation installed
	Water hammer noted	Fix steam trap
Condensate return	Uninsulated	Insulate if hot to touch
Condensate tank	Steam plumes at tank vents	Check and repair leaking steam traps
	No insulation	Install insulation
Condensate pumps	Excessive noise	Check and repair
	Leaks	Replace packing: overhaul or replace pump if necessary

Steam traps located on the equipment allow condensate to drain back into the condensate return line, where it flows back to the condensate receiver. Steam traps also perform other functions, such as venting air from the system on start-up. Comparison of steam trap types and its characteristics are presented in Table 39.

Table 39: Comparison of Steam Trap Characteristics

Characteristic	Inverted Bucket	F&T	Disk	Bellows Thermostatic
Method of operation	Intermittent	Continuous	Intermittent	Continuous [a]
Energy conservation (time in service)	Excellent	Good	Poor	Fair
Resistance to wear	Excellent	Good	Poor	Fair
Corrosion resistance	Excellent	Good	Excellent	Good
Resistance to Hydraulic shock	Excellent	Poor	Excellent	Poor
Vents air and CO_2 at steam temperature	Yes	No	No	No
Ability to vent air at very low pressure (1/4 psig)	Poor	Excellent	NR [b]	Good
Ability to handle start-up air loads	Fair	Excellent	Poor	Excellent
Operation against back pressure	Excellent	Excellent	Poor	Excellent
Resistance to damage by freezing	Good	Poor	Good	Good
Ability to purge system	Excellent	Fair	Excellent	Good

Characteristic	Inverted Bucket	F&T	Disk	Bellows Thermostatic
Performance on very light loads	Excellent	Excellent	Poor	Excellent
Responsiveness to slugs of condensate	Immediate	Immediate	Delayed	Delayed
Ability to handle dirt	Excellent	Poor	Poor	Fair
Comparative physical size	Large [d]	Large	Small	Small
Ability to handle "flash steam"	Fair	Poor	Poor	Poor
Mechanical failure (open-closed)	Open	Closed	Open [e]	Closed [f]

[a] *can be intermittent on low load*
[b] *not recommended for low pressure operation*
[c] *cast iron traps not recommended*
[d] *in welded stainless-steel construction - medium*
[e] *can fail closed due to dirt*
[f] *can fail open due to wear*

The amount of blowdown required for satisfactory boiler operation is normally based on allowable limits for water impurities as established by standards such as the American Boiler Manufacturers Association (ABMA). The recommended limits for ***boiler-water concentrations*** is presented in Table 40.

Table 40: Recommended Limits for Boiler-Water Concentrations

Drum pressure (psig)	Total Solids		Alkalinity		Suspended Solids		Silica
	ABMA	Possible	ABMA	Possible	ABMA	Possible	ABMA
0 to 300	3500	6000	700	1000	300	250	125
301 to 450	3000	5000	600	900	250	200	90
451 to 600	2500	4000	500	500	150	100	50
601 to 750	2000	2500	400	400	100	50	35
751 to 900	1500	—	300	300	60	—	20
901 to 1000	1250	—	250	250	40	—	8
1001 to 1500	1000	—	200	200	20	—	2

Optimum ***burner performance*** of the boiler is of prime importance. Table 41 lists common burner difficulties that can be rectified through observation and maintenance.

Table 41: Malfunctions in boiler firing system

Malfunction	Fuel			Detection	Action
	Coal	Oil	Gas		
Uneven air distribution to burners	x	x	x	Observe flame patterns	Adjust registers (trial and error)
Uneven fuel distribution to burners	x	x	x	Observe fuel pressure gages, or take coal sample and analyse	Consult manufacturer

Malfunction	Fuel			Detection	Action
	Coal	Oil	Gas		
Improperly positioned guns or impellers	x	x		Observe flame patterns	Adjust guns (trial and error)
Plugged or worn burners	x	x		Visual inspection	Increase frequency of cleaning; install strainers (oil)
Damaged burner throats	x	x	x	Visual inspection	Repair

Table 42 gives a list of the most common boiler maintenance actions that need to be performed annually. Table 43 gives a checklist of other routine maintenance items. If your staff is trained in boiler operation and maintenance, then this table can be used to help define a pattern of boiler maintenance.

Table 42: Boiler checklist for routine maintenance

Action	Frequency
Check safety controls	Daily
Check stack-gas analysis	Daily or more often
Blow down water in gauges	Weekly
Blow down sludge from condensate tanks	Whenever needed; frequency depends upon amount of makeup water used
Have water chemistry checked	Quarterly
Perform combustion efficiency check; log results	Daily or weekly
Check and record pressures and readings from boiler gauges	Daily or weekly

Table 43: Boiler checklist for annual maintenance

Check	Examine for
Safety interlocks	Operability—must work
Boiler trip circuits	Operability
Burner	
Oil tip openings	Erosion or deposits
Oil temperatures	Must meet manufacturer’s specifications
Atomizing steam pressure	Must meet manufacturer’s specifications
Burner diffusers	Burned or broken, properly located in burner throat
Oil strainers	In place, clean
Throat refractory	In good condition
Gas injection system	
Orifices	Unobstructed
Filters and moisture traps	In place, clean, and operating
Burner parts	Missing or damaged
Coal burners	
Burner components	Working properly
Coal	Fires within operating specifications

Check	Examine for
Grates	Excessive wear
Stokers	Location and operation
Air dampers	Unobstructed, working
Cinder reinjection system	Working, unobstructed
Combustion Controls	
Fuel valves	Move readily, clean
Control linkages and dampers	Excessive “play”
Fuel supply inlet pressures on atomizing	Meet manufacturer’s specifications steam or air systems
Controls	Smooth response to varying loads
Gauges	Functioning and calibrated
Furnace	
Fire-side tube surfaces	Soot and fouling
Soot blowers	Operating properly
Baffling	Damaged; gas leaks
Refractory and insulation	Cracks, missing insulation
Inspection ports	Clean
Water treatment	
Gauges	Working properly
Blowdown valves	Working properly
Water tanks	Sludge
Water acidity	Within specifications

5.2. Cold rooms and Industrial Refrigeration

Cold rooms are enclosed refrigeration spaces designed to maintain precise low-temperature conditions for storing perishable goods, raw materials, and temperature-sensitive products. These systems consist of high-performance insulated panels, refrigeration units with compressors and evaporators, precision temperature controls, and air circulation systems to ensure stable thermal conditions. Their primary function is to prevent product spoilage, maintain quality standards, and meet regulatory requirements across various industries.

In industrial settings, cold rooms represent a major energy-consuming system, particularly in food processing, pharmaceutical manufacturing, and chemical storage applications. The most common configurations include modular prefabricated cold rooms, deep-freeze storage units, pharmaceutical-grade cold chambers, and multi-temperature warehouse zones. These systems serve critical functions such as extending the shelf life of food products, preserving medicinal compounds, and maintaining stable environments for industrial processes. Their design and operation must comply with stringent industry standards including food safety protocols and pharmaceutical storage regulations, while also optimizing energy efficiency to reduce operational costs.

Cold room equipment in major industrial sectors in Mauritius – **Food Processing, Agro processing and beverages, medical devices and Pharmaceuticals, etc.**

Performance assessment

The performance assessment test for cold rooms will verify the performance of the refrigeration system based on values as assessed through field measurements. The performance assessment will measure net cooling capacity (tons of refrigeration) along with the energy requirements at operating conditions. The objective of the test is to estimate the energy consumption at actual load vis-à-vis design conditions.

The cooling capacity be estimated by following relation:

$$\boldsymbol{Tonnes\ of\ Refrigeration\ (TR)} = \frac{\boldsymbol{Q \times c_p \times (T_i - T_o)}}{\boldsymbol{3024}}$$

Alternatively, British Thermal Unit (BTU)[19] could also be used to measure refrigeration capacity of equipment:

$$\boldsymbol{BTU = Q \times c_p \times (T_i - T_o) \ \times 3.968}$$

Where:
TR - cooling TR duty
BTU - British thermal unit
Q - mass flow rate of coolant (kg/hour)
C_p - coolant specific heat (Kcal /kg °C)
T_i - inlet Temperature of coolant to evaporator (chiller) (°C)
T_o - outlet temperature of coolant from evaporator (chiller) (°C)

Equipment required for cold room performance: Hygrometer, Power analyzer, Vane anemometer, Vernier Caliper

The efficiencies of cold rooms are usually measured in terms of their Energy Efficiency Ratios or EERs, or COP.

EER of cold room:

$$\boldsymbol{EER} \ = \frac{\boldsymbol{Btu\ of\ cooling}}{\boldsymbol{watt\ hours\ of\ electric\ energy\ input}}$$

Where:
EER - Energy Efficiency Ratios
Btu - British thermal unit
Electric energy is denoted as watt-hour (Wh)

Equipment required for assessment: Hygrometer, Power Analyzer, Anemometer, Vernier Caliper

Cold room performance is usually measured in terms of a Coefficient of Performance (COP) and EER.

COP of cold room:

$$\boldsymbol{COP} = \frac{\boldsymbol{Heat\ absorbed\ by\ evaporator}}{\boldsymbol{(Heat\ rejected\ by\ condenser -} \atop \boldsymbol{Heat\ absorbed\ by\ evaporator)}}$$

EER of cold room:

$$\boldsymbol{EER = COP \ \times 3.412\ Btu/Wh}$$

Where:
COP - Coefficient of Performance

[19] One TR is equivalent to 12,000 BTU

EER - Energy Efficiency Ratios
Btu - British thermal unit
Electric energy is denoted as watt-hour (Wh)

Equipment required for assessment: Hygrometer, Power Analyzer, Anemometer, Vernier Caliper

Common monitorable parameters

The common monitorable parameters for cold rooms section are given below.

Procedures for rational use of energy

Management

- The management shall use energy management manuals as provided by the equipment manufacturer for optimal performance of the cold storage unit.
- Operating under best practices to reduce cooling load by using segregation, partitions etc., adjusting the temperature of the room, operational time of equipment as per the energy management manual
- The industries should incorporate the impacts of seasonal changes in weather to obtain best efficiency from cooling equipment installed in the industry

Monitoring and Evaluation

- The industry should facilitate development of energy operations manual for monitoring and evaluation of energy consumption by cooling facilities
- The temperature should be regularly monitored and recorded for the operational areas

Maintenance and inspection

- Properly inspect and monitor the operations of cold rooms to ensure energy efficient cooling operation of the industry
- The automatic temperature devices that are installed in the cold rooms should be regularly inspected and monitored

New Installations

- The new equipment being installed in the industries should comply with the standards and regulations as per the energy efficiency law
- Each cooling equipment to be independently controlled by each operational area adjustable to demand

The standard and target values for cold rooms depends on the energy efficiency ratios.

Table 44: Standard and target values for rated EER of cold rooms

Rated EER of cold rooms	
Standard value	2.0
Target value	3.5

5.3. Stenters & Dryers

Stenters are essential in the **textile industry**, playing a crucial role in dyeing, heat setting, drying, and finishing processes. They consist of a pair of traveling chains equipped with clips or pins. Stenters stretch the fabric to the desired width and influence the final length and other characteristics of the material through heating and curing operations. The fabric movement speed is adjustable between 10-

100 meters per minute, depending on the fabric type. Inside the stenter, temperatures reach around 150-200°C as heated air passes over the fabric. Multiple stenters in a textile facility can account for 40-60% of the total energy consumption. The primary energy-consuming areas are evaporation and air heating, followed by fabric motion and drives. Different industries have varying requirements based on their scale and operations.

Performance assessment

The efficiency of stenters is calculated using the specific energy consumption assessment.

Specific Energy Consumption

The specific power consumption of stenter can be calculated by following formula

$$SEC = \frac{P_i(kW)}{W_f(kg/h)}$$

Where:
P_i – Power input in kW
W_f – Weight of fabric flow in kg/hour

The specific energy consumption of stenter machines serves as an effective guide in efficiencies of different stenter machines**.**

Equipment required for the assessment: power analyzer

Exhaust Humidity Measurement

The humidity of exhaust air of stenter serves as an effective guide in efficiencies of different stenter machines**.** The exhaust humidity of stenters varies based on the speed of fabric and temperature of the air input to stenter.

The desirable values for exhaust humidity of the stenters is 0.10 to 0.15 kg water/kg dry air. The exhaust humidity above this indicates that the fabric has not been heated properly. However, value below this indicated over drying of fabric and increased energy consumption. This is called Wadsworth criterion.

Specific exhaust humidity of stenter can be calculated by

$$Exhaust\ Humidity = \frac{Mass\ of\ water(kg/s)}{Mass\ of\ dry\ air(kg/s)}$$

Where:
Flow rates of water and dry air in the exhaust are in kg/s

Equipment required for the assessment: psychrometer, Hygrometer

Common monitorable parameters

The following common parameters can be monitored by industry to assess the performance of stenter.

Table 45: Common monitorable parameters – stenter

Parameter	Unit	Instrument	Frequency
Fabric feed rate	Meter/min	Stenter monitoring system	Daily
Fabric GSM	Grams/meter	Fabric data	Daily

Parameter	Unit	Instrument	Frequency
Power consumption	kWh	Energy meter	Daily
Gas or steam consumption	SCM	Gas or steam flow meter	Daily
Surface temperature	°C	Thermocouple	Daily
Hot air exhaust temperature	°C	Thermocouple	Daily
Inlet and outlet moisture	%	Fabric data	Daily

The specific energy consumption of stenters vary depending upon their use and area of installation. An indicative list of specific energy consumption of the different stenters is as shown in the Table 46.

Table 46: Specific Energy Consumption of stenters[20]

Type	Standard SEC range(kWh/kg)	Target SEC range(kWh/kg)
Drying Stenter	0.70 – 2.08	< 0.70
Heat Setting Stenter	1.11 – 2.50	< 1.10

Procedures for rational use of energy

Management

- The industry shall ensure the clean operation of stenter for optimum performance and follow the operational controls as provided in the energy management (EM) manual for the stenter
- Feed fabric at the centre of the machine from the batch or trolley.
- Ensure crease-less fabric and even feeding & set required feed and squeezer rolls pressure
- Check temperature, width, pressure and machine speed at regular intervals.
- Adopt safe working practices in the processing unit.
- Prepare standard operating procedures (SOPs) for worker trainings.

Monitoring and Evaluation

- The industry shall undertake an on-line monitoring of fabric flow rate and exhaust humidity and the specific energy consumption of the stenters to assess the performance, i.e., Specific Energy Consumption (SEC) which shall be described in the EM Manual.

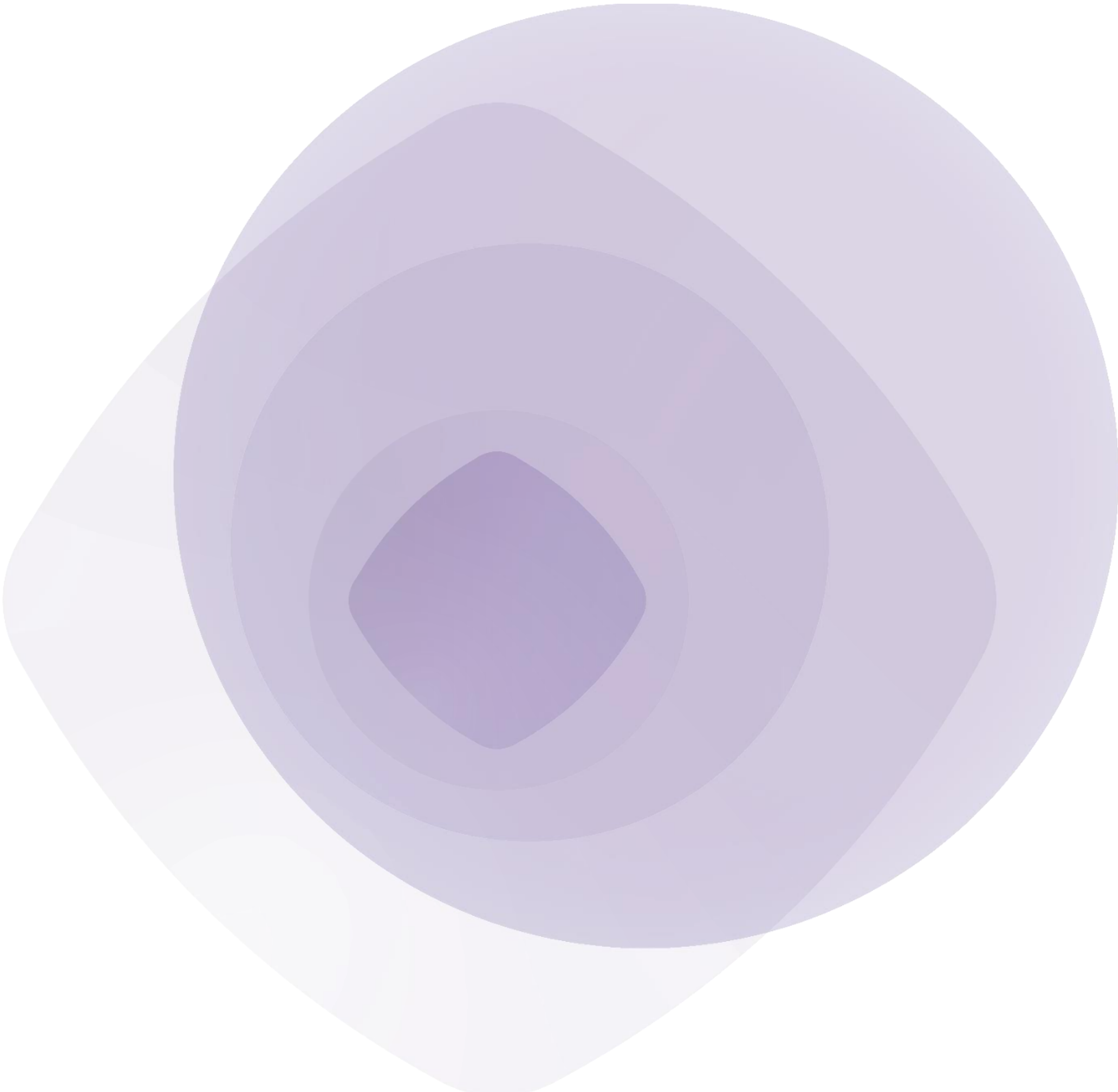
Maintenance and inspection

- Ensure machine is always clean
- Periodic preventive maintenance schedule
- Cool down the machine after job completion
- Ensure proper air, water and steam quality being fed to the stenter machine

New Installations

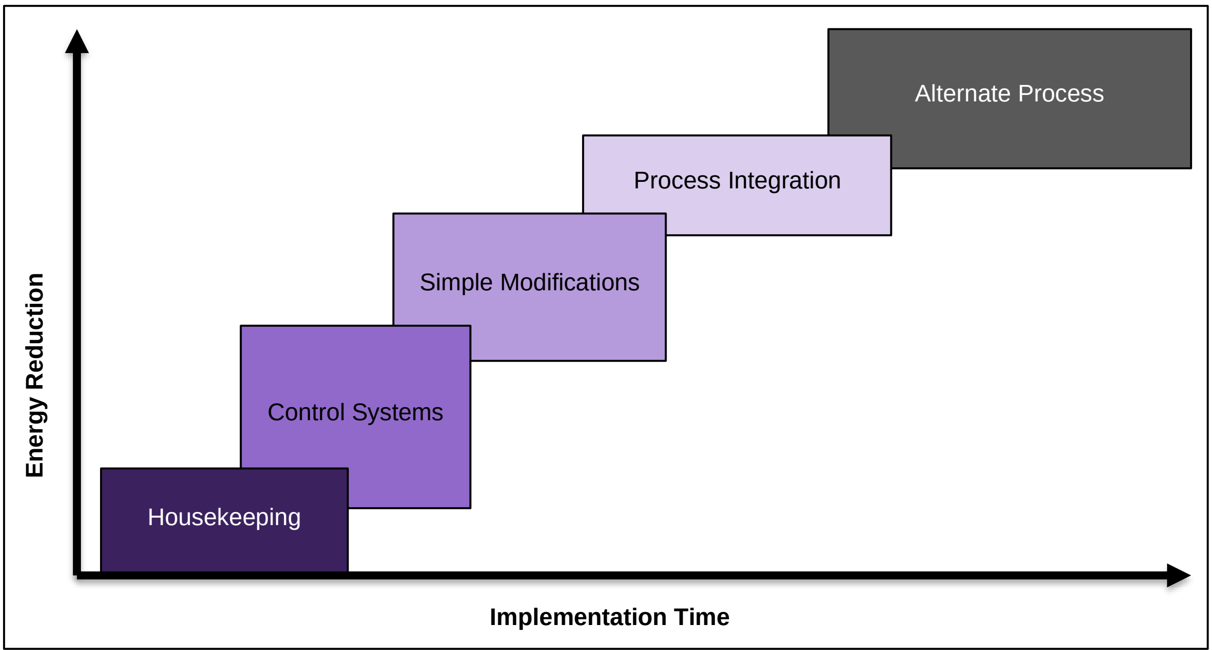
- The industry shall undertake demand assessments of fabric production to select a suitable stenter system based on the existing requirements as well as considering the immediate expansion plans. This includes energy-efficient systems, such as an inbuilt VFD, motor with permanent magnet, gas fired heater, waste heat recovery, automated control, etc.
- The industry shall select and install stenters with the lowest SEC while meeting the process demands such as heat-setting or drying.

[20] *Source: Pali Textile Cluster Report, http://sameeeksha.org/pdf/dpr/PAL_TXT7.pdf*



6. Energy Efficiency Measures and Action Plan

Improving energy efficiency in industrial facilities needs to be done within the context of an energy management system (EnMS). Within any energy management system (EnMS) in an existing plant, the best way to maximise the quantity of energy savings and minimising investment cost is to follow the following-stage process based on the energy maturity matrix shown in figure below.



The unit can undertake the actions given below to implement energy management and improving energy efficiency in the unit in a stepwise manner:

Good housekeeping: The first step is to prioritize housekeeping opportunities. Often, low-cost or no-cost measures include implementing good maintenance practices, turning off equipment when not in use, improving insulation and sealing air leaks, reducing waste and leaks, minimizing idle time, preventing production rate losses, and turning off taps and hoses when not needed. Consistent and diligent housekeeping can significantly reduce energy consumption, thereby decreasing the size and capital investment required for subsequent energy-saving measures.

Use of control systems: Introducing and tightening control systems for existing processes and utilities can further reduce energy consumption variability, allowing operations to run closer to their designed control limits. Some small investments may be needed to repair, reinstate, replace, or introduce new control parameters.

Need for systems re-thinking: Integration of energy use is a more complex form of plant modification and retrofit but gives further energy savings. Some examples include recovering heat from one process to be reused in another process, thermal pinch analysis, process intensification, de-bottlenecking and uprating, and overall plant or site-wide optimization to minimize overall energy consumption.

Changes in process design and/or energy supply: The highest level of energy efficiency, yielding the greatest energy savings, comes from significant changes in process design, energy supply, or both. This approach is the costliest and carries the highest business risks compared to other projects in the energy efficiency spectrum.

Energy Efficiency Measures

Industries should conduct energy audits to identify equipment and areas with potential for improvement by calculating the performance assessment of the equipment and machines. Calculating Specific Energy Consumption (SEC) for different processes and equipment enables industries in identifying the areas where energy efficiency measures can be implemented. Industries should evaluate the techno-economic feasibility of the energy efficiency measures. This process aids managers in understanding how energy and fuel are used in their industry, identifying areas where waste occurs, and determining where improvements are needed.

The energy conservation measures identified post the analysis of measurements done and data collected through energy audits shall be categorised based on their economic feasibility and cost benefit analysis. The measures should be prioritized based on their targeted implementation timelines which would depend on the economic returns of the measure. The energy efficiency improvement measures can be defined into short term, medium term and long term based on the simple payback period of each measure. The categorisation for short term, medium term and long term can be tentatively done as per the Table 47.

Table 47: Categorisation of energy conservation measures

Short Term	The energy saving measures, which are having a simple payback period of less than a year, are considered to be short term measures
Medium Term	The energy saving measures, which are having a simple payback period of 1 to 3 year, are considered to be medium term measures
Long Term	The energy saving measures, which are having a simple payback period greater than 3 years, are considered to be long term measures.

Based on the equipment given in previous section for Industrial Energy Efficiency and Conservation Guideline for common equipment and process equipment, the energy efficiency technologies can be categorised as per the Table 48.

Table 48: Equipment-wise energy conservation measures

Equipment	Energy Conservation Measures
Common Equipment	
Compressed air system	**Short Term** ▪ Arresting compressed air leakages ▪ Installing Variable Speed Drive (VSD) on compressor ▪ Sequence controller/Intelligent flow controller in case of multiple compressors in use ▪ Pressure setting optimisation based on demand and end use pressure requirement ▪ Use of trans-vector nozzles and regulator at end use **Medium Term** ▪ Switching from reciprocating air compressors to rotary screw air compressors ▪ Proper pipeline layout and sizing to optimise pressure drop in the system. Use of ring main system ▪ Use of seamless aluminium or CPVC pipelines **Long Term** ▪ Installing IPM based screw compressor

Equipment	Energy Conservation Measures
	▪ Waste heat recovery to generate hot water
Pumping system	**Short Term** ▪ Avoid valve control and use Variable Speed Drives (VSD) ▪ Optimisation/sequence control of pumps in parallel operation **Medium Term** ▪ Technology upgradation such as replacing old mono block pumps with energy efficient vertical pumps ▪ Selection/sizing of pump parameter to operate it at best efficiency point of the pump
HVAC	**Short Term** ▪ Temperature controls ▪ Insultation of cold and hot network ▪ Installation of auto condenser cleaning system **Medium Term** ▪ High EER Air conditioners ▪ Variable refrigerant flow systems (VRF) chillers **Long Term** ▪ Installing magnetic bearing chillers
Fans & blowers	**Short Term** ▪ Use of cogged belts instead of flat V belts for blowers ▪ Use of direct coupled motor instead of belt driven system **Medium Term** ▪ Replace conventional ceiling and table fans with efficient BLDC motor-based fans ▪ Installation of HVLS (High Volume Low Speed) fans **Long Term** ▪ Replacement of conventional fans in Air Handling Units (AHUs) with EC+ fans
Cooling towers	**Short Term** ▪ Installing thermostatic control ▪ Replacement of clogged fins **Medium Term** ▪ Installation of Fibre Reinforced Plastic (FRP) blades ▪ Installing Variable Speed Drive in Cooling tower **Long Term** ▪ Natural draft cooling tower ▪ Use of BLDC fans in cooling tower
Electrical Utilities	**Short Term** ▪ Automatic Power Factor Correction **Medium Term** ▪ Installation of IoT based energy monitoring and data analytics system **Long Term**

Equipment	Energy Conservation Measures
	▪ IE4/IE5 motors instead of non-standard motors
Lighting System	**Short Term** ▪ Replacing old fluorescent tube lights with LED tube lights ▪ Replacing compact lights with LEDs
Power generator	**Short Term** ▪ Optimization and air filter cleaning **Medium Term** ▪ Waste heat recovery system to generate hot water or VAM system
Process Equipment	
Boiler and steam system	**Short Term** ▪ Installation of automatic blow down system instead of manual blowdown ▪ Installation of oxygen analyzer and PID controller for boiler (maintaining air fuel ratio) ▪ Condensate recovery systems **Medium Term** ▪ Proper insulation of boiler surface and steam distribution line reduce the surface heat losses ▪ Waste heat recovery from flue gas (Air Pre-heater and Economiser) ▪ Use of auto steam traps **Long Term** ▪ Energy efficient boilers ▪ Upgrade of boiler to use multi-fuel including biomass
Stenters & Dryers	**Short Term** ▪ Automation system (moisture-based temperature and speed control) in stenter machine **Medium Term** ▪ Stenter exhaust waste heat recovery for preheating circulation air **Long Term** ▪ Use of all electric stenter
Cold Storages and industrial refrigeration	**Short Term** ▪ Use of appropriate insulation of cold room envelope. **Medium Term** ▪ Variable frequency drives in condenser fans ▪ High Efficiency Condenser System ▪ High Efficiency Fan Coil Systems including redesigning of cooling network ▪ Waste heat recovery by using ammonia desuperheater **Long Term** ▪ Replacement of reciprocating compressor with scroll compressor

Periodical Update

Updating energy efficiency and conservation guidelines periodically is crucial to keep pace with technological advancements and evolving environmental challenges. As new technologies emerge and our understanding of energy consumption deepens, guidelines must reflect the latest best practices to maximize efficiency and minimize waste. Regular updates ensure that policies remain relevant, effective, and aligned with current sustainability goals. The **guidelines shall be updated every five years** to keep pace with technological advancements and industrial trends in the country.

Updating energy efficiency and conservation guidelines on a periodic basis is essential for several reasons:

1. **Technological Advancements**: As technology evolves, new energy-efficient solutions and practices emerge. Regular updates ensure that guidelines incorporate the latest innovations, maximizing energy savings and reducing environmental impact.

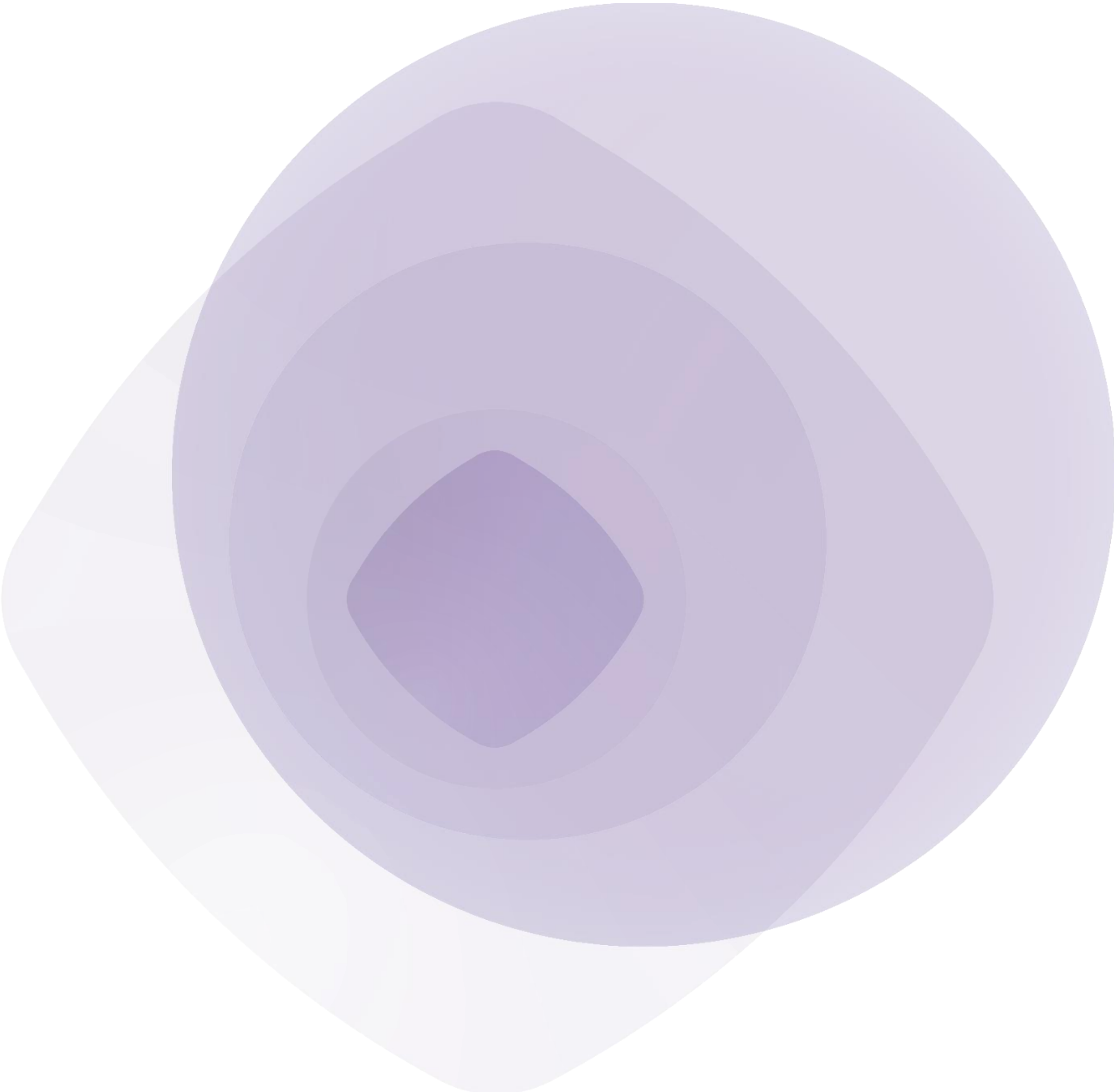
2. **Environmental Changes**: Climate change and other environmental factors continuously influence energy consumption patterns. Periodic updates allow guidelines to adapt to these changes, promoting sustainability and resilience.

3. **Economic Benefits**: Updated guidelines can lead to significant cost savings for consumers and businesses by promoting more efficient energy use. This can also stimulate economic growth by encouraging the adoption of new technologies and practices.

4. **Regulatory Compliance**: Keeping guidelines current ensures compliance with national and international regulations, helping to avoid penalties and fostering a culture of responsibility and sustainability.

5. **Stakeholder Engagement**: Regularly revising guidelines involves stakeholders in the process, ensuring that diverse perspectives are considered and that the guidelines are practical and effective.

By periodically updating energy efficiency and conservation guidelines, we can ensure they remain relevant, effective, and aligned with our evolving needs and goals, ultimately contributing to a more sustainable and energy-efficient future.



Annexure – Table of motor efficiency values

Minimum 50 Hz efficiency values defined in IEC/EN 60034-30-1:2014 (based on test methods specified in IEC 60034-2-1:2014)

Output	IE1				IE2				IE3				IE4			
kW	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole
0.12	45.0	50.0	38.3	31.0	53.6	59.1	50.6	39.8	60.8	64.8	57.7	50.7	66.5	69.8	64.9	62.3
0.18	52.8	57.0	45.5	38.0	60.4	64.7	56.6	45.9	65.9	69.9	63.9	58.7	70.8	74.7	70.1	67.2
0.20	54.6	58.5	47.6	39.7	61.9	65.9	58.2	47.4	67.2	71.1	65.4	60.6	71.9	75.8	71.4	68.4
0.25	58.2	61.5	52.1	43.4	64.8	68.5	61.6	50.6	69.7	73.5	68.6	64.1	74.3	77.9	74.1	70.8
0.37	63.9	66.0	59.7	49.7	69.5	72.7	67.6	56.1	73.8	77.3	73.5	69.3	78.1	81.1	78.0	74.3
0.40	64.9	66.8	61.1	50.9	70.4	73.5	68.8	57.2	74.6	78.0	74.4	70.1	78.9	81.7	78.7	74.9
0.55	69.0	70.0	65.8	56.1	74.1	77.1	73.1	61.7	77.8	80.8	77.2	73.0	81.5	83.9	80.9	77.0
075	72.1	72.1	70.0	61.2	77.4	79.6	75.9	66.2	80.7	82.5	78.9	75.0	83.5	85.7	82.7	78.4
1.1	75.0	75.0	72.9	66.5	79.6	81.4	78.1	70.8	82.7	84.1	81.0	77.7	85.2	87.2	84.5	80.8
1.5	77.2	77.2	75.2	70.2	81.3	82.8	79.8	74.1	84.2	85.3	82.5	79.7	86.5	88.2	85.9	82.6
2.2	79.7	79.7	77.7	74.2	83.2	84.3	81.8	77.6	85.9	86.7	84.3	81.9	88.0	89.5	87.4	84.5
3	81.5	81.5	79.7	77.0	84.6	85.5	83.3	80.0	87.1	87.7	85.6	83.5	89.1	90.4	88.6	85.9
4	83.1	83.1	81.4	79.2	85.8	86.6	84.6	81.9	88.1	88.6	86.8	84.8	90.0	91.1	89.5	87.1
5.5	84.7	84.7	93.1	81.4	87.0	87.7	86.0	83.8	89.2	89.6	88.0	86.2	90.9	91.9	90.5	88.3
7.5	86.0	86.0	84.7	83.1	88.1	88.7	87.2	85.3	90.1	90.4	89.1	87.3	91.7	92.6	91.3	89.3
11	87.6	87.6	86.4	85.0	89.4	89.8	88.7	86.9	91.2	91.4	90.3	88.6	92.6	93.3	92.3	90.4
15	88.7	88.7	87.7	86.2	90.3	90.6	89.7	88.0	91.9	92.1	91.2	89.6	93.3	93.9	92.9	91.2
18.5	89.3	89.3	88.6	86.9	90.9	91.2	90.4	88.6	82.4	92.6	91.7	90.1	93.7	94.2	93.4	91.7
22	89.9	89.9	89.2	87.4	91.3	91.6	90.9	89.1	92.7	93.0	92.2	90.6	94.0	94.5	93.7	92.1
30	90.7	90.7	90.2	88.3	92.0	92.3	91.7	89.8	93.3	93.6	92.9	91.3	94.5	94.9	94.2	92.7
37	91.2	91.2	90.8	88.8	92.5	92.7	92.2	90.3	93.7	93.9	93.3	91.8	94.8	95.2	94.5	93.1
45	91.7	91.7	91.4	89.2	92.9	93.1	92.7	90.7	94.0	94.2	93.7	92.2	95.0	95.4	94.8	93.4
55	92.1	92.1	91.9	89.7	93.2	93.5	93.1	91.0	94.3	94.6	94.1	92.5	95.3	95.7	95.1	93.7
75	92.7	92.7	92.6	90.3	93.8	94.0	93.7	91.6	94.7	95.0	94.6	93.1	95.6	96.0	95.4	94.2
90	93.0	93.0	92.9	90.7	94.1	94.2	94.0	91.9	95.0	95.2	94.9	93.4	95.8	96.1	95.6	94.4
110	93.3	93.3	93.3	91.1	94.3	94.5	94.3	92.3	95.2	95.4	95.1	93.7	96.0	96.3	95.8	94.7
132	93.5	93.5	93.5	91.5	94.6	94.7	94.6	92.6	95.4	95.6	95.4	94.0	96.2	96.4	96.0	94.9
160	93.8	93.8	93.8	91.9	94.8	94.9	94.8	93.0	95.6	95.8	95.6	94.3	96.3	96.6	96.2	95.1
200	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.3	95.4
250	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.5	95.4
315	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
355	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
400	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
450	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
500-1000	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4