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Energy Audit Guidebook

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ABBREVIATIONS

ACB	Air Circuit Breaker
ATS	Automatic Transfer Switch
BEE	Bureau of Energy Efficiency, Ministry of Power, India
BEP	Best Efficiency Point
CO_2	Carbon Dioxide
COP	Coefficient of Performance
DB	Distribution Board
DoIT	Department of Industry and Trade
EE&C	Law on Energy Efficiency and Conservation
EnMS	Energy Management System
ESP	Energy Service Provider
EVN	Electricity of Vietnam
FRP	Fibre-reinforced Plastic
GDE	General Directorate of Energy
GDP	Gross Domestic Product
GHG	Green House Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GCV	Gross Caloric Value
HVAC	Heating, Ventilation and Air Conditioning
IGA	Investment Grade Audit
IQF	Individual Quick Freezer
MCCB	Modeled Case Circuit Breaker
MOIT	Ministry of Industry and Trade
MSB	Main Distribution Board
SEC	Specific Energy Consumption
TOE	Ton of Oil Equivalent
VFD	Variable Frequency Drive
VNEEP	Vietnam National Energy Efficiency Program
VSD	Variable Speed Drive

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General

GENERAL

Objectives

The guidebook is developed to instruct energy auditors and other stakeholders to assess and conduct well-structured and effective energy audits in industrial facilities as well as in commercial building. Following topics are considered:

- Framework of the audit which will describe scopes, tasks, quality requirements, budget, time frame, kickoff meeting, energy audit team etc.
- A summary of the regulatory requirements, including Vietnamese Standards on energy efficiency of industrial process system
- Collecting required data and reviewing
- Conducting site inspection and measurement
- Analyzing data, interpreting and findings
- Energy audit report including potential energy saving measures

Audiences

Targeted audiences of the Guidebook are:

- Energy Auditors
- Energy and facility managers
- Energy Management Department of Provincial/City level of Department of Industry and Trade (DOIT)
- Ministry of Industry and Trade
- Lecturers

Energy auditors are assumed to have adequate knowledge of energy and energy systems. Thus, this guidebook is designed to provide a systematic approach in conducting audit in industrial/commercial facilities, which includes methodology and approaches of an audit and supporting tools of checklist, questionnaire and data analysis etc.

Assessment of Current Energy Auditing

Energy Auditing can be seen as a diagnostic of the current conditions of a facility regarding its energy performance and consumption. Energy auditing defines viable measures toward the improvement of energy efficiency or lower cost energy source alternatives. Overall objective is to support the audited facility in outline action plan to improve either higher energy efficiency or lower energy cost and in some cases both of them.

In Vietnam, energy auditing is needed to compensate for the rising energy prices (especially electricity), reduce manufacturing cost, reduce pollutant emission, and conservation of energy resources.

The Law No. 50/2010/QH12 on Energy Efficiency and Conservation (EE&C) approved on 17 June, 2010 is a key milestone in the development process of EE&C legislation in the country. Accordingly energy audit is mandatory to state-owned agencies and intensive energy consuming enterprises, which annual energy consumption is from 1,000 TOE – Industrial and from 500 TOE – Commercial. These enterprises and organizations have to develop a plan to conduct their energy audits in accordance with the existing regulations and procedures to identify energy saving opportunities.

Currently, there are more than thousands of energy audits which has been taken place in Vietnam in various industrial sub-sectors. However, the quality of these activities seems inadequate. In addition, there is no technical guidebook in detail for energy audits to standardize and ensure the compliance of the audit activities to the regulated procedure.

Category or Level of an Energy Audit

An Energy Audit is typically categorized based on the level of detail for investigation. Two level categorization is normally used regarding the mentioned aspects:

Table 1. Energy audit levels

	Level 1 – Preliminary Audit	Level 2 – Detailed Audit
Objectives:	Quick assessment of energy consumption and energy performance Provide action plan and focus points to Level 2 – Detailed Energy Audit Can be used as guide toward detailed energy audit	Different energy systems (pump, fan, compressed air, steam, process heating, etc.) are assessed in detail Provide energy saving measures with cost analysis and priority to be invested
Pros:	Lowest cost Overall assessment Short time	High confidence Give a more accurate picture of the energy performance and more specific recommendation for improvements
Cons:	Low cc nfidence	High cost

Level 2 – Energy Audit is preferred by the Law of EE&C, Degree 21/2011/ND-CP and the Circular 09/2012/BCT due to its level of details. This guidebook only focuses on level 2 energy audit.

Chapter 01

Required Contents For Energy Audit

PART I.

REQUIRED CONTENTS FOR ENERGY AUDIT

1. AUDIT PLAN AND RESOURCE

Planning for audit and defining the necessary resources are important steps that should be performed before the audits. This first chapter of the guidebook will help the audience to understand the importance of planning and what are the resources needed prior to audit.

1.1. Audit plan

An audit plan outlines the strategy and procedure of the audit. Audit objective should be defined clearly before the audit planning.

The audit plan should provide the following information:

- Preparation steps for the audit
- Audit procedure, in which time of the audit and the timetable for each step should be defined clearly. The audit time depends on the organization's conditions and status. Audit time can be shortened if the audit planning is well established
- Responsibilities and tasks of each audit team member should be clarified.

Audit resources consist of human resources, finance resources, time resources, and available measurement devices. Safety procedure and equipment should be well prepared. An audit plan is also a vital communications tool for ensuring that the audit will be consistent, complete and effective in its use of resources.

Key steps need to be planned in the audit procedure including:

- Prepare pre-audit questionnaire
- Preliminary audit plan
- Audit check list preparation: Detailed daily work plan with timetable for on-site survey: work description, area, support required from audited facility (e.g. technician, technical manager etc.)
- Data analysis and report with timetable.

An audit plan must be flexible enough to accommodate adjustments to allow for unexpected information and/or changed conditions. Methodology to implement each of the steps will be described in the part2.

1.2. Resources

The necessary resources to implement energy audit are human and technical resources. These two resouces should be prepared well to ensure the quality of the audit.

1.2.1. Human resource

Energy audit is carried out by a certified auditor including an energy manager in the company or outsourced to external specialists.

1.2.1.1. Auditors

Qualification

The auditor must be a competent and professional one, who is familiar with energy auditing process and techniques. Energy auditors can be accredited separately for electrical and thermal energy audits, according to their qualifications. Energy auditors must be either electrical, thermal or energy related engineers with above 3 years experience in energy.

There are certain requirements to be an Energy Auditors:

- Technical/Engineering background is preferred e.g. bachelor of engineering
- Participate in at least two energy audits
- Participate and pass the training course of energy auditor, hosted by Directorate of Energy, Ministry of Industry and Trade.

Item of #1 and #2 are not regulated in the current legal documents, however, these are screening criteria to candidates who want to register in the item #3. Certificate of energy auditor is proof that an energy auditor has participated in the training course and passed the exam.

Certificate

Energy auditor must be certified by Ministry of Industry and Trade, by an international organization with mutual recognition agreements according to the Circular 39/2011/TT-BCT. According to circular No. 39/2011/TT-BCT, only the Ministry of Industry & Trade is authorized to offer exams and issue official certifications for energy auditors and energy managers. These certifications are signed by the Minister and are considered to be the official professional licenses issued by the State.

The energy auditors must be trained on work safety and electrical safety.

Experience

Energy auditor should understand well the production process and have experience on the same field which they are assigned to perform the audit.

1.2.1.2. Energy audit team leader

Energy audit team leader will assign the task for team members. He should have the following skills:

- Strong communication and organizational skill
- Ability to think critically and attend to detail
- Ability to interact effectively and positively with prospective customers
- A positive attitude and ability to work well in a team setting
- Time management skills
- Problem solving skills.

1.2.2. Technical resource

Technical resources include instrumentation required for data collection. The technical availability for the measurement should be considered and the feasibility of data collection should be estimated.

Instrumentation could be available at the audited factories, or rented from other professional organization.

2. AUDIT METHODOLOGY AND APPROACH

2.1. Approach

The necessary output information or expectation findings of the audit should be understood clearly before the audit. Approach and methodology of energy audit are described briefly in this chapter.

Approach is, in a systematically way, to propose a suitable energy management solutions applying in energy consumers and equipment.

The pathway solution is presented in the Figure 1, including three stages (1) benchmark energy consumption within the sectors, (2) establish and study energy balance and (3) find out solutions for energy consumption reduction in energy management strategy

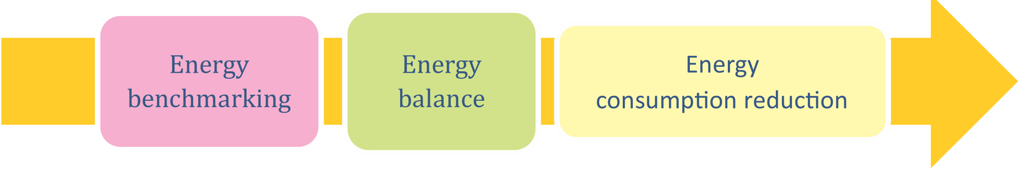


Figure 1. Approach to energy audits

2.1.1. Energy benchmarking

Energy benchmarking is a method to evaluate the energy performance of the audit plant by comparing with something similar. "Something similar" might be internal, like performance at the same time last year. Or it might be external, like performance compared to similar facilities elsewhere.

Energy performance indicator is used for comparing the specific energy consumption of the organization to energy benchmarking in the same production line or product type in an industry.

Through benchmarking, the key metrics for assessing performance are identified, baselines are established, and goals are set. This process helps to identify the key drivers of energy use and provides an important diagnostics tool for improving performance.

It is a key step in identifying opportunities to increase profitability by lowering energy and operating costs.

2.1.2. Energy balance

Energy balance is an analytical method to provide information of plant's energy performance and the cause of loss. One of the implications of the energy balance principle is that we can quantify all energy inputs and balance them against all energy outputs. Loss of energy is identified by energy balance analysis.

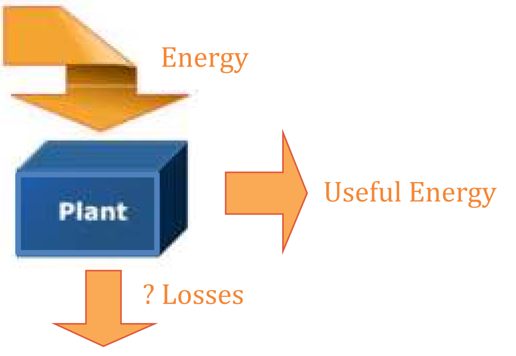


Figure 2. Energy balance to indentify the loss

Main tasks of energy audit are to inspect, survey and analysis of energy flows, balancing the energy input and output of the operation, defining loss in the flow, and propose solutions to reduce the amount of energy input into the system.

Based on the energy balance analysis results, opportunities to reduce energy consumption would be identified. Methodology to study energy balance is explained in part2.2.3.5.

2.1.3. Propose energy consumption reduction solutions

Energy efficiency defined as the goal to reduce the amount of energy required to produce products and services. In other words, energy efficiency is doing the same amount of work while using less energy, without compromising on the comfort or quality levels. For convenience of interpretation, electrical and thermal energy has been separately mentioned.

The electricity consumption investigation and thermal energy consumption investigation are good starting points in the search of energy saving opportunities.

By benchmarking analysis and energy balance study, energy losses are identified, and the measures for energy consumption reduction will be recognized by minimizing the losses.

2.2. Audit methodology

A step-by-step methodology, referred to Circular 09 (Annex IV) will be described in Chapter 3. An audit procedure usually consists of three steps: (1) preparation; (2) data collection, (3) data interpretation and findings, and writing a report.

2.2.1. Audit preparation

The key to a successful audit is proper audit preparation. Inadequate preparation may cause delays in report submission, excessive audit fees, penalties, non-compliance with regulations or debt covenants and ultimately, embarrassment.

2.2.1.1. Define audit objective and expectation output

The audit objective may vary from one organization to another. An energy audit is usually conducted to

- Understand how energy is used within the organization
- Find opportunities for improvement and energy saving
- Faise energy using awareness for employees
- Provide a benchmark (reference point) for managing energy in the organization
- Evaluate the effectiveness of an energy efficiency project or program.

The audit can be carried out to meet the need to reduce energy costs, to participate in an energy program or be regulated by the government.

According to the Decree 09/2012/TT-BCT, the key energy used organizations are responsible to establish, register and report their enegy consumption annually. They are regulated to conduct the energy audit every three years *(Clause 33, Efficient Energy Consumption and Savings Law)*.

Other organizations are motivated to perform the energy audits and report their energy consumption regularly (*Clause 25, Decree 21/2011/NĐ-CP)*.

2.2.1.2. Scope of audit and focus

The audit team should:

- Identifies the system boundary
- Specifies the physical extent of the audit by setting the terms of the boundary around the audited energy consuming system
- Identifies energy inputs that cross the boundary to be audited.

The audit scope depends on the audit objective, audit program, the available resources and the organization's demand.

Based on (1) Function and type of industry, (2) Depth to which final audit is needed, and (3) Potential and magnitude of cost reduction desired, a scope of audit can be:

- The entire plant
- The department, production line, or process step, such as the kiln or the packaging plant
- Specific (energy) equipments or resources, such as steam, compressed air, motors, or fans.

The focus area is chosen based on:

- Size of the plant
- Management's areas of interest or concern
- High energy / resource consumption or costs
- High potential energy savings area
- Areas for which energy efficiency audits or project have not yet been carried out
- Plans for construction or upgrading.

2.2.1.3. Set up the audit team

Number of required auditors with specific tasks should be determined. The factory's engineers and technician could be invited to participate in energy audits for their knowledge and experience on equipment, O&M, etc.

Auditors could be internal staff(s) or external specialists.

Audit team leader with required skills should be appointed, and she/he will organize and assign the task for team members when establishing the audit plan.

A meeting for the team members should be organized before the audit starts to have better interaction for the efficient teamwork.

2.2.1.4. Time and cost estimation

The time and cost of energy audits is highly variable depending on:

- The sector
- The size of the facility
- The qualifications of the energy auditor and/or auditing firm
- The type of audit (buildings, processes or transport or a combination)
- The accuracy and completeness of information provided by the client; and the detail provided by the expert.

The energy cost including:

- Labor cost for auditors and external professionals when needed
- Rental fee for measurement devices and other facilities if not available at the factory.

2.2.1.5. Preliminary audit

The preliminary analysis helps providing a general picture of the plant energy use, operation, and energy losses.

The initial walk-through visit is for the energy audit team to become familiar with the facility to be audited. The audit team can observe the existing measurement instrumentation on the equipment and the data recorded, so that they can determine what extra measurement and data collection are required during the audit.

Information should be defined during preliminary audit:

- Layout of the organization to plan with time frame
- Operational status of the audited plant, operating characteristics of equipment, database of production and energy consumption.
- Load inventory and key energy consuming area to be surveyed during the audit
- Energy flow (input/output) of the common load
- Measurement points, existing instrumentation and additional metering required
- Whether any meters will have to be installed prior to the audit e.g., power meter, steam, oil or gas meter.

A brief meeting – kickoff meeting with all division heads and personal concerned could be organized to develop orientation awareness creation and build up the cooperation. The auditors can inquire for comments from the facility staff and can collect readily-available data during the walk-through visit.

In the preliminary analysis, a flowchart can be constructed that shows the energy flows of the system being audited. An overview of unit operations, important process steps, areas of material and energy use, and sources of waste generation should be presented in this flowchart.

The auditor should identify the various inputs and outputs at each process step. The preliminary flowchart is a simple but detailed information and data about the input and output streams can be added later after the detailed energy audit.

2.2.1.6. Audit Checklist Preparation

Audit checklist is designed to stimulate questions about energy practices. Audit checklist should be prepared before onsite auditing for each sections/utilities. The checklist helps gathering the right data, with the appropriate amount of detail, which is a key component to realize the maximum savings from an energy audit.

The checklist should be arranged according to the itinerary of the audit. Itinerary of data collection is set up based on the layout of the organization which should be obtained during the preliminary audit.

Process for data collection is currently non-standardized, and crucial data can be overlooked or the level of detail is insufficient for the required energy and financial analyses. To address these issues, template data collection forms have been created. The purpose of these sample forms is to assist energy auditors collect data required to complete comprehensive energy and financial analyses of proposed modifications to the organization.

In the following part, standardized templates of audit checklists of common load system will be introduced. However, the actual checklist or template should be modified after the preliminary audits because actual load inventories, data availability, and operation conditions are varied from plants to plants.

2.2.1.7. Measurement equipment preparation

Depending on energy type to be audited, a list of instrumentations will be defined and prepared. The number of measurement points are determined based on the needs and practical ability. A more detailed breakdown will require more measurements, measurement equipment and expertise.

The operating instruction for all Measurement equipment must be understood and staff should familiarize themselves with the instruments and their operation prior to actual audit use.

The Measurement equipment should be calibrated regularly. List of common measurement equipment is described in part. II.

2.2.1.8. Work Safety Preparation

Auditors have to conduct surveys in lot of areas in factories and buildings, such as transformer stations, cold storage, boiler area, the waste water treatment, etc. Each place is potentially harmful to auditors. Therefore, auditors need to talk to the organization's safety officers to take measures to secure suitable work.

Auditors should be trained or understand well on workplace safety and fully equipped with safety before entering the audited sites.

Work safety training for auditors should include:

- Electrical Safety
- Chemical Safety
- Boiler and pressure vessel safety.
- Safety at height

Work safety requirement and practices are described more details in the part II.

2.2.2. Data collection

Data collection is an important step in audit process. The Data collection should be enough and accurate for the analysis, therefore the quantity and quality of the data is always a challenge to auditors. Auditors should know which data they need to collect and how to obtain the accuracy of the data.

Some data are available at the facility and can be provided through questionnaire and interview survey. Data which are not available will be obtained through measurement and calculation.

2.2.2.1. Available data collection

Energy bills along with other current and historical energy- and production-related data and information should be collected at the beginning of the audit process.

The data that can be collected at the beginning of an energy audit include the followings:

- General information about the plant (year of construction, ownership status, renovations, types of products, operation schedule, operating hours, scheduled shutdowns, etc.)
- Energy bills and invoices (electricity and fuels) for the last 3 years
- Monthly production data for the last 3 years
- Possible archived records with measurements from existing recorders
- Architectural and engineering structure of the plant and its equipment
- Status of energy management and already implemented energy-saving measures
- The technical specifications of the equipment and production lines to be audited (in which case it should be noted the building floor area, structure, direction and number of devices)
- Operating parameter (temperature, pressure, capacity, etc.)
- Operating procedures and equipment repair guidelines.

A comprehensive questionnaire template should be prepared and send to the audited plant to collect the general information. Other information would be surveyed during the preliminary audit, brief meeting, plant's staff interview and more insufficient details are collected during the audit.

A checklist should be prepared in advance to ensure data sufficiency to be collected.

2.2.2.2. Measurement

Energy audits require identification and quantification of energy necessitates measurements with equipment. Auditors should select the parameters to measure and points to measure in the energy flow. Measurement equipment should be portable, durable, easy to operate and relatively inexpensive.

The audit team should define which information could be collected by available data and information that needed to be collected by measurement after preliminary audit. Additional equipment, which is not available at the audit facility should be defined and prepared before audit.

Basic measurement during energy audit may include the following:

- Basic electrical parameters in alternative and direct current systems-Voltage (V), Current (I), Power factor, active power (kW), reactive power (kVAR)
- Energy consumption (kWh), Frequency (Hz)
- Temperature
- Heat flow
- Air and gas flow, air velocity
- Liquid flow
- Moisture content
- Relative humidity
- Flue gas analysis-CO_2, O_2, CO, SO_x, NO_x
- Combustion efficiency.

2.2.2.3. Instrument inspection requirements

In order to perform data collection effectively and accurately, the instrument shall be inspected and calibrated. According to the Circular No. 23/2013/TT-BKHCN dated September 26, 2013 of the Ministry of Science and Technology on group 2 measuring instruments, there are three types of inspection:

- Initial inspection is performed before the instrument is put into operation
- The periodic inspection means inspection of the measuring instruments which are in operation
- The inspection after repair means inspection of the measuring instrument in one of the following cases:
  - The repaired measuring instrument fails to satisfy technical metrological requirements;
  - Inspection certifications (inspection seals, stamps, certificates) of the measuring instrument is lost or damaged, but its structure and metrological characteristics are not changed compared to the approved type;
  - The inspection is necessary according to the conclusion of the competent authority or person;
  - Users of the measuring instrument suspects that the measuring instrument does not satisfy technical metrological requirements and requests a re-inspection.

Measuring instruments, metrological control measures, and measuring instrument inspection intervals are specified in the Table 74.

2.2.3. Data analysis

The initial work of energy audit is to assess the current operational status of the equipment, establish performance indicators of respondents.

Information that needed to be studied after the audit are:

- Energy consumption
- Energy cost
- Energy demand / supply (energy flow)
- Energy distribution and loss.

After data collection and measurement, auditors screen and synthesis the data into analysis factors and identify the value. Data fluctuation should be analyzed.

Energy performance of the whole organization would be analyzed after defining the energy consumption indicators, and benchmarking analysis. To find out the loss and potential savings, study on energy flow should be conducted on key energy consumption areas.

Energy savings potentials will be proposed after data analysis and auditors have to propose the proven amount of savings or saving percentage for each energy savings solutions.

Tools for data analysis of common energy consumer will be introduced in part II.

2.2.3.1. Energy bill analysis

Energy auditors should understand well the energy price system and all energy cost, which is important to calculate the amount of savings.

Energy bills reflect the energy consumption of the factory. By analyzing monthly and annually energy bills, auditors can assess the energy consumption status of the facility, trend of increasing or decreasing in energy consumption throughout the time.

Tabulating historical energy consumption records provides a summary of annual consumption at a glance.

Utility and fuel supplier invoices also contain valuable information about consumption that can be tabulated. Templates for tabulating, graphing and analyzing historical energy consumption and purchase data could be generated when necessary.

A theoretical assessment of specific processes yields a linear relationship when plotting energy against production, producing a straight line of the general form

$$Y = mx + c$$

Linear regression, i.e. by finding the best fit of a straight line using the least squares method to the plot of energy consumption vs. production, could help to define the case of consistent performance, installed improve or breakdown. Example is illustrated in Figure 3.

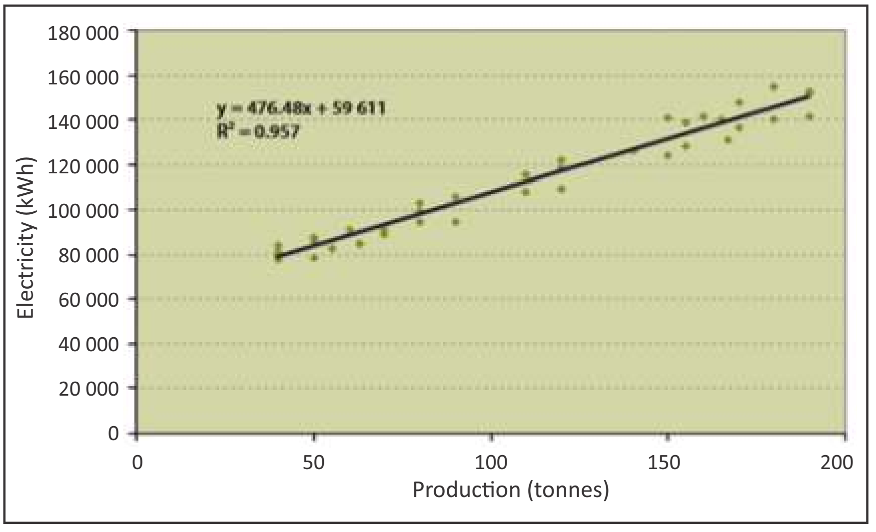


Figure 3. Example of regression analysis for electricity consumption and production

The baseline and the target of the performance can be set in consistent performance that is unaffected by improvements or breakdowns.

2.2.3.2. Energy performance indicator

Energy Performance Indicators (EPI) are used to explain the status and effect of the management externally. The most practical and frequently used energy performance indicator is energy intensity or specific energy consumption (SEC), which refers to energy necessary for a certain production unit (ton, piece, set, etc.) as shown in the following formula.

$$\textbf{Energy performance indicator (EPI)} = \frac{\textbf{Energy consumption (\textit{converted to MJ, KWh or TOE})}}{\textbf{Production volume (mostly in tons)}}$$

Benchmarking the energy intensive with other factories or workplaces in the same industry evaluate the possibility to improve energy efficiency or the achievement level of energy conservation for a factory.

2.2.3.3. Energy efficiency analysis by historical trend and benchmarking

The energy performance within the plants should be studied including historical energy consumption and trend in three recent years.

Energy intensity is often used as indicator to evaluate by way of comparison with the followings:

- Planned value
- ##Value in the same period of the previous year

- Other factory or facilities in the same industry
- Benchmark between companies an area.

Historical trend of energy consumption in the last three years would provide a picture of energy practices of the plants, improving in energy efficiency may be observed showing the effectiveness of energy management application.

An example of historical trend analysis based on weekly data of glass melting is illustrated in the Figure 4.

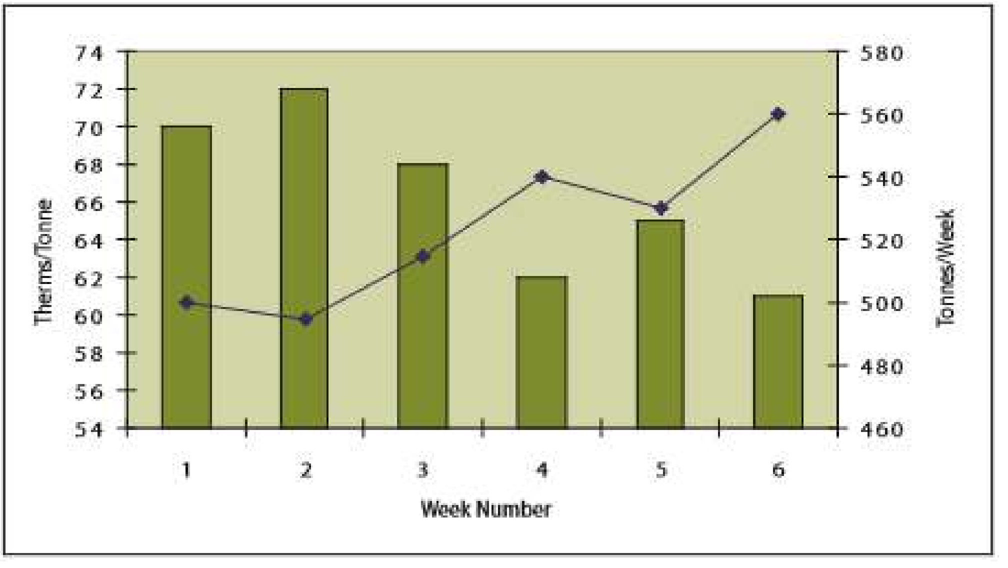


Figure 4. EPI for glass melting

Existing regulated EPI, or international best practices of the similar process or of the same industry should be collected to perform the analysis.

The gap in EPI between existence plant and the best practices helps to estimate energy savings potential for the plant, as demonstrated in Figure 5.

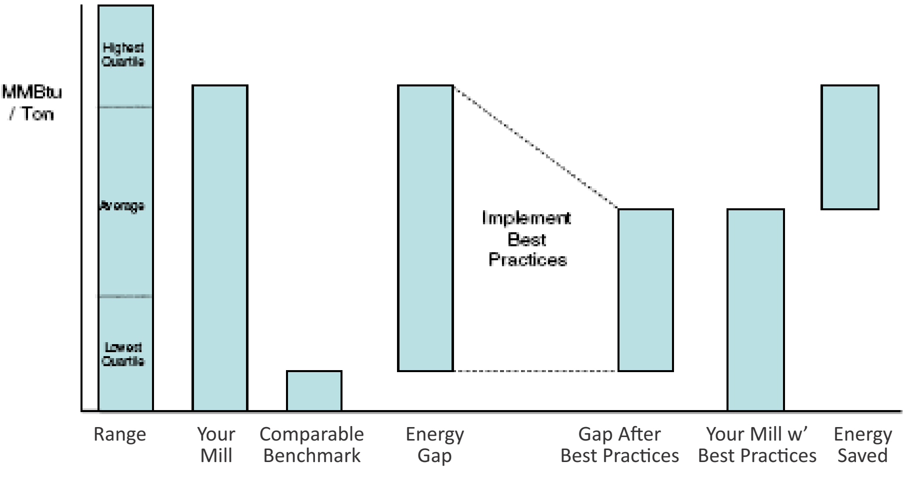


Figure 5. Comparison between the mill and the benchmark and estimated energy savings

Source: EcoEnergy, 2008

Benchmarking defines high-efficiency equipment in order to identify and give the priority to improve low-efficiency equipment immediately

2.2.3.4. Process flow chart and key energy consumption area analysis

The process flow chart of performing in the entire plant, line technology, key equipment, and identifying the energy flow, material flow and product in/ out of "the box" would be drawn. The key energy consumption area should be identified in the flow chart.

An example of the process flow chart is presented in Figure 6.

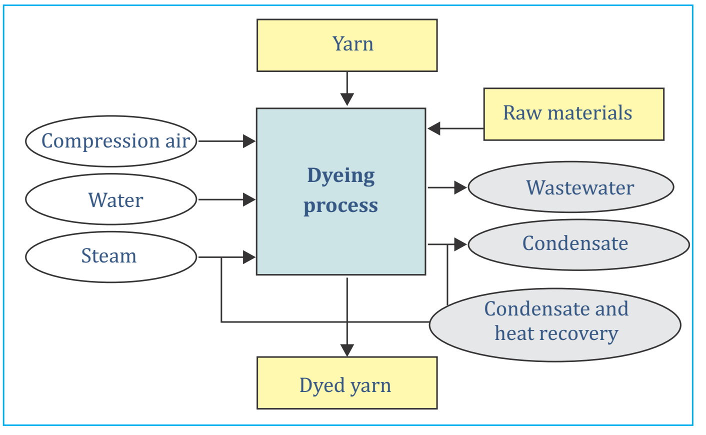


Figure 6. Flow chart of a dying process with energy and material flow

Energy balance, physical balance would be set up for audited objects (block diagram a "black box"); operational characteristics of devices using energy.

Characteristic of key energy consumption areas would be identified, consisting of (but not limited) to:

- The type and characteristics of the heating boiler, and steam supply system
- The type and capacity of the cooling system, the technical characteristics (refrigeration pressure, temperature, flow and temperature of cooling water, pressure, etc.)
- Type of air-conditioning systems, system components (pumps, fans, compressors, pipes, etc.), operating characteristics (flow, temperature, pressure, etc.)
- The level of mobilization of equipment, systems and equipment
- The mechanism controlling the devices, system devices (controllers, devices Executive, sensors, control logic, etc.)
- Lighting equipment type, specification and control structure
- Characteristics of the electricity distribution system.

In case of audits of buildings, auditors need to understand:

- Features of the building
- Operating characteristics of the system lifts, escalators (service area, type of drive motor, control system, etc.).

Comparisons should be made to for key energy consumption areas and equipment to identify the lost and saving potentials by minimizing the loss. All comparisons included:

- Boiler Efficiency, losses in fuel combustion
- Loss on heat supplying pipe (Pa/m)
- The performance efficiency of the engine (%)

- The performance efficiency of the cooling operation
- The capacity of the system fan power (kW / liter of air supply / sec)
- The performance efficiency of the fan (%)
- Pump Performance efficiency (%)
- The performance efficiency of the compressor (%)
- Lighting power density (W/m^2)
- Illuminance of the lighting system (Lm/W)
- Loss of lighting control systems (W).

For heating systems, ventilation, air conditioning (HVAC), wasted area can be determined from the data record keeping on traffic changes corresponding to changes in temperature and pressure.

For power supply systems, waste area can be determined from the record book in current, voltage.

In the absence of the record book, the measurements are done to determine the equipment / system devices are working inefficiently.

2.2.3.5. Energy flow and energy balance

Breakdown of energy use by areas/processes/functions…. and identifying the energy flow of each point are performed.

Energy balance is analyzed and energy flows would be identified in the form of Sankey diagram and pie chart.

Sankey diagram

The Sankey diagram is an important tool in identifying inefficiencies and potential for savings when dealing with resources.

Sankey diagram represents all the primary energy flows into factory. The widths of the bands are directly proportional to energy production, utilization and losses. The primary energy sources are gas, electricity and coal/oil and represent energy inputs at the left-handed side of the Sankey diagram.

The Sankey should look like the picture below – a steam system without condensate recovery, no waste heat recovery, all units in kg/day.

Area	Boiler heat loss	Pipe heat loss	Steam leakage	Condensate losses	Heat transfer losses
Losses>>>	28%	8%	9%	15%	20%

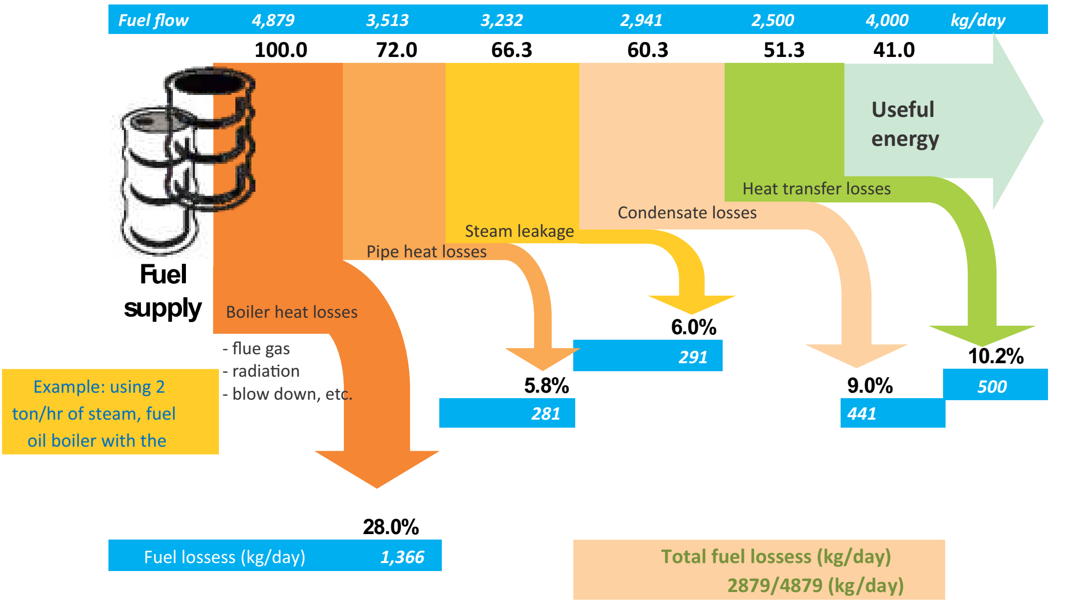


Figure 7. Sankey diagram for the energy loss in steam system

Pie chart

Pie charts showing the distribution of fuels and flows going through the selected energy consumers. The pie charts could be used to present:

- Distribution of fuels passing through the node
- Distribution of the energy content of the incoming flows
- Distribution of the energy content of the outgoing flows.

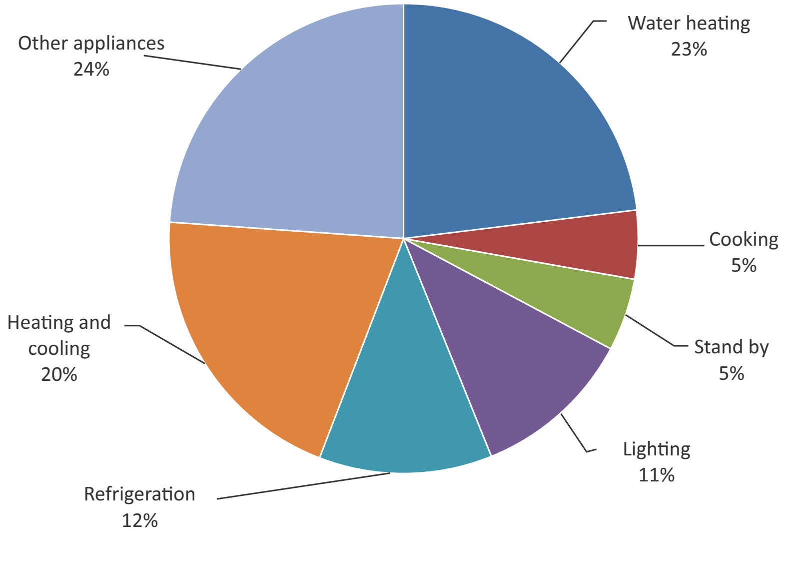


Figure 8. Share of the energy users

2.2.3.6. *Energy saving opportunities*

The key energy consumption area would be defined from the energy flows diagram (pie chart) and the high saving opportunities area would be observed from the Sankey diagram where high energy loss areas are observed.

The audit team should compare the operational characteristics of the device with design data or with the technical documentation to detect differences. Detection areas are energy wasters and energy-saving potential.

2.2.3.7. *Propose energy saving solutions*

Most of the measures are simple good housekeeping measures which can be implemented immediately. Other measures are low cost (e.g. fitting timers, pipe insulation, draught proofing, etc.) and will involve some expenditure and/or contacting estates.

Energy saving solutions are classified into three groups:

Solutions which do not require investment cost

Includes practical solution without investment costs, does not affect the normal operation of equipment/ technology line:

- Change properly manipulation of operation
- Rationalize the production line
- Arrange tidy buildings and facility
- Apply simple measures (air conditioning off, turn off the lights, stop power to the device when not in use, set the temperature of air conditioning in the room properly, etc.)

Solutions with low investment cost

Including solutions which require low investment costs, and do not significantly disrupt the operation of the device or process line.. Some examples are

- Installation of additional time controllers to on/off equipment and open/close devices in technology lines;
- Replace power-saving lights;
- Equip online meters, and more...

Solutions with high investment cost

Includes solutions with high investment costs, can significantly disrupt the operation of the device/ line technology

- Installation of the inverter to the motor
- Equipment installation for power factor adjustment
- Replacement, reconstruction of boiler
- Replacing the coolers (chillers).
- Equipment installation for waste heat recovery

Technical and finance constraint analysis should be performed when proposing and analyzing the energy saving solutions. Impractical solutions with significant investment cost should not be avoided.

Technical feasibility analysis should address the following conditions

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

Economic feasibility can be conducted by using the variety methods which are explained in the next Section.

2.2.3.8. Financial and feasibility analysis

Energy saving projects must be competitive compared to other projects by increase of cost savings or profit expectations.

Finance analysis is required to determine the appropriate investment options by comparing the options to achieve the objectives of the organization.

The energy efficiency projects involving different types of costs.

Investment costs

The scale of the investment is a very important factor in the financial evaluation of energy efficiency projects. This cost are often expressed in a large amount of money spend on projects being implemented in a year.

Investment costs include the following costs:

- Installation costs (construction, installation)
- Equipment expenses
- Taxes, customs fees
- The costs of staff training
- Other expenses (Insurance, Engineering and Transport).

Operation cost

The operating costs and maintenance associated with the operation are analyzed. The different types of expenses including in operation costs include:

- Energy and related costs
- Labor costs (salaries of operating personnel and management,)
- The cost of repairs and maintenance
- Other expenses (supplementary material, administrative costs, etc.).

Other cost

- Replacement cost: cost to remove the device at the end of life cycle
- Lost production due to stop production while installing the equipment and put the system into operation.

Profits can be earned from an energy project may be

- Energy savings
- Income from the sale of energy
- Reduce maintenance costs

- Income from improving quality
- Income from increased productivity.

The financial criteria to evaluate project

- Simple payback time:

The time required to recover the investment from cash flow. This is a quantitative method which is widely used to assess the cost effectiveness of energy-saving investments

Simple payback = Cost of investment/Net annual savings

When applying this method, savings after payback time is not calculated and the variation in money value over time is not considered.

- Rate of return (ROI)

ROI = (Gain from Investment - Cost of Investment)/Cost of Investment

Description "annual benefit" from the project cost as a percentage of capital. Cost comparison is not considered.

- Net present value (NPV)

All these net benefits are depreciated return at the lowest appeal to determine the equivalent present value.

- Internal rate of return (IRR)

The discount rate at which the net present value of the accrued benefits of an investment equal to the investment costs. If the IRR value is higher, project is more effective.

- Life cycle analysis

For example, consider the comparison of traditional fluorescent lights (FL), spot lights, to Compact fluorescent lights (CFL) or light-emitting diode (LED) replaced. CFL lamp life is 5 times higher than halogen lamp and LED lifespan at least 20 times more than halogen lamps.

The calculation will take into account the life cycle to compare the original equipment and replacement.

3. STANDARD AUDIT REPORT TEMPLATE

Audit report format should be standardized with the contents regulated by the Circular 09. This chapter recommends a standard audit report template, consisting of two main contents:

- Status of the organization including their general information, description production process and energy flows. The energy consumption status, annual EPI, and energy loss should be included.
- Energy savings solutions consisting of list of energy saving solutions classified in three groups as mentioned in chapter 2. Effectiveness of the energy audit should be evaluated in this report and economic analysis for each energy saving measures should be reported.

Content of the standard audit report should be organized as below:

3.1. Summary

- Summary of energy consumption in the enterprise
- Summary of the energy saving measures with priority
- Propose the selected measures to be implemented and invested.

The content should be summarized in the following table

Table 2. Summary of energy saving potential and estimation of investment cost

No.	Measures	Energy savings		Expected Investment (10^6 VND)	Cost savings (10^6 VND/year)	Payback Period (Year)
		Electricity (kWh/year)	*Fuel (ton/year)*			
1						
2						
3						
	...					
	Total					

3.2. Introduction

- Brief introduction of the audit organization
- Objective and necessary of the audit
- Scope of the audit
- Introduction of the audit team, and their task
- Measurement method and device, listed in the table below

Table 3. The list of dedicated equipment used in the energy audit

No.	Name	Code	Quantity	Origin
...				

3.3. General Information of the audit organization

- Development history and their status
- Operation structure and frequency of production, including operation hours

The raw material and main products is descripted by following tables:

Table 4. Raw material and main products

No.	Item	Unit	Data
I	Raw material in year ...		
...			
II	Main products in year		
...			

Table 5. Operating hour per a year of energy consumption areas /workshop

No.	Area / Workshop	Operation time (hour/year)

3.4. Description of operation process

- Flow chart or black box description of the production process, including in/out flows of energy, materials, and water
- Identify the inefficiency energy consumers during the survey
- Energy saving potentials

3.5. Energy demand, supply and consumption

- Source of energy supply and cost, fuel characteristic

Table 6. Electricity tariff (applied from ...)

No.	Item	Applied time	Tariff (VND/kWh)	
			Monday – Saturday	Sunday
1	Peak hours (5 hours)			
2	Normal hours (13 hours)			
3	Off-peak hours (6 hours)			

- Energy demand and consumption

Table 7. Electricity consumption and electricity costs in monthly (...)

Month	Hourly electric consumption (kWh)				Electricity cost (VND)		
	Normal hours	Peak hours	Off-peak hours	Total	Normal hours	Peak hours	Off-peak hours
1							
...							
12							
Whole year							
Ratio (%)							

Table 8. Fuel consumption and costs in monthly (..)

Fuel 1		Fuel 2		Fuel 3		Total cost (10^3VND/yr)
Amount (ton/yr)	Cost (10^3VND/yr)	Amount (ton/yr)	Cost (10^3VND/yr)	Amount (ton/yr)	Cost (10^3VND/yr)	
1						
2						
..						
12						
Whole year						

- Water demand and consumption

Table 9. Water consumption in monthly (...)

Month	Quantity of water (m^3)	Water source
1		
2		
...		
12		
Whole year		

3.6. Economic and technical constraints

- Energy loss analysis, and area which required further analysis
- Technical constraints by comparing the actual operation status with design capacity
- Economic constraints, cost of energy, and fuel and CO_2 emission constraints
- The increasing of energy cost and requirement of energy substitution should be analyzed

Table 10. Energy constrains and standards

Energy type and standard	Unit	Heat value/unit		CO_2 emission	
		MJ/unit	kWh	Kg/MJ	Kg/kWh
Solid fuel					
- Coal	Kg				
- Antracite coal	Kg				
- Biomass (Wood/Rice husk)	m^3				
Liquid fuel					
- Diesel Oil DO (ρ=0.86 kg/dm³)	Littre				
- Fuel Oil (ρ=0.94 kg/dm³)	Kg				
Gas fuel					
- Natual gas – NG	m^3				
- Liquid petrolium gas – LPG	Kg				
Electricity consumption	MWh				

3.7. Energy saving measure

- Identify group of energy saving measures, list of measures in each group with details description
- Priority of measures to be implemented
- Financial analysis of selected measures, amount of savings, payback period and environmental aspect analysis
- Conclusion and recommendations, proposing an energy management program for the organization.

3.8. Conclusion and future plan

- Conclusion and recommendation on energy audit result
- Proposed action plan for the enterprise:
  - 1-year plan
  - 5-year plan.

3.9. Annexes

- Primary data tables: Summary of production volume, energy, etc.
- Actual load profile
- Energy saving calculations for proposed measures mentioned in the energy audit report
- Energy price
- Energy type conversion
- Conversion coefficient of CO_2 emission

...

Chapter 02

Recommendation For Energy Audit Practices

PART I.

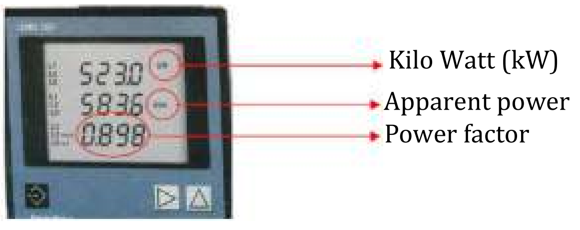
RECOMMENDATION FOR ENERGY AUDIT PRACTICES

1. MEASUREMENT DEVICES

1.1. Electricity measurement

Measuring instruments mainly for electricity as power, power factor, reactive power, electrical current, voltage. Some instruments are measured both harmonics.

The devices are getting to the line, where the engines are working without having to stop the motor. Hand-held measuring devices can be used for instant measurements. Other advanced instruments combining data can be read with prints in a certain time period.



Watt-hour Meter: Used to measure the power used on the line by time cycle. The meter includes a small motor running at speeds proportional to the power used.

Watt meter: Used to measure the use power of an electrical device. Portable watt meter allows direct reading of electricity demand. Limit work of 300kWs, 650V and 600A. Watt meter can be used for both line one phase and three phase

Ampere meter: Used to measure the electric current. Portable clamp type ampere meter is very popular and convenient in the energy audit when a fixed meter is not required

Voltmeter: Used to measure the voltage between two points of the power lines. Most of the actual measured voltage is below 600V.

Power Factor Meter: Initial measuring device for power factor is three-phase. Can measure the power factor early of 1.0 to delay 1.0 and accept the current to 1500A at 600V. This range includes the major applications in the light Industry.

Power Analyzer: The system analysis one phase and three phase, Volt, Amps, Watts, VARs, VA, W, Hz kWh

Clamp automatic type used to (20A, 200A & 1000A)

Clamp-on Power

These devices are getting up to lines to measure the electrical parameters of the motor, transformer and the electric heating without stopping operation.

Used to measure parameters:

- Voltage: 150 V to 600 V,
- Current: 200 A to 1000 A,
- Voltage / current peak
- Effective power / reactive / apparent (one phase or three-phase): 30 kW to 1200 kW, 14 combination

Type

- Load factor
- The phase angle
- Frequency
- The synchronous level of voltage / current

Lighting system measurement equipment

Lux meter:

Illumination is measured by lux meter, consisting of a photovoltaic cell sensitivity to emission light, converted into electrical pulses and are formatted to lux.

1.2. Thermal measurement equipment

Dust filter

Flue gas analyzer (ORSAT)

Tube is arranged inside the device to measure chemical gases such as O_2, CO, NO_x and SO_x. This device is important implicated for the boiler system, in calculating the amount of excess air in the flue gases and losses due to uncompleted burn out.

Combustion efficiency measurement

Oxygen measurement, flue gas temperature. The heat value of the common fuels is loaded into the processor to calculate the combustion efficiency.

Relative humidity meter

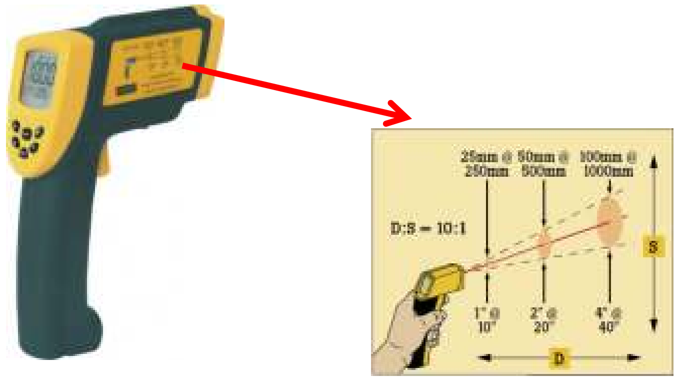
Wet and dry bulb with filtration combined with mercury thermometers.

Quantity: 150 gms

Temperature: -5 ° C to 50 ° C or 20 ° F to 120 ° F

Fyrite tube

Use a manual pump to suck the smoke into the device processor. The chemical reaction changes the liquid volume of the volume of air express. The different Fyrite tubes can used to measure the O_2 and CO_2



Infrared thermometers

Range: up to 1000 ° C

Reading accuracy within ± 1%

Contact thermometer:

This is a thermocouple to measure the flue gas temperature, hot air, hot water, etc. by bringing the probe into the flow.

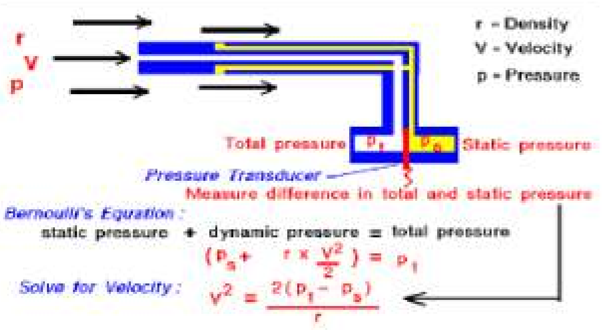
For surface temperatures, leaf type probe is used with the same device.

The thermometer is attached to the pipe, used to measure the temperature both hot and cold water, and steam,.

1.3. Pressure, velocity and flow rate measurement equipment

Pito tube and manometer

Measure wind speed in tubes, pressure gauge attached to calculate the flow properties



Air velocity meter

Air velocity meter is a device used for measuring the air velocity with **fan** blades sensor. Large fan blade is used for large surface area to ensure the accuracy of the measurement.
Measuring range: +0.3 to +20 m/s
Accuracy: ± (0.1 m/s + 1.5 % measuring value)

Resolution: 0.01 m/s

Measure water flow rate:

Contactless flow measuring device use the Doppler effect/ ultrasound principles (Ultra Sonic). There is a transmitter and receiver set lying opposite pipe. The meter directly displays water flow or fluid inside the tube.

Leak detection tools

Ultrasonic instrument can detect leaks on compressed air piping and other gases that are usually difficult to detect by eye.

Speed measurement

In any public energy auditing, rotation speed measurement is important because speed may vary due to power frequency, load and under load skating.

Contact type speed meter is may be used in areas accessible.

Stroboscopic device is non- direct contact type, sophisticated and safer.

2. OVERALL ENERGY CONSUMPTION AND ENERGY MANAGEMENT ASSESSMENT

2.1. General information

General information of the organization should consist of:

- Name and address
- Contact person
- Main activities
- Starting year of operation
- Production capacity (design, actual)
- Number of employees (managers, technical, production)
- Organization chart and layout (if available).

2.2. Material consumption and product volume

Information is collected:

- Material types and products
- Product quantity of enterprises in recent years

From collected data can be analyzed by changing product trends, and production capacity of the enterprises.

2.3. Power and water consumption data

Monthly power and water consumption in a year and the last 3 years should be collected. From current status of energy consumption and production volume, it is possible to identify.

- Energy consumption status of the company in last years. Thus, the energy consumption of the company can be predicted.
- The type and cost of energy consumption. The cost saving potential and greenhouse gas emission in case the company use a new type of energy with lower cost and greenhouse gas emission (e.g. renewable energy)

There are many different energy types can be consumed by enterprise include: electricity, coal, DO oil, FO oil, LGP and natural gas, biomass, steam ... and water.

The unit of fuel consumption data would be converted to be consistent when analyzing and reporting.

Energy data analysis

Depend on fuel types, it is necessary to collect their calorific value of fuel, especially coal and biomass. Coal and biomass have their calorific value, that can vary widely according to fuel type, percentage of moisture, ash in the fuel. Thus, in order to analyze the total actual energy consumption of enterprises, or convert to TOE unit Auditor can ask enterprises or coal/biomass supplier provide sample testing results of these fuels that enterprises are using. In necessary cases, bringing those samples to testing center to check their calorific value.

With natural gas (NG) or compressed natural gas (CNG): Due to limited pipeline or limited distribution, those fuels only provide for some factories at industrial areas such as Ba Ria-Vung Tau and Dong Nai province. CNG can provide to HCM, Dong Nai, Binh Duong province…

Power supply can take from national Grid or produced by the enterprises (by backup generation, cogeneration systems, solar…). Now, national Grid is the most popular. Cogeneration systems can be found in large enterprises and company such as: sugar, paper industry… Other power supply can be generated by recover heat of cement or steel industry.

For national Grid, electricity price is different, depends on business types, voltage supply and according to the time of use in a day (normal hour, off-peak hour, peak hour). The electricity price for enterprises in recent years is in the Table 71.

Moreover, according to Circular 15/2014/TT-BCT, May 28th, 2014, prescribed about purchase and sale of reactive power. The electricity buyer has transformer or without transformer, but has the maximum power utilization registered in purchase agreement from 40 KW or more and the power factor less than 0.9, have to buy reactive power. The power factor can be calculated on the basis of data measured by the electricity meter in recording cycle meter, by following formula:

$$\mathbf{Cos\varphi} = \frac{\mathbf{A_p}}{\sqrt{\mathbf{A_p^2} + \mathbf{A_q^2}}}$$

A_p: Active power (kWh)

A_q: Reactive power (kVArh)

Price for reactive power:

$$\mathbf{T_q = T_p \times k\%}$$

T_q: Price for reactive power

T_p: Price for active power.

k: Off-set price factor due to using excess reactive power.

Determine k in below table.

Table 11. Power factor

Power factor Cosϕ	k (%)	Power factor Cosϕ	k (%)
From 0,9 and above	0	0,74	21,62
0,89	1,12	0,73	23,29
0,88	2,27	0,72	25,00
0,87	3,45	0,71	26,76
0,86	4,65	0,7	28,57
0,85	5,88	0,69	30,43
0,84	7,14	0,68	32,35
0,83	8,43	0,67	34,33
0,82	9,76	0,66	36,36
0,81	11,11	0,65	38,46
0,8	12,50	0,64	40,63
0,79	13,92	0,63	42,86
0,78	15,38	0,62	45,16
0,77	16,88	0,61	47,54
0,76	18,42	0,6	50,00
0,76	20,00	below 0,6	52,54

Therefore, when collecting data on power consumption, take care about the price of reactive power, that enterprises must pay, if any.

The conversion into TOE, MG and emission factors of some energy types is in theTable 72.

2.4. Energy performance indicator and benchmarking references

Methodology of EPI calculation and benchmark approach have been introduced in previous sections. In this section, energy consumption in enterprises and energy rate in some industries in Viet Nam will be presented as a reference tool.

From data on product quality and energy consumption, will help determine energy consumption for each product unit, or consumption power per area m^2 at building, commercial center, service center…. So, we compare energy consumption rate of the sector in the country and in the world.

At Viet Nam, some industries were ruled their energy consumption rate by Ministry of industry Trade such as: steel, cement, drinks (beer or beverage), chemistry (rubber, fertilizer NPK, paint water, solvent). Here is shortlist about energy consumption rate in the sector/ sub-sectors:

- Circulars 19/2016/TT-BCT, published in 14/09 /2016, prescribed power consumption rate in beer and beverage industry.

Table 12. Energy consumption rate until 2020s.

TT	Industry	Power scale (million litre)	Rate (MJ/hl)
1	Beer	> 100	140
		20 – 100	215
		< 20	306
		Product type	
2	Beverage	Soda or both soda or non soda.	55
		Non soda	111

Table 13. Energy consumption rate from 2021s – to 2025s

TT	Industry	Power scale (million litre)	Rate (MJ/hl)
1	Beer	> 100	129
		20 - 100	196
		< 20	286
		Product type	
2	Beverage	Soda or both soda or non soda.	52
		Non soda	107

- Circulars 20/2016/TT-BCT, published in 20/09 /2016, prescribe energy consumption rate in steel industry:

Table 14. Energy consumption rate for steel industry until 2020s

TT	**Product phase**	**Units**	**Rate**
1	Sintering of iron ore	MJ/ tonne	2,350
2	Production of cast iron by blast furnace	MJ/ tonne	14,000
3	Production of steel billet by (top-blown) converter	MJ/ tonne	150
4	Production of steel billet by electric arc furnace	MJ/ tonne	2,600
5	Production of steel billet by induction furnace	MJ/ tonne	2,600
6	Hot rolling of long steel products	MJ/ tonne	1,650
7	Cold rolling of steel plates	MJ/ tonne	1,600

Table 15. Energy consumption rate for steel industry from 2021s to 2025s.

TT	Product phase	Units	Rate
1	Sintering of iron ore	MJ/ tonne	1,960
2	Iron making by blast furnace	MJ/ tonne	12,400
3	Production of steel billet by (top-blown) converter	MJ/ tonne	100
4	Production of steel billet by electric arc furnace	MJ/ tonne	2,500
5	Production of steel billet by induction furnace	MJ/ tonne	2,500
6	Hot rolling of long steel products	MJ/ tonne	1,600
7	Cold rolling of steel plates	MJ/ tonne	1,500

- Circulars 02/2014/TT-BCT, published in 16/01/2014, prescribe energy consumption rate in chemistry industry

Table 16. Energy consumpation rate in chemistry industry

TT	Industry	Power scale	Rate (kOE/tons)
1	Rubber	Designed power below 5,000 tons/ year	44
		Designed power from 5,000 to 10,000 tons/year	36
		Designed power above 10,000 tons/year	28
2	Fertilizer NPK	Designed power below 4,000 tons/year	14.8
		Designed power from 4,000 to 9,000 tons/year	16.8
		Designed power above 9,000 tons/year.	19.7
3	Paint water	all	12.1 kOE/tons
4	Solvent	all	17.7 kOE/tons

Factories which only produce a single product, calculate their energy consumption intensive by dividing determined total energy consumption with total production.

For factories which produces vary products or when analyzing energy consumption at each stage, it is necessary to measure energy consumption for particular production or by production stage. You can also use multivariate regression methods to analyze, in this case, the accuracy of data affects the purity of the analytical results.

2.5. Energy management assessment

2.5.1. Objectives

This tool helps the auditor to identify the energy management status of the enterprise and propose solutions to improve energy efficiency via management improvement.

2.5.2. Evaluation method

In assessing the status of energy management, auditor may use different methods. In this manual, only the PDCA cycle (Plan – Do - Check - Act) is introduced. This approach provides the auditor an overview of the company's energy management system, starting from leaders' commitments to the performance implementation and evaluation, as well as improvement activities.

Below is a table of criteria to evaluate the current status of energy management. There are six criteria to evaluate the current status of energy management, which are designed based on the Plan-Do-Check-Act model, including:

- Criteria 1: Energy policy (Planning)
- Criteria 2: Organization (Planning)
- Criteria 3: Training (Do)
- Criteria 4: Information exchange (Do)
- Criteria 5: Checking and evaluation (Check)
- Criteria 6: Investment (Act)

Each criterion will be scored in the rating column, the score range is from 0 to 4, in which 0 corresponds to the lowest management level and 4 is the highest.

Table 17. A matrix of energy management evaluation

Ranking	Energy policy	Assessment
4	Have energy policy, action plan, periodical checking, top management commitment in the energy management implementation.	
3	There is a formal policy but no top commitment.	
2	There is a policy, but it is not yet implemented	
1	There are unwritten set of guidelines.	
0	No energy policy	

Ranking	Energy management	Assessment
4	Energy management is fully integrated into company management; There is clear energy consumption regulation.	
3	There is energy manager; there is energy board with head of board is top leader of the enterprise.	
2	There is energy manager; there is energy board with head of board is head of department [1]. (not top leader of the enterprise)	
1	There is energy manager; but not official, the authority is limited. There is no energy board.	
0	There is no one who is in charge of energy monitoring.	
Ranking	**Training**	**Assessment**
4	There are regularly trainings, awareness and sensitization campaigns on energy saving inside the enterprise and outside (equipment suppliers, services, customers…) systematically, officially. There are regularly training courses on energy saving in the enterprise.	
3	There are regularly trainings, awareness and sensitization campaigns on energy saving but only inside the enterprise.	
2	There are trainings, awareness and sensitization campaigns on energy saving in the enterprise but not regularly.	
1	There are trainings, awareness and sensitization campaigns on energy saving but not officially.	
0	There is no training, awareness and sensitization campaigns.	
Ranking	**Motivation**	**Assessment**
4	There is information channel and all staff can exploit in order to know energy consumption status and results of energy saving activities.	
3	There is an energy board and this board is the channel to interact with all main energy users in the enterprise. This board is led by top leader in the enterprise.	
2	Interactions between some main energy users/staff is conducted by board/team, organization in charge of energy (head of organization)	
1	There are only unofficial interactions between factory engineers or between technical department staff with some main energy users/staff	
0	There is nothing	

Ranking	Information system	Assessment
4	There is comprehensive information system of recording, analyzing, targeting, planning, cost benefit analysis, investment plan.	
3	There is information system of recording, analyzing, reporting energy consumption though at local level but results of energy saving activities, information of energy saving are not announced to energy users	
2	There is monitoring, analyzing of energy data system but mainly based on bills and some calculated data, there is not much data from measuring instrument; but the energy manager has important role of budgeting energy cost and energy investment	
1	There is energy report but not much analysis, data is based on bills. All energy data is used for internal technical department.	
0	There is nothing.	
Ranking	**Investment policy**	**Assessment**
4	Detailed investment plan with particular cost/ benefit ratio given high priority.	
3	There is detailed investment plan with particular cost/ benefit ratio, but only considering energy saving investment as not high priority one.	
2	There is detailed investment allege and plan but only considering measures with short payback period.	
1	There is detailed investment plan but only considering measures with low investment cost.	
0	There is not investment plan.	

After completing the assessment, the results can be reported in various forms, such as column charts, line charts, or spider web charts, etc. The figure below shows a sample of assessment results represented in line chart at an enterprise

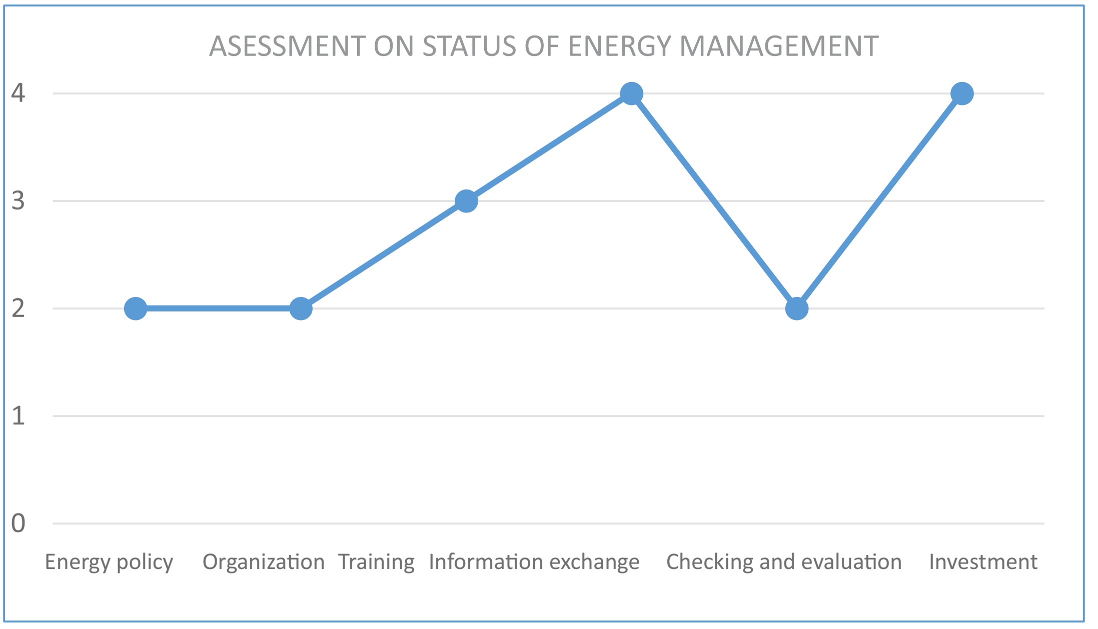
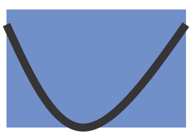
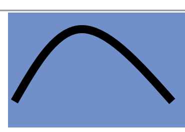
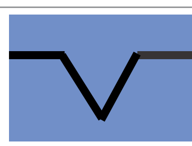
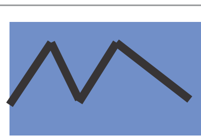


Figure 9. Energy management assessment chart

From the results of evaluation/ graph show some strengths and weaknesses in energy management of the enterprises. Auditors need to raise recommendation in short term and long term. The short-term recommendation aimed at improving the weakness management, and long-term recommendation to help improve comprehensive management level of whole enterprises.

Below are some typical assessment results and recommendations for energy management improvement.

Table 18. Assessment results and improvement actions

Shape	Picture	Description	Results	Action
1.High balance		Score of 3 or more for all columns	Excellent performance	Maintain this level
2.Low balance		Score under 3 for all columns	All aspects in energy management should be improve	Commitment from the leader. Set up an energy management strategy. Set goals, action plans & checking process
3. U form		Two outer columns with scores of 3 or more	Have commitment on energy efficiency. High expectation, but the team performs poorly	Set up an energy management board, establish a formal communication channel with all employees. Set goals, action plans & checking process.
4. N form		The two outer columns are too low	No commitment. Have an energy specialist to perform. The middle column good result is wasted	Commitment from leaders
5. Gutter		The middle column is lower than the outer columns	The weakness of this column can reduce the success of other columns	Focus more on the weak aspect
6. Peak		The middle column is higher than the outer columns.	The effort of this column can be wasted by the stagnation of other columns.	Focus more on the weak aspect
7.Unbalance		Two or more columns are higher or lower than average	The more the imbalance, the harder to perform.	Focus on the lower aspects and try to lift them up

3. COMMON ENERGY CONSUMPTION SYSTEM ANALYSIS

This section will present technical guidelines for data collection and analysis at key and common energy consumers in factories and buildings.

Brief explanation and calculation for each system will be introduced. Standard data collection template will be suggested. Some calculation tools to accrue he required data will also be introduced in this Section.

Key energy consumption system including;

- Energy supply system
- Key electricity consumption system: motors, pump, fan, air compression system, refrigeration system, air conditioning system
- Key thermal energy consumption systems: boiler, furnace, steam distribution.

3.1. Electricity supply system

3.1.1. Introduction

3.1.1.1. Components of electrical distribution system

Transformer

A transformer is a static electrical device, which transforms electrical energy from one voltage level to another voltage level.

Figure 10. The transformer in power system

Table 19 describes the classification of transformers:

Table 19. Classification of transformers

Criteria	Types	Comment
Input voltage	step up	Convert low voltage to high voltage
	step down	Convert high voltage to low voltage (popular transformer)
Operation	Power transformer	Located at distribution station to increase voltage and transmit large power
	Distribution transformer	Located at sub-distribution station to transmit low power.

	Measuring transformer	Used to measure voltage and current with measurement devices.
Location of installation	Outdoor	Located outdoor on concrete or iron shelf
	Indoor	Located indoor on concrete or iron shelf
Number of phases	3 phases	Input and output are three phases (R, Y, and B) with or without neutral wire.
	1 phase	Input and output are one phase

Source: BEE, 2004

Distribution board

Distribution board is the important part of an electricity supply system and is used to divide an electrical power feed into subsidiary circuits. Moreover, it is also a place for installation and protection of circuit breaker and controller devices. Two types of distribution board are main distribution switchboard (MSB) and distribution board (DB) in electrical system.

Figure 11. Main distribution switchboard

Figure 12. Distribution board

Main distribution switchboard is installed right after step down transformer. Its main function is to shut down to protect electrical consumption systems. There are many cabinets inside MSB with specific functions such as storing main ACB/MCCB, storing MCCB/MCB output, storing compensates capacitor, or storing ATS sources.

DB is used in low voltage networks and it is installed after MSB. It is the smallest electrical cabinet and supply electricity for equipment such as pumps, motors and etc.

3.1.1.2. Single line diagram of supply power systems

Single line diagram is designed to analyse electrical system. It can help auditor understand the design and structure of electrical distribution system. Then, the auditor can have survey plans to measure systems logically and effectively.

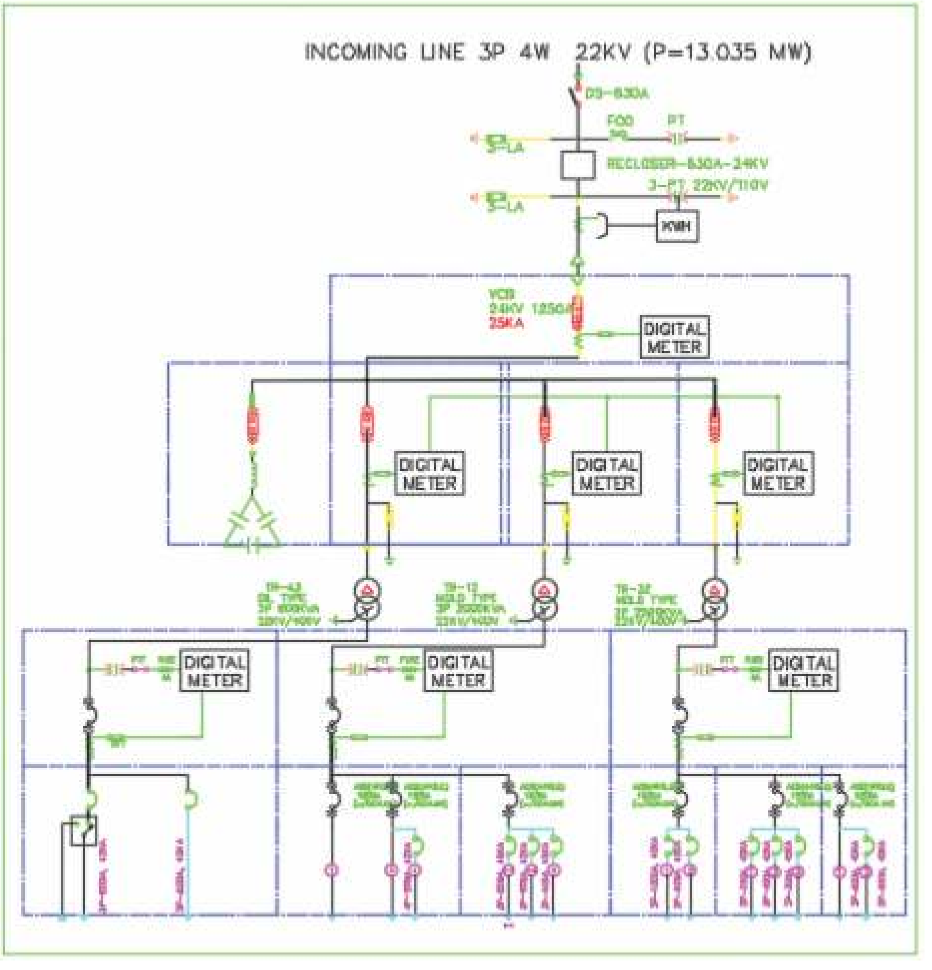


Figure 13. Example of single line diagram of electrical supply

3.1.2. Load graph and electrical load management

3.1.2.1. Load curve

A Load curve shows the load demand of a consumer versus time. If power consumption is plotted for 24 hours of a day, it is called "hourly load curve" and if power consumption is plotted for days of a month, it is called "daily load curve".

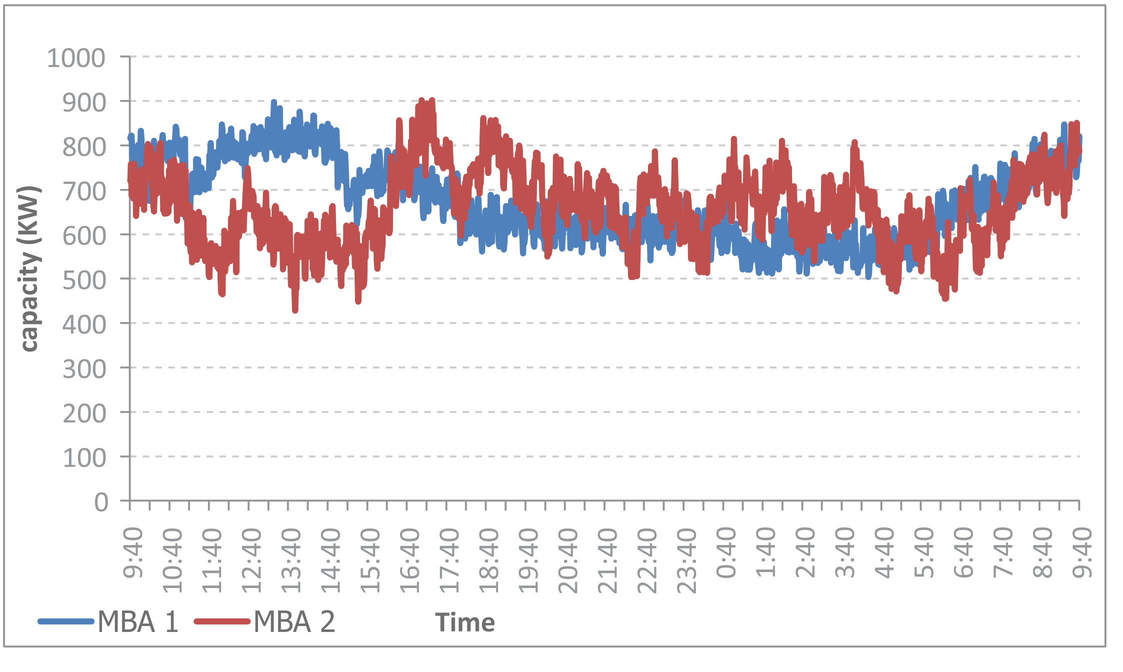


Figure 14. A daily load curve

A Load curve is used to predict high/low demand of part of factory, entire factory, or a distribution system, etc. It also shows peak power, off-peak power and average power of the factory. Based on that information, the auditor will propose the proper energy saving solutions.

3.1.2.2. Load management

At the macro level, the power consumption and electrical demand increase during certain times in a day and then they will lead to shortfall in capacity to meet demand. The better load management at the user end helps to minimize peak demands on the utility infrastructure and improve the utilization of power factory capacity. The following table lists some techniques to help better load management:

Table 20. Strategy to manage peak load

Solution	Perform
Shifting Non-Critical and Non-Continuous Process Loads to Off-Peak time	Rescheduling of large electric loads and equipment operations, in different shifts can be planned and implemented to minimize the simultaneous maximum demand. For this purpose, it is advisable to prepare an operation flow chart and a process chart. Analyzing these charts and with an integrated approach, it would be possible to reschedule the operations and equipment in such a way as to improve the load factor which reduces the maximum demand.
Shedding of Non-Essential Loads during Peak Time	When the maximum demand tends to reach a preset limit, shedding some of non-essential loads temporarily can help to reduce it. It is possible to install direct demand monitoring systems, which will switch off nonessential loads when a preset demand is reached. Simple systems give alarms, and the loads are shed manually. Sophisticated microprocessor controlled systems are also available, which provide automatic load shedding options.
Operating Air Conditioning units during off-peak times and utilizing cool thermal storage	It is possible to reduce the maximum demand by building up storage capacity of products/ materials, water, chilled water / hot water, using electricity during off peak periods. Off peak hour operations also help to save energy due to favorable conditions such as lower ambient temperature etc.
Installation of Power Factor Correction Equipment	The maximum demand can also be reduced at the plant level by using capacitor banks and maintaining the optimum power factor. These systems switch on and off the capacitor banks to maintain the desired. Power factor of system and optimize maximum demand thereby.

Source: Energy Efficiency Management Agency, 2004

3.1.3. Harmonic effects

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

The harmonics causes such the below effects in power systems:

- ###Overheating of electrical distribution equipment, cables, transformers, standby generators, etc.

- Metering errors
- Increased internal energy losses in equipment, causing component failure and shortened life span
- False tripping of circuit breakers
- Lower system power factor, resulting in penalties on monthly utility bills

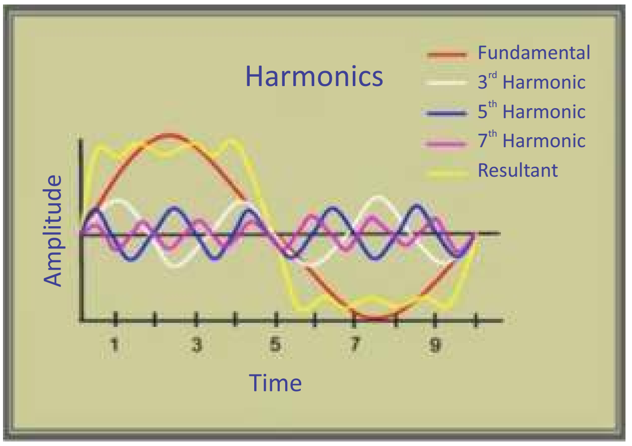


Figure 15. Waveforms of harmonics

Source: www.hersheyenergy.com

There are many options to attenuate harmonics:

- Add Alternating Current or Direct Current chokes
- Use passive filtering
- Use low harmonics drive.

3.1.4. Data collection

The energy auditor needs to collect the following data for electricity system:

- Single-line diagram of electrical systems
- All transformers data and their power capacity
- Total power consumption and annual cost
- Operating capacity: max, min, average
- Power factor
- The balance between electrical phases
- Power consumption of each system or area
- Electricity rate

Electricity rate is regularly updated at the website of Vietnam Electricity (EVN). As the different operating time between factories, the average electricity rate should be calculated as the following formula:

$$\textbf{Average electricity rate} = \frac{\textbf{Total electricity cost}}{\textbf{Total electricity consumption}}$$

For equipment with unstable operating time, the average electricity rate will be used to calculate electricity cost in energy saving measures. For equipment with stable operating time, electricity rate should be used according to specific period.

3.2. Lighting system

3.2.1. Introduction

Definitions and commonly used terms

Lumen (lm): is the photometric equivalent of the watt, weighted to match the eye response of the "standard observer". 1 watt = 683 lumens at 555 nm wavelength. One lux is equal to one lumen per square meter.

Luminaire: consisting of a lamp or lamps together with the parts designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply.

Lux: is the metric unit of measure for illuminance of a surface. Average maintained illuminance is the average of lux levels measured at various points in a defined area. One lux is equal to one lumen per square meter.

Luminous Intensity and Flux: One lumen is equal to the luminous flux, which falls on each square meter (m^2) of a sphere one meter (1m) in radius when a 1-candela isotropic light source (one that radiates equally in all directions) is at the center of the sphere. The luminous flux emitted by an isotropic light source of intensity I is given by:

$$\textbf{Luminous flux (lm)} = 4\pi \times \textbf{luminous intensity (cd)}$$

The Inverse Square Law: The intensity of light per unit area is inversely proportional to the square of the distance from the source (essentially the radius):

$$E = I / d^2$$

Where E = illuminance, I = luminous intensity and d = distance

Distance is measured from the test point to the first luminous surface - the filament of a clear bulb, or the glass envelope of a frosted bulb.

Color Temperature (K): is the color appearance of the lamp itself and the light it produces.

Color Rendering Index: The ability of a light source to render colors of surfaces accurately can be conveniently quantified by the color-rendering index. This index is based on the accuracy with which a set of test colors is reproduced by the lamp of interest relative to a test lamp, perfect agreement being given a score of 100.

Table 21. Applications of color rendering groups

Color rendering groups	CIE general color rendering Index (Ra)	Typical application
1A	Ra > 90	Wherever accurate color rendering is required e.g. color printing inspection
1B	80 < Ra < 90	Wherever accurate color judgments are necessary or good color rendering is required for reasons of appearance e.g. display lighting
2	60 < Ra < 80	Wherever moderate color rendering is required
3	40 < Ra < 60	Wherever color rendering is of little significance but marked distortion of color is unacceptable
4	20 < Ra < 40	Wherever color rendering is of no importance at all and marked distortion of color is acceptable

Source: Bureau of Energy Efficiency, 2005

Characteristics and applications

Auditors should understand the lamp characteristic and application to propose energy saving solution for lighting system.

The following table describes performance characteristics of commonly used luminaries.

Table 22. Luminous performance characteristics of commonly used luminaries

Type of Lamp	Lm /Watt		Color rendering index	Typical application	Life
	Range	Avg.			(Hours)
Incandescent	8-18	14	Excellent	Homes, restaurants, general lighting, emergency lighting	1,000
Fluorescent lamps	46-60	50	Good w.r.t coating	Offices, shops, hospitals, homes	5,000
Compact fluorescent lamps (CFL)	40-70	60	Very good	Hotels, shops, homes, offices	8,000-10,000
High pressure mercury (HPMV)	44-57	50	Fair	General lighting in factories, garages, car parking, flood lighting	5,000
Halogen lamps	18-24	20	Excellent	Display, flood lighting, stadium exhibition grounds, construction areas	2,000-4,000
High pressure sodium (HPSV) SON	67-121	90	Fair	General lighting in factories, ware houses, street lighting	6,000-12,000
Low pressure sodium (LPSV) SOX	101-175	150	Poor	Roadways, tunnels, canals, street lighting	6,000-12,000

Source: Asia Energy Efficiency

3.2.2. Energy flow diagram of lighting systems

The lamp is only part of the lighting system. The entire lighted space should be also considered part of the system, since many factors such as wall color, reflectivity, window design and interior partitions can have just as great an effect on the amount of light that is delivered to the task point. The end-use of a lighting system can be measured as the light level at the task point (useful illumination). A detailed energy audit should consider the various energy losses occurring in lighting systems, as indicated in the Sankey diagram below:

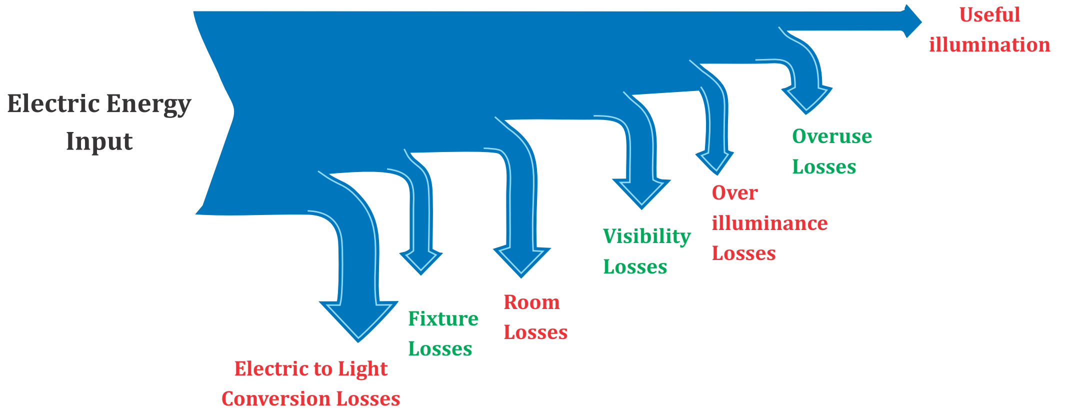


Figure 16. Sankey diagram of lighting system

Source: Enerteam

The various losses in the above Sankey diagram are listed below:

- Electric-to-Light-Conversion Losses: light output (lumens) of light source per unit of input power (watts)
- Fixture Losses: Light trapped within fixture
- Room losses: Light lost before it reaches task due to physical room characteristics
- Visibility Losses: Excess light supplied to overcome lighting quality problems
- Over-Illuminance Losses: Excess light supplied to overcome poor lighting distribution or consistency
- Overuse Losses: Lighting left switched on when not required.

3.2.3. Energy savings measure for lighting system

3.2.3.1. Use natural day lighting

Some of methods to incorporate day lighting are:

- Innovative designs are possible which eliminate the glare of daylight and blend well to illuminate buildings, industrial workshops and warehouses
- A good design incorporating sky lights with Fibre-reinforced plastic (FRP) material along with transparent or translucent false ceiling can provide good glare free lighting; the false ceiling will also cut out the heat comes with natural lights
- Use of atrium with FRP dome in the basic architecture can eliminate the use of electric lights in passages of tall buildings

Natural light from window should also be used. However, it should be well designed to avoid glare. Light shelves can be used to provide natural light without glare.

Figure 17. Day lighting with poly carbonated sheets

Figure 18. Atrium with FRP dome

3.2.3.2. De-lamping to reduce excess lighting

The amount of light bulb can be reduced by:

- Reducing the mounting height of lamps
- Providing efficient luminaires and then de-lamping has ensured that the illuminance is hardly affected
- De-lamping at empty space where active work is not being performed is also a useful concept
- Task lighting.

Another method to reduce the amount of light bulb is to provide the required good illuminance only in the actual small area where the task is being performed. The concept of task lighting if sensibly implemented, can reduce the number of general lighting fixtures, reduce the wattage of lamps, save considerable energy and provide better illuminance and also provide aesthetically pleasing ambience.

3.2.3.3. Timer, twilight switches and occupancy sensors

Automatic control for switching off unnecessary lights can lead to good energy savings:

- Twilight switches can be used to switch the lighting depending on availability of daylight
- Electronic dimmer is suitable for dimming incandescent lamps. Dimming of fluorescent tube lights is possible, if there are operated with electronic ballasts; these can be dimmed using motorized autotransformers or electronic dimmers (suitable for dimming fluorescent lamp; presently, these have to be imported).

3.2.3.4. Lighting maintenance

Light levels decrease over time because of aging lamps and dirt on fixtures, lamps and room surfaces. The following basic maintenance suggestions can help prevent this:

- Clean fixtures, lamps, and lenses every 6 to 24 months
- Replace lenses if they appear yellow
- Clean or repaint small rooms every year and larger rooms every 2 to 3 years. Dirt collects on surfaces, which reduces the amount of light they reflect.

3.2.3.5. Selection of high efficiency lamps and luminaries

Currently, LED technology has been developed with high luminous efficacy, longer operating life, and lower production cost. LED are gradually replacing all current conventional lights, including high pressure lamp in traffic lighting. Some advantages of LED are listed as follows:

- ##Generate higher illumination than other lamps
- ##Lesser heat

- Not contain toxic substances such as: mercury, lead, cadmium and harmful radiation.

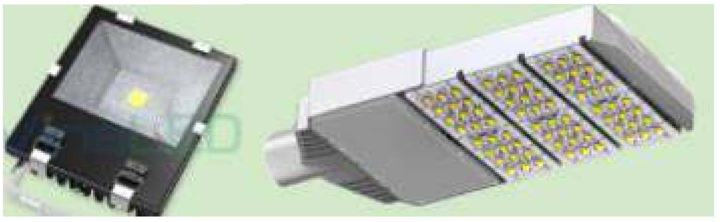


Figure 19. LED phase and around lighting

The table below describes the energy saving of LED:

Table 23. Energy saving by using LED

Current lamp	Replaced with	% Energy saving
Tungsten halogen lamps	LED	75 to 83
Fluorescent lamp		62 to 73
Mixed mercury lamp		80
High pressure mercury (HPMV)		72
Metal halide lamps		64
High pressure sodium (HPSV)		64

Table 24. Energy saving calculation table

Items	Unit	Current lamps	LED
Power capacity (+ ballast)	W/unit		
The number hours in a day	Hr /day		
The number days in a year	Day/year		
Number of luminaires			
Power consumption in a year	kWh/year		
Energy saving in a year	kWh/year		
Average electricity price in a day	VND/kWh		
Money saving in a year	Million VND		
Luminaires price	Million VND		
Total investment	Million VND		
Payback time	Year		

3.2.4. Data collection

- Step 1: Prepare equipment checklist for lighting system and transformers:

Table 25. Rated power, number and current status

No.	Factory location	Lighting type and ballast	Rated power	Number	Shift I/II/II date
1					
2					
3					

Table 26. Lighting transformer, rated power and numbers

No.	Factory location	Rated power of lighting transformer (kVA)	Number	Voltage/Ampe/kW/
1				
2				
3				

- Step 2: use lux meter to measure lux at various plant locations
- Step 3: measure and record power consumption at different inputs such as distribution board, lighting transformer
- Step 4: compare the measured value with lux standard. Use the values as a reference and identify locations of under lit and over lit areas
- Step 5: Analyze the failure rates of lamps, ballasts and the actual life expectancy levels from the past data
- Step 6: Based on careful assessment and evaluation, identify improvement options.

3.3. Motor

3.3.1. Introduction

Electric motor is a device that consumes electricity and converts electrical energy into mechanical energy. Two most popular electric motors in Vietnam are squirrel cage rotor and wound rotor.

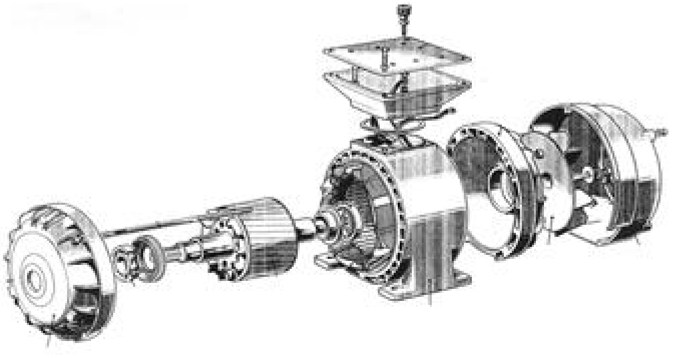


Figure 20. Squirrel cage rotor motor

Advantages of squirrel cage rotor motor are simple design, inexpensive, easy to operate, low maintenance cost, and high reliability.

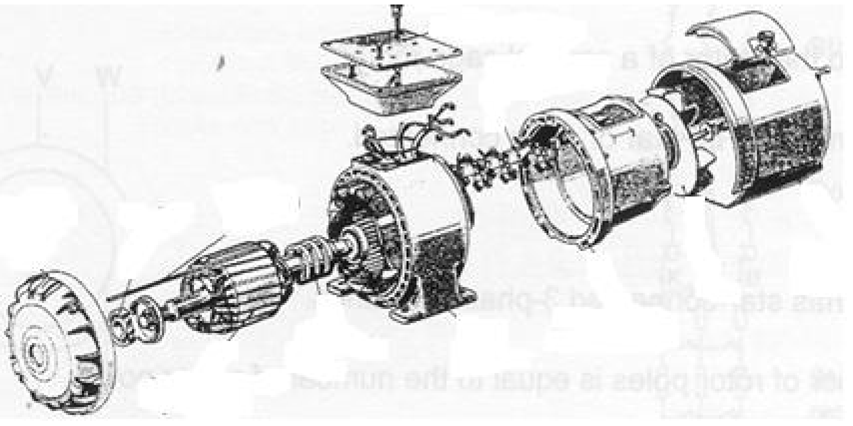


Figure 21. Wound rotor motor

The following table describes the basic motor load types:

Table 27. The basic motor load types

Load types	Description	Example
Constant torque	Output energy changes but torque is unchanged.	Conveyors, rotating ovens, vacuum pump
Changed torque	Torque is proportional to the square of speed	Centrifugal pumps, fans
Fixed load	Torque is inversely proportional to speed	Machine tool

3.3.2. Energy flow for motor

Operating cost and investment in a motor are presented in the following pie chart:

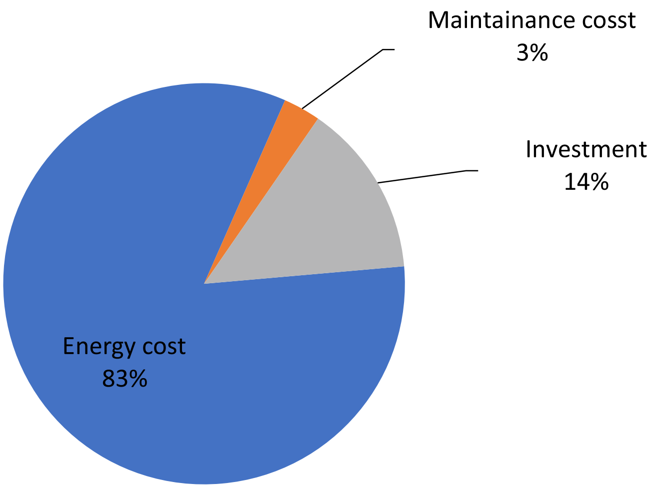


Figure 22. Cost distribution of motor

Source: PECSME

Based on the above chart, energy costs account for over 80% of the total life cycle cost of motor. Therefore, optimizing utilization will significantly reduce the operating costs of the motor.

3.3.3. The energy saving measures

There are some energy saving solutions for motor system:

- Optimize the operating capacity and ensure that the system is operating at the highest efficiency
- Reduce the partial load operating time of motor
- Optimize the operating conditions of equipment
- Selecting proper motor
- Using high performance motor
- Using inverter for motor.

The methods for energy saving solutions are discussed in the following sections.

3.3.3.1. Motor selection

Underload motors: Choosing a motor with a greater capacity than demand will reduce the performance efficiency of the engine

Motor selection should be based on the performance graph and percentage of full load. Motor efficiency can be calculated as follows:

Motor efficiency (%) = output power/input power x 100%

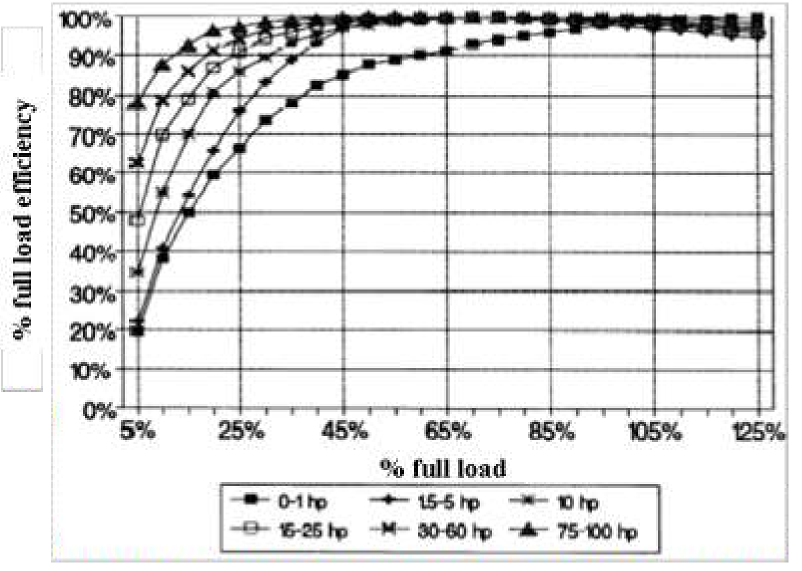


Figure 23. Efficiency and full load percent

Source: Asia Energy Efficiency

The above figure shows that the motor efficiency is significantly reduced when the motor operates at 30-40% rated power (% full load measured when the motor operates).

At the same rated power, higher speed motor has higher efficiency.

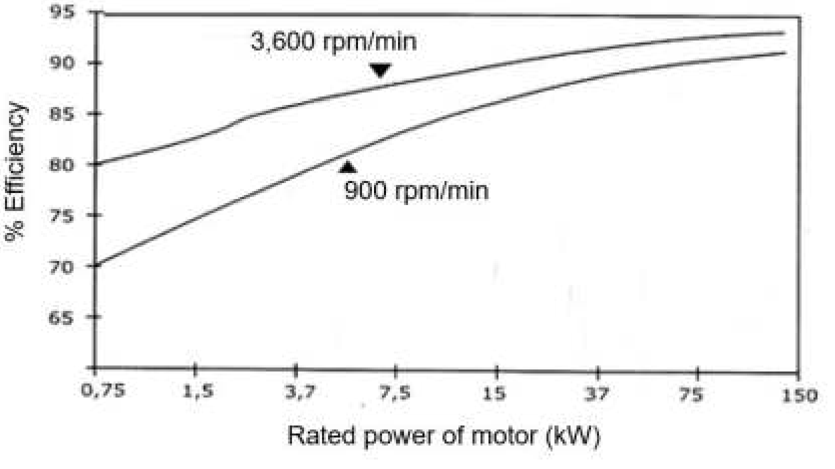


Figure 24. Efficiency and rotating speed of squirrel cage rotor

Source: PECSME

Example: Calculation benefit when choosing right motor for load demand 7,5 hp. The calculation results are presented in the below table:

Table 28. Operating cost estimation of selected motors

Requirement				
(1) Required power	hp	**7,5**		
Selected Measure				
		(A)	(B)	
(2) Design power	hp	**15**	**10**	
(3) Full Load Efficiency	%	86,3%	86,0%	*Based on catalogue*
(4) Load factor	%	50%	75%	(1) / (2)
(5) Diminishing efficiency	%	98,0%	100%	*Based on % load and efficiency chart*
(6) Operational efficiency	%	84,6%	86,0%	(3) x (5)
(7) Operating hours	hours/year	7.920	7.920	*(by actually operational hours)*
(8) Electricity price	VND/kWh	1.671	1.671	*(by average electricity price)*
Result				
(9) Operational power	kW	6,62	6,51	(2) x 0,746 x (4) / (6)
(10) Electricity consumption	kWh	52.395	51.526	(7) x (9)
(11) Annual cost	VND	87.551.754	86.100.024	(8) x (10)
(12) Different of operating cost	VND/year		1.451.730	(A) - (B)

From above calculation, choosing right motor match load demand, we can save power consumption as well as operating costs.

3.3.3.2. High-Efficiency motor

Benefits of high-efficiency motor selection:

- High performance and motor lifetime
- Reduce power consumption, reduce operating costs
- Reduced affect power quality, increase power factor, stable load.

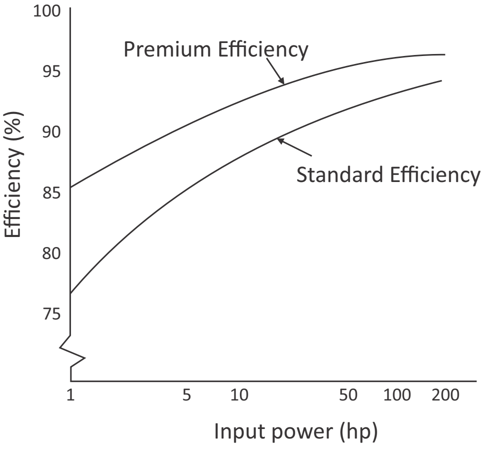


Figure 25. Standard efficiency motor vs. premium efficiency motor

Source: PECSME

The costs of high efficiency motors are higher than those of standard motors. The payback period will be rapid due to reducing operating costs, particularly in new applications or end-of-life motor replacements. However, replacing existing motors that have not reached the end of their useful life with energy efficient motors may not always be financially feasible. Therefore, the replacement is recommended when the existing motor is failed.

Table 29. Standard efficiency motor vs. premium efficiency motor

Power		**Efficiency (%)**			**Price ($)**		
HP	kW	Standard motors	High efficiency motors	Diffirent	Standard motors	High efficiency motors	Diffirent
5	3,7	38,3	87,3	4,6	344	448	104
7,5	5,5	85,2	89,5	4,8	494	647	153
10	7,5	86,0	89,4	3,8	614	780	166
15	11,0	86,3	90,4	4,5	811	1.042	231
20	15,0	88,3	92,0	4,0	1.025	1.268	243
25	18,5	89,3	92,5	3,5	1.230	1.542	312
30	22	89,5	92,6	3,3	1.494	1.824	330
40	30	90,3	93,1	3,0	1.932	2.340	408
50	37,5	91	93,4	2,6	2.487	2.881	394
60	45	91,7	94,0	2,4	3.734	4.284	550
75	55	91,6	94,1	2,7	4.773	5.520	747
100	75	92,1	94,7	2,6	5.756	6.775	1.019
125	100	92,0	94,7	2,9	7.425	9.531	2.106
150	120	93,0	95,0	2,1	9.031	11.123	2.092
200	150	93,8	95,4	1,7	10.927	13.369	2.442

Source: Asia Energy Efficiency

The following illustration compares the energy savings and annual costs between energy efficiency motor trand standard motor:

Table 30. Motor investment comparison

Requirement				
Power	*hp*	**30**	**50**	**75**
Operating hours in day	*hours/year*	7.920	7.920	7.920
Full load factor	*%*	80	80	80
Avarage electricity price	*VND/kWh*	1.671	1.671	1.671
Selected measure				
High-efficiency model efficiency	*%*	92,6	93,4	94,1
Normal model efficiency	*%*	89,5	91,0	91,6
Different os price	*VND*	5.280.000	6.304.000	11.952.000
Result				
Annual electricity savings	*kWh*	5.892	7.603	11.880
Annual savings	*VND*	9.846.334	12.704.947	19.851.480
Simple payback period	*months*	6,4	6,0	7,2

According to the above table, the motor with rating of 50HP is the best choice since it can save 7,603 kWh/year which is equivalent to 13 million VND / year and its payback period is shortest.

3.3.3.3. Variable speed drive

For pumps and fans: the valve system and the vent doors must not be fully opened during operation due to overcapacity design or due to the necessary changes according to production status.

The reason for motor speed control:

- Mechanical power is controlled by cycle or on/off according to output power requirements
- In fan or pump system, fluid flow is adjusted by control valves at inlet and outlet while the motor is operating at a fixed rate. This control strategy will affect to the pump characteristics curve. In this method, the flow is reduced, while power consumption does not change, so that the total head increases. The following figure shows how the system curve moves upwards and to the left when a discharge valve is half closed

Some motors and actuator devices use mechanical coupling and gear box to adjust speed.

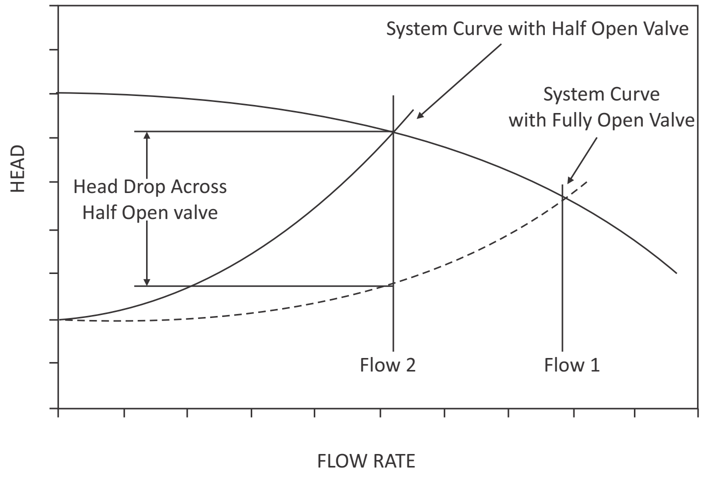


Figure 26. Performance curve of pump with flow control valve

Source: Asia Energy Efficiency

VSD improves energy efficiency by balancing the rotation speed with variable load.

Affinity laws describe the relationships between speed, flow rate and power:

$$Q_2 = Q_1\left(\frac{N_2}{N_1}\right) \qquad P_2 = P_1\left(\frac{N_2}{N_1}\right)^3$$

Q: Flow rate, P: Power, N: rotation speed

A small reduction in speed will result in a very large reduction in power consumption. The below table shows the correlation between the rotation speed, flow, and power capacity of the centrifuge machine.

Table 31. Correlation between the rotation speed, flow, and power capacity

Rotation speed	Flow	Power capacity
100%	100%	100%
90%	90%	73%
80%	80%	50%
70%	70%	34%

60%	60%	22%
50%	50%	13%
40%	40%	6%
30%	30%	3%

Source: PECSME

VSD controller is applied well in the following cases:

- Flow variations require the control valve and by-pass valve
- Motor rating is much larger than power requirement
- The system has on/off cycle controller.

3.3.3.4. Optimize motor operation

Example based on load curve: Load diagram of compressor and cooling water pump. We see that the compressor works intermittently while cooling water pump works continuously. So, operating system doesn't work optimally.

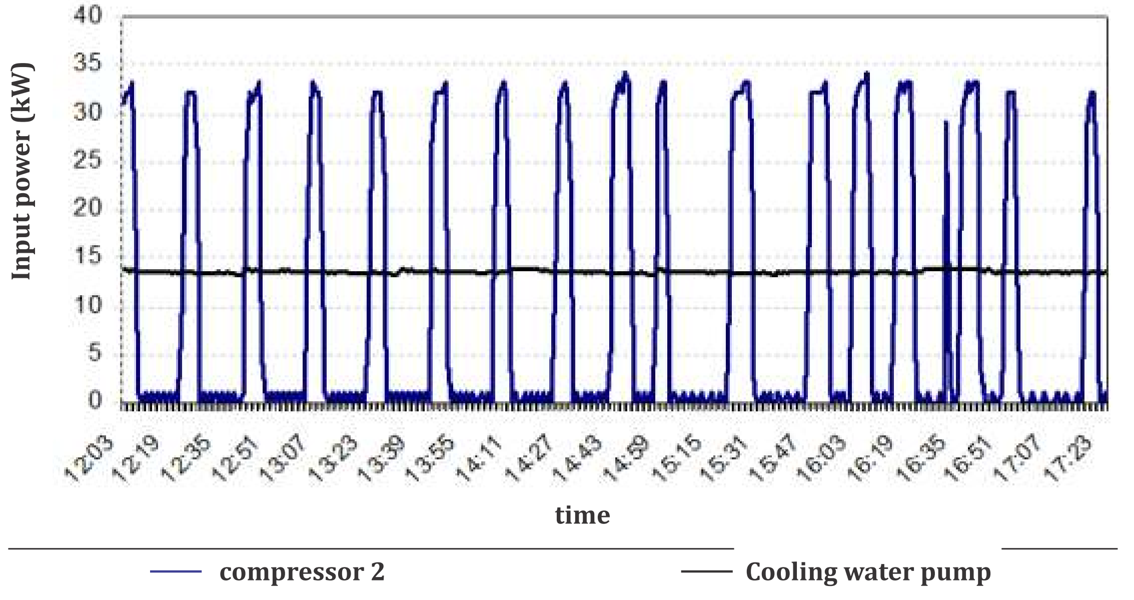


Figure 27. Load diagram of air conditioning

3.3.4. Data collection

In order to evaluate the operation of motor system, the following information need to be collected:

- Load diagram: actual capacity, the difference between actual capacity and design capacity, operating time
- Operation control strategy
- Parameters affecting the operation of system.

The data collection table for motors can be referenced below:

Table 32. Motor data collection

No.		1	2	...
- Name				
- Code				
- Rated power (motor)	kW/hp			
- Efficiency (motor)	%			
- Rated speed	rpm			
- Primary speed	rpm			
- Secondary speed	rpm			
- Voltage	V			
- Current	A			
- Cos j				
- Operating power	kW			
- Operating time	Hour/year			
- Control (aperture valve, VSD)				
- Notes				

3.4. Fans

3.4.1. Introduction

Based on operation pressure, classification of fans, blowers, compressors are as below:

- Fans: operate with pressure below 1,4 mH_2O
- Blowers: operate with pressure from 1,4 mH_2O to 14 mH_2O
- Compressors: operate with pressure above 14 mH_2O.

There are two types of industrial fan:

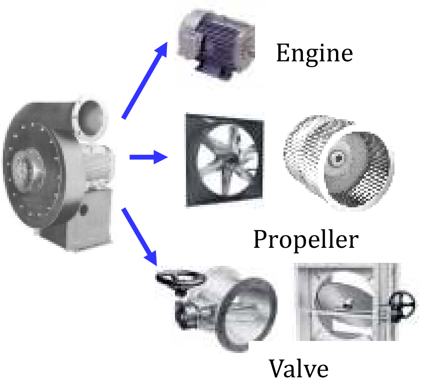
- Axial fan: High flow, low pressure
- Centrifugal fan: low flow, high pressure (normally, $\Delta p < 2{,}04 mH_2O$).

3.4.1.1. Fan system

Fan system includes the following main components:

- Motor
- Propeller

Valves, vents control flow.



3.4.1.2. Flow control

Methods used for flow control include:

- Circulation: a part of air velocity is circulated to the fan inlet
- Air inlet: used for mitigating air velocity in the air inlet or outlet
- Flow change: the motor speed is fixed, but propeller speed is changed by using embrayage.
- Inverter: inverter control unit is used for changing motor and fan speed.

3.4.1.3. Basic information

$$P = Q\,\frac{\Delta p}{1000\,.\,h}$$

P: Power capacity (kW)

Δp Pressure difference (Pa):

Q: Flow (m^3/s):

(h is efficiency (<0,85). Higher differential pressure has lower efficiency)

Fan efficiency

Table 33. Efficiency of types of fan

Types of fans	Minimum performance	Maximum performance
Centrifugal fan with hollow blades.	75%	86%
Centrifugal fan with convex blades	50%	73%
Centrifugal fan with straight blades	50%	60%
Axial Fans	60%	86%

Source: PECSME

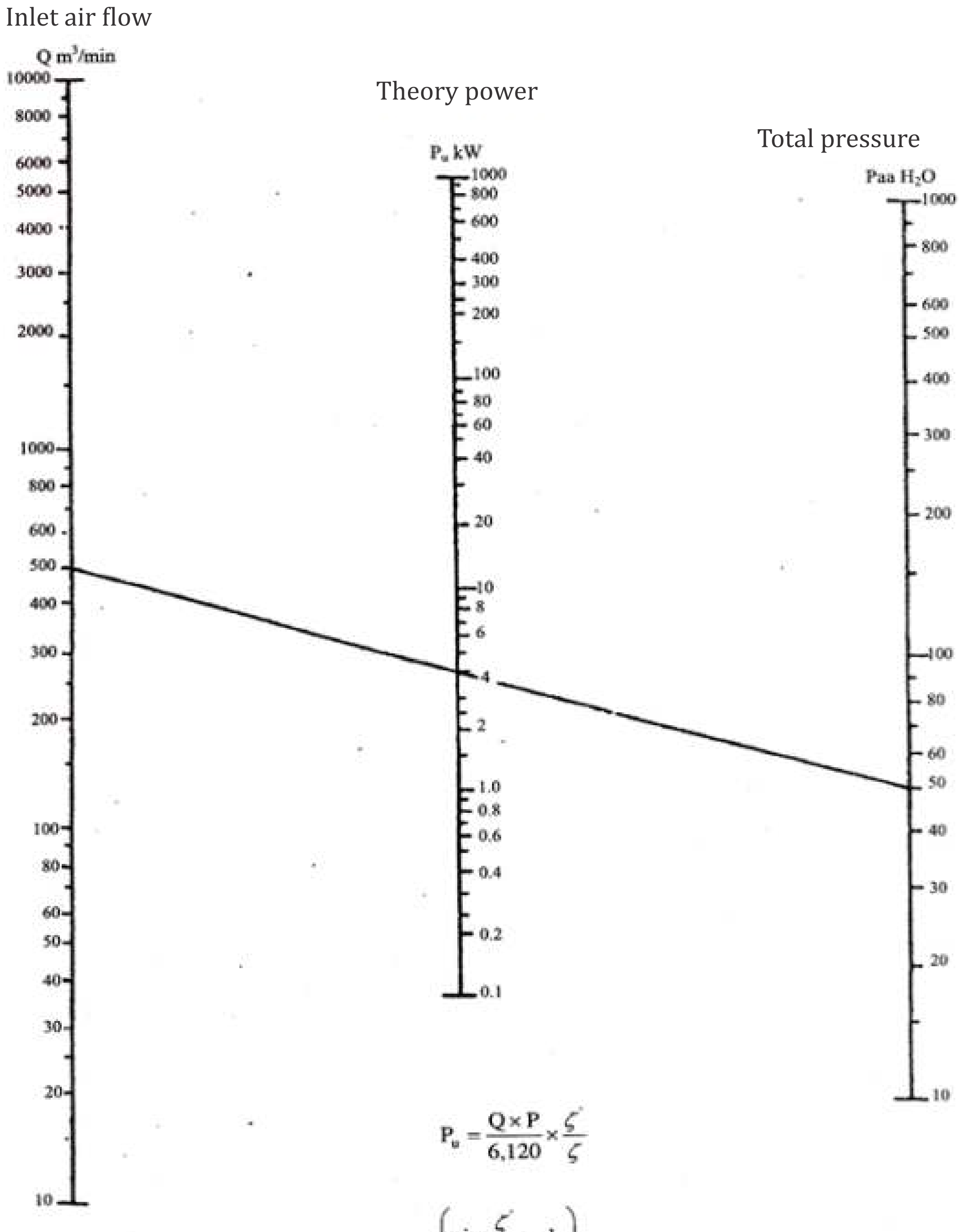
$$h = h_{fan} .\ h_{transmission} .\ h_{motor}$$

h_{fan} Compare theorical power consumption and actual power consumption at the same point

$H_{transmission:}$ transmission efficiency. Transmission systems by cogged raw-edged belt with power capacity above 10kW has efficiency of at least 95%. Transmission losses can be ignored if it is direct transmission systems.

H_{motor} : motor efficiency. Check manufacturer catalogue

Theoretical fan capacity is calculated as the following diagram:



$$P_u = \frac{Q \times P}{6{,}120} \times \frac{\zeta'}{\zeta}$$

$$\left(\text{air: } \frac{\zeta'}{\zeta} = 1\right)$$

Figure 28. Fan power calculation

Source: PECSME

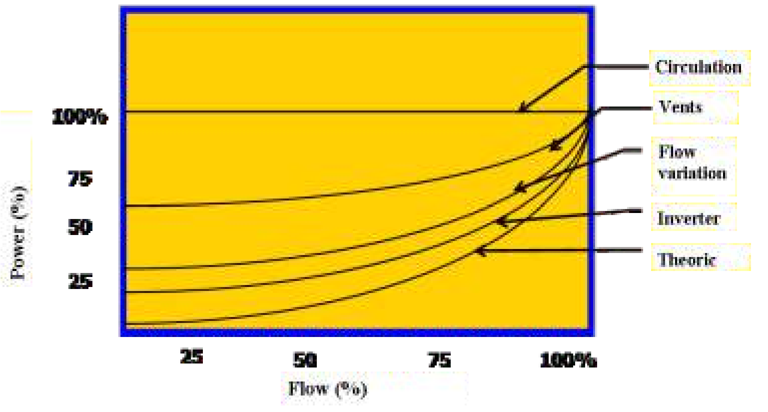


Figure 29. Calculation of fan capaciy

Effect of flow control and system efficiency:

Table 34. Fan speed vs. flow

Fan speed (round/minute)	Flow (%)
800	55
900	62
1.000	69
1.100	76
1.200	83
1.450	100

Source: PECSME

Table 35. Fan speed vs. power capacity

Fan speed (round/minute)	Power capacity (% rated)
800	17
900	24
1.000	33
1.100	44
1.200	57
1.450	100

Source: PECSME

Table 36. Percentage of power consumprion by flow percentage

Flow (%)	Output vents	Input vents	Inverter
100	81	78	83
90	61	74	81
80	44	58	80
70	31	42	76
60	21	28	70
50	14	18	66

Source: PECSME

3.4.2. Energy flow for fan

3.4.2.1. Cost distribution of fan

Operating cost and investment in a fan are presented in the pie chart:

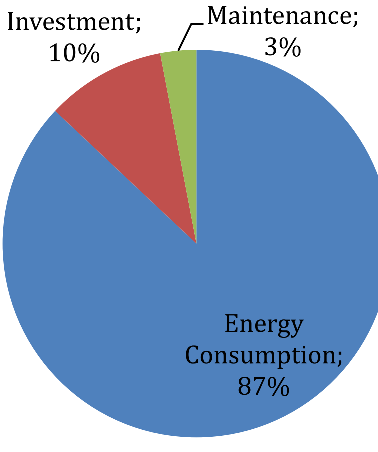


Figure 30. Cost distribution of fan

Source: PECSME

Based on the above chart, we can see energy costs account for over 67% of the total life cycle cost of fan. Therefore, optimizing utilization will significantly reduce the operating costs of the fan.

3.4.2.2. Sankey diagram of fan

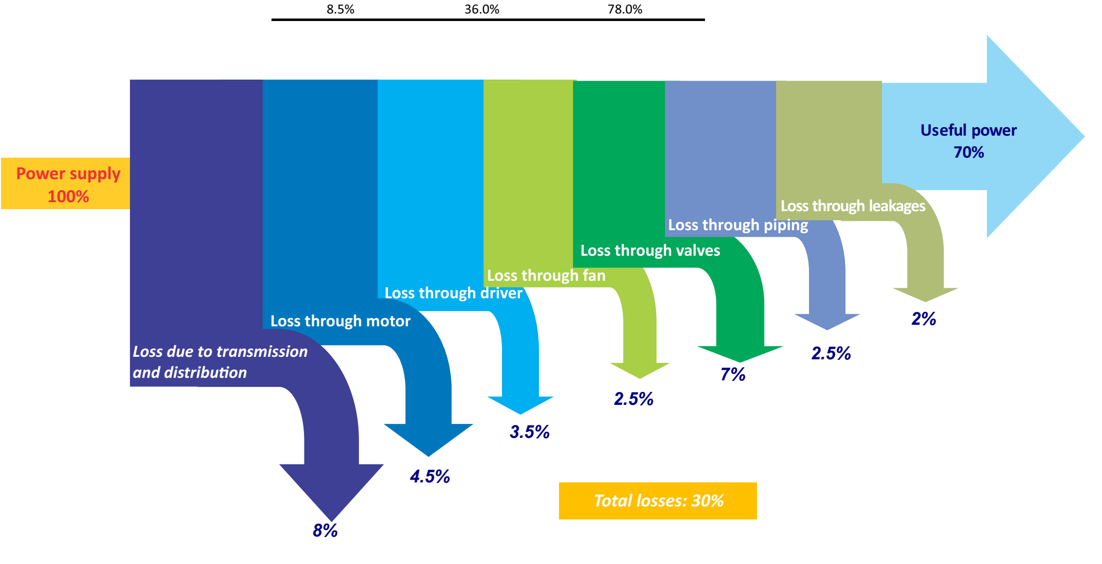


Figure 31. Sankey diagram of fan

Source: Enerteam

According to the above Sankey diagram, the useful energy is only about 70% and the rest is loss through the valves, leakages, piping, fan structure…

3.4.3. Energy efficiency for fan

3.4.3.1. Choose the right fan

- Important considerations:
  - Noise level
  - Rotating speed
  - Air flow characteristics
  - Temperature range
  - Operating range
  - Space constraint and system layout
  - Investment cost/ operation and operating life.
- Avoid buying oversized fan:
  - Unable to operate at the highest efficiency
  - Risk of unstable operation.
  - High noise level.

3.4.3.2. System resistance reduction

System resistance will reduce fan efficiency:

- Check periodically
- Check after repairing system
- Reduce elbows and remove dead legs of piping system.

3.4.3.3. Operate close to BEP

- Best Efficiency Point (BEP)
- Usually close to rated capacity
- Deviation from the BEP will result in increased loss and inefficiency.

3.4.3.4. Frequent maintenance

- Inspect fan components periodically
- Lubricate and replace bearing if necessary
- Motor repair or replacement if necessary
- Fan cleaning.

3.4.3.5. Control the fan air flow

- Pulley change: reduce drive pulley size -> Reduce speed and energy consumption.

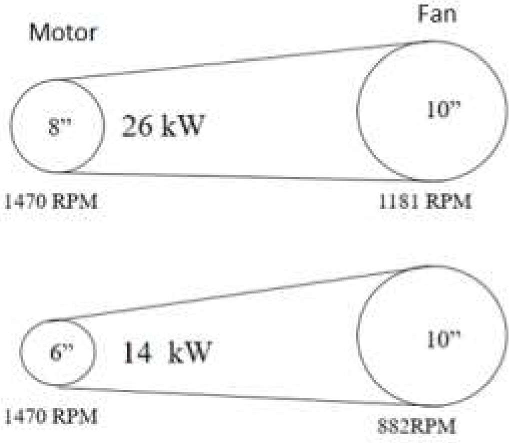


Figure 32. Reduce motor speed by decreasing the pulley size

Source: Enerteam

- VSDs: reduce speed of motor to meet reduced flow requirements
  - Classification: mechanical type, electrical type.
  - Advantage:
    - Most improved and efficient flow control
    - Speed is adjusted in a continuous range.
    - High operating efficiency.
  - Disadvantage: high investment costs.

3.4.3.6. Operating multiple parallel fans (instead one high power fan)

- Advantage:
  - High efficiency with large load range
  - Avoid off- motor risk
  - Cheaper and better properties than one large fan
  - Combined with other flow controller.
- Disadvantage: only suitable for system that has low resistance.

3.4.3.7. Operating multiple serial fans

- Advantage:
  - The average pressure of fluid pipe is lower
  - Lower noise
  - Lower requirements for structure and auxiliary equipment
  - Suitable for system that has long pipe, high resistance.
- Disadvantage: not suitable for system that has low resistance.

3.4.4. Data collection

Data collection for fan system:

- Design parameters of fan, motor, and duct:

  - Rated power, maximum flow
  - Control scheme, open/ close mode of vents.
- Operating power of motors:
  - Average electrical power (kW)
  - DC motor or AC motor
- Motor speed and fan speed.
- Collect technical information, specification sheets, characteristic curve, and flow diagrams.

Measurement method:

- Electrical power measurement
- Mechanical devices such as: anemometer, Pitot tubes, temperature indicator, pressure gauge.

Table 37. Data collection template for fan

Order		1	2	3
- Name				
- code				
- Flow type				
- rated flow	m^3/h			
- Efficiency (pump, fan)	%			
- Inlet pressure	bar (Kg/cm^2)			
- Outlet pressure	bar (Kg/cm^2)			
- Flow speed	m/s			
- Pipe size	mm			
-Designed flow	m^3/h			
- Operating time	Hour/year			
- Control (aperture valve, VSD)				
- Notes				

3.5. Pump

3.5.1. Introduction

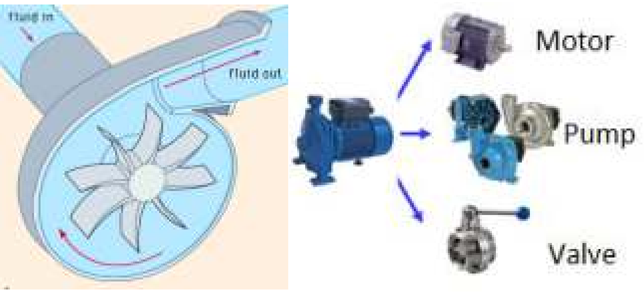
3.5.1.1. Pump classification:

- Volumetric pump: low flow, high pressure (piston, gear, screw, roto)
- Blade pump: high flow, low pressure (centrifugal, axial direction).

3.5.1.2. Pump systems include:

- Motors
- Pumps
- Valves

Piping system



3.5.1.3. Basic information

- Pump power:

$$P = \frac{p.Q.H}{102.h}$$

P – Power (kW)

H - static head (m)

Q - flow rate (m^3/s)

r - Density (kg/m^3),

h: Pump efficiency (0.7 – 0.85)

Pump capacity is shown as the following diagram:

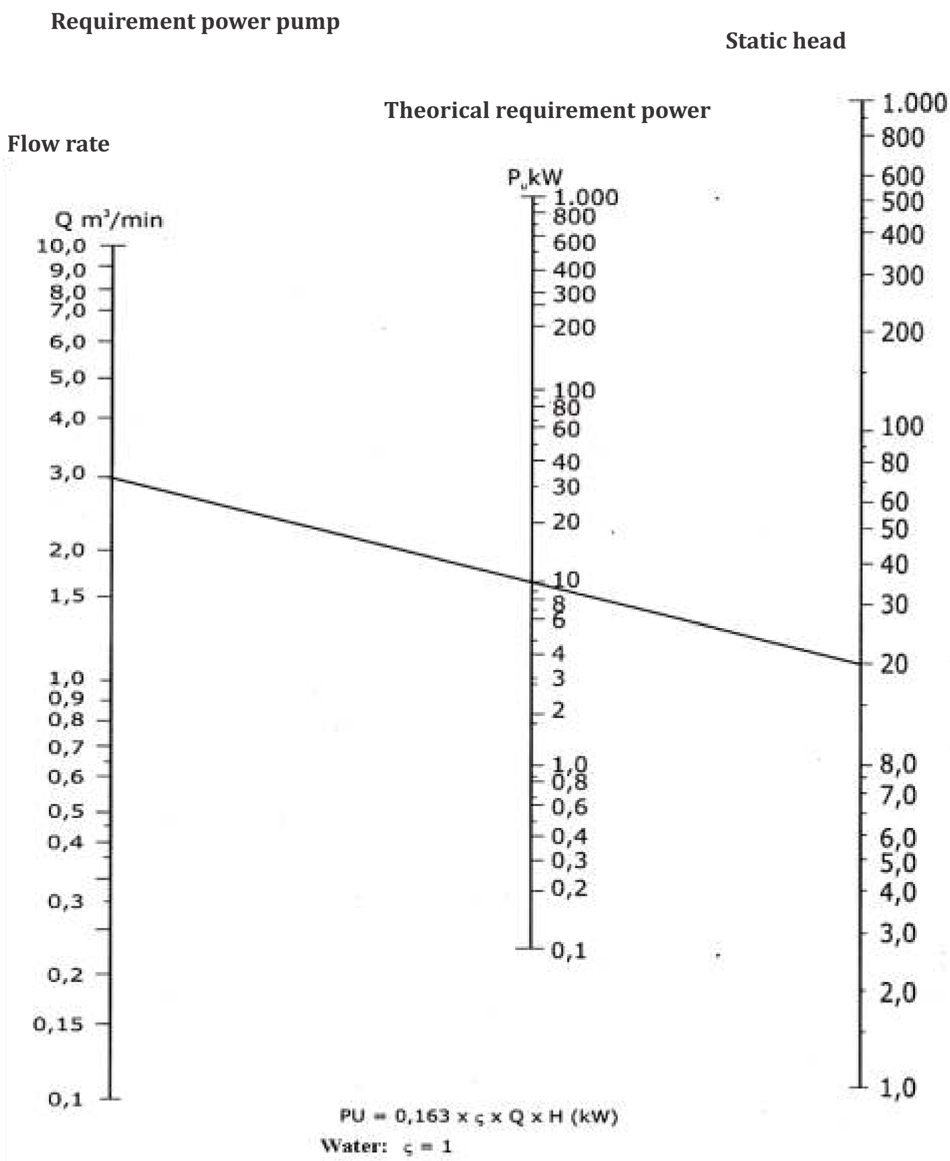


Figure 33 Calculate pump power

Source: PECSME

- Static head (H, m): includes the difference of hydrostatic pressure, high difference, and resistance on the pipeline.

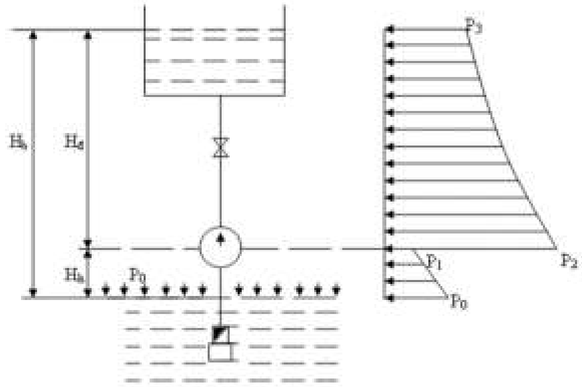


Figure 34. Parameters of Pump system

- Identify the pump operating point: intersection between pump curves and system curves.

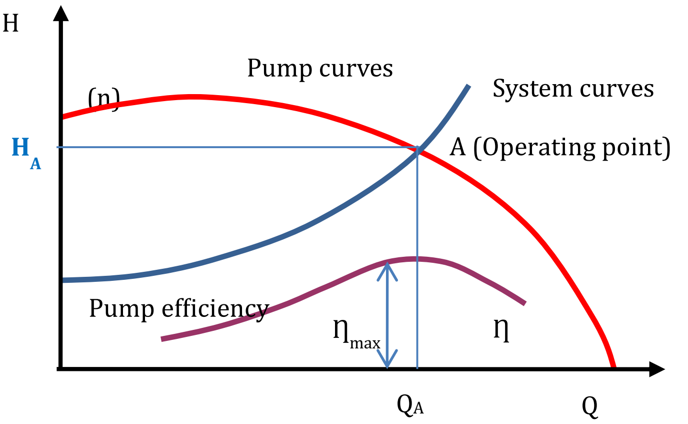


Figure 35. Pump Performance Curve

- Pumps in parallel operation

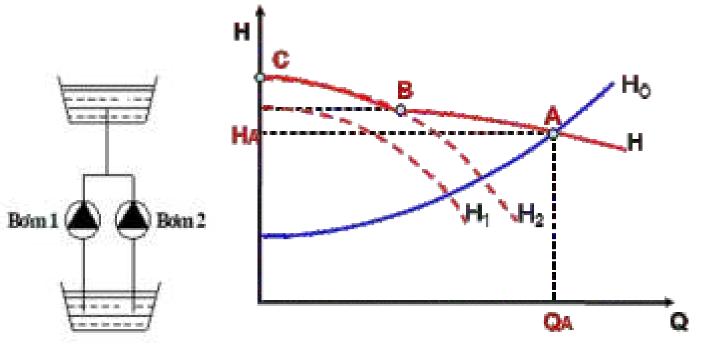


Figure 36. Parallel Pumps & pumps curve

- Static head of system is equal to each static head of pump.

$$\mathbf{H = H1 = H2}$$

- Flow rate of system is equal to total flow rate.

$$\mathbf{Q_T = Q_1 + Q_2}$$

3.5.1.4. Control flow rate

Method of flow rate control for pump is illustrated below:

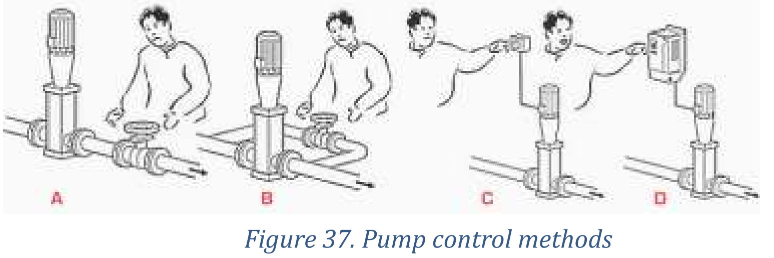


Figure 37. Pump control methods

- Adjusting pipe characteristics by valves (keep pump characteristics)
  - Throttle valve reduces system pressure, changes the system characteristics, and reduces pump efficiency (A)
  - Circulation: this is not energy saving strategy (B).

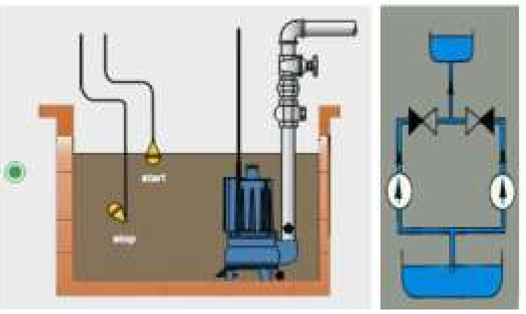


Figure 38. ON-OFF control for pump

- Adjusting pump characteristics by valves (keep pipe characteristics) (C,D)

· ###Use VSD for motor: adjust the electrical frequency of power supplied to a motor to change the motor's rotational speed.

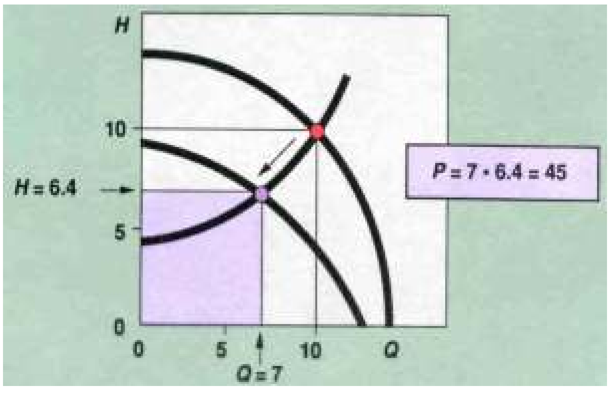


Figure 39. Performance curve of pump with VSD

- Compare pump power consumption between flow control strategies.

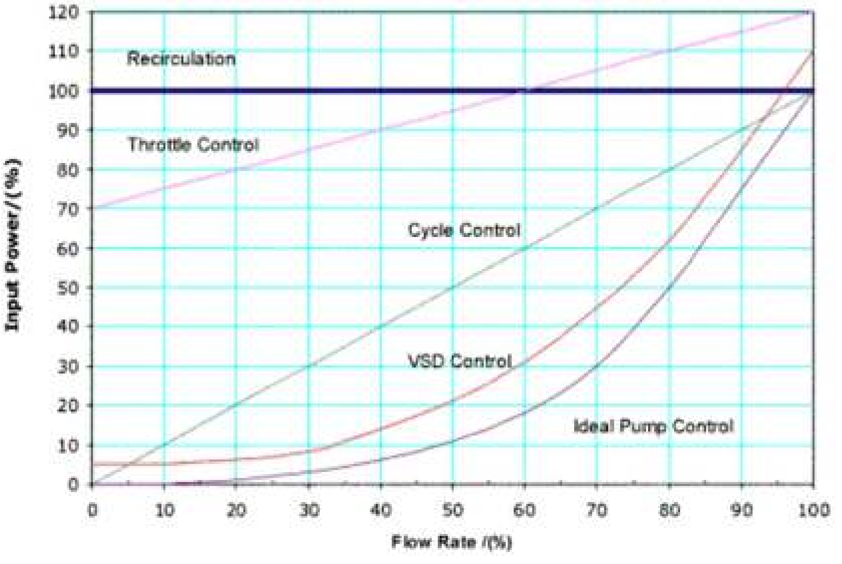


Figure 40. Power Requirements for various pumping control options

From the above graph, with the same pump flow, the power consumption percentage in the VSD Control solution (red line) is lower than that in Valve control solution.

- Closed loop control:
  - Flow can vary from 20% to 100% of motor speed

- The pump is designed close to the BEP at 100% flow
  - Operation close to BEP point
- Flow control for high static pressure system
  - The flowrate should not be adjusted in the whole operation range
  - Use multiple pumps to meet the flow change demand.

3.5.2. Energy flow for pump

3.5.2.1. Cost distribution of pump

Operating cost and investment of a pump are presented in the following pie chart:

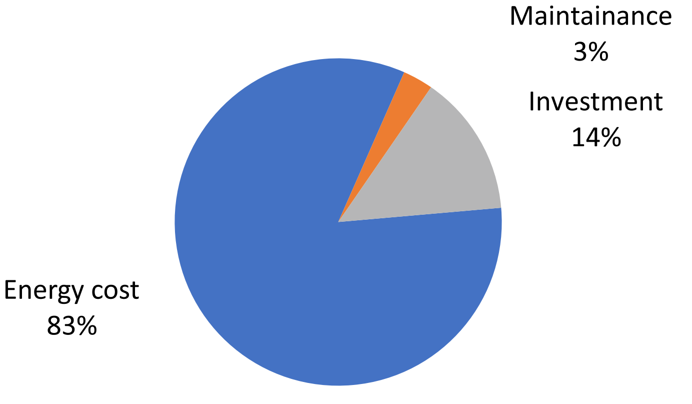


Figure 41. Cost distribution of pump

Source: PECSME

Based on the above chart, we can see energy costs account for over 80% of the total life cycle cost of pump. Therefore, optimizing utilization will significantly reduce the operating costs of the pump.

3.5.2.2. Sankey diagram of pump

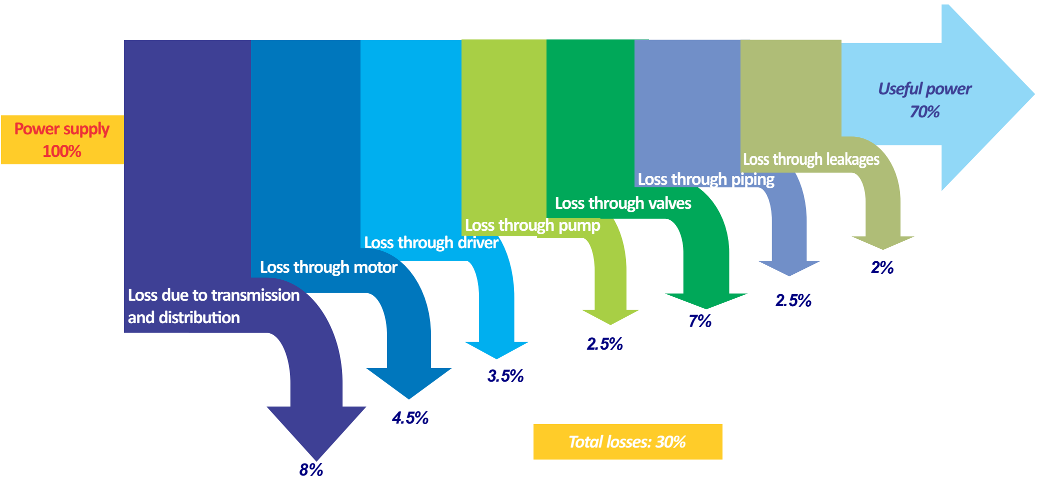


Figure 42. Sankey diagram of pump

Source: Enerteam

According to the above Sankey diagram, the useful energy is only about 70% and the rest is loss through the valves, leakages, piping, pump structure…

3.5.3. Energy savings measures

3.5.3.1. Select the right pump

The reason of oversized pump fairly common:

- Ensure the operation has ample capacity
- Due to limited availability from supplier
- Use spare pump without the proper size in the inventory.

The pump is affected when the selected pump is oversized

- Controlled with different methods such as throttle valve or by-pass line
- Increase the head due to friction
- The system curve will be shifted to the left
- Reduce pump efficiency.

Solution for pumps in stock:

- Use VSD or multi speed drives.
- Lower rotating speed
- Trim the impeller.

3.5.3.2. Use adjustment the flowrate

- Speed adjustment over a continuous range
- Reduce power consumption
- Two types of systems:
  - Mechanical: fluid couplings, adjustable belts
  - Electrical VFD: variable frequency drives (VFDs).

3.5.3.3. Install pumps in parallel to change load

- Install of multiple pumps: stop some of them when low load
- System curve does not change by running pumps in parallel
- The total flow rate of parallel pumps is smaller than the sum of the flow rates of different pumps.
- To match the pump with the same characteristics

3.5.3.4. Eliminate flow control valve.

Effects of control valve:

- The power consumption is not reduced as the total head increases
- Vibration and corrosion increase maintenance costs and reduce pump's lifetime.

3.5.3.5. Eliminate by-pass control

- Discharge part is divided into two separate pipes:
  - One pipe delivers the fluid to the delivery point
  - The second pipe returns the fluid to the source.

Energy wastage is due to part of fluid circulated unnecessarily by pump.

3.5.3.6. Start/stop control of pump.

- Stop pump when not needed
- Pump at non-peak hours.

3.5.3.7. Impeller trimming

- Changing the impeller diameter gives change in the impeller's velocity
- Notes:
  - Cannot be used where varying flow pattern exist
  - Do not trim more than 25% of original impeller size
  - Trim diameter all sides
  - Changing impeller is more expensive.

3.5.3.8. Completing the pump system

Minimize static head by the following methods:

- Use large diameter pipe
- Use long curve bend rather than sharp-edged bend.

3.5.4. Data collection

Steps to evaluate the pump efficiency

- The measurement tools: 3 phases power meter, pressure gauge meter, and ultrasonic flow meters
- Data collection: name plate, specification sheet, pump curve, and process flow system
- Measurement steps:
  - Measure input power of motor by 3 phases power meter
  - Measure pressure at suction and pushing of pump
  - Measure pressure and temperature at the input and output of pump
- Measure flow rate. If flow rate is not possibly measured, it can be estimated from the pump curve
  - Site discussion with operators and plant engineers
  - Check throttle valve and control valves in entire piping system. If it was throttled, measuring pressure at its input or output
  - Check by-pass line of system
  - Estimate operating time of pumps and equipment.

Table 38. Data collection tool for pump

Items		1	2	3
- Name				
- Code				
- Flow type				
- Flow rate	m^3/h			
- Efficiency	%			
- Inlet pressure	bar (Kg/cm2)			
- Outlet pressure	bar (Kg/cm^2)			
- Flow speed	m/s			
- Diameter	mm			
- Actual flow rate	m^3/h			
- Operating time	Hour/year			
- Control method (aperture valve, VSD)				
- Notes				

3.6. Air compressor

3.6.1. Introduction

Compressed air systems are commonly used in most industries such as packaging systems, product transfer, industrial hygiene, garment processing, agricultural products processing, heavy industry, etc.

The main components of the air compressor system:

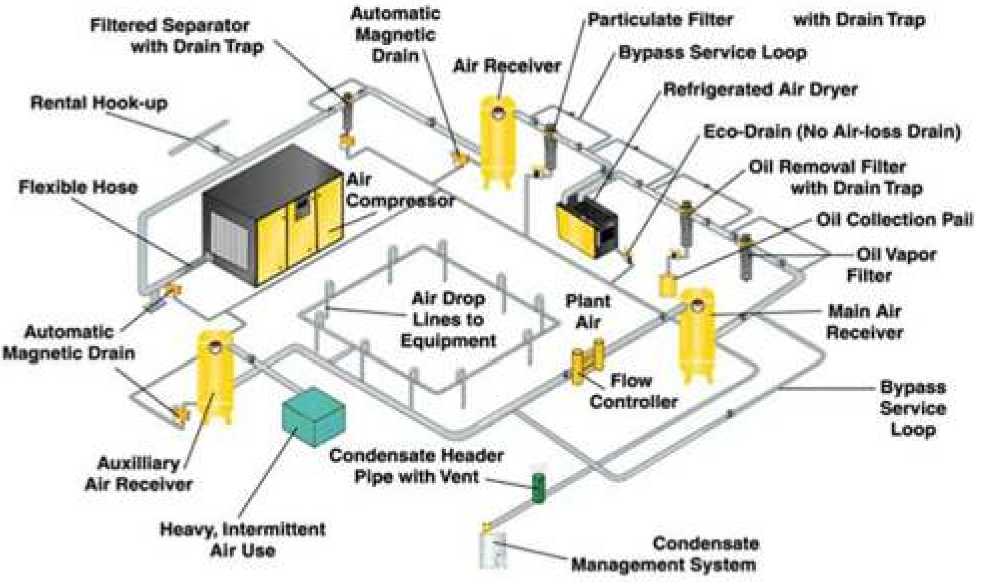


Figure 43. Air compression system illustration

A typical compressed air system components and network

- Air compressor
- Filter
- Intermediate cooling
- Compressor cooling
- Dryer
- Dehumidifier
- Tank.

3.6.1.1. Classification of air compressors:

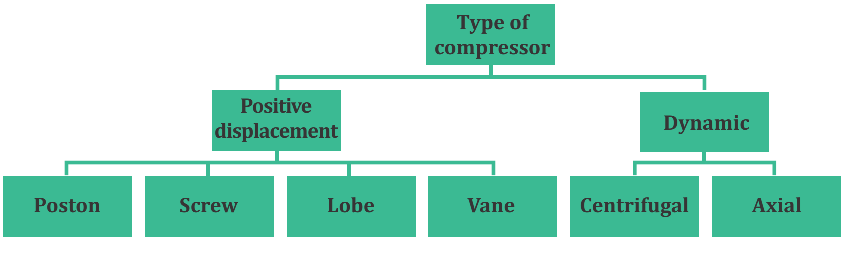


Figure 44. Type of air compressors

- Reciprocating compressor:

- Advantage:
  - High capacity
  - High pressure ratios
  - Simple to operate / repair.
- Disadvantage:
  - low compression ratio
  - Low efficiency
  - The large size, noise, high vibration
  - Irregular flow.

· Screw air compressor:
- Advantage:
  - High compression ratio (max=25)
  - High full load efficiency
  - Low cost operating.
- Disadvantage:
  - Expensive
  - More complex and good maintenance is very important.

3.6.1.2. Compression ratio

Compression ratio

$$\varepsilon = \frac{P_2}{P_1}$$

P_1= suction pressure

P_2= discharge pressure

· Power N (kW):

$$N = \frac{n}{n-1}.m.R.T_1\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right]$$

R= Individual gas constant (286. 7 J/kg.K).

T_1 = absolute initial temperature of gas (K).

m= mass flow (kg /s)

n = ratio of specific heats

The higher the pressure, the larger the power consumption. The relationship between the pressure and power consumption is described in the following table.

Table 39. Relationship between pressure and power consumption

Pressure	Power consumption
3	2.08
4	2.73
5	3.06
6	3.71
7	4.11

Source: PECSME

- Capacity Q (m^3tc/s) (at 0^0C, 1,013bar)

$$Q = 22{,}4.\frac{V}{\mu R \Delta \tau}\left(\frac{P_b}{T_b} - \frac{P_a}{T_a}\right)$$

V = tank volume (m^3)

μ - air mass of one kmol (μ =29 kg/kmol)

Dt - Compressor time from P_1 to P_2 (s)

T_a,P_a– Temperature and Pressure at suction (K), (Pa)

T_b,P_b– Temperature and Pressure at discharge (K), (Pa)

3.6.1.3. Compressor efficiency

- Isothermal efficiency

Isothermal efficiency = isothermal power/ actual measured input power

$$\textbf{Isothermal power (kW)} = P_1 \times Q_1 \times log_e\left(\frac{r}{36.7}\right)$$

P_1= absolute inlet pressure (kg/cm^2)

Q_1= free air delivered (m^3/hr)

r = compression ratio.

The calculation of isothermal power does not include power needed to overcome friction and generally gives an efficiency that is lower than adiabatic efficiency. The reported value of efficiency is normally the isothermal efficiency. This is an important consideration when selection compressors based on reported values of efficiency.

- Volumetric efficiency

$$\text{Volumetric efficiency} = \frac{\text{actual free air delivery of compressor} \left(\frac{m^3}{min}\right)}{\text{Compressor displacement}}$$

$$\textbf{Compressor displacement} = \Pi \times D^2/4 \times L \times S \times \chi \times n$$

D= cylinder bore, m

L = cylinder stroke, m

S= compressor RPM

x= 1, for single acting, and 2 for double acting cylinders

n= number of cylinders

For practical purposes, the most effective guide in comparing compressor efficiencies is specific power consumption kW/volume flow rate, for different compressors that would provide identical duty.

3.6.1.4. Typical pressure drop in compressed air pipeline for different pipe size

The following table describes the energy loss of piping with different diameters:

Table 40. Pressure drop for different pipe size

Pipe Nominal Bore (mm)	Pressure drop (bar) per 100 meters	Equivalent power loss (kW)
40	1.80	9.5
50	0.65	3.4
65	0.22	1.2
80	0.04	0.2
100	0.02	0.1

Source: PECSME

3.6.1.5. Air leakage

- Consequence
  - Wasting 20 to 30 percent of a compressor's output
  - Pressure drop in system.
- Common air leakage area:
  - Couplings, hoses, tubes, and fittings
  - Pressure regulators
  - Open condensate traps and shut-off valves
  - Pipe joints, disconnects, and thread sealants.
- The system leakage is calculated as follows:

$$\textbf{\% leakage = (Tx100) / (T + t)}$$

T–on-load time (s)

t –off-load time (s)

Good management systems has air leakage rate less than 10%

- System leakage

$$\textbf{System leakage } (m^3/s) = Q \times T / (T + t)$$

Q- actual capacity (m^3/s)

3.6.1.6. Inlet air temperature and power consumption

Effect of inlet air temperature on power consumption is described in the below table :

Table 41. Inlet air temperature vs. Power saving

Inlet temperature	Power saving (%)
10,5	+1,4
15,5	0,0
21,1	-1,3
26,6	-2,5
32,2	-4,0
37,7	-5,0
43,3	-5,8

Source: PECSME

Every 5⁰C rise inlet air temperature results in a higher energy consumption by 1.5% to achieve equivalent output.

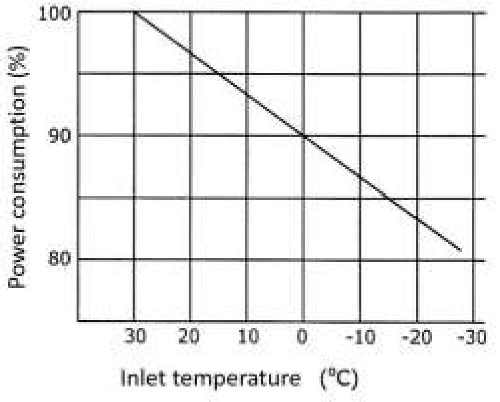


Figure 45. Effect of inlet temperature and power consumption

Source: PECSME

3.6.2. Energy flow diagram

- Cost distribution of air compressor

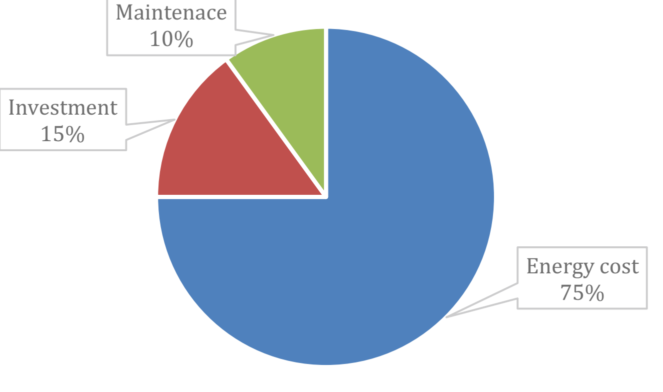


Figure 46. Cost distribution of air compressor

Source: UNIDO

- Sankey diagram

Air compressor system usually has low energy efficiency. The power range of industrial air compressor is from 5 to over 50,000hp, but 70 to 90 percent of consumed energy is lost.

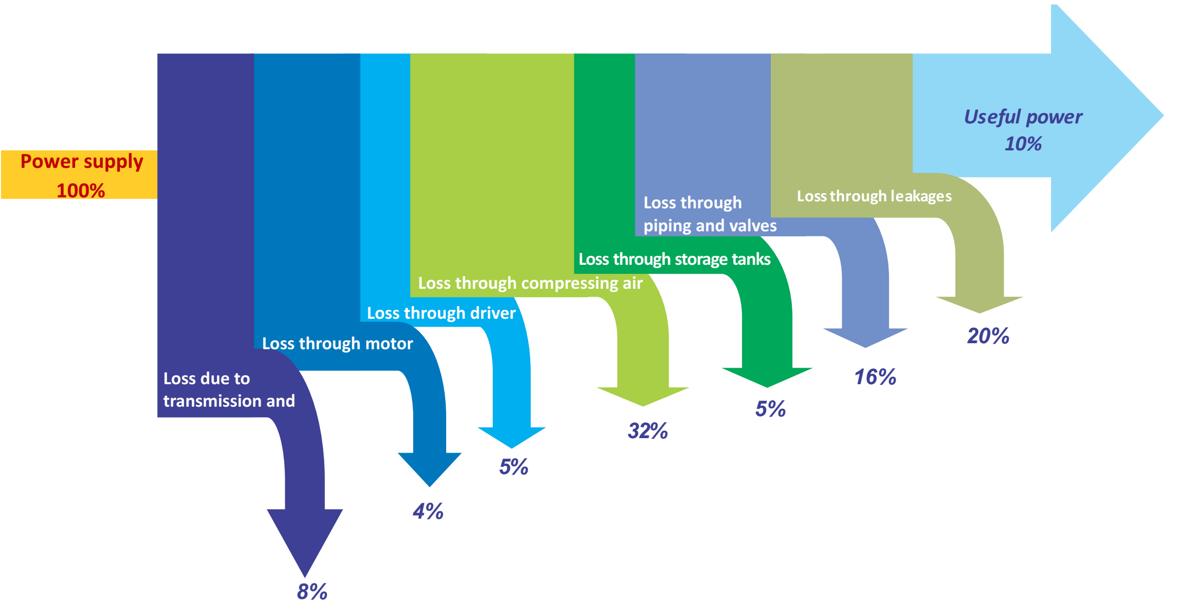


Figure 47. Sankey diagram for compressed air system

Source: VNEEP

3.6.3. Energy savings measures

The energy savings achieved when implementing energy saving solutions for the compressor system are shown in the figure below:

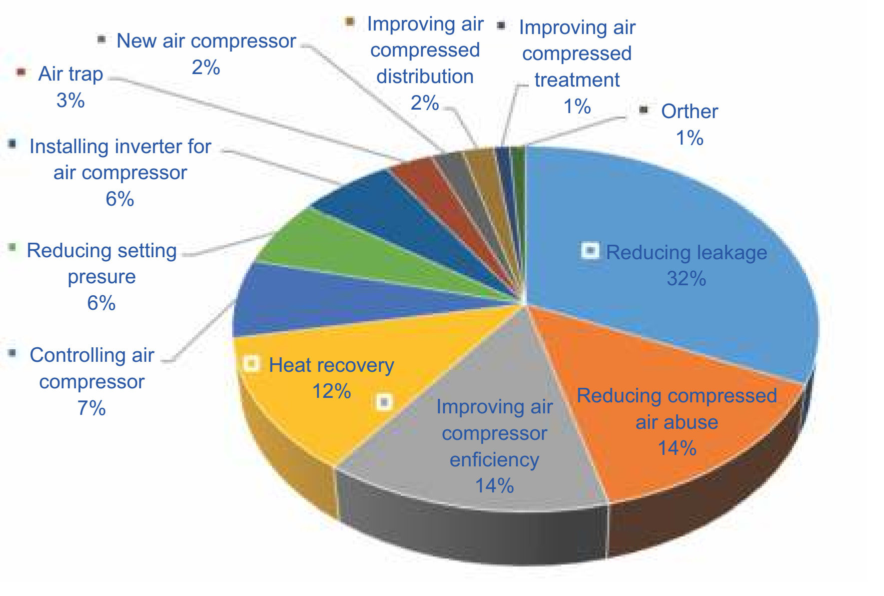


Figure 48. Energy savings potential for air compressed system

Source: UNIDO

3.6.3.1. Location of air compressor

Elevation of air compressor and the quality of air: the altitude of a place has a direct impact on the volumetric efficiency and higher altitude consumes more power.

3.6.3.2. Air intake

- Prevent air contamination from moisture, dust

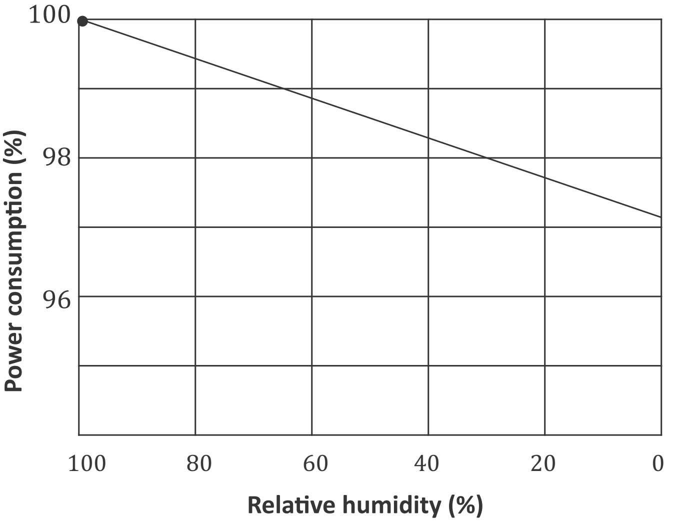


Figure 49. Effect of relative humidity and power consumption

Source: PECSME

- Maintain inlet air at low temperature 4°C rise in inlet air temperature results in a higher energy consumption by 1%
- Locate the inlet pipe of compressor outside the room or building so that the inlet air temperature can be kept at a minimum.

3.6.3.3. The pressure drop in air filter

- Install the air filter at the cool location
- The pressure drop across the intake air filter should be kept at a minimum.

For every 250 mm WC pressure drop increase across at the suction path due to choked filters, the compressor power consumption increases by about 2%.

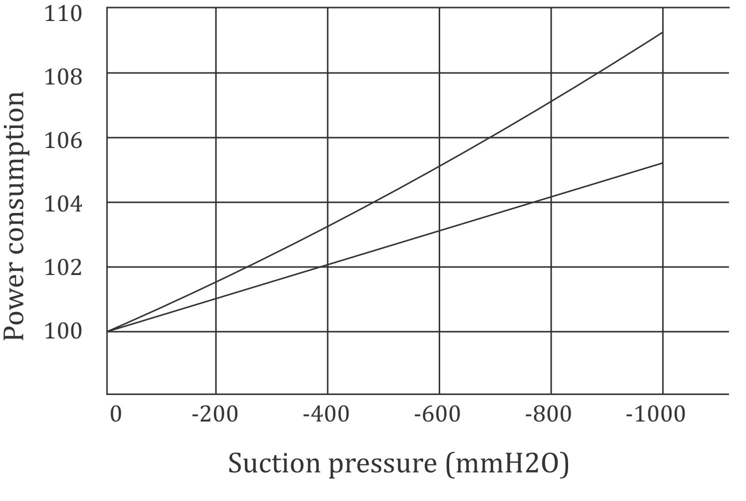


Figure 50. Effect of suction pressure and power consumption

Source: PECSME

According to above graph, the power consumption increases as the suction pressure decreases.

3.6.3.4. Inter-coolers and After-coolers

- The inlet air temperatures at subsequent stages are higher than the normal levels resulting in higher power consumption
- Intercoolers: Heat exchangers to remove the heat of compression between the stages
- After-coolers are installed after the final stage of compression to reduce the air temperature
- Use of cooling water at lower temperature reduces specific power consumption.

3.6.3.5. Pressure setting

- At higher delivery pressures: compressor consumes more power for the same capacity, the volumetric efficiency of a compressor is lower.
- Reducing delivery pressure
  - Operating a compressor at 100 PSIG instead of 120 PSIG, for instance, requires 10 percent less energy as well as reducing the leakage rate
  - A reduction in the delivery pressure by 1 bar in a compressor would reduce the power consumption by 6 – 10 %.
- Compressor modulation by optimum pressure settings
  - If all compressors are similar: only one compressor handles the load variation, whereas the others operate more or less at full load
  - If compressors are of different sizes, the pressure switch should be set such that only the smallest compressor is allowed to modulate (vary in flow rate)
  - If different types of compressors are operated together: The compressor with lowest no load power must be modulated.
- Segregating high and low pressure requirements: Using low pressure and high-pressure air separately and feed to respective demands.
- Minimum pressure drop in distribution line:
  - Pressure drop: the reduction in air pressure from the compressor discharge to the actual point-of-use
  - A properly designed system should have a pressure loss of much less than 10 % of the compressor's discharge pressure
  - Use a loop system to reduce pressure drop.

3.6.3.6. Minimizing leakage

- Use an ultrasonic leak detector
- Tightening a connection and a joints
- Replace faulty equipment.

3.6.3.7. Condensate removal

- Water vapor is condensed when compressor's after-cooler reduces the discharge air temperature
- Install condensate separator-trap to remove this condensation.

3.6.3.8. Controlled usage

- Don't's use for low-pressure applications such as agitation, pneumatic conveying or combustion air
- Use a blower that is designed for lower pressure operation.

3.6.3.9. Maintenance

- Lubrication: Inspect periodically (check oil level daily and change oil filter monthly)
- Air Filters: checked and replaced regularly
- Condensate Traps: Ensure to drain any accumulated fluid and compressed air is not leaked.
- Air Dryers: check and replace pre-filter or deliquescent dryers.

3.6.3.10. Heat Recovery

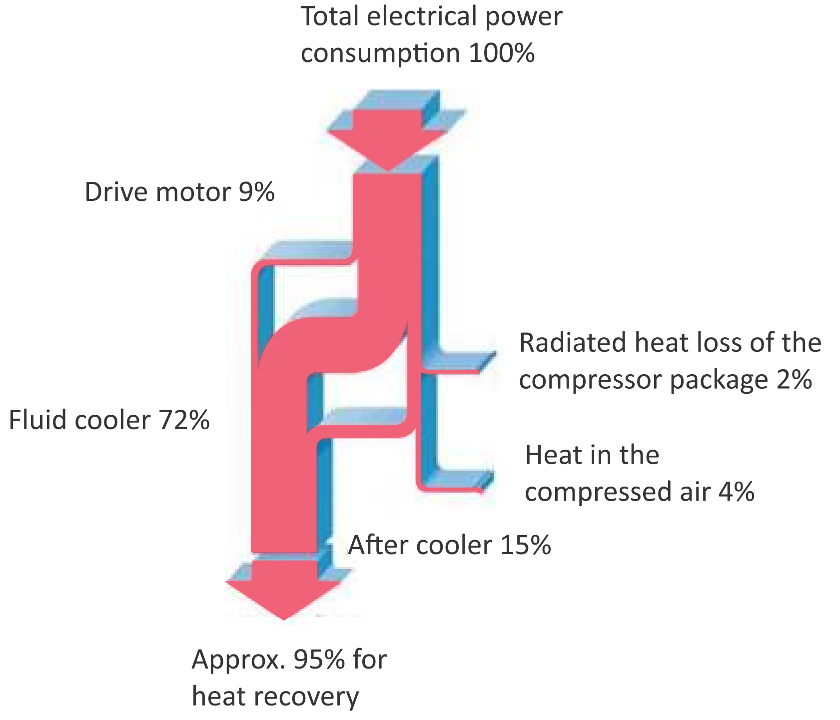


Figure 51. Heat recovery

Source: UNIDO

Average 85% of input energy is used to provide heat. Heat recovery depends on:

- Heat demand of factory
- The compatibility between the operation and the heat demand
- Distance from compressor station to user/distribution compressor pipeline.
- Temperature.

The application can recover heat from compressor such as:

- Building services: hot water, heating
- Process: drying and heating
- Preheat for boiler: intake water, air.

3.6.4. Data collection

Table 42. Base database to compressor system

Items		1	2	...
Compressor type				
Has VSD?				
No. of compressor stage				
Rated power	kW			
Compressor capacity	Nm^3/min.			
Intake pressure	bar			
Operating pressure (Load - Unload)	bar			
Load time	s			
Unload time	s			
Load power	kW			
Unload power	kW			
Intake air temperature	^0C			
Ambient temperature	^0C			
Condensate removal Type				
Leakage percent	%			

Table 43. Current compressors

No.	Manufacturer/type	Model / Cooling System	Compressor Fluid	Rated Motor Power	Type of Control (dual)	FAD (m^3)	Running / Load Hours	Load / Unload Pressure Settings	Power Consumption Load / Unload (kW)
1	/	/					/	/	/
2	/	/					/	/	/
3	/	/					/	/	/

Table 44. Components of compressor

Component Example: Flow Controller, Condensate Management, Dryer, Drain, Filter	Manufacturer	Model	Capacity (m^3)	Dew Point Temperature (°C)	Remark

Table 45 Tanks and relief valve

Tank 1: Volume: (m^3)				
MWP: (bar)	Pressure Gauge	Drain (select appropriate type below)	Relief Valve Set Pressure	Relief Valve Rated Capacity (m^3)
	Yes ☐ No ☐	Auto☐ Manual☐ Both☐		
Tank 2: volume: (m^3)				
MWP: (bar)	Pressure Gauge	Drain (select appropriate type below)	Relief Valve Set Pressure	Relief Valve Rated Capacity (m^3)
	Yes ☐ No☐	Auto ☐ Manual ☐ Both ☐		

Table 46. Master controllers and air main charging

Master Controller	Manufacturer	Model	Type of Control (cascade, pressure band)	Air Main Charging System
Yes ☐No ☐				Yes ☐ No ☐ Pipe Size (in/mm)

Table 47. Distribution system, pipe, connections, and distribution air line

Distribution Air Line						Drop Pipe-Connections		
System	Diameter	Material	Total Length	Connections	Does pipe extend outside?	Number of Connections	Diameter	Drops from top of header?
					Yes ☐ No ☐			Yes ☐ No ☐

Table 48. Compressor room measurements, openings etc.

Power Supply	(V) (Hz) (phase)		Power Costs $/kW-hr.
Cooling System	Water Inlet Temp. (°C)	Water Pressure [psig]	Water Costs $/per liter
Compressor Room	L x W x H (m) x (m) x (m)		
Number of Inlet Openings:	Cooling Air Exhaust: Yes ☐ No ☐	Heat Recovery: Yes ☐ No ☐	

Table 49. Air condition at compressor room

Ambient temp.			Elevation above sea level	Relative humidity		Room has Heating	Room has cooling	Quality of intake air
Min (°C)	Max (°C)	Current (°C)	(m)	(Avg.%)	(Max.%)			
						Yes ☐ No ☐	Yes ☐ No ☐	
Process of neighboring facilities:								

Table 50. Air requirements (Operating time, pressure demands)

No. of operating hours							
Day	Ca 1	Ca 2	Ca 3	**Weekend**	Ca 1	Ca 2	Ca 3
Hr/day				Hr/day			
Day/week				Day/week			
Average m^3/shift				Aver m^3/ca			
The minimum pressure required at user.	Current pressure of system	Do air systems turn on during unload time	Average capacity. m^3 during unload time	Required compressor quality			
				Pressure DP (°C)	Particle (micron)	Oil (mg/m^3)	
		Yes ☐ No ☐					
Depend on season:							

3.7. Air conditioning system

3.7.1. Introduction

Air conditioning is the process used to control or improve air condition (temperature, humidity) in a certain space.

The choice of which air conditioner system to use depends upon a number of factors including how large the area is to be cooled, the total heat generated inside the enclosed area, etc. An HVAC designer would consider all the related parameters and suggest the system most suitable for your space.

3.7.1.1. Unitary air condition system

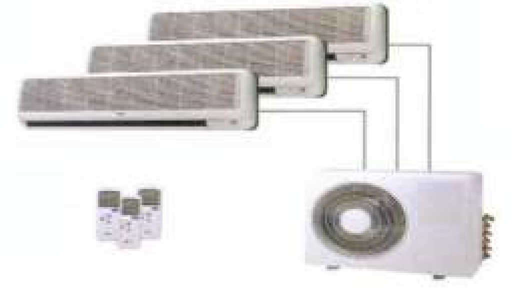
Unitary air condition system only adjusts air condition in narrow place, such as private room, small rooms.

Unitary air condition system has four common types:

- Window type
- Split type
- Multi-split type
- Cabinet.

Window type

Split type



Multi-split type

Cabinet

Figure 52. Air condition system types

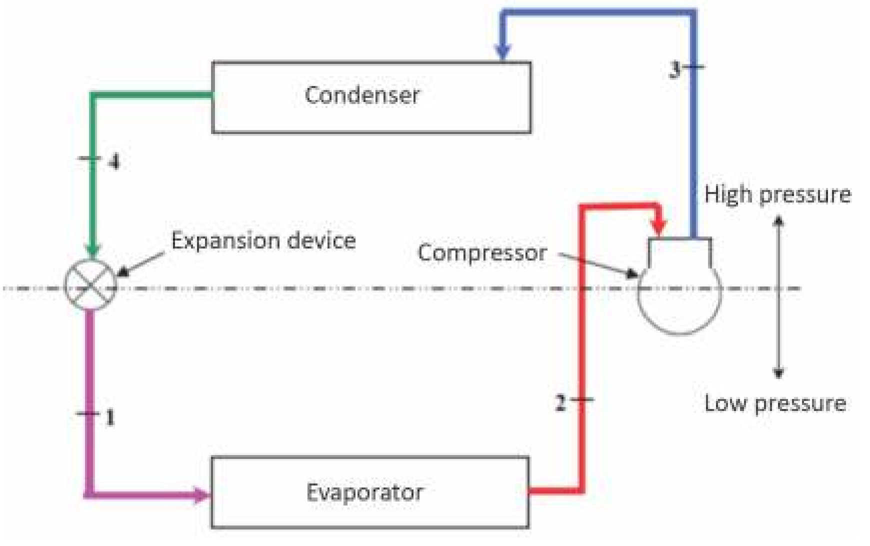
3.7.1.2. Central air conditioning system

Central air conditioning is used for cooling big buildings, offices, hotels, gyms, etc. If the whole building is to be air conditioned, HVAC engineers find that putting individual units in each of the rooms is very expensive making this a better option. A central air conditioning system is comprised of a huge compressor that has the capacity to produce hundreds of tons of air conditioning.

Figure 53. Air-cooled chiller

Figure 54. Water-cooled chiller

The refrigeration cycle is shown as below:



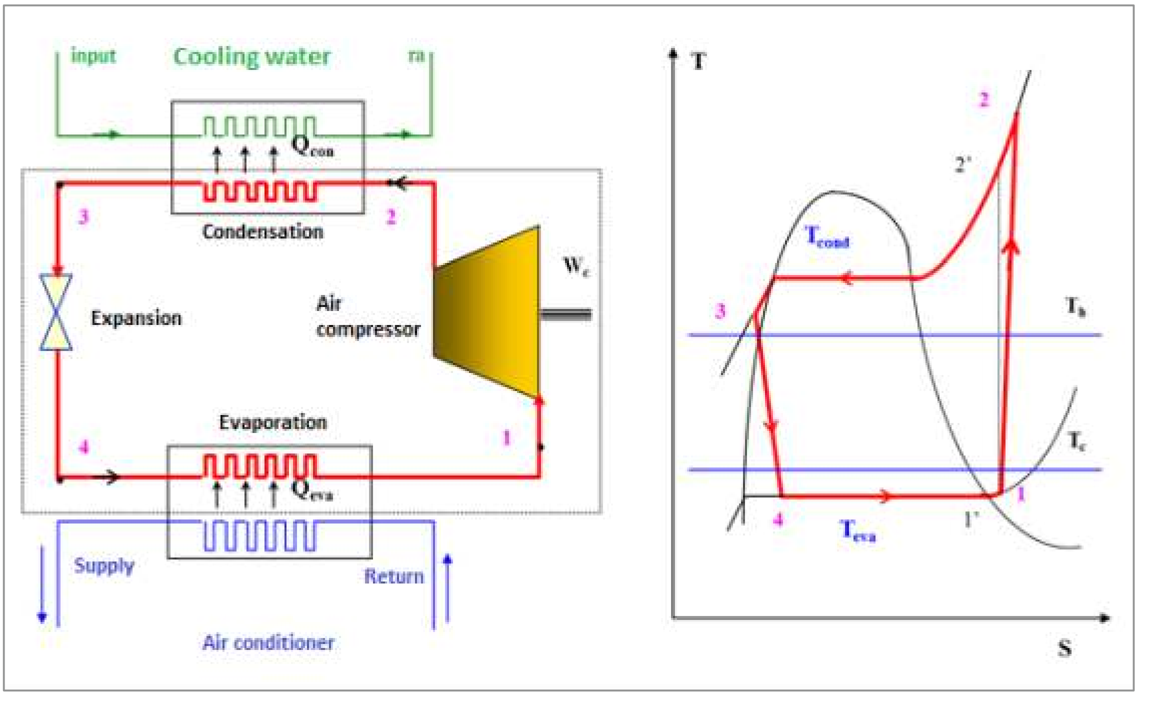


Figure 55. Operating Principles of air conditioner

Source: BEE, 2004

- 1-2: Compression: The superheated vapour enters the compressor where its pressure is raised. The temperature also increases
- 2-3: Condensation: The high pressure superheated gas turned back into liquid in the condenser. The refrigerant liquid is sub-cooled
- 3-4 Expansion: The high-pressure sub-cooled liquid passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator
- 4-1 Evaporator: Low pressure liquid absorbs heat from its surrounding, changes its state from a liquid to low pressure gas.

3.7.2. Assessment of air conditioning

3.7.2.1. Coefficient of performance:

COP = Useful Cooling (Qeva)/Power (P)

- The theoretical coefficient of performance (Carnot), (COP_{carnot} a standard measure of refrigeration efficiency of an ideal refrigeration system):

$$COP_{Carnot} = \frac{T_e}{T_c - T_e}$$

T_e : Evaporator temperature

T_c: Condenser temperature

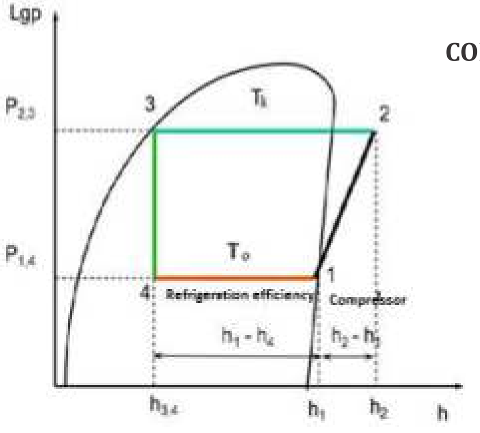
- Actual COP:

$$COP = \frac{Q_{eva}}{W_c} = \frac{h_1 - h_4}{h_2 - h_1}$$

Q_{eva} = cooling effect

W_c = power input to compressor.

h1, h2, h3, h4= enthalpies of refrigerant at states 1, 2, 3, 4.



$$COP = (h_1 - h_4)/(h_2 - h_1)$$

$$COP_{Carnot}$$

$$COP = \frac{T_o}{T_k - T_o}$$

$$PIC = \frac{1}{COP}$$

Figure 56. Calculation method of COP

3.7.2.2. Assess actual cooling performance cooling:

- Collect information about HVAC systems (HVAC type, design capacity, refrigerant, design COP...)
- Collect operating information (inlet pressure, outlet pressure, evaporation temperature, condense temperature, electrical consumption). Data can be collected through the screen monitor or measured by hand instruments.

Figure 57. HVAC system data collection

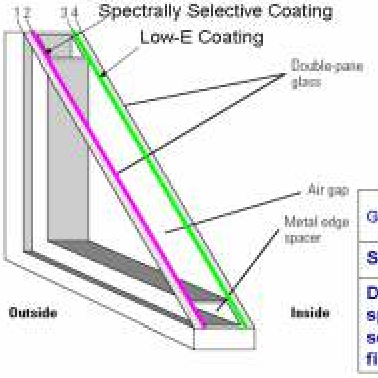
- Calculate theoretical cooling capacity and COP. Each refrigerant has particular thermodynamic parameters.

3.7.3. Energy savings measures

HVAC system consumes a lot of energy in building or factory. Therefore, there are many opportunities for energy saving. Some methods are listed below:

3.7.3.1. Prevent heat penetration from outside

Prevent heat penetration from outside by using double layers of glass and reflective glass lamination.



Glass type	Heat %	Light %	U-Value W/m2K
Single	85	85	6
Double, spectrally selective, gas filled	25	50	1

Figure 58. Glass properties

- Keep doors or windows closed

3.7.3.2. Limit internal heat sources inside the conditioned space

Heat sources come from the power consumption devices: lighting, motors, or cooking…

The determination of heat sources can be detected by the infrared instrument.

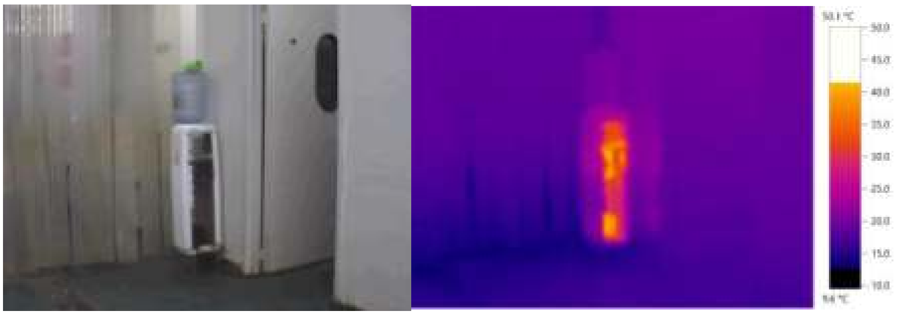


Figure 59. Detect heat sources inside HVAC space

When the heat source is identified, remove them from conditioned space to reduce waste energy.

3.7.3.3. Maintain the heat exchanger

Maintenance helps the air conditioner to operate efficiently. According to the below table, effective maintenance is the important key for optimized power consumption:

Table 51. Table of effective maintenance for power consumption of the compressor

Condition	Evaporation temp (°C)	Condensation temp (°C)	Refrigeration capacity (tons)	Specific power consumption (kW/ton)	Increase in kW/ton (%)
Normal	7.2	40.5	17.0	0.69	
Dirty condenser	7.2	46.1	15.6	0.84	20.4
Dirty evaporator	1.7	40.5	13.8	0.82	18.3
Dirty condenser and evaporator	1.7	46.1	12.7	0.96	38.7

Source: Asia Energy Efficiency

3.7.3.4. Matching Capacity to System Load

During part-load operation, the evaporator temperature rises and the condenser temperature falls, effectively increasing the COP. But at the same time, deviation from the design operation point and the fact that mechanical losses form a greater proportion of the total power negate the effect of improved COP, resulting in lower part- load efficiency. Therefore, consideration of part-load operation is important, because most refrigeration applications have varying loads.

3.7.4. Data collection

- Collect information about HVAC systems
  - HVAC type
  - Design capacity
  - Refrigerant
  - Design COP...
- Collect operating information:
  - Inlet pressure, Outlet pressure
  - Evaporation temperature
  - Condense temperature,
  - Electrical consumption

Data can be collected through the screen monitor or measured by hand instruments.

3.8. Industry refrigeration system

3.8.1. Introduction

3.8.1.1. Overview of refrigeration system

The refrigeration system is used to cool the air or a product. In order to maintain the temperature of cool air, the input work is required to remove heat from a cool area and transfer to warm area.

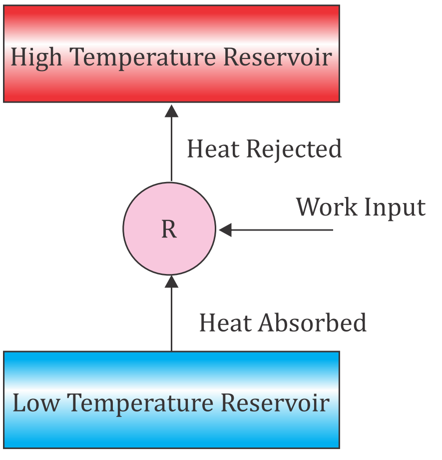


Figure 60. The refrigeration cycle

Source: Asia Energy Efficiency

3.8.1.2. Characteristics of refrigeration system

There are 4 main components in refrigeration system: compressor, condenser, expansion device, and evaporator. The refrigeration cycle of refrigeration system is similar to the one of air conditioning system. Please refer to section 3.7 for more details.

The most commonly types of compressors in industrial refrigeration systems are reciprocating compressor, screw compressor, piston compressor, and centrifugal compressor.

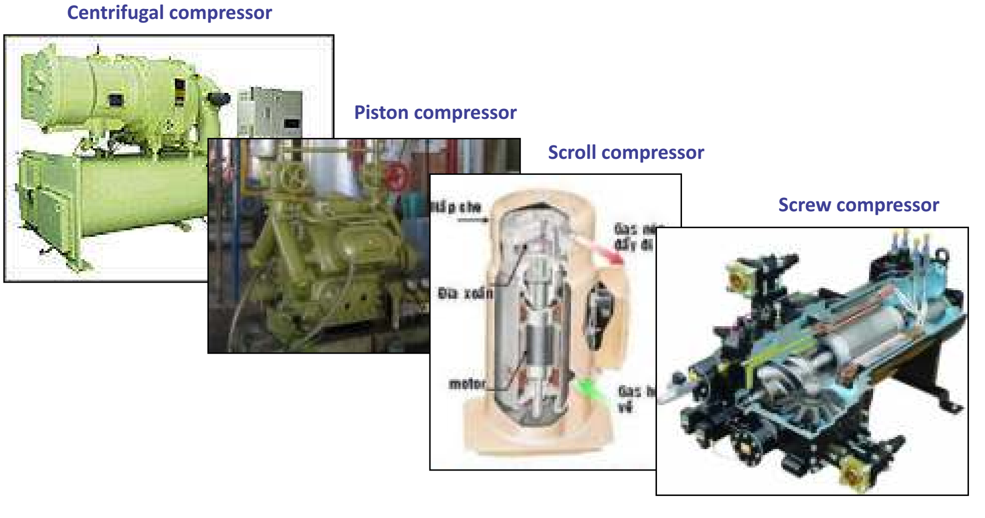


Figure 61. Basic types of compressors

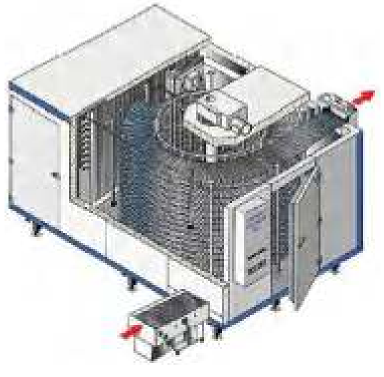
The power consumption of compressor is almost 70% of the total power consumption of the refrigeration system. Therefore, proper design is the key to reduce the power consumption and improve its efficiency of a refrigeration system.

3.8.1.3. Application of refrigeration system

The industry refrigeration system is commonly used in the central air conditioning of building, refrigerators, chilled water plants, etc.

Some common applications are:

- Individual Quick Freezer (IQF): which is used to freeze products individually rather than in a group. The speed of the conveyor can be adjusted to meet actual demand



Spiral Freezer

Straight Freezer

Impingement Freezer

- Contact Freezer & Air-Blast Freezer are designed to freeze amounts of goods, for instance food production.

Contact Freezer

Air-Blast Freezer

- Cold Storage is used to store frozen foods products.

Cold Storage

- Ice machines: Block Ice Machine and Flake Ice Machine

Block Ice Machine

Flake Ice Machine

3.8.1.4. Basic data

The basic parameters of a refrigeration system, which need to be collected are the load, temperature and refrigeration time. If the operating parameters of a refrigeration system are not available, the design parameters can be used for assessment.

- Cooling Capacity

$$Q\ (kW) = m * Cp * (t_i - t_0)$$

m : mass flow rate of coolant, kg/s.

Cp: coolant specific heat in kJ/kg ^0C

t_i : inlet temperature of coolant to evaporator, ^0C.

t_0 : outlet temperature of coolant from evaporator, ^0C.

The specific power consumption kW/TR is a useful indicator of the performance of a refrigeration system. By measuring the refrigeration duty performed in TR and the kW inputs, kW/TR is used as an energy performance indicator.

In a centralized chilled water system, apart from the compressor unit, power is also consumed by the chilled water (secondary) coolant pump, the condenser water pump (for heat rejection to cooling tower) and the fan in the cooling tower. Effectively, the overall energy consumption would be the sum of power consumption of:

- Compressor kW
- Chilled water pump kW
- Condenser water pump kW
- Cooling tower fan kW, for induced / forced draft towers
- Evaporator kW.

- Coefficient of Performance

$$COP_{Carnot} = T_e / (T_c - T_e)$$

T_e is evaporator temperature and

T_c is the condenser temperature

This equation also indicates a higher COP_{Carnot} is achieved with higher evaporator temperatures and lower condenser temperatures. But COP_{Carnot} is only a ratio of temperatures, and does not take into account the type of compressor. Hence the COP normally used in industry is calculated as follows:

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

3.8.2. Energy flow

The following figure describes the refrigeration cycle of industrial refrigeration system:

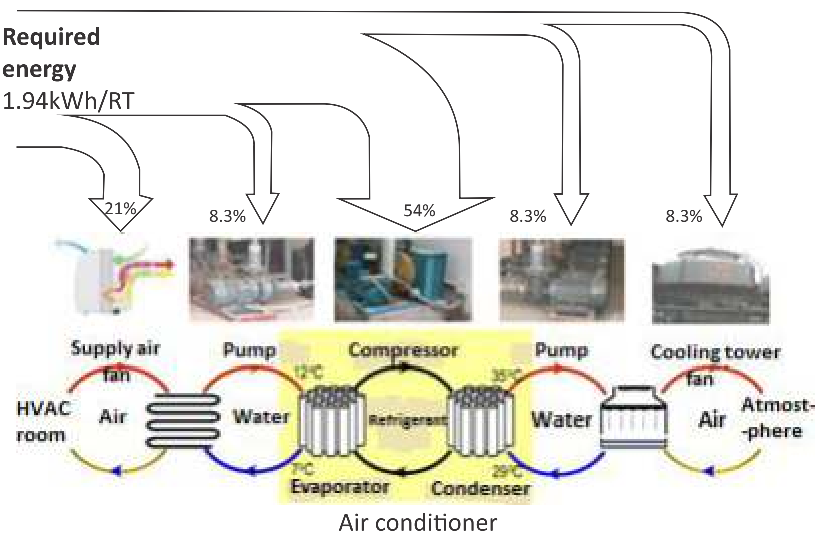


Figure 62 Typical heat transfer loop in refrigeration system

Source: Enerteam

3.8.3. Energy savings measures

3.8.3.1. Compressor

In order to generate energy savings the factory could consider either to replace the low efficiency compressor with the high efficiency compressor or to install VSD for the compressor.

- Replacing a piston compressor with screw compressor

Piston Compressor

Screw Compressor

- The Installation of VSD for the compressors with variable loads would reduce the power consumption of compressor but it also reduces the compressor efficiency
- Avoid part-load operation: two compressors operating at 60% of full load consume less power than a compressor operating at 100% full load and a compressor operating at 20% of full load.
- The temperature of coolant in piston compressor is usually greater than 100^{0}C. Therefore, heat exchanger can be installed to remove the heat from coolant and use this heat for process

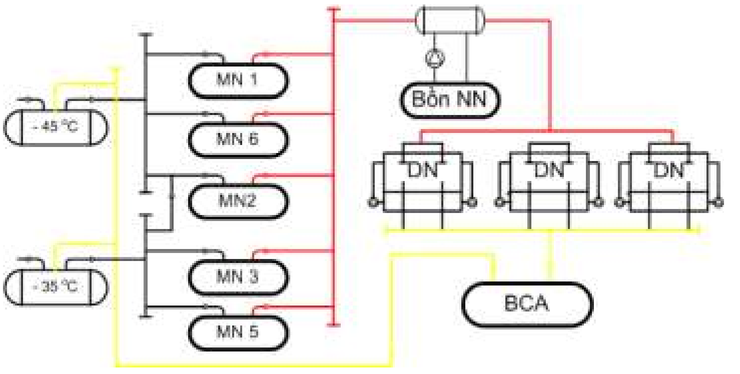


Figure 63. Diagram of Heat Recovery from discharge outlet from compressor

- Reduce condenser temperature: the 5.5°C reduction of condenser temperature will reduce 20-25% of power consumption
- Apply the control system for the refrigeration compressor.

Operating compressor at the partial load or improperly will reduce the efficiency of the refrigeration system. It is obvious when the refrigeration system has multiple compressors or the demand of refrigeration various. The efficiency of a screw compressor can be reduced by 30% when it operates at partial load as illustrated in the following figure.

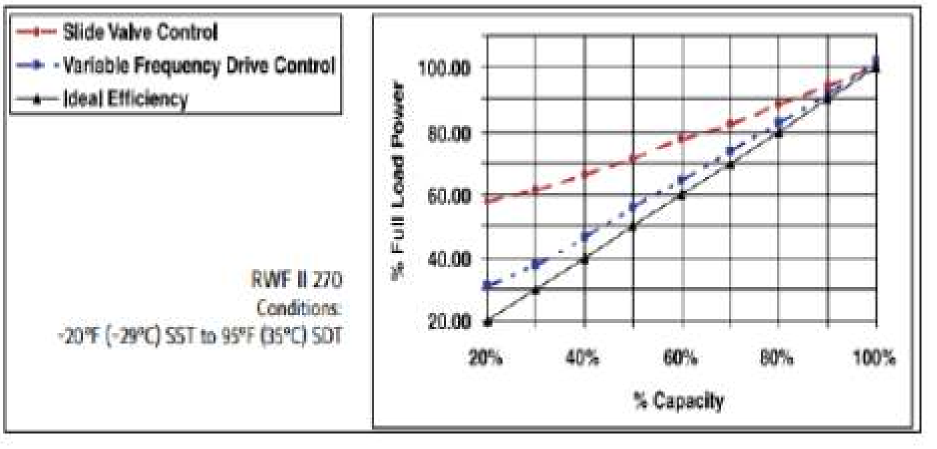


Figure 64. Comparison of power consumption by different regulation methods (screw compressor)

According to the figure above, highlights the fact, power consumption is still relatively high even though the capacity is reduced by 50% using a slide valve control. This can be avoided by using a proper control system.

For a new or updated refrigeration compressor, the control system solution can be relevant under the following circumstances:

- The existing system is old and equipped with old control system.
- The refrigeration system has changed from its original design (multi units)
- Loads or operation patterns have changed.
- VSD has been installed for some of the compressors
- The refrigeration plant consists of different type and/or sizes of compressors
- There is no functioning compressor control system.

3.8.3.2. Optimize the evaporator

The inlet pressure of a compressor is important for power consumption of refrigeration system. A 1°C raise in evaporator temperature can save almost 3 % of the power consumed.

It is generally observed that the evaporator pressures are much too low compared to the required cooling temperature of an industrial refrigeration in Vietnam This is caused by a number of reasons:

- Too small evaporators
- Plate heat exchangers are not used (drums/spirals or old and poor technology)
- Moist (ice) has built up on the evaporator.

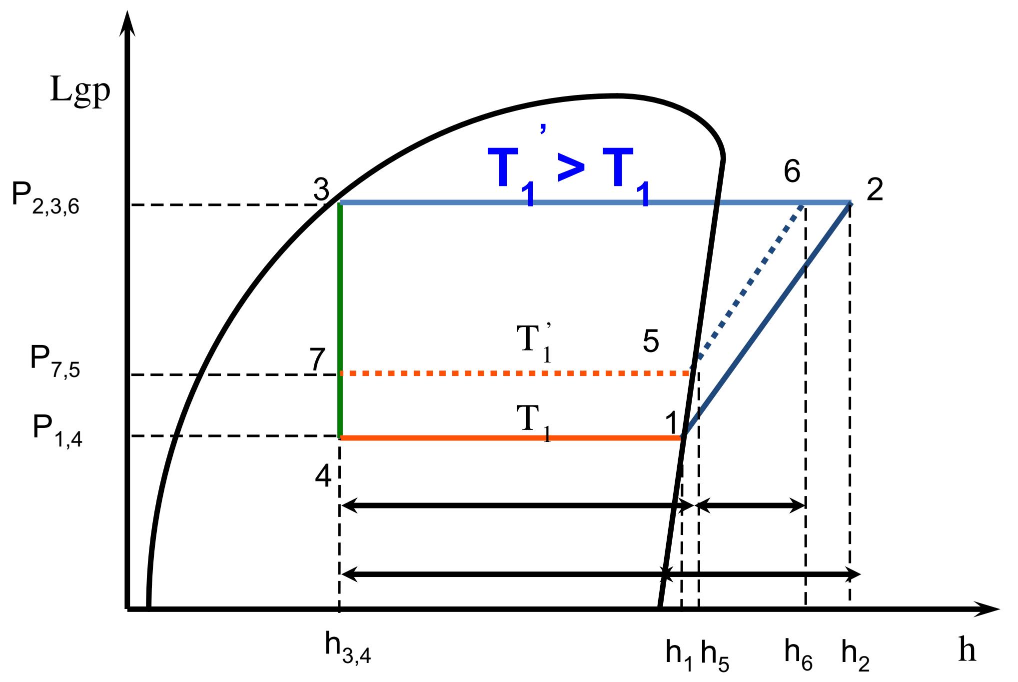


Figure 65. Relationship of the condensation temperature and the performance of the refrigeration

According to the above figure, when the evaporation temperature rises, the required input work is reduced ($h_6 - h_5 < h_2 - h_1$) and the cooling effect is increased ($h_1 - h_4 < h_5 - h_7$). Therefore, the COP of the refrigeration system will be increased. The COP is very dependent on the evaporation temperature.

In practice, this means that if the temperature difference of the two mediums at the coolest point is greater than 2 ºC (see below), there is room for improvements since 2 ºC delta-T is the optimal design.

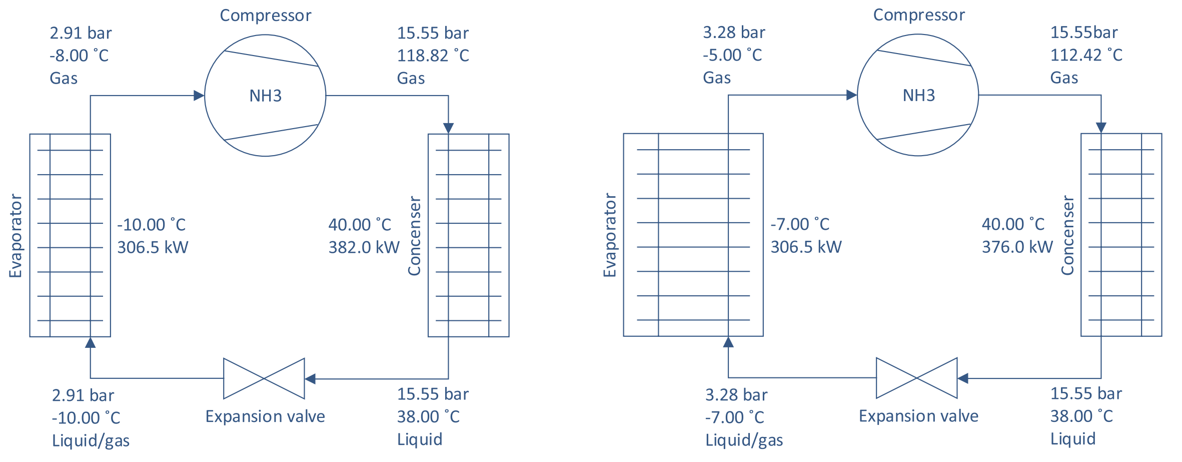


Figure 66. Principle schematic of two refrigeration systems with the different of the cevaporator temperature

Source: LCTU (MOIT)

The only difference is the size of the evaporator. By increasing the size of the evaporator the temperature increase from -10ºC (left part of figure) to -7ºC (right part of figure),which saves much as 9% of the power consumption of the compressor.

The table below illustrates the effect of the evaporator temperature on the compressor power consumption:

Table 52. Effect of variation in evaporator temperature on the compressor power consumption

Evaporator temperature (°C)	Refrigeration capacity* (ton)	Specific power consumption	Increase in kW/ton (%)
5,0	67,58	0,81	
0,0	56,07	0,94	16,0
-5,0	45,98	1,08	33,0
-10,0	37,20	1,25	54,0
-20,0	23,12	1,67	106,0

Note: * Condensate temperature at 40°C

Source: Asia Energy Efficiency

In order to improve the efficiency of the evaporator, there are some requirements:

- Perform periodic maintenance for evaporator. Remove obstacles on air fan.
- Inspect the expansion device.
- Replace the manual valve with automation valve.
- Determine the proper heat transfer areas as well as rationalize the temperature requirement to highest possible value.

3.8.3.3. Optimize the condenser

The condensation temperature is also as important as the evaporation temperature. A 1°C raise in condensation temperature consumes additional 3% of the power consumption of a refrigeration system. The condensation temperature and its corresponding pressure of any refrigerant are dependent on the heat transfer area, the effectiveness of heat exchange and the type of cooling chosen. The requirements to improve efficiency of condenser are similar to the ones of evaporator. The below table illustrates the effect of variation in condenser temperature on the compressor power consumption.

Table 53. : Effect of variation in condensate temperature on the compressor power consumption

Condensing Temperature (°C)	Refrigeration Capacity (tons)	Specific Power Consumption (kW / TR)	Increase in kW/TR (%)
26.7	31.5	1.17	-
35.0	21.4	1.27	8.5
40.0	20.0	1.41	20.5

It is generally observed that condenser pressures of industrial refrigeration in Vietnam is too high, which is caused by a number of reasons:

- Poorly maintained (fouled) condensers
- Air in the condensers
- Too small condensers
- Inefficient operation of the condensers.

The saving potential for this measure is high due to influence on all cooling devices connected to the condenser. If all condensers are changed or removed it is possible to save 5 to 15% of the total electricity used for refrigeration. Investments in such measures will have medium to high payback-periods

However, if the measure is introduced at the same time as more refrigeration capacity is introduced, investments and payback period for the extra size of the condenser might be low.

3.8.3.4. IQF Freezer

The energy saving could be obtained for IQF system by the following measures

- By Increasing the evaporation pressure while maintain the required temperature a 5.5°C raise in evaporator temperature can save 20 - 25% of the power consumed.
- Pre-cool the product before they are frozen
- Use 2-stage IQF freezer

Energy loss in the IQF freezer includes:

- Losses due to poor insulation
- Losses due to mechanical friction of the fan or the motor of conveyor
- Loss through openings in the refrigeration system.

3.8.3.5. Contact freezer and air blast freezer

The energy saving could be obtained by the following measures

- Ensure the freezer is full with products
- Install the Variable Frequency Drive (VFD) to slow evaporator fans for low demands
- Pre-cool the product before transferring into freezer.

Energy loss in the Air Blast Freezer includes:

- Loss due to poor insulation
- Loss due to auxiliary devices in the freezer.

3.8.3.6. Cold storage

Energy saving could be obtained for cold storages by implementing the below measures

- Close the door immediately after going in and going out. Install automatic door closer

- Ensure the insulation of storage is still good in service.
- Keep monitoring the inside temperature and outside temperature of storage.

3.8.3.7. Flake ice machine

Energy saving could be obtained for flake ice machines by implementing the below measures

- Operate at non-peak schedule
- Pre-cool the water before transferring into machine
- Well insulated.

3.8.4. Data collection

In order to assess the performance of the refrigeration system, a template of data collection to audit a refrigeration system is proposed as below:

Section no.	Refrigeration compressor	Unit	Machine reference			
			1	2	3	4
1	Make					
2	Type					
3	Capacity (of cooling)	TR				
4	**Chiller:**					
A	No. of tubes	..				
B	Dia. of tubes	m				
C	Total heat transfer area	m^2				
D	Chilled water flow	m^3/h				
E	Chilled water temp. difference	^0C				
5	**Condenser**					
A	No. of tubes					
B	Dia. of tubes					
C	Total heat transfer area	m^2				
D	Condenser water flow	m^3/h				
E	Condenser water temp. difference	^0C				
6	**Chilled water pump**					
A	Nos	..				
B	Capacity	m^3/h				
C	Head developed	mWC				
D	Rated power	kW				
E	Rated efficiency	%				
7	**Condenser water pump**					
A	Nos	..				
B	Capacity	m^3/h				
C	Head developed	mWC				
D	Rated power	kW				
E	Rated efficiency	%				

8	Cooling tower					
A	Nos	..				
B	Cooling capacity	kCal/h				
C	Air volume	m^3/h				
D	Rated power fan	kW				
E	Inlet cooling water temp.	ºC				
F	Outlet cooling water temp.	ºC				
G	Ambien temp.	ºC				

3.9. Boiler

3.9.1. Introduction

3.9.1.1. Steam

Steam is the common medium to transfer heat to a process. Usually it is produced by boilers and distributed through distribution steam system. Advantages of steam are:

- Low risk
- Inexpensive
- High heat transfer coefficient
- Easy to distribute
- Easy to control.

In order to determine the state of the heat transfer fluid (steam) three systems parameters: are used to define the state of water: Pressure, Temperature, Specific volume.

Steam table:

Table 54. Properties of saturated water and steam

Pressure		Temperature	Specific enthalpy of evaporation			Volume dry sat.
Bar	kPa	°C	Water (kJ/kg)	Latent heat (kJ/kg)	Saturated steam (kJ/kg)	m³/kg
0	0	100	419	2257	2676	1.673
0.5	50	112	468	2226	2694	1.149
1.0	100	120	506	2201	2702	0.880
1.5	150	128	536	2181	2717	0.714
2.0	200	134	562	2163	2725	0.603
3.0	300	144	605	2133	2738	0.461
4.0	400	152	641	2108	2749	0.374
5.0	500	159	671	2086	2757	0.315
6.0	600	165	697	2066	2763	0.272
7.0	700	170	721	2048	2769	0.240
10.0	1000	184	782	2000	2782	0.177
14.0	1400	198	845	1947	2792	0.132

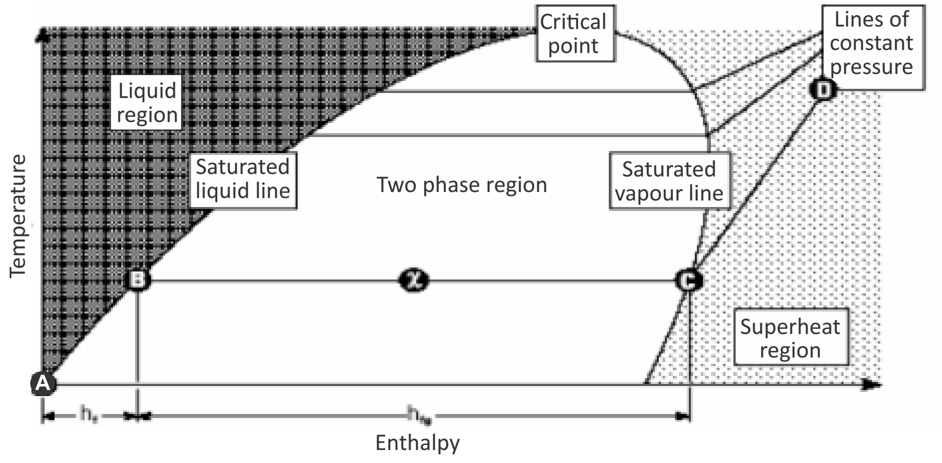


Figure 67. Steam phase diagram

Source: Asia Energy Efficiency

The above figure describes the relationship between the enthalpy and the temperature of water and steam at different pressures. The liquid region or water region is on the left side of saturated liquid line and the superheated region or superheated steam region is on the right side of saturated vapor line. The saturated vapor line and saturated liquid line intersect at the critical point and create an envelope of two phase regions.

The line ABCD describes the phase change of water at the constant pressure. Initially, Water is heated from subcooled liquid temperature (point A) to saturation temperature (point B). If further heat continues to be added, liquid water will be converted gradually from saturated liquid (point B) to saturated vapor (point C) at constant saturation temperature until it reaches 100% vapor. If heat is still heated, the saturated vapor (point C) will be converted to superheated vapor (point C – point D). The temperature will be increased during converting to superheated steam.

3.9.1.2. Boiler introduction

A boiler is an equipment that transfers heat energy from the combustion of fuels to water in order to convert water to steam. A boiler produces steam at various pressures to supply for different demands.

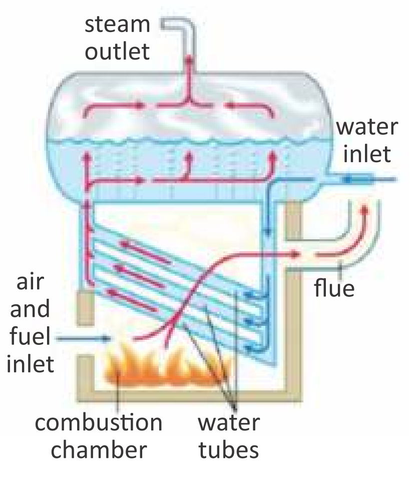


Figure 68. Simple diagram of Tube boiler

Boiler examples

- Fire Tube Boiler

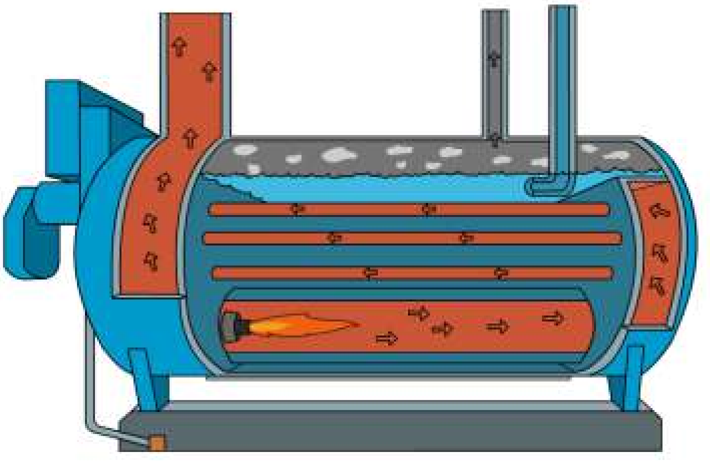


Figure 69. Fire tube boiler

Table 55. Advantage and disadvantage of Fire tube boiler

Advantages	Disadvantages
Used for small scale Easy to operate and maintain Inexpensive	Require time to fill water Require longer time to increase pressure Steam might contain water

- Water tube boiler:

Figure 70. Water tube boiler

Table 56. Advantage and disadvantage of water tube boiler

Advantages	Disadvantages
Higher thermal efficiency Able to produce superheated steam Customizable design	More complex construction Complex control systems required

- Water tube boiler with steam drum:

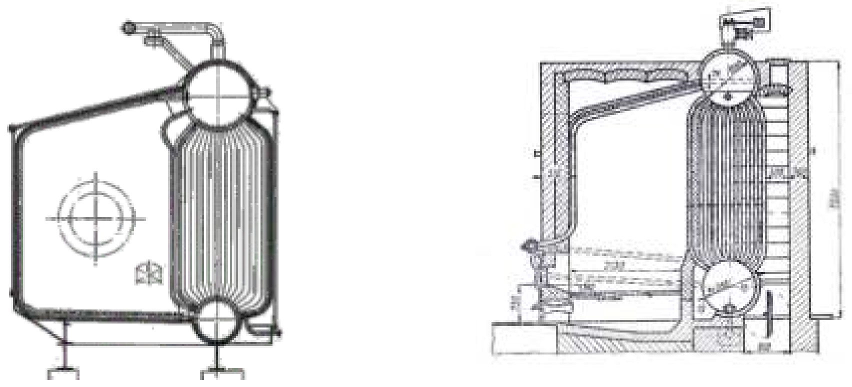


Figure 71. Water tube boiler with steam drum

Table 57. Advantage and disadvantage of water tube boiler with steam drum

Advantage	Disadvantage
- Suitable for all fuels - High parameters (capacity, pressure, ability to produce superheated steam). - Good circulation. - Bended pipe: able to self-expand.	- Bulky size - Long installation time - High capital investment - High water quality requirements - Complex operation (blow down at multiple positions) - Difficult cleaning of pipe surface

Cost of generating steam from boiler can be estimated by the following formula:

$$\textbf{Sc (VND/kg)} = \frac{(h''-h')}{\eta} \times \frac{R}{(D \times GCV)}$$

h'' : enthalpy of steam (kcal/kg)

h' : enthalpy of boiler feed water (kcal/kg)

η *: boiler efficiency (%)*

R : fuel cost (VND/lit)

D : density (kg/lit)

GCV: Gross Calorific Value (kcal/kg)

3.9.1.3. Boiler efficiency evaluation

Boiler efficiency can be evaluated by data collection and calculation as decribed below:

- Boiler efficiency is calculated directly by following formula:

$$\textbf{Boiler efficiency} = \frac{Q \times (hg - hf)}{q \times GCV} \times 100$$

Q (kg/hr): Steam generated per hour

h_s (kcal/kg): Enthalpy of saturated steam

h_w (kcal/kg): Enthalpy of feed water

m (kg/hr): fuel used per hour

GCV (kcal/kg of fuel): Gross calorific value of fuel

Example:

Steam generated: 2.5 ton / hr

Quantity of Diesel FO : 180 liters/ hour (density: 0.95 kg / liter)

Feed water temperature : 85^{0}C

GCV of Diesel FO : 9.800 kCal/kg

Enthalpy of steam at 8 kg/cm2: 666 kCal/kg (saturated steam)

Enthalpy of feed water: 85 kCal/kg

Boiler efficiency :

$$\frac{2500 ´ (666- 85)}{180 ´ 0,95 ´ 9800} ´ 100 = 86,67\%$$

Advantages	Disadvantage
Few required parameters Quick calculation Few required instruments	Unable to define specific losses

- The boiler efficiency can be calculated by indirect method. This methodology requires data of the principle losses:

$$\textbf{Boiler Efficiency} = 100\% - (q_1 + q_2 + q_3 + q_4 + q_5 + q_6 + q_7)$$

Heat losses due to:

q1 (%) : Dry flue gas

q2 (%) : Hydrogen in fuel burnt

q3 (%) : Moisture in fuel

q4 (%) : Moisture in air

q5 (%) : Unburnt fuel in fly ash

q6 (%) : Unburnt fuel in bottom ash

q7 (%) : Radiation and other unaccounted losses.

The heat loss through the boiler is determined by the boiler heat balance

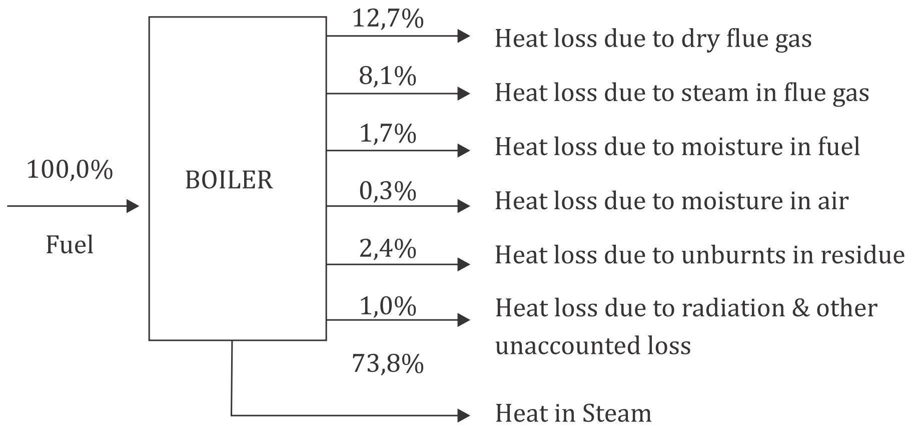


Figure 72. Typical losses from coal fired boiler

Source: Asia Energy Efficiency

The following Excel template shows an example of boiler efficiency by using an indirect method (including formulas):

Table 58. Boiler efficiency calculation

#	Parameter	Unit	Value: Coal	Value: Diesel FO
1	**Absolute Analysis**		**Coal**	**Diesel FO**
	Carbon	%	46.15	82.7
	Hydro	%	3.06	10.9
	Oxy	%	10.21	0.5
	Sulphur	%	0	3.5
	Nitrogen	%	1.58	0.4
	Moisture	%	7.2	0.1
	Ash	%	31.8	0.1
2	GCV of fuel	KCal/kg	4400	9856
3	O_2 in flue gas	%	9	7.8
4	CO_2 in flue gas	%	8.5	9.9
5	flue gas temperature (T_f)	^0C	180.4	181
6	Ambient temperature (T_a)	^0C	31	31
7	Moisture in air	Kg/kg dry gas	0.018	0.018
8	Ash content	%	10	0
9	GCV of ash	KCal/kg	800	0
10	Excess Air (EA) $(O_2 \times 100)/(21 - O_2)$	%	**75**	**59**
11	Theoretical Air Requirement (TAR) $[11.43 \times C + \{34{,}5 \times (H_2 - O_2/8)\} + 4{,}32 \times S]/100$	kg/ kg of fuel	**5.89**	**13.34**
12	Actual air supplied (AAS) {1 + EA/100} x theoretical air	kg/ kg of fuel	**10.31**	**21.23**
13	% heat loss due to dry flue gas $\{k \times (T_f - T_a)\}$ / % CO2 Where k = 0,65 for coal = 0,56 for Diesel = 0,40 for Natural Gas	**%** **Input K** **0.65**	**11.42**	**8.48**
14	% heat loss due to evaporation of water formed due to H2 in fuel $[9 \times H2\ \{584 + 0{,}45(T_f - T_a)\}]$/ GCV of fuel	%	**4.08**	**6.48**
15	% heat loss due to evaporation of moisture present in fuel $[M \times \{584 + 0{,}45 \times (T_f - T)\}]$ / GCV of fuel	%	**1.07**	**0.01**
16	% heat loss due to moisture present in air $\{AAS \times \text{Humidity Factor} \times 0{,}45\ (T_f - T_a) \times 100\}$ / GCV fuel	%	**0.28**	**0.26**
17	% heat loss due to unburnt fuel in ash {ash x (100 – burnt fuel in ash) x GCV of ash /100} / GCV fuel	%	**5.20**	**0.00**
18	heat loss due to radiation and other accounted loss	%	**2.00**	**2.00**
19	Total loss	%	**24.05**	**17.24**
20	Efficiency	%	**75.95**	**82.76**

3.9.2. Energy flow

Sankey diagram

The following Sankey diagram illustrates how the input energy from the fuel is transformed into the steam energy and energy loss flows. Major losses are stack gas losses, blow down losses, and losses by unburnt fuel in stack and ash.

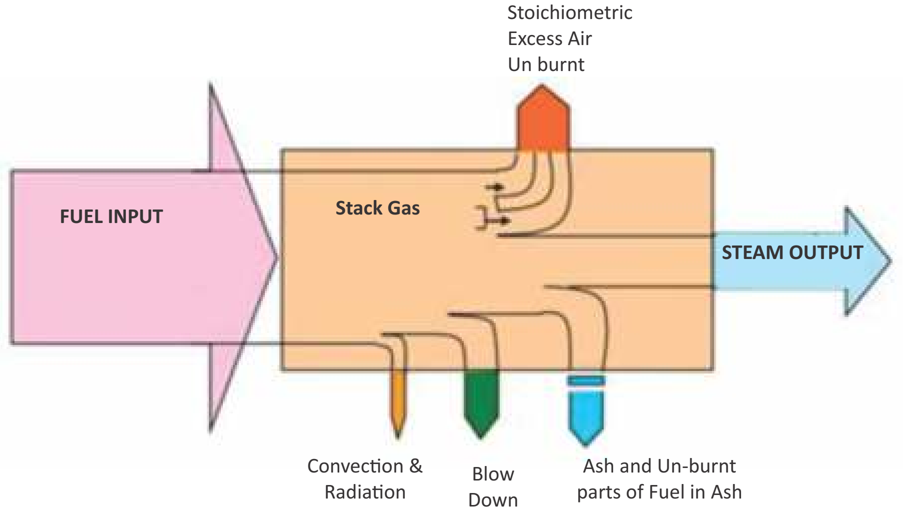


Figure 73. Sankey diagram of boiler

Source: Asia Energy Efficiency

3.9.3. Energy saving measures

3.9.3.1. Insulate heated piping system and users

Heat loss will occur if the piping system and equipment are not well insulated. The amount of heat loss is described in the following tables:

Table 59. Heat loss due to uninsulation

Temperature difference steam to air ^{o}C	Pipe size									
	15 mm	20 mm	25 mm	32 mm	40 mm	50 mm	65 mm	80 mm	100 mm	150 mm
	W/m									
56	54	65	79	103	108	132	155	188	233	324
67	68	82	100	122	136	168	198	236	296	410
78	83	100	122	149	166	203	241	298	360	500
89	99	120	146	179	205	246	289	346	434	601
100	116	140	169	208	234	285	337	400	501	696
111	134	164	198	241	271	334	392	469	598	816
125	159	191	233	285	285	394	464	555	698	969
139	184	224	272	333	333	458	540	622	815	1133
153	210	255	312	382	382	528	623	747	939	1305
167	241	292	357	437	437	602	713	838	1093	1492
180	274	329	408	494	494	676	808	959	1190	1660
194	309	372	461	566	566	758	909	1080	1303	1852

Source: Enerteam

Table 60. Heat loss calculation due to uninsulation

Heat loss of 1m piping		501	W/m
	Length of piping	32	m
	Heat loss	16,032	W
	Steam pressure	**5**	bar
Production information	Operating time	7,920	hr/year
	Cost of steam generation	516,250	VND/ton
	Equivalent steam loss	**20.94**	kg/hr
	Waste money	**85,609,121**	VND/year

REQUIRED INSULATION THICKNESS			
	Steam temperature	**150.9**	^{0}C
	Outer diameter	100	mm
Piping	Inner diamete	90	mm
	Heat transfer coefficient	50	W/m.C
	Insulation temperature	50	^{0}C
Insulation	Heat transfer coefficient	0.051	W/m.C
	Unwanted heat loss	100	W/m
	Insulation+B12:F41 thickness	**19**	mm

3.9.3.2. Install economizers to recover heat for feed-water preheating

A flue gas of boiler is usually discharged at high temperature. Therefore, recovering heat from flue gas to preheat the feed water is a beneficial energy saving measure. An additional economizer is an essential equipment for this measure.

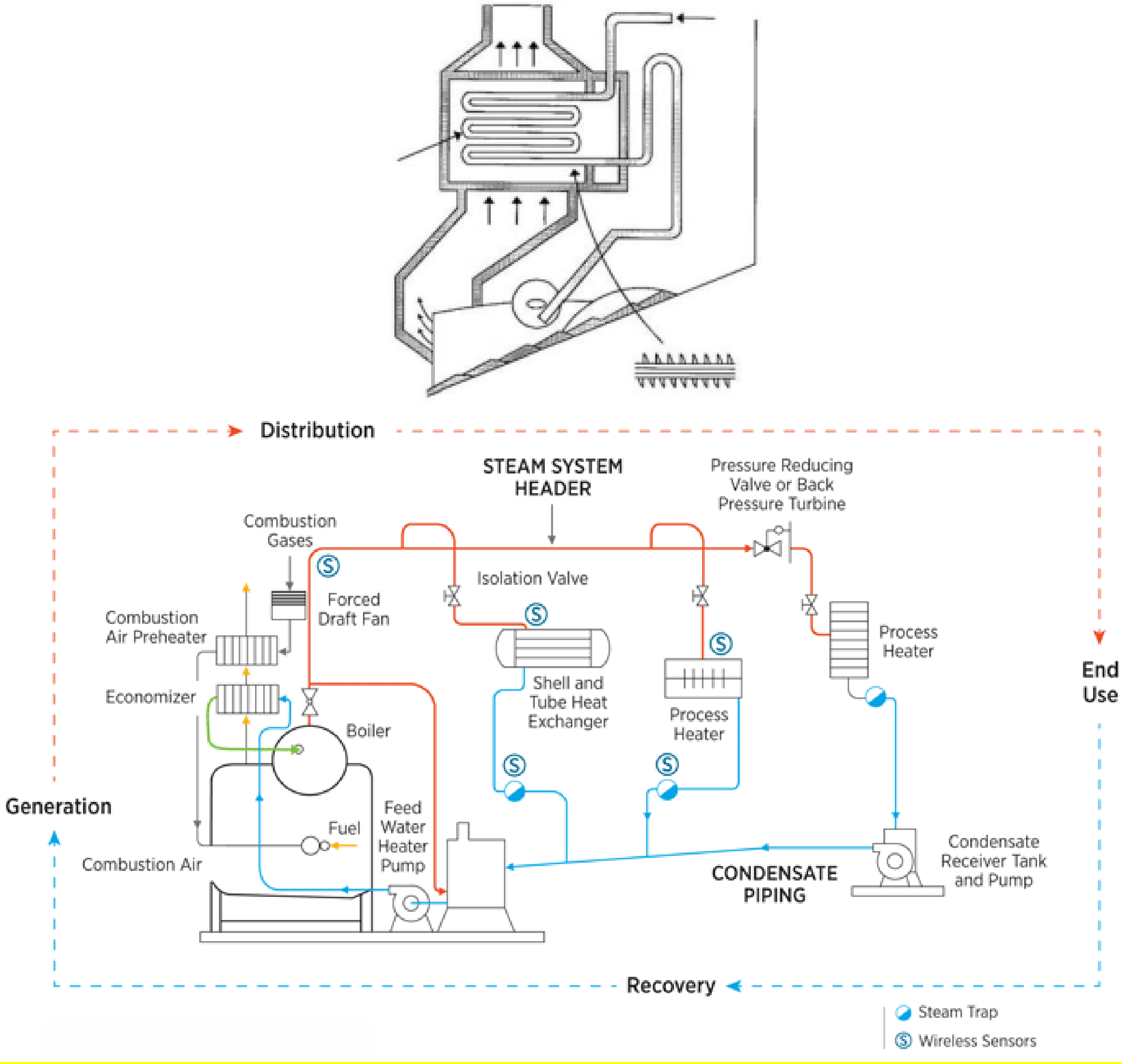


Figure 74. Heat recovery flow diagram

Source: US Department of Energy

Moreover, the economizer is also used to dry the air.

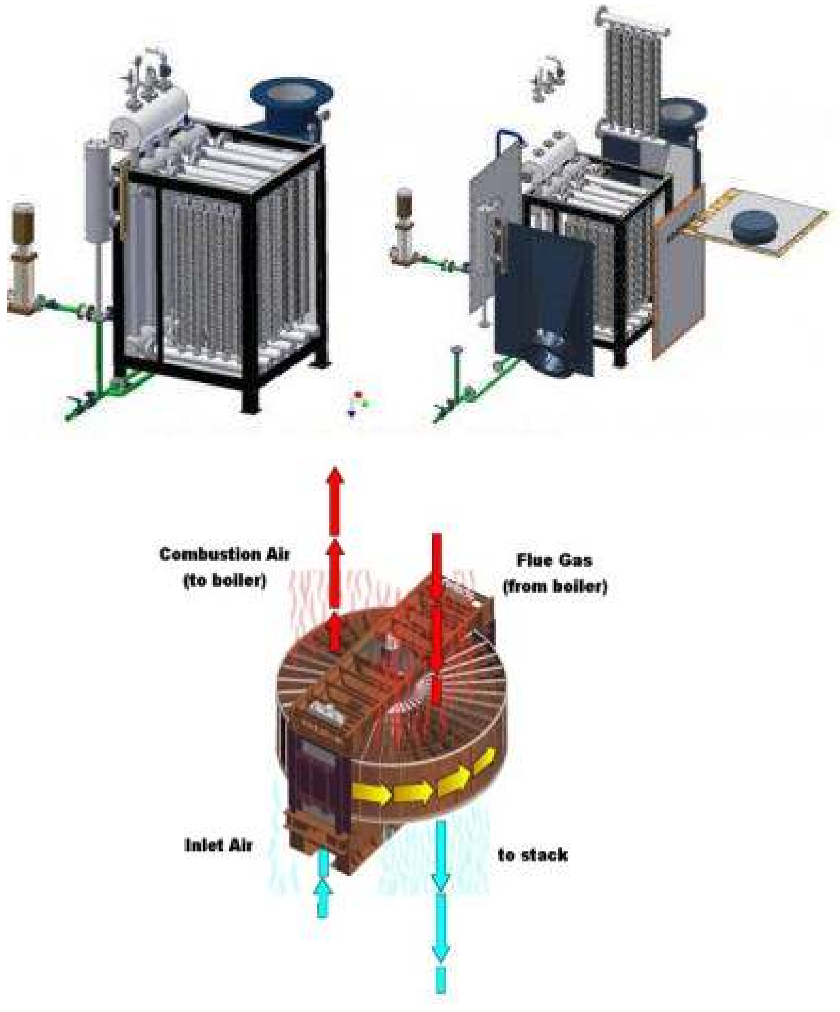


Figure 75. Water pre-heater and air dryer

3.9.3.3. Optimize the operating conditions

The boiler operating conditions should be optimized to reduce the energy loss, some proposed measures are

- Controlling properly the amount ratio of fuel / air will maintain the high efficiency of combustion process
- Evaluate the size of boiler
- Automatic blow down control
- Install variable speed control for air supply and exhaust fans.

3.9.3.4. Upgrade and Replace the boiler

Another option to benefit from energy saving is the upgrade or replace of the boiler. Following measures are possible:

- Install combustion analyzer for continuous monitoring
- Recover heat from flue gas
- Replace the low efficiency boiler
- Replace fossil fuel fired boilers by biomass fired boilers

3.9.3.5. Install steam trap to recover condensate

A steam trap has the following main functions:

- Discharge the condensate
- Prevent steam loss
- Remove air.

Figure 76. Typical steam traps

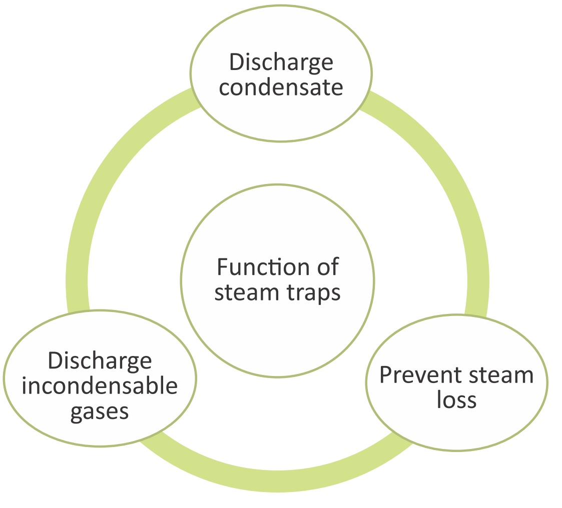
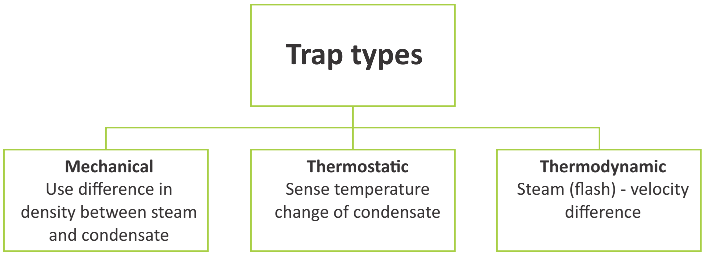


Figure 77. Functions of steam traps

Classification of steam traps:

Figure 78. Classification of steam traps



Mechanical steam trap – Free float

- Structure:

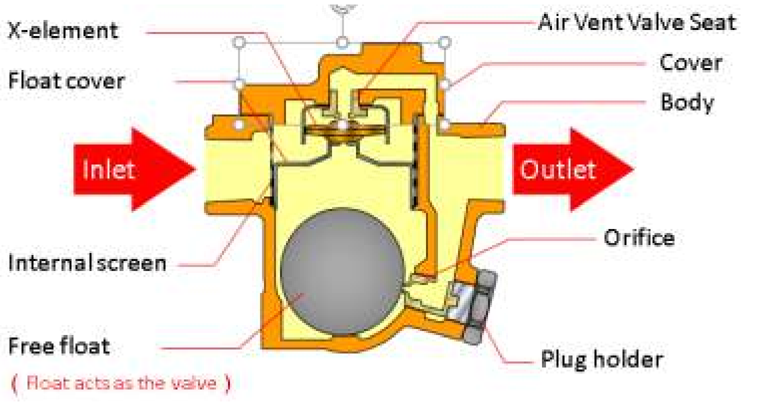


Figure 79. Mechanical steam trap – Free float (source: TLV)

- Operating Principles

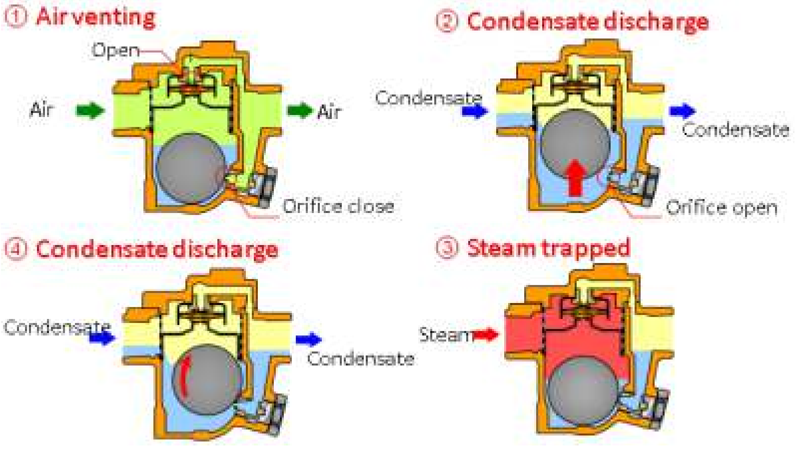


Figure 80. Operating principles of mechanical steam trap – Free float

- When the trap is cool, X-element contracts and Air Vent Valve opens to discharge initial air. After cold condensate enters the trap, the float of steam trap will rise to allow discharge of condensate from orifice. Both air and condensate are also discharged from Air vent valve
- After initial air and cold condensate have been discharged, hot condensate heats the X-element and closes Air Vent Valve in order to avoid steam loss. At this time, the condensate continues to be discharged through orifice
- As condensate stops flowing into the trap and the steam occupies the upper section, the float will close the orifice and X-element is also closed. Therefore, the trap is completely sealed to prevent steam leakage.

Table 61. Advantages and disadvantages of steam trap – free float

Advantages:	Disadvantages:
- Continuously discharge condensate at steam temperature. - Can handle heavy or light condensate - Large capacity - Resistant to water hammer	Traps operating on high differential pressures need to have smaller orifices

Mechanical steam trap – inverted bucket

- Structure:

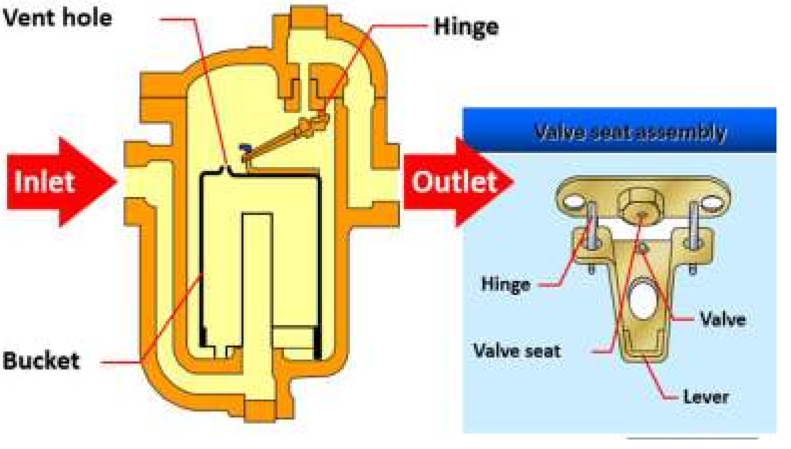


Figure 81. Mechanical steam trap – inverted bucket (source: TLV)

- Operating Principles

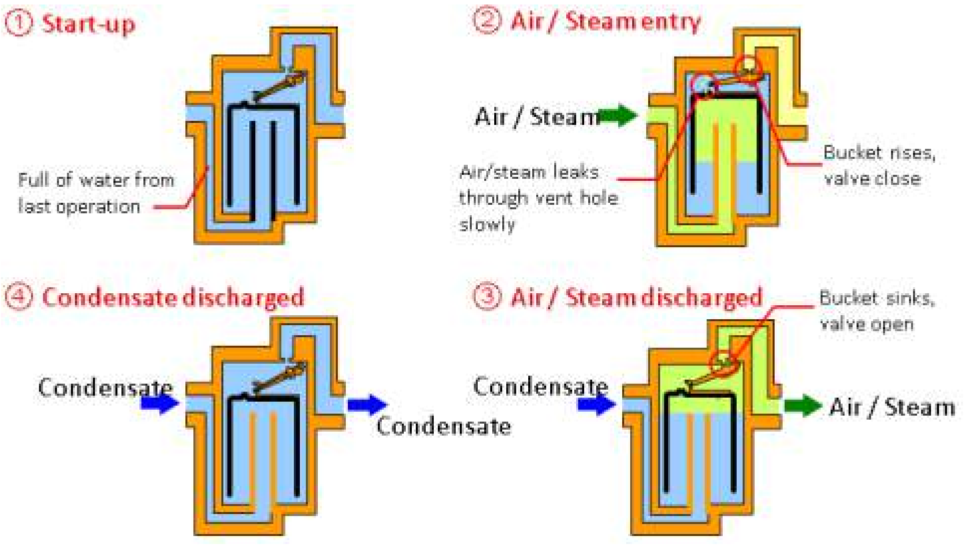


Figure 82. Operating Principles of mechanical steam trap – Inverted bucket

- The trap body is initially full of water from last operation and the bucket is still settled down. The condensate is pushed out through the open discharge port
- When the air / steam leaks through vent hole slowly and the bucket rises up to close the discharge port
- Trap is closed until the steam inside the bucket is condensed or the outside condensate flows into the bucket. The discharge valve will be pulled off
- Accumulated condensate is released and the cycle is repeated.

Table 62. Advantages and disadvantages of steam trap – Inverted bucket

Advantages	Disadvantages
- Withstand high pressures Good tolerance to water hammer conditions	Discharge air very slowly Steam might be lost through discharge port if the trap loses water sea

Thermodynamic Steam Trap

- Structure

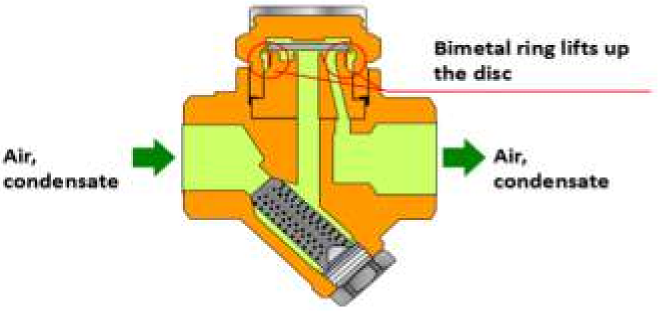


Figure 83. Thermodynamic steam trap (source: TLV)

- Operating principles

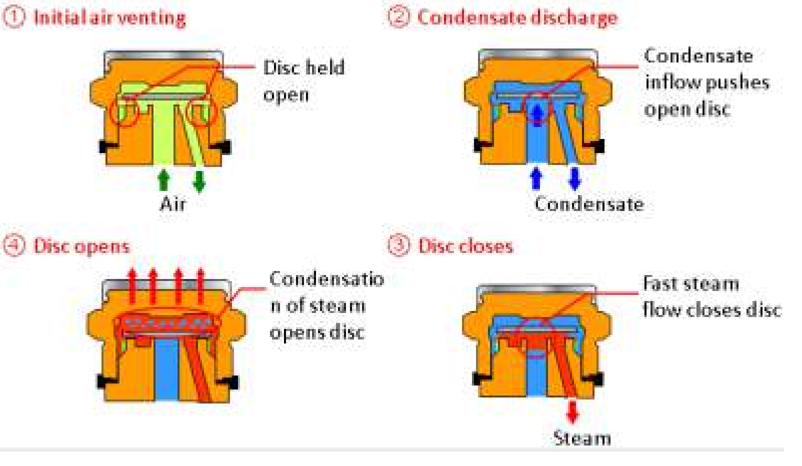


Figure 84. Operating principles of thermodynamic steam trap

- On start-up, incoming pressure raises the disc, and cool condensate plus air is immediately discharged from the inner ring under the disc
- The condensate inflow pushing open disc causes the pressure drop and releases flash steam with high velocity. This high velocity creates a low pressure area under the disc, drawing it towards its seat
- At the same time, the flash steam pressure builds up inside the chamber above the disc, forcing it down against the incoming condensate until it seats on the inner and outer rings. At this point, the flash steam is trapped in the upper chamber, and the pressure above the disc equals the pressure being applied to the underside of the disc from the inner ring
- Eventually the trapped pressure in the upper chamber falls as the flash steam condenses. The disc is raised by the now higher condensate pressure and the cycle repeats.

Table 63. Advantages and disadvantages of thermodynamic steam trap

Advantages	Disadvantages
- Compact, simple, and light weight Large condensate capacity Install horizontally or vertically	Removal condensate also carries steam Low efficiency The discharge of the trap can be noisy

Thermostatic steam trap – Balanced pressure

- Structure:

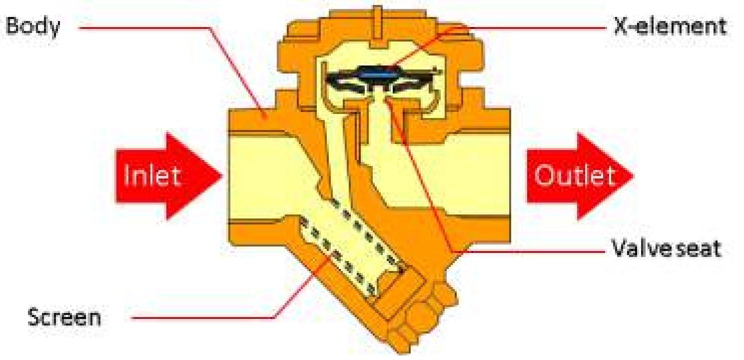


Figure 85. Thermostatic steam trap – Balanced pressure (source: TLV)

- Operating Principles

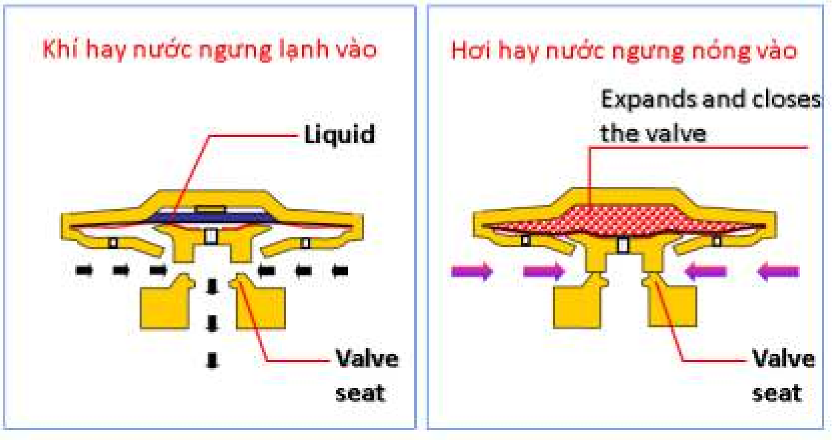


Figure 86. Operating principles of thermostatic steam trap – balanced pressure

As condensate passes through the balanced pressure steam trap, heat is transferred to the liquid in the capsule. The liquid vaporises before steam reaches the trap. The vapour pressure within the capsule causes it to expand and the valve shuts. Heat loss from the trap then cools the water surrounding the capsule, the vapour condenses and the capsule contracts, opening the valve and releasing condensate until steam approaches again and the cycle repeats.

Table 64. Advantages and disadvantages of thermostatic steam trap – balanced pressure

Advantages:	Disadvantages
Compact, simple, and light weight Simple maintenance Large capacity	Valve is not opened until the condensate temperature is below steam temperature.

Steam trap selection notices:

Table 65 Steam trap selection

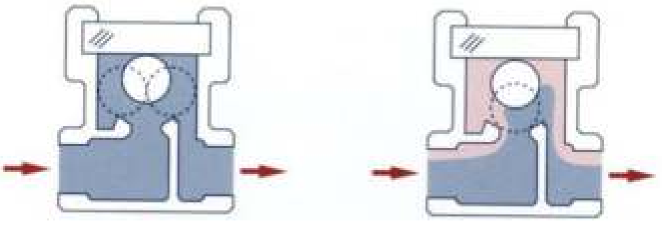
Application	Feature	Suitable trap
Steam piping	Small capacity Frequent change in pressure Low pressure – high pressure	Thermodynamic Mechanical: float
Equipment Reboiler Heater Dryer Heat exchanger	Large capacity Variation in pressure and temperature is undesirable Efficiency of the equipment is a problem	Mechanical: float, bucket, inverted bucket
Instrumentation	High reliability	Thermodynamic Thermostatic

Two types of failures:

- Failed in open position: steam loss increases the production cost
- Failed in closed position: water hammer causes damage to equipment.

There are four ways to check for leaks, and check for steam traps

Visual testing: This method allows us to observe the operation of steam trap when production is running. Disadvantage: the sight glass needs maintenance, which might cause increasing production cost.



Normal operation *Steam leakage*

Figure 87. Steam trap operation

- Temperature testing
  - Use infrared guns, surface pyrometers, or temperature tapes to measure temperature
  - The steam trap operates well if the difference temperature between the steam and condensate is small.
- Ultrasonic testing: Use the ultrasonic leak detector to determine if the trap is functioning properly

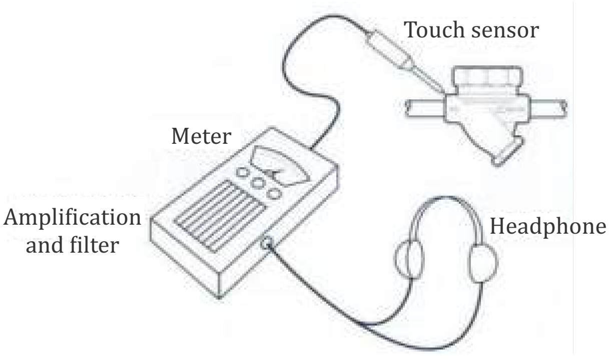


Figure 88. Ultrasonic testing

- Leak detection by using Spira-tec equipment.

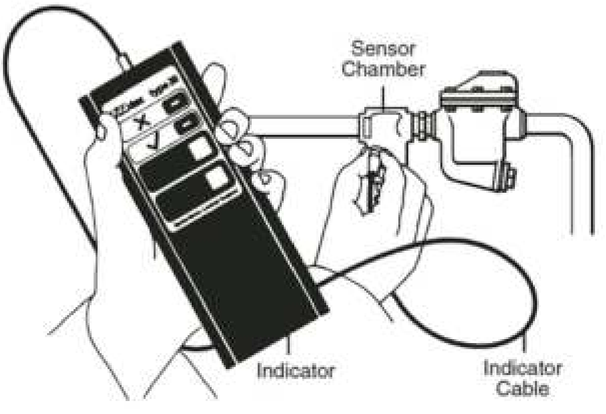


Figure 89. Spira-tec measurement

SLDS Spira-tec monitoring equipment is used to detect if there is leak of any steam trap during its operation.

3.9.4. Data collection

Necessary parameters for boiler efficiency calculation:

- Ultimate analysis of fuel (%C, %H2, $\%O_2$, %S, moisture content, ash content)
- Flue gas temperature
- Ambient temperature
- Humidity of air
- $\%O_2$ or $\%CO_2$ in flue gas
- GCV of fuel
- GCV of ash
- Blowdown water.
- Fuel temperature.

3.10. Furnace

3.10.1. Introduction

A furnace is an equipment used to melt metals for casting or to heat materials to change their shape (e.g. rolling, forging) or properties (heat treatment).

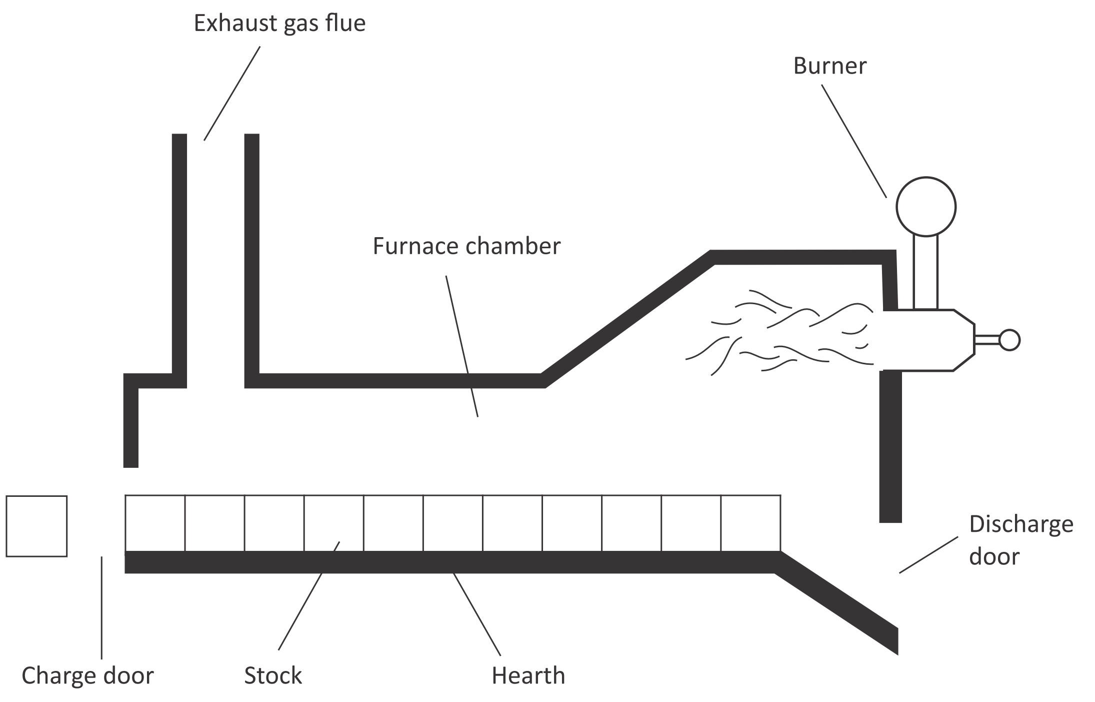


Figure 90. Types of furnaces

3.10.1.1. Main furnace components

- Heating system: fuel fired or electrical heating type
  - Fuel fired: heat is produced by burning an appropriate mixture of air and fuel
  - Electric furnace: heat is produced by resistance, induction or arc.
- Refractory: prevent heat loss to the surrounding. It should also be chemically inert to the process
- Loading – unloading system: the material is supplied and taken out of the furnace through a loading and unloading system. Energy losses of furnace might occur during system operation
- Heat exchanger: uses waste heat to preheat the air and material which is loaded in the furnace or used in external applications
- Instrumentation and control: this includes sensors and controllers to control several processes like fuel supply, current supply, exhaust – gas analysis, loading and unloading of material etc.

3.10.1.2. Classification

Table 66. Classification of furnaces

Classification method	Types
Type of fuel used	Oil
	Gas
	Coal
Mode of charging materials	Batch
	Periodical (Forging, re-rolling, pot)
	Continuous (pusher, walking beam, walking heart)
Mode of heat transfer	Radiation
	Convection
Mode of waste heat recovery	recuperative
	Regenerative

3.10.1.3. Energy performance assessment of furnaces

The efficiency of a furnace increases when the percentage of heat which is transferred to the stock or load inside the furnace increases. The efficiency of the furnace can be calculated in two ways:

- Direct method

The efficiency of a furnace can be determined by measuring the amount heat absorbed by the stock and dividing this by the total amount of fuel consumed.

$$\textbf{Thermal efficiency of the furnace} = \frac{\textbf{Heat in stock}}{\textbf{Heat in the fuel consumed}}$$

Heat in stock (Q) can be calculated with this equation: $Q = m \times C_p \times (t_2 - t_1)$

Q = quantity of heat in stock in kCal.

m = mass of the stock in kg.

Cp = specific heat of stock in kCal/kg.⁰C

t_2 = final temperature of stock in ⁰C

t_1= initial temperature of the stock before it enters the furnace in ⁰C

- Indirect method

Furnace efficiency can also be calculated after subtracting sensible heat loss in flue gas, heat loss due to moisture in flue gas, heat loss due to openings in furnace, heat loss through furnace skin and other unaccounted losses from the input to the furnace.

- **Heat loss in flue gas:**

$$\textbf{Percent of heat loss in flue gas} = \frac{m \times C_p \times \Delta T \times 100}{\text{GCV of fuel}}$$

m = weight of flue gas (air + fuel)

C_p = specific heat of flue gas

$\triangle T$ = temperature difference

GCV = gross calorific value of fuel, kCal/kg.

- Heat loss from moisture in fuel:

$$\text{Percent of heat loss from moisture in fuel} = \frac{m \times \{584 + 0.45 \times (T_{fg} - T_{amb})\}}{\text{GCV of Fuel}} \times 100$$

m = % moisture of in 1 kg of fuel oil

T_{fg} = flue gas temperature, ^0C.

T_{amb} = ambient temperature, ^0C

- Heat loss due to hydrogen in fuel:

$$\text{Percent of heat loss due to hydrogen in fuel} = \frac{9 \times H_2 \times \{584 + 0.45 \times (T_{fg} - T_{amb})\}}{\text{GCV of Fuel}} \times 100$$

H_2= % of H_2 in 1 kg of fuel oil.

- Heat loss due to opening in furnace:

Percent ofheat loss from opening in furnace:

$$= \frac{(\text{black body radiation factor} \times \text{emissivity} \times \text{factor of radiation} \times \text{area of opening}) \times 100}{\text{quantity of oil} \times \text{GCV}}$$

The factor of radiation through openings and the black body radiation factor can be obtained from standard graphs as shown in figures bellows.

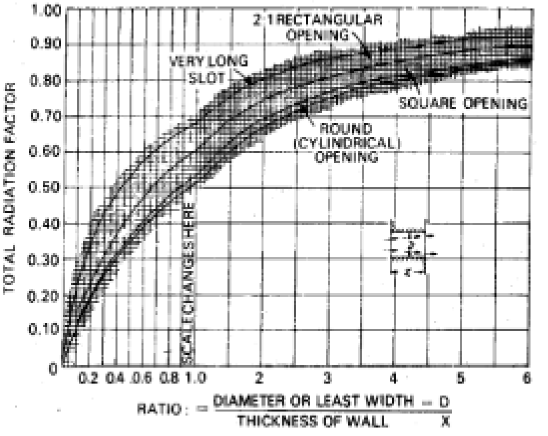


Figure 91. Radiation factor for heat

Source: BEE, 2005

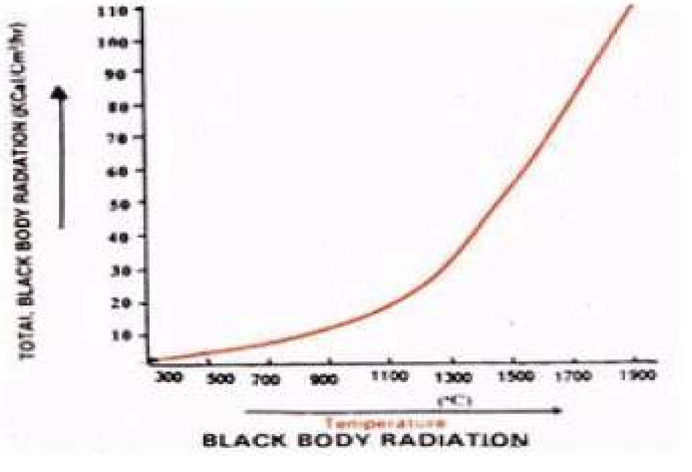


Figure 92. Black body radiation at different temperature

Source: BBE, 2005

- **Heat loss through furnace skin:** to determine the heat loss through the furnace skin, first the heat loss through the roof and sidewalls and through other areas must be calculated separately.

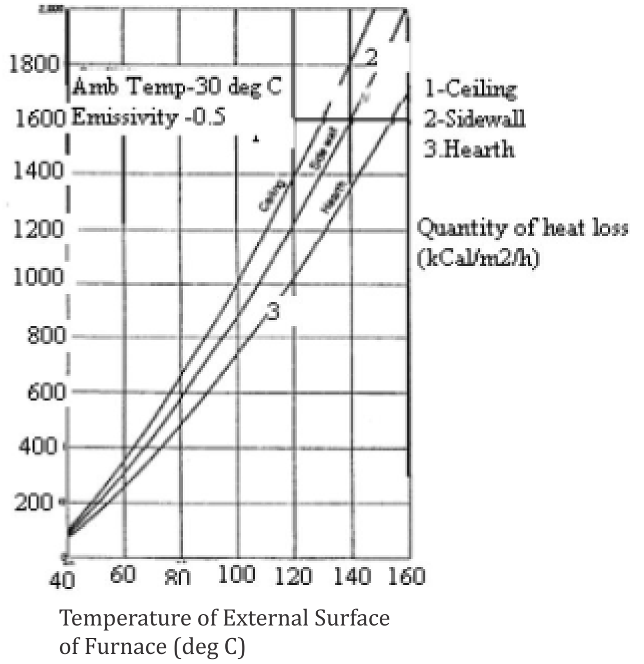


Figure 93. Heat loss from the ceiling, sidewall and hearth of furnace

Source: BEE, 2005

- **Heat loss through roof/ ceiling and sidewalls (= heat and soaking zone).**

The average surface temperature t_{st} is estimated from data points of practical measurement

Heat loss at t_{st} ^{0}C (refer to figure 39), kCal/m^{2}hr.

Total area of heating + soaking zone, m^2

So total heat loss through furnace roof/ceiling is: Heat loss at t_{st} ^{0}C kCal/m^{2}hr. x Area m^2, kCal/hr.

- **Heat loss from area other than heating and soaking zone.**

The average surface temperature t_{st} is estimated from data points of practical measurement

Heat loss at t_{ost} ^{0}C (refer to figure 39), kCal/m^{2}hr.

Total area, m^2.

So total heat loss through other areas is: Heat loss at t_{ost} ^{0}C kCal/m^{2}hr. x Area m^2, kCal/hr.

The % heat loss through furnace skin is:

$$\%\ \textbf{heat loss:} = \frac{(\text{heat loss i} + \text{heat loss ii}) \times 100}{\text{quantity of oil} \times \text{GCV}}$$

- **Unaccounted Loss**

These losses comprise of heat storage loss, loss of furnace gases around charging door and opening, heat loss by incomplete combustion, loss of heat by conduction through hearth, loss due to formation of scales.

Adding all of heat losses above give the total losses to construct a heat balance for typical furnace.

3.10.2. Heat losses affecting furnace performance

The total heat input is provided in the form of fuel or power. The desired output is the heat supplied for heating the material or process. Other heat outputs in the furnaces are undesirable heat losses.

The energy flow is depicted in the figure below:

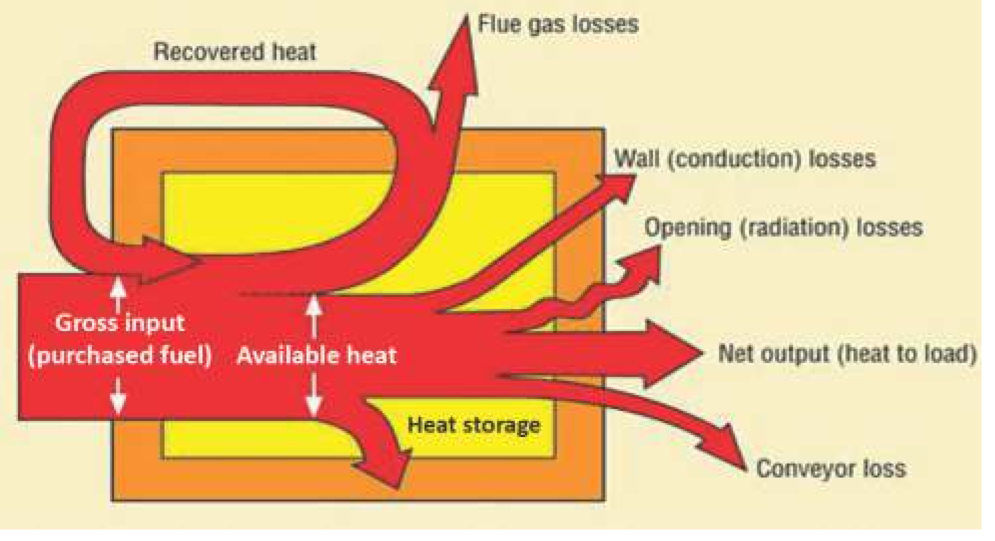


Figure 94. Heat lossed in a furnace

Source: Asia Energy Efficiency

These furnace heat losses include:

- Flue gas losses: part of heat remains in the combustion gases inside the furnace
- Loss from moisture in fuel: fuel usually contains some moisture and some of the heat issued to evaporate the moisture inside the furnace
- Loss due to hydrogen in fuel which results in the formation of water
- Loss through openings in the furnace: radiation loss occurs when there are openings in the furnace enclosure and these losses can be significant. A second loss is through air infiltration
- Furnace skin/ surface losses: while temperatures inside their furnace are high, heat is conducted through the roof, floor and walls and emitted to the ambient air once it reaches the furnace skin or surface.

Other losses: there are several other ways in which heat is lost from a furnace, although quantifying these is often difficult. Some of these include:

- Stored heat losses: when furnace is started the furnace structure and insulation is also heated, and this heat only leaves the structure again when the furnace shuts down
- Cooling media losses: water and air are used to cool down equipment, rolls, bearing and rolls, but heat is loss because these media absorb heat
- Incomplete combustion losses: heat is lost if combustion is incomplete because unburnt fuel or particles have absorbed heat but this heat has not been put to use
- Loss due to formation of scales.

Table 67 Heat balance

Heat input			Heat loss		
Item	kCal/kg	%	Item	kCal/ kg	%
Combustion heat of fuel			Flue gas loss		
Electricity			Moisture in fuel loss		
			Hydrogen in fuel loss		
			Cooling water loss		
			Heat loss due to opening		
			Heat loss due to furnace skin		
			Heat loss in flue gas		
Total					

3.10.3. Energy savings measures

The goal of an energy auditor is to minimize heat loss and optimize the performance. Potential energy savings areas in furnaces are listed below:

3.10.3.1. Complete combustion with minimum excess air

To complete combustion of fuel with minimum amount of air, it is necessary to control

- Air infiltration
- Maintain pressure of combustion air
- Fuel quality
- Excess air monitoring
- Equipped an automatic oxygen (air) / fuel ratio controller.

3.10.3.2. Proper heat distribution

A furnace should be designed to ensure that within a given time the stock is heated uniformly to a desired temperature with minimum amount of fuel.

Where burners are used to fire the furnace, the following should be ensured for proper heat distribution

- The flame should not touch or be obstructed by any solid object
- The flame of different burners should stay clear of each other
- The burner flame has a tendency to travel freely in the combustion space just above the material. For this reason, the axis of the burner in small furnaces is never placed parallel to the hearth but always at an upward angle, but the flame should not hit the roof
- In small furnaces using oil, a burner with a long flame with a golden yellow color improves uniform heating. But the flame should not be too long, because heat is loss of the flame reaches the chimney or the furnace doors
- Maintaining clean surface by using a soot blower
- Complete combustion of carbon on radiant surface
- Keeping heat exchangers clean
- Select and locate burners and fans effectively.

3.10.3.3. Waste heat recovery from furnace flue gases

Waste heat in flue gases can be recovered for preheating of the charge, preheating of combustion air or for other processes.

- Charge pre-heating:

When raw materials are preheated by exhaust gases before being placed in a heating furnace, the amount of fuel necessary to heat them in the furnace is reduced.

- Preheating of combustion air:

The energy contained in the exhaust gases can be recycled to preheat the combustion air. Since the volume of combustion air increases when it is preheated, it is necessary to consider this when modifying air duct diameters and blowers. It should be noted that preheating of combustion gases from high density oils with a high sulphur content, could cause clogging with dust or sulphides and corrosion.

- Utilizing waste heat as a heat source for other processes:

The waste heat can be used to produce steam or hot water. Sometimes exhaust gas heat can be used for heating purposes in other equipment such as tank, reactor, etc.

3.10.3.4. Minimizing furnace skin losses

There are several ways to minimize heat loss through the furnace skin:

- Choosing the appropriate refractory materials
- Increasing the wall thickness
- Installing insulating bricks
- Planning operating times of furnaces.

3.10.3.5. Prevent heat loss through openings

There are several ways to minimize heat loss through opening:

- Keep the opening as small as possible and seal them
- Opening the furnace doors less frequent and for the shortest time period as possible
- Check air leakage frequently.

3.10.3.6. Control of furnace draft

If negative pressures exist inside the furnace, air can infiltrate through cracks and openings and affect the air fuel ratio control. This in turn can cause metal to not reach the desired temperature or non-uniform temperatures. To avoid this, installing furnace pressure controllers help maintain inside positive furnace pressure.

3.10.3.7. Operation at the optimum furnace temperature

It is important to operate the furnace at its optimum temperature. Operating temperatures of various furnaces are given in table below. Operating at too high temperatures causes heat loss, excessive oxidation, decarbonization and stress on refractories. Automatic control of the furnace temperature is preferred to avoid human error.

Slab reheating furnaces	1200^0C
Rolling mill furnaces	1200^0C
Bar furnace for sheet mill	800^0C
Bogie type annealing furnaces	650^0C -750^0C

3.10.3.8. Optimum capacity utilization

One of the vital factors affecting efficiency is load. This includes the amount of material placed in the furnace, the arrangement inside the furnace and the residence time inside the furnace.

3.10.3.9. Optimum load

If the furnace is under loaded, the proportion of total heat available that will be taken up by load is smaller, resulting in a lower efficiency. Overloading can lead to the load not heated to right temperature within a given period of time.

There is a particular load at which the furnace will operate at maximum thermal efficiency, where the amount of fuel per kg of material is lowest.

3.10.3.10. Optimum arrangement of the load

The loading of materials on the furnace hearth should be arranged so that:

- It receives the maximum of radiation from the hot surfaces of the heating chambers and flames
- Hot gases are efficiency circulated around the heat receiving surfaces of the materials.

3.10.3.11. Optimum residence time of the load

Fuel consumption is kept at a minimum and product quality is best if the load only remains inside the furnace until it has the required physical and metallurgical properties. Excessive residence time will increase oxidation of the material surface, which can result in rejection of products. Temperature is increased to make up for shorter residence time. The higher the working temperature, the higher is the loss per unit of time.

Optimum utilization of furnace can be planned at design stage, by selecting the size and type that matches the production schedule.

3.10.3.12. Use of ceramic coatings (high emissivity coating)

Ceramic coating in the furnace chamber promotes rapid and efficient transfer of heat, uniform heating and extended life of refractories. The emissivity of conventional refractories decreases with increase in temperature whereas for ceramic coatings it increases slightly. This outstanding property has been exploited by using ceramic coating in hot face insulation. Ceramic coating is high emissivity coating and a have a long life at temperatures up to 1350^0C.

3.10.3.13. Selection of refractories

The selection of refractories aims to maximize the performance of the furnace. Furnace manufacturers or users should consider the following points in the selection of a refractory:

- Type of furnace
- Type of metal charge
- Presence of slag
- Area of application
- Working temperature
- Extent of abrasion and impact

- Structural load of the furnace
- Stress due to temperature gradient in the structures and temperature fluctuations
- Chemical compatibility to the furnace environment
- Heat transfer and fuel conservation
- Cost considerations.

3.10.4. Data collection

3.10.4.1. Checklist

It is difficult to make a checklist of general options for furnaces, because options to improve energy efficiency vary between different types of furnaces. But the main options that are applicable to most furnaces are:

- Check against infiltration of air: use doors or air curtains
- Monitor O_2, CO_2, CO and control excess air to the optimum level
- Improve burner design, combustion control and instrumentation
- Ensure that the furnace combustion chamber is under slight positive pressure
- Use ceramic fibers in the case of batch operations
- Match the load to the furnace capacity
- Retrofit with heat recovery device
- Investigate cycle times and reduce
- Provide temperature controllers
- Ensure that flame does not touch the stock.

3.10.4.2. Measuring instruments for furnace

Table 68. Measuring instruments

No.	Parameters to be measured	Location of Measurement	Instrument required	Value
1	Operating temperature	Soaking zone side wall	Measure temperature	°C
2	Exit flue gas temperature after preheat (T_{fg})	Flue gas exit from furnace-chimney	Measure temperature	°C
3	Ambient temperature (t_{amb})	Around furnace	Measure temperature and humidity	°C, %RH
4	Flue gas analyzer	Flue gas exit from furnace-chimney	Measure the flue gas	°C, % of Oxygen, CO, CO_2
5	Average surface temperature of heating and soaking zone	Surface furnace	Measure temperature	°C
6	Average surface temperature of area other than heating and soaking zone	Surface others	Measure temperature	°C

3.10.4.3. Data collection template

Table 69. Data collection template for furnace performance

Items	Unit												
Name													
Model:													
Fuel types													
Designed capacity	tons/ hr												
Heating zone	m^2												
Fuel Loading door	m^2												
Wall thickness	mm												
Cooling water flow rate (if any)	M^3/hr												
Measurement		1	2	3	1	2	3	1	2	3	1	2	3
Ambient temperature	^0C												
Operating temperature	^0C												
Air temperature	^0C												
Surface furnace temperature	^0C												
Oxygen	%												
CO	ppm												
CO_2	%												
Note													

4. SAFETY REQUIREMENT AND EQUIPMENT

Energy audit requires auditors to survey in many areas of the factory and buildings such as transformers, refrigeration system, boilers, wastewater treatment areas, etc. Each area has its own risks as the exposure to specific hazards could cause serious injuries, or diseases. Safety managers or safety specialists are responsible for ensuring safety performance in the plant. Therefore, the energy auditor needs to discuss with these staffs to define the appropriate safe work practices. Moreover, energy auditors should be aware of the below safety concerns.

4.1. Electrical safety

Electricity plays an important role in industrial and residential environments, but it also has hazardous potentials. Electricity can cause many serious accidents if its safety standards are not complied. When the electric passes through body, it can cause brain damage, burns, pleurisy and organs damage. The major task of energy auditor is to evaluate the efficiency of a lot of electrical equipment such as motors, transformers, and electricity distribution system. Therefore, the auditor has to be aware of the electrical safety.

Electrical accidents can occur due to electric shocks or arc flashes. To prevent electrical accidents, the auditor should understand the electrical system diagrams and define the high voltage areas. Then, the auditor should discuss with managers to define the appropriate safe work practices. The personal protective equipment (PPE) should comply with the Vietnamese standards (TCVN) or international standards.

Some personal protective equipment for works related to electricity are listed as follows:

- Clothing shall be made of arc-rated flame-resistant materials, have electrically non-conductive properties, and have long sleeves and long pants
- Hard hat has to comply with the International Safety Equipment Association Z89.1 Class E or equivalent standards
- Safety glasses with non-conductive side shields
- Safety gloves or boots
- Since electrical accidents can result in hazardous noise levels, the hearing protection is required.

Some legal documents related to electricity safety:

- Degree 14/2014/NĐ-CP - Stipulating in detail the implementation of electricity law regarding electricity safety
- Circular 31/2014/TT-BCT - Stipulating certain details of electrical safety.
- Circular 39/2013 / TT-BLDTBXH promulgates national technical regulations on labor safety for insulation shoe or boot.

4.2. Chemical safety

The energy auditor is not required to use chemicals, but they may enter areas where there are dangerous chemicals are handled. Identification of dangerous chemicals by their names and structures requires advanced knowledge of chemicals and long-term training. However, the auditors can recognize the danger of chemicals from its label in order to choose an appropriate PPE when entering hazardous areas.

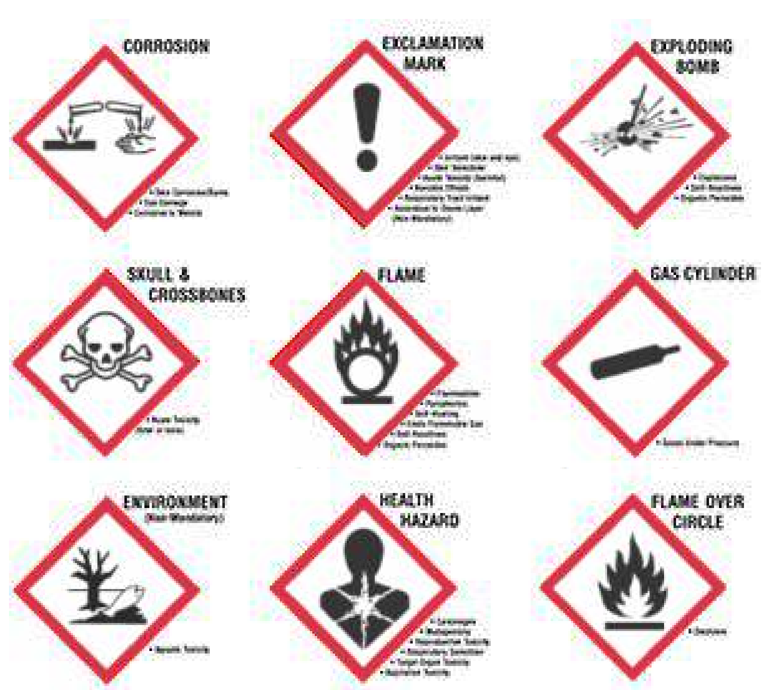


Figure 95. GHS Pictograms

Depending upon the actual conditions in a factory, the necessary PPE for chemical safety are shown as follows:

PPE	Purpose
Safety glasses with side shields	Protect eyes from splashing chemicals such as solvents, toxic gases, etc.
Impervious gloves	Protect against skin exposure to chemicals hazard when hands contact to chemical equipment
Safety masks	Protect against exposure to air-bone dust or chemical particles and protect against nuisance odors from solvent vapors
Safety shoes	Protect against skin exposure in work locations where liquid contact with the feet is likely.

Source: Global Harmonized System

Some legal documents related to electricity safety:

- Circular 04/2012/TT-BCT- Regulations on the classification and labelling of chemicals
- Circular 20/2013/TT-BCT – Stipulating the plan and measures for prevention and response against chemical incidents in industry.

4.3. Pressure equipment safety

Pressure equipment is used to conduct hydraulic processes, thermal processes, chemical processes, or to store materials at the pressure greater than atmospheric pressure. According to the local regulations, the equipment with the design pressure of 0.7 bar is considered as pressure equipment. For example, boiler, chiller system, and compressors are the common pressure equipment. Energy auditor should propose the energy saving measures such as changing the operating conditions as well as procedures. Therefore, understanding the safety parameters of pressure equipment will benefit energy auditors to propose the appropriate energy saving measures.

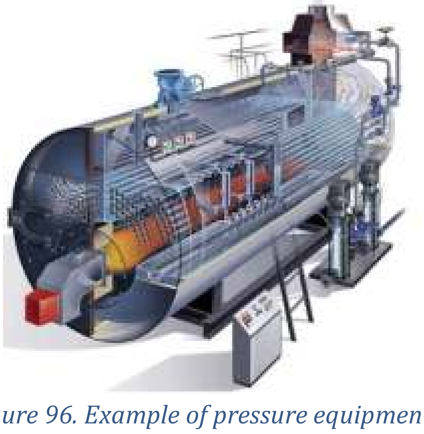


Figure 96. Example of pressure equipment (boiler)

The common cause of exploded pressure equipment accident is operation under the overpressure condition. Energy saving measures should consider not only the efficiency of equipment but also safety conditions. In order to satisfy both requirements, energy auditor needs to evaluate the drawing, specification sheet, inspection sheet, and operating procedure related to process equipment. Collecting the data from those documents and comparing data with the requirements of local regulations (TCVN, QCVN…) or international standards (ISO, ASME…) will help energy auditor to define the appropriate operating conditions. Moreover, the auditor could consult a technical specialist or equipment supplier for more information.

Some legal documents related to pressure equipment safety:

- ###TCVN 8366:2010- National Technical Regulation of pressure vessels- Requirement of design and manufacture

- QCVN 01:2008/BLĐTBXH- National Technical regulation on safe work of steam boiler and pressure
- 50/2015/TT-BLĐTBXH – National technical regulation on safe work of refrigerating system.

4.4. Safety for working at Heights

The energy auditor sometimes has to climb up the roof of building or go up to the high elevation to collect equipment data. Thereby, a fall hazard exists due to an unintended loss of body balance while working in heights. There Some safety measures can reduce the fall hazard:

- The first approach should be to review activities require working at height and to look for the other alternatives to carry out the work such as undertaking the work at ground level
- If fall hazards can't be completely eliminated, installation of stairs, guardrails, barriers, and travel restriction systems can lead to fall prevention work environment
- ###As a last line of protection against fall from height, it is essential to use fall-arresting equipment such as harness, lanyards, shock absorbers, lifelines, anchorages etc.

Figure 98. Working at height

Some legal documents related to working at heights:

- QCVN 23:2014/BLDTBXH: National technical regulation of personal fall-arrest systems
- TCVN 7802: 2007: Personal fall arrest systems
- TCVN 8207: 2009: Personal equipment for protection against falls.

In these documents, some common issues related to safety for energy audit are mentioned. To evaluate exactly the safety for each auditor, the factory has to provide and discuss equipment and production process with the auditor. The safety manager or safety specialist of a factory needs to provide equipment information and inform about the hazards so that the energy auditor gets the appropriate safe work practices. Moreover, it is necessary to regularly provide training courses on Occupational Safety and Health (OSH) for auditors at training centres which have the permit of the Ministry of Labour- Invalids and Social Affairs.

APPENDIXES

Table 70. Spreadsheet for energy saving calculation

Energy saving spreadsheets are divided into many sheets, each of which introduce a specific topic related to energy efficiency, including:	
1.	Electricity bill: for analysis & calculation of electricity consumption, cost, power factor, ...
2.	Hourly load graphs: to draw load graphs based on the power consumption records per hour
3.	Hourly load graphs: to draw load graphs based on the power consumption records per minute
4.	Reactive power compensation: Supports the calculation of power factor, compensation factor, and reactive power capacity to be used
5.	Load conversion: Supports load conversion calculations simply
6.	Incandescent and compact lamps: Supports computational comparisons between these two lamps
7.	Ferromagnetic ballast & electronic ballast: supports the computational comparison between the use of fluorescent lamps with different types of ballasts
8.	Motor selection: supports the evaluation of motor efficiency performance
9.	High Efficiency Motors: Compare the efficiency of high efficiency motors
10.	VS-VSD motor: Evaluate the result of the conversion from VS motors to the motors with VSD
11.	Pump - inverter: evaluate the efficiency of the pump system using inverter
12.	Pump Efficiency: to assess and calculate pump efficiency
13.	Boiler Efficiency – Direct method: supports the calculation of boiler efficiency by direct method
14.	Boiler Efficiency – Indirect method: supports the calculation of boiler efficiency by indirect method
15.	Insulation: Supports calculation of pipe heat losses and insulation thickness
16.	Steam Leaks: Supports steam Leakage assessment
17.	Chiller efficiency
18.	Cooling tower : Efficiency of cooling tower
19.	Other Appendix

Table 71. The electricity prices for enterprises in recent years

	Items	01/01/2007	01/03/2009	01/03/2010	01/03/2011	20/12/2011	01/07/2012	22/12/2012	01/08/2013	01/06/2014	16/03/2015
1	**Electric price for production**										
1.1	Above 110 kV.										
	a) Normal hour	785	835	898	1043	1102	1158	1217	1277	1267	1388
	b) Off-peak hour	425	455	496	646	683	718	754	792	785	869
	c) Peak hour	1590	1690	1758	1862	1970	2074	2177	2284	2263	2459
1.2	From 22 kV to 110 kV										
	a) Normal hour	815	870	935	1068	1128	1184	1243	1305	1283	1405
	b) Off-peak hour	445	475	518	670	710	746	783	822	815	902
	c) Peak hour	1645	1755	1825	1937	2049	2156	2263	2376	2354	2556
1.3	From 6 kV to 22 kV										
	a) Normal hour	860	920	986	1093	1164	1225	1286	1350	1328	1453
	b) Off-peak hour	480	510	556	683	727	773	812	852	845	934
	c) Peak hour	1715	1830	1885	1999	2119	2224	2335	2449	2429	2637
1.4	Below 6 kV										
	a) Normal hour	895	955	1023	1139	1216	1278	1339	1406	1388	1518
	b) Off-peak hour	505	540	589	708	767	814	854	897	890	983
	c) Peak hour	1775	1900	1938	2061	2185	2306	2421	2542	2520	2735

2	**Electricity price for business and service**										
2.1	Above 110 kV.										
	a) Normal hour	1410	1540	1648	1713	1808	1909	2004	2104	2007	2125
	b) Off-peak hour	770	835	902	968	1022	1088	1142	1199	1132	1185
	c) Peak hour	2615	2830	2943	2955	3117	3279	3442	3607	3470	3699
2.2	From 22 kV to 110 kV										
	a) Normal hour	1510	1650	1766	1838	1939	2046	2148	2255	2158	2287
	b) Off-peak hour	885	960	1037	1093	1153	1225	1286	1350	1283	1347
	c) Peak hour	2715	2940	3028	3067	3226	3388	3557	3731	3591	3829
2.3	From 6 kV to 22 kV										
	a) Normal hour	1580	1727	1846	1863	1965	2074	2177	2285	2188	2320
	b) Off-peak hour	915	995	1065	1142	1205	1279	1343	1410	1343	1412
	c) Peak hour	2855	3100	3193	3193	3369	3539	3715	3900	3742	3991

Note:

- *Normal hour: from 4h00 – 9h30; 11h30 – 17h00; 20h00 – 22h00 from Monday to Saturday and from 4h00 – 22h00 in Sunday.*
- *Peak hour: from 9h30 – 11h30 and from 17h00 – 20h00 from Monday to Saturday.*
- *Off-peak hour: from 22h00 – 4h00 all of day in a week.*

Electricity prices for other business, organizations, please visit EVN web site (http://www.evn.com.vn/) to know more information.

Table 72. The conversion into TOE, MJ and emission factors of some energy types

Energy types	Units	Energy consumption(**) (MJ/Unit)	TOE equivalent(*)	Emission factors (tons CO_2/unit)
Electricity	kWh	3.6	0.0001543	0.0006612
Coke coal	Tons	31,402.5	0.70 - 0.75	3.36
Anthracite coal 1, 2	Tons	29,309.0	0.70	2.88
Anthracite coal 3, 4	Tons	25,122.0	0.60	2.47
Anthracite coal 5, 6	Tons	20,935.0	0.50	2.06
DO oil	Tons	42,707.4	1.02	3.16
	1.000 litre	36,845.6	0.88	2.73
FO oil	tons	41,451.3	0.99	3.21
	1.000 litre	39,357.8	0.94	3.05
LPG	tons	45,638.3	1.09	2.88
Natural gas (NG)	1000 m^3	37,683.0	0.9	2.11
Gasoline	tons	43,963.5	1.05	3.05
	1.000 litre	34,752.1	0.83	2.41
Jet Fuel	tons	43,963.5	1.05	3.08

Note:

(*)TOE coefficients prescribed in Official dispatch No. 3505/BCT-MOST, April 19, 2011

(**)Energy conversion coefficient is calculated based on 1 TOE = 41,870 MJ by IPCC ((http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=167). This value is for reference only, recommends using results of calorific value is the actual fuel

Table 73. The emission factor of some common energy types

Energy types	Value	Units
Electricity grid (*)	0.6612	kg CO_2/kWh
Coke coal	0.1070	kg CO_2/MJ
Anthracitecoal	0.0983	kg CO_2/MJ
DO oil	0.0741	kg CO_2/MJ
FO oil	0.0774	kg CO_2/MJ
LPG	0.0631	kg CO_2/MJ
NG	0.0561	kg CO_2/MJ
Gasoline	0.0693	kg CO_2/MJ
Jet Fuel	0.070	kg CO_2/MJ
Wood and wood waste	0.112	kg CO_2/MJ
Others biomass	0.100	kg CO_2/MJ

Source: IPCC guidelines for National Greenhouse Gas Inventories" issued in 2006

Note:

(*) Emission factor of VN electricity grid is issued annually by the Bureau of Meteorology, Hydrology and Climate Change, Ministry of Natural Resources and Environment.

(http://www.noccop.org.vn/modules.php?name=Airvariable_ldoc&menuid=33)

With CO_2 emission factor for other energy types, know more at IPCC website.

(https://www.ipcc.ch/meetings/session25/doc4a4b/vol2.pdf).

From the information on energy consumption and CO_2 emission factor corresponding energy/ fuel consumption can be converted CO_2 emission factor of energy consumption (see conversion tool in excel file).

Table 74. Metrological control measures and instrument inspection intervals

No.	Measuring instrument	Metrological control measures				Inspection interval
		Type	**Inspection**			
		approval	**Once**	**Periodi -cally**	**After repair**	
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Length measurements						
1	Measuring tape	-	x	-	-	
Volume and flow measurement						
2	Mechanical residential water meter	x	x	x	x	60 months
3	Electronic residential water meter	x	x	x	x	36 months
4	Oil and gas meter	x	x	x	x	12 months
5	LPG meter	x	x	x	x	x
6	Industrial airflow meter	x	x	x	x	12 months
7	Common volume meter	-	x	x	x	24 months
Pressure measurement						
8	Spring manometer	-	x	x	x	12 months
9	Electronic manometer	-	x	x	x	12 months
Temperature measurement						
10	Macroscale electronic contact medical thermometer	-	x	x	-	06 months
11	In-ear medical infrared thermometer		x	x	x	12 months
Physical-chemical measurement						
12	Seed moisture meter	-	x	x	x	12 months
13	Hydrometer	-	x	x	x	24 months
14	Vehicle exhaust gas tester	-	x	x	x	12 months
15	Equipment for measuring concentration of SO_2, CO_2, CO, NO_x in air	-	x	x	x	12 months
16	Equipment for measuring pH, dissolved oxygen, electrical conductance, water opacity, total dissolved solids in water	-	x	x	x	12 months
Electricity & EMF measurement						
17	1-phase AC electricity meter	x	x	x	x	60 months
18	3-phase AC electricity meter	x	x	x	x	24 months
Optical measurement						
19	Illuminance meter	-	x	x	x	12 months

Source: Circular No. 23/2013/TTBKHCN dated September 26, 2013

Where: - "x" indicates mandatory tasks;

- "-" indicates optional tasks.

REFERENCE

	Date	Content
Law No. 50/2010/QH12	17/6/2010	ECONOMICAL AND EFFICIENT USE OF ENERGY
Decree No. 21/2011/NĐ-CP	29/3/2011	DETAILING THE LAW ON ECONOMICAL AND EFFICIENT USE OF ENERGY AND MEASURES FOR ITS IMPLEMENTATION
Circular No. 09/2012/TT-BCT	20/4/2012	PROVIDING FOR ELABORATION OF PLANS, REPORT ON IMPLEMENTATION OF PLANS ON ECONOMICAL AND EFFICIENT ENERGY USE; IMPLEMENTATION OF ENERGY AUDIT
Circular No. 23/2013/TT-BKHCN	26/9/2013	GROUP 2 MEASURING INSTRUMENTS
Circular No. 02/2014/TT-BCT	16/1/2014	Prescribed energy consumption rate in chemistry industry
Circular No. 19/2016/TT-BCT	14/9/2016	Prescribed energy consumption rate in beer and beverage industry
Circular No. 20/2016/TT-BCT	20/9/2016	Prescribed energy consumption rate in Steel industry

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