Co-Funded by the European Union

# Energy Efficiency in the Lebanese Industrial Sector

## A Guideline Report

**Editorial**

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# EXECUTIVE SUMMARY

In the balance sheet of industrial facilities and large service institutions, energy consistently occupies a significant position. Frequently, energy expenses alone surpass 30% of the recorded costs at the conclusion of the fiscal year for these establishments.

When it comes to the industrial sector, where competition is intense and maintaining a strong market position hinges on the ability to minimize costs per production unit, prioritizing energy efficiency and adopting energy conservation measures are equally crucial factors alongside product quality and the supply chain.

Achieving a one-cent decrease in energy costs per kilowatt-hour (KWh) has the potential to result in significant savings for manufacturing a standard one-liter plastic bottle, including its cap and packaging. This reduced expense provides the manufacturer with a valuable competitive edge in a market where even small cost reductions can make a notable impact.

The initial phase in implementing an energy-efficient manufacturing and processing approach involves conducting an energy audit. An energy audit is a comprehensive evaluation conducted by proficient energy auditors and specialized engineers to assess the energy efficiency of a facility. It involves analyzing energy consumption on-site, identifying areas with potential for savings, and generating data to derive performance indicators. This advanced technical and financial study aims to provide valuable insights into the facility’s energy performance.

The energy audit is designed to determine where, when, why and how energy is being used. As a result, a set of recommendations known as Energy Efficiency Measures (EEMs) are identified, which lead to energy conservation and cost reduction.

As part of the UNDP-CEDRO 5 project activities, this report is intended to be an updated guideline for industries and large facilities on efficient use of resources and effective energy management in production processes.

The set of EEMs developed hereafter are generally applicable to the Lebanese Industrial Sector. A set of EEMs covering major categories such as monitoring and energy management, compressed air systems, steam systems, and heat recovery are analyzed, presenting technical and financial details for each measure in these categories.

EEMs vary in terms of investment requirements, saving potential and payback period, ranging from low and no cost investment to heavy investment solutions. These are outlined in Table below. The provided table displays the potential savings associated with different energy efficiency measures. These savings have the capacity to significantly enhance the energy performance of the facility while simultaneously reducing energy costs. Initiating this process begins with a crucial milestone: conducting an energy audit. By undertaking an energy audit, these goals become achievable and pave the way for improved energy efficiency.

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Efficient Lighting | Lighting Retrofit | Retrofit of non LED fixtures to LED | - | 50% - 60% | Lighting Electrical Energy | <2 |
| Monitoring And Energy Management | Energy Metering And Control | Energy monitoring system for optimized energy utilization (Enterprise Energy Management, SCADA, etc.) | $ 10,000 - $50,000 | 5% - 35% | Total Energy | 2 |
| Power Factor | Power Factor Correction | Power factor correction aims to optimize the efficiency of electrical systems by improving the relationship between real power and apparent power. | N/A | 3% - 6% | Electrical Energy | N/A |
| CHP/CCHP | Combined Cooling/ Heat and Power generation | CHP involves an integrated and efficient system that combines electricity production with heat recovery. | $ 760,000 | 30 - 35% | Electrical Energy | <6 |
| Compressed Air System | System Optimization | Following proper maintenance practices, and properly sizing the system. In addition to implementing of good housekeeping measures | $0-$ 10,000 | Up to 10% | Electrical Energy | <2 |
| | Leakage Prevention | Avoiding leakages and treatment of damaged pipes, accessories, elbows, and other leaking items that lead to wasting compressed air | $ 0 - $5,000 | Up to 5% | Electrical Energy | <1 |
| | Temperature Optimization | Relocating the air compressor or installing a piping extension that allows the inlet of outdoor air to the air compressor | $0 -$500 | 1% - 3% | Electrical Energy | <1 |

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Compressed Air System | Pressure Reduction | Reduction of set pressure to the lowest possible value. Could be applied at the point of usage or at the air compressor point | $0 | 1% - 3% | Electrical Energy | 0 |
| Process Heat | Process Heat | Improving the energy efficiency of process heat systems crucial for reducing energy consumption, lowering operating costs, and minimizing environmental impact. | 0$ - N/A | 5% - 15% | Thermal Energy | <2 |
| Refrigeration | Refrigeration Free Cooler | Free Cooling is an advanced process whereby, the air blast cooler can be used to offload the chiller and provide chilled water temperatures direct onto the process system in the cooler months of the year, thereby reducing system energy usage | $2,000-$ 10,000 / Piece | 50%-70% | Electrical Energy | <1 |
| | Refrigeration EER Improvement | Elevating the EER of refrigeration systems in industrial applications represents a pivotal step toward minimizing energy consumption, reducing operational costs, and curbing greenhouse gas emissions. | 0$ | 50% | Electrical Energy | - |
| Steam System | Combustion Optimization | Optimizing combustion efficiency by fuel to air ratio control and oxygen trimming, avoiding losses and reducing fuel consumption | $500-$10,000 | 2%-5% | Thermal energy | <3 |

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Steam System | Condensate Return Vented and Pressurized | through a condensate recovery system that recovers condensate from steam installations in order to maximize their overall energy efficiency | $100,000 | 3%-10% | Thermal energy | 3 |
| | Blowdown Steam Recovery | Recovering energy from blowdown steam and reducing energy losses caused by this necessary maintenance measure | $5,000 | 2% | Thermal energy | <3 |
| | Thermal Insulation | Improving insulation conditions to all steam network elements as well as boilers and hot mediums. This improvement also includes proper maintenance practices | $500-$5,000 | 1%-5% | Thermal energy | 1 |
| | Steam Traps Management | Management of steam traps including maintenance, care, cleaning, and replacement if the item is totally damaged | <$15,000 | 1%-2% | Thermal energy | <1 |
| | Steam Leakage Repair | Avoiding leakages and treatment of damaged pipes, accessories, elbows, and other leaking items that lead to wasting steam | $0-$3,000 | 5%-10% | Thermal energy | <2 |
| Heat Recovery | Economizer | Flue gas heat recovery through the use of an economizer that reuses the exhaust gas boiler that generates thermal energy for water heating | $15,000-$40,000 | 1%-5% | Thermal energy | <3 |

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Heat Recovery | Exhaust Gas Boiler | Heat Recovery from generator exhaust connecting it to a single unit called exhaust gas boiler that generates thermal energy for water heating | $200,000-<br>$500,000 | 5%-15% | Thermal energy | 3 to 7 |
| | Heat Exchanger - Jacket Water | Heat recovery from generator exhaust by the installation of a heat exchanger on the engines jacket water coolant to produce hot water | $20,000-$120,000 | 1-%15% | Thermal energy | 1 to 5 |
| | Absorption Chiller | heat recovery from generator exhaust to be used in an absorption chiller to generate chilled water and save on electricity expenses | $200,000-<br>$500,000 | 5%-15% | Thermal energy | 5 |
| | Compressed Air | Compressed air waste heat recovery involves the capture and utilization of the waste heat generated during the compression of air in industrial processes | N/A | 12% | Total Energy | N/A |
| VFDs | Installation of VFDs | Installing VFDs on air compressors and centrifugal pumps which leads to reduced speed and increase in energy savings. | $10,000 - $50,000 | 27%-49% | Electrical Energy | <5 |
| Renewable Energy Technologies | Installation of Renewable Energy Sources | Implementation of renewable energy projects to reduce greenhouse gas emissions, decrease energy costs, and increase the sustainability of industrial operations. | N/A | 1%-100% | Electrical Energy | N/A |

Given that local companies and consultants have been conducting energy audits for over 15 years, combined with the current global energy efficiency trends and the ongoing energy crisis in Lebanon, it is an opportune moment for industries and large facilities to seriously consider conducting their energy audit studies. The implementation of an energy audit study holds the potential to bring about a significant transformation in the operating expenses of the facility, ultimately providing a competitive advantage. This, in turn, leads to a more profitable operation and a more appealing product, positioning the facility for long-term success.

# 02.

# Introduction

Implementing Energy Management Programs at the national level offers significant advantages due to the strong connection between energy, economic growth, and the environment. These benefits include guaranteeing a reliable domestic energy supply, boosting the competitiveness of Lebanese industries and large facilities, and mitigating greenhouse gas emissions. Moreover, an increase in the efficiency of energy resource utilization contributes to achieving these advantages.

Economic development: Efficient energy end-use and demand side leads to a reduction in required generation growth rate, which is significant to economic development.

- Sustainability of national energy supply: Efficient Electricity production, distribution, and use would contribute to the country's energy security through sustainability of its domestic supplies.
- Environmental protection: Reducing energy consumption in addition to expanding the use of cleaner energy systems and technologies reduces the threat of adverse environmental and health-related impacts.

This report is intended to be an updated guideline for industries and large facilities on efficient use of resources and effective energy management in production processes. This type of energy management and efficient use of resources is done through presenting the best adapted EEMs (Energy Efficiency Measures) in the industrial sector.

# 03.

# What is an energy audit?

The process of conducting industrial and commercial energy audits is quite similar, but there are variations in the specific areas that the auditor emphasizes and considers significant.

At the core of developing a comprehensive energy management program lies the energy audit, which involves quantifying the energy consumption at a particular site. The audit aims to identify potential areas for energy savings and provides data that can be used to establish performance indicators.

In essence, the purpose of an energy audit is to determine the specifics of how, where, when, and why energy is being utilized. This information is then utilized to identify opportunities for enhancing efficiency, reducing energy costs, and mitigating greenhouse gas emissions that contribute to climate change. Additionally, energy audits can be employed to assess the effectiveness of implemented Energy Efficiency Measures (EEMs).

Therefore, while the process of conducting industrial and commercial energy audits is similar, there are variances in the specific aspects that auditors concentrate on and consider significant.

## 3.1. Industrial Energy Audit

An Industrial energy audit is an important foundation towards the implementation of an energy management program.

Typically, in most industries the three top operating expenses are often found to be energy – whether it is electrical or thermal – labor, and materials. Clearly, the energy side is the one that provides the highest flexibility and is the best option to optimize.

An effective energy audit enables owners and managing teams to better understand the ways energy is being used in their industry, and locate areas where waste can occur and where improvement can be done.

The main objective of an industrial energy audit is to find methods to reduce energy consumption per unit of production output or to lower the operating costs. The energy audit provides a benchmark, or reference point for management and assessment of energy use across an organization; it also provides the bases for ensuring more effective use of energy.

**The industrial energy audit is performed following the steps below:**

**Step 1:** Understanding the industrial operations
**Step 2:** Undertaking a Preliminary Energy Audit (OEA)
**Step 3:** Identifying the preliminary Energy Efficiency Measures
**Step 4:** Undertaking the Detailed Energy Audit (DEA) including:
  i. Preparation of measurements Plans.
  ii. Detailed analysis of existing energy end uses.
  iii. Development of all Energy Efficiency Measures wit their technical background, savings calculations, and financial analysis.
  iv. Preparation and presentation of the DEA report including the Action Plans.

A PEA is essentially a data gathering exercise that aims to develop an understanding of how energy is used in a factory, and to layout the groundwork for a detailed energy audit (DEA) implementation. It starts by gathering all the utilities' accounting details and building a baseline energy consumption; then it delimits key areas and processes where energy cost savings are possible, identifying the quick wins (Low Cost/No Cost Savings) and finally paves the way for the DEA in terms of additional requirements and planning.

The figure below provides a flowchart that includes the key steps and data gathered during the PEA:

Source: https://beeindia.gov.in/sites/default/files/1Ch3.pdf

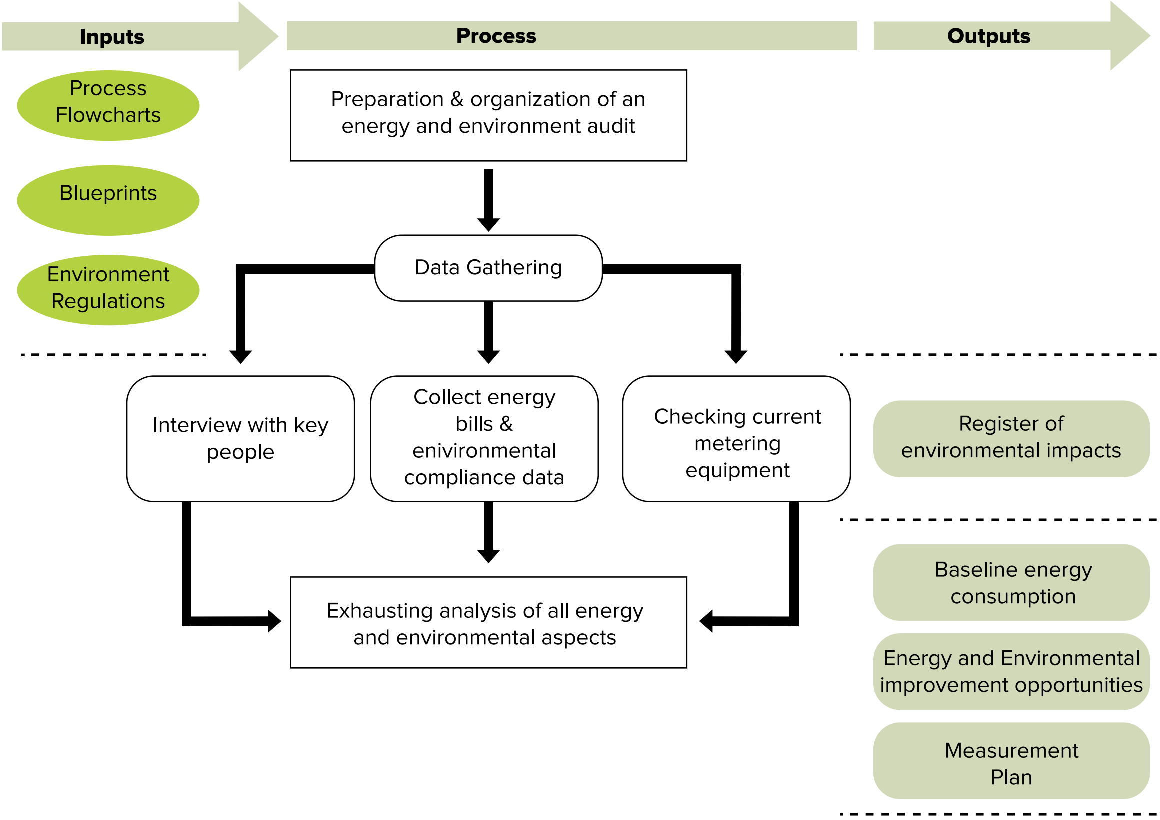


*Figure 1: Flowchart of a Preliminary Energy Audit (PEA)*

A **Detailed Energy Audit** aims at establishing actual energy performance of the various end-users and processes of a plant, and it also aims at providing a comprehensive implementation plan for an energy efficiency program. It offers an approximate estimate of energy savings and cost, accounting for the energy use of major equipment, including energy cost saving calculations and project cost. The DEA includes a specific metering campaign which is done according to a carefully prepared measurement plan. The measuring results are analyzed in order to establish energy balances, specify performance improvement measures and catty out an economic and financial analysis of performance improvement projects.

Therefore, while the process of conducting industrial and commercial energy audits is similar, there are variances in the specific aspects that auditors concentrate on and consider significant.

The figure below provides a flowchart depicting the DEA steps and tasks:

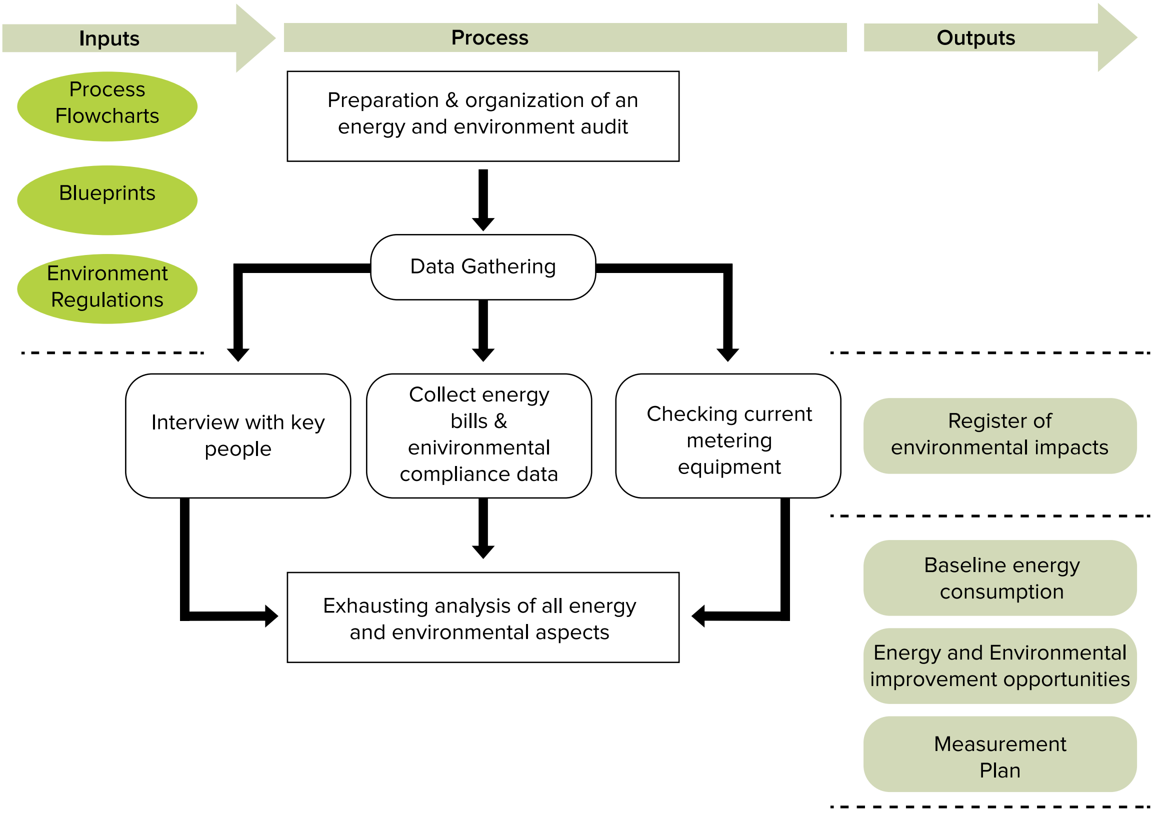


*Figure 2: Flowchart of a detailed energy audit (Morvay 2008)*

Combining all the steps into one comprehensive plan will lead to the below simplified process for undertaking an Industrial Energy Audit.

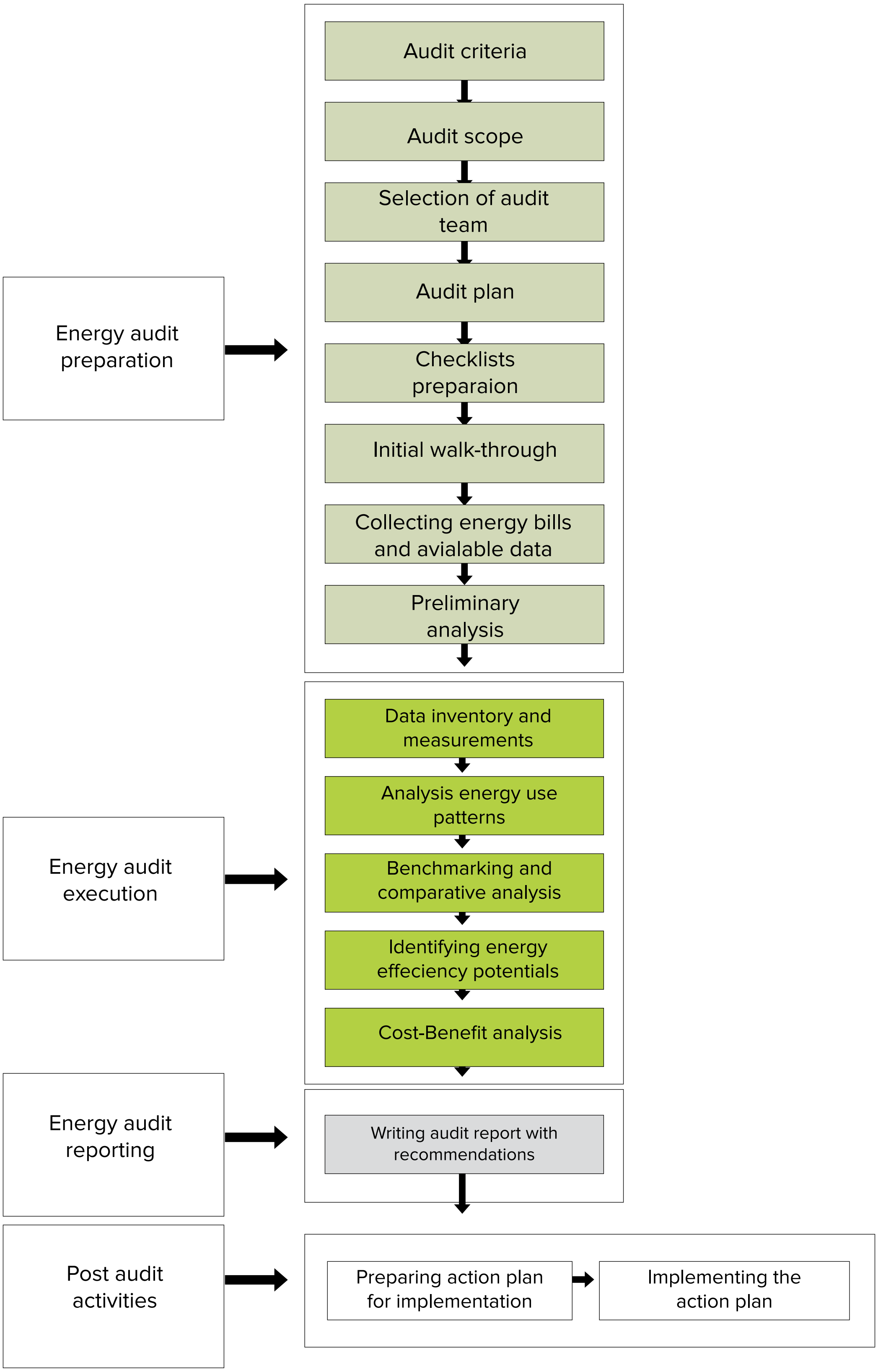


*Figure 3: Steps for a Detailed Energy Audit*

# 04.

# Energy Efficiency Measures

When considering Energy Efficiency Measures (EEMs), it is generally important to focus on optimizing energy production, supply, and purchase, while also taking into account electrical and thermal loads. This emphasis is particularly relevant for industrial processes and operations with high energy demands.

Within the industrial sector, energy conservation efforts commonly target motor systems, steam systems, compressed-air systems, pumps, and fan systems. These areas offer significant potential for savings due to the substantial energy costs associated with these operations and their criticality to overall industrial facility performance. These technologies are often referred to as “cross-cutting” technologies. However, due to the diverse range of production technologies and machinery across different industrial sub-sectors, it is beyond the scope of this guidebook to provide a detailed discussion of energy efficiency opportunities for each specific technology, system, or industry.

A wide range of measures identified in this guideline could potentially be applicable to most industrial facilities throughout Lebanon. The covered measures focused on the below categories/management:

- Efficient Lighting
- Monitoring and Energy Management
- Power Factor Correction
- Combined Cooling / Heat and Power Generation
- Compressed Air Systems
- Process Heat
- Refrigeration
- Steam Systems
- Heat Recovery
- Installation of Variable Frequency Drives
- Renewable Energy Technologies

Finally, it should be stressed that facility operators should optimize their internal loads through the application of an overall energy management program, prior to seeking an alternative energy source.

## 4.1. Efficient Lighting

### Introduction

In absolute numbers, the energy demand for lighting is growing due to the overall growth of economy and population while the energy consumption for lighting is shrinking due to the increased share of efficient lighting. Lighting plays a crucial role in the industrial sector, significantly impacting productivity, safety, and overall operational efficiency. As one of the fundamental components of any industrial facility, proper lighting not only ensures a well-lit work environment but also contributes to energy savings and sustainability.

### Application

In this context, the application of lighting in the industrial sector extends beyond mere illumination; it becomes a strategic asset that enhances the overall functioning of industrial facilities. From traditional high-intensity discharge lamps to cutting-edge LED technology and smart lighting systems, the industrial sector has seen a significant transformation in its approach to lighting.

When planning a retrofit, the following aspects should be looked at: efficacy, efficiency, illuminance, Color Rendering Index, Colour temperature, and lamp lifetime.

Selecting the right technology, such as upgrading from conventional lighting sources to energy-efficient LED fixtures, is crucial for achieving energy savings and better illumination. Additionally, compliance with industry-specific regulations and standards, particularly in sectors with stringent safety requirements like manufacturing or chemical processing, is a top priority.

Furthermore, the retrofit process should be carefully planned to minimize disruptions to ongoing industrial processes, ensuring a smooth transition to the upgraded lighting system.

**Advantages**

A LED lamp or LED light bulb produces light using light emitting diodes (LEDs). The LED lamps are significantly more energy-efficient than equivalent incandescent lamps and can be significantly more efficient than most fluorescent lamps. The advantages of the LED lamps are:

- High luminance efficacy, up to 200 lm/W

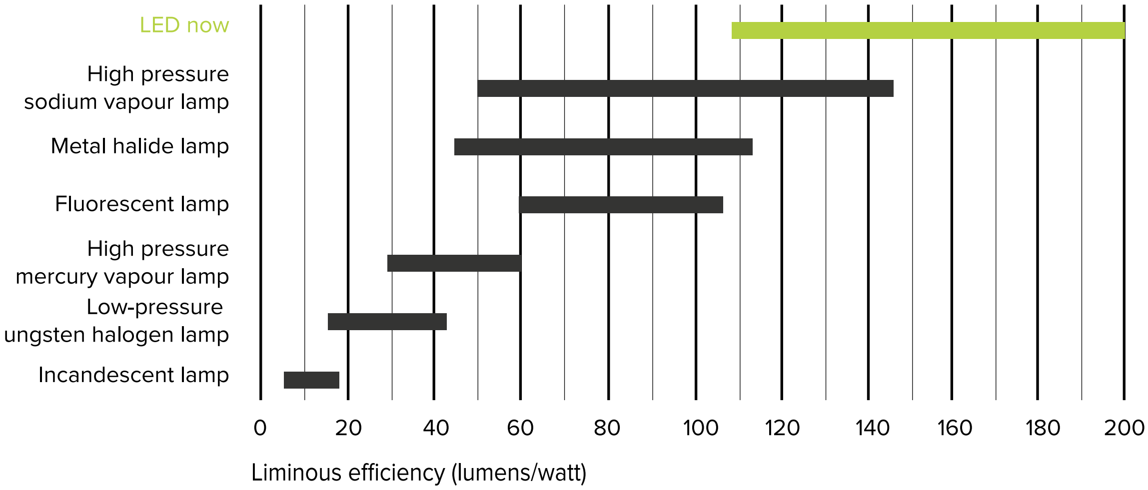


*Figure 1: Flowchart of a Preliminary Energy Audit (PEA)*

- Excellent CRI (Colour Rendering Index) reaching 70 to 100 CRI
- Reduced Electricity cost
- Very high lifetime up to 100,000H
- Complete insensitivity to damage upon impact
- Direct response to switching on and off
- No damage due to frequent switching
- Low heat emittance
- Highest efficiency compared to other lighting types

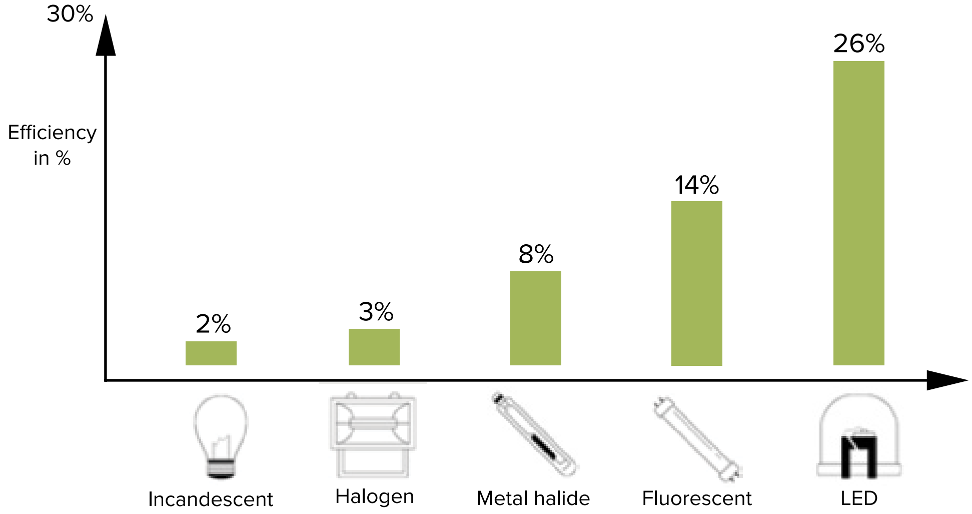
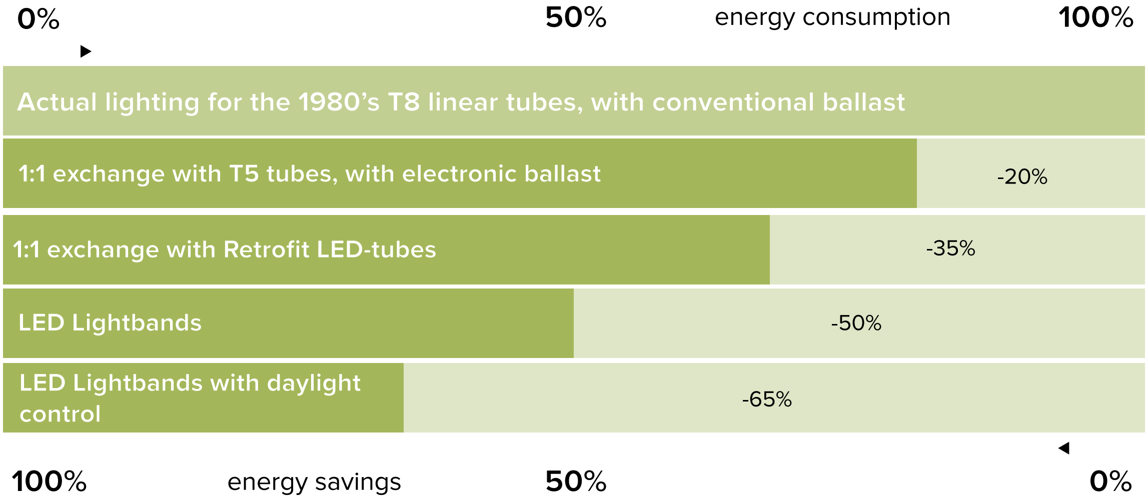


*Figure 5: lighting efficiency %*

**Financial Savings**

Savings from retrofitting conventional lamps to LED can reach up to 50% but also extend to lighting controls, where integrating sensors, timers, and dimming capabilities can optimize energy usage by aligning lighting with occupancy and operational needs and increase the savings to reach 65%.

Example: Saving Potential with LED Lighting



## 4.2. Monitoring and Energy Management

### 4.2.1 Energy Metering and Control

**Introduction**

Energy metering involves the utilization of a range of meters, sensors, and monitoring devices to gather data pertaining to energy usage within a process, a production line, a specific segment, or the entire facility. This data collection enables facility operators to establish targets, performance indicators, and generate regular monitoring reports.

The design of the energy metering system varies based on factors such as the specific facility, its architectural structure, and the existing control methodology. One prevalent solution is Enterprise Energy Management, which provides facility operators with comprehensive information and control capabilities, simplifying the management of intricate power supplies and building operations. This solution facilitates efficient and streamlined monitoring and control processes.

**Application**

In a majority of industrial and large-scale facilities in Lebanon, inadequate metering systems and insufficient availability of accurate energy information are commonly observed. As a result, it becomes imperative to prioritize the installation of networked metering systems accompanied by host software as part of the comprehensive industrial energy management program.

To illustrate the concept, a diagram displaying the components, connections, and networking involved in an Energy Information Management system is presented in the following figure. This serves as a sample scheme demonstrating the various elements and their interconnections.

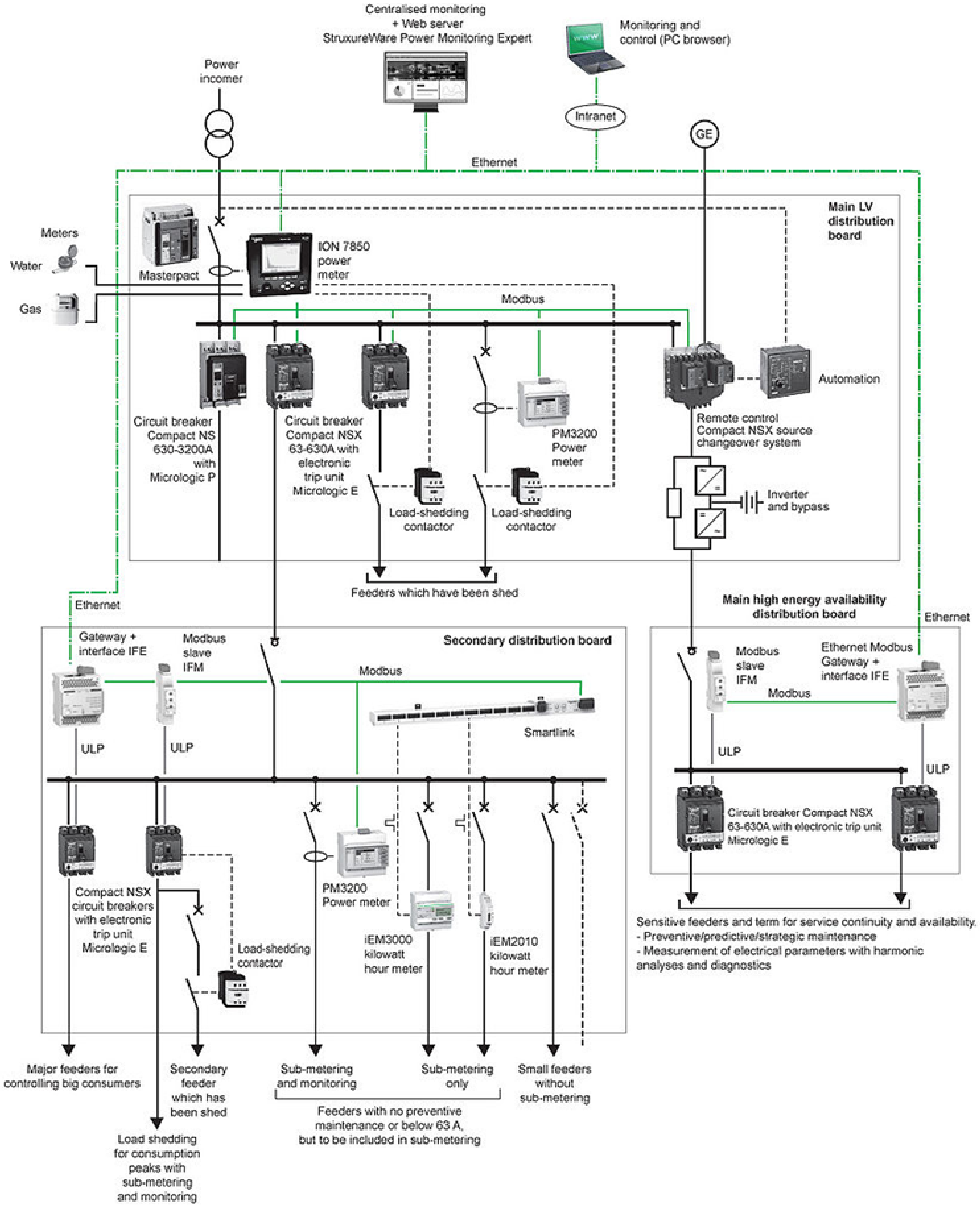


*Figure 6: Energy Information System Architecture (Courtesy: Schneider Electric)*

Depending on the nature of the facility, the metering system covers a hierarchy of information related to energy use with levels such as the following:

- **Plant level:** information can be derived from the Main distribution Panels including both the utility (EDL) and generators consumption.
- **Plant Department level:** information is taken in a comparative energy consumption data for a group of electrical loads combined into processes or departments that could also be ultimately correlated with plant use and production data.
- **System level:** performance data is determined from sub-metering data, subjected to regression analysis against key independent variables. Examples are boiler plant, compressed air systems or refrigeration plant.
- **Equipment level:** information can be derived from nameplate data, run-time and schedule information, and sub-metered data on specific energy consuming equipment such as a chiller, for instance, or an individual large air compressor.

Ultimately a plant will need to build a metering and targeting program whereby its detailed metering practices are benchmarked through specific targets that are set based on the on the planned energy efficiency improvements.

The chart below showcases various parameters. The important point to be noted here is that all of these data are useful since they can all be processed to yield information about facility performance.

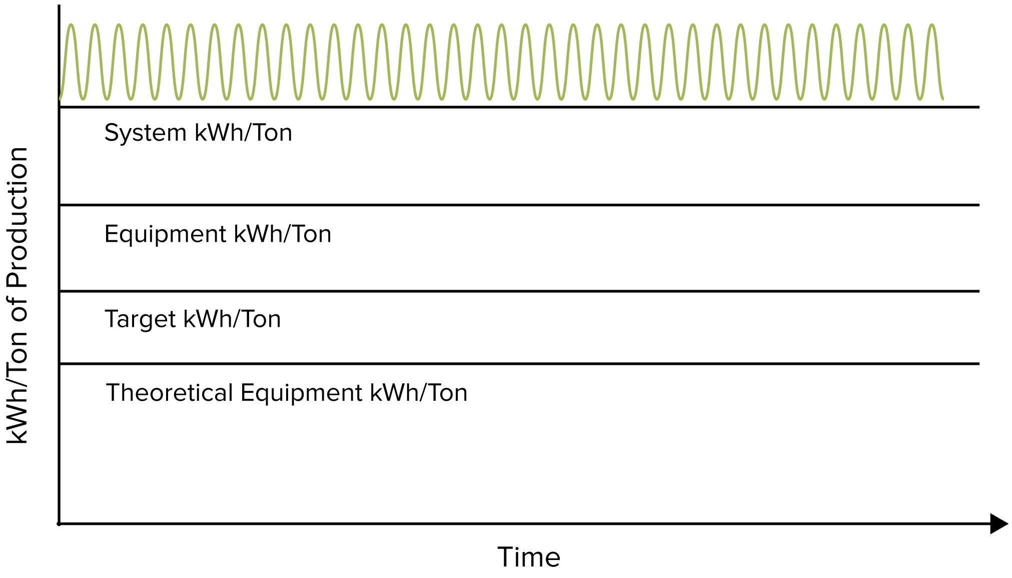


*Figure 7: Plant's Metering & Targeting (The Graph is not zero based and not to scale)*

The Enterprise Energy Management system runs 24 hours a day, 7 days a week, monitoring energy assets and infrastructure, and tracking costs by building, tenant or Process.

Enterprise Energy Management is a key element or a comprehensive strategic energy management process that enables and sustains opportunities for increased profitability, maximized property values, and offers you uptime guarantees.

Using a standard web browser, the EEM system instantly translates energy usage into financial data and key performance indicators and analyzes:

- Utility tariffs
- Equipment Operations
- Power Quality
- Maintenance

**Advantages**

Adhering to the notion that "You can't manage what you don't measure," energy monitoring and metering play a crucial role in effective energy management within multi-operation facilities. These practices enable the day-to-day monitoring of energy performance across processes, machinery, operations, and the facility as a whole.

A common oversight among manufacturers and facility operators is underestimating the impact of variable energy costs and lacking strategic management of these expenses.

This underestimation often stems from the absence of tracking energy costs specific to manufacturing lines, equipment, or products. For instance, they may not have a clear understanding of which line consumes more energy and the reasons behind it.

By gaining insights into their energy usage, operators acquire a better understanding of where and why energy is being consumed, as well as the effectiveness of that consumption. However, acquiring such knowledge necessitates close monitoring of energy usage at specific locations within the facility and assessing the reasons behind the energy consumption associated with particular products. Measurements also provide valuable insights into the impact of energy improvement initiatives on consumption, whether it be by product, line, or machinery.

Recognizing plant-level energy consumption and comprehending how changes in product combinations, lines, and machinery can enhance overall plant performance and profitability signify significant progress for a facility. Through a dedicated energy strategy, a facility can set ambitious targets and achieve meaningful bottom-line results.

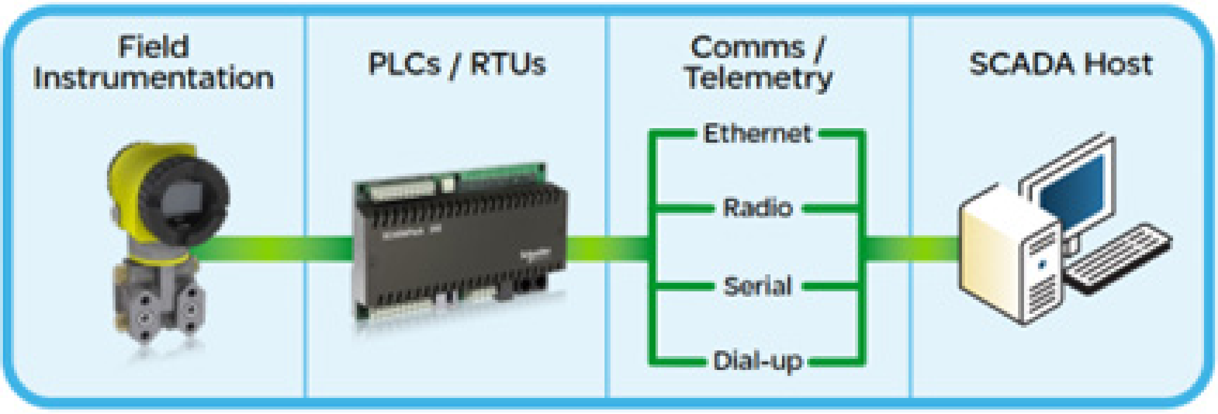
**SCADA – The next level**

SCADA refers to 'Supervisory Control and Data Acquisition'. The major aim of a SCADA system is to acquire data from remote devices such as valves, pumps, transmitters, etc. and provide overall remote control through a SCADA Host software platform. This provides process control locally so that these devices turn on and off at the right time, supporting the control strategy and a remote method of capturing data and events (alarms) for monitoring these processes.

SCADA Host platforms also provide functions for graphical displays, alarming, trending and historical storage of data.

A SCADA system usually consists of the following subsystems:

- A human–machine interface or HMI: is the apparatus or device that presents processed data to a human operator, and through this data, the human operator monitors and controls the process.
- A supervisory (computer) system: it gathers (acquires) data on the process and sending commands (control) to the process.
- Remote terminal units (RTUs): it connects to sensors in the process, converts sensor signals to digital data and sends digital data to the supervisory system.
- Programmable logic controller (PLCs): it is used as field devices because it is more economical, versatile, flexible, and configurable than special-purpose RTUs.
- Communication infrastructure: it connects the supervisory system to the remote terminal units.
- Various process and analytical instrumentation.



Typically, a SCADA system will automate much of the control process so that plant operators can focus on other tasks. The system gives the operator flexibility to remotely control the equipment where desired. SCADA systems are also installed to collect and store information for reporting, troubleshooting, maintenance indications, and much more.

There are a number of advantages to having a SCADA system installed:

- Ability to significantly reduce operating costs and to improve the efficiency of the plants' assets, while improving system performance and reliability. SCADA systems are equipped to make immediate corrections in the operational system, so they can increase the life-period of equipment and save on the need for costly repairs.

- Costly after-hours alarm call-outs can often be avoided since a SCADA system would indicate the nature and degree of a problem.

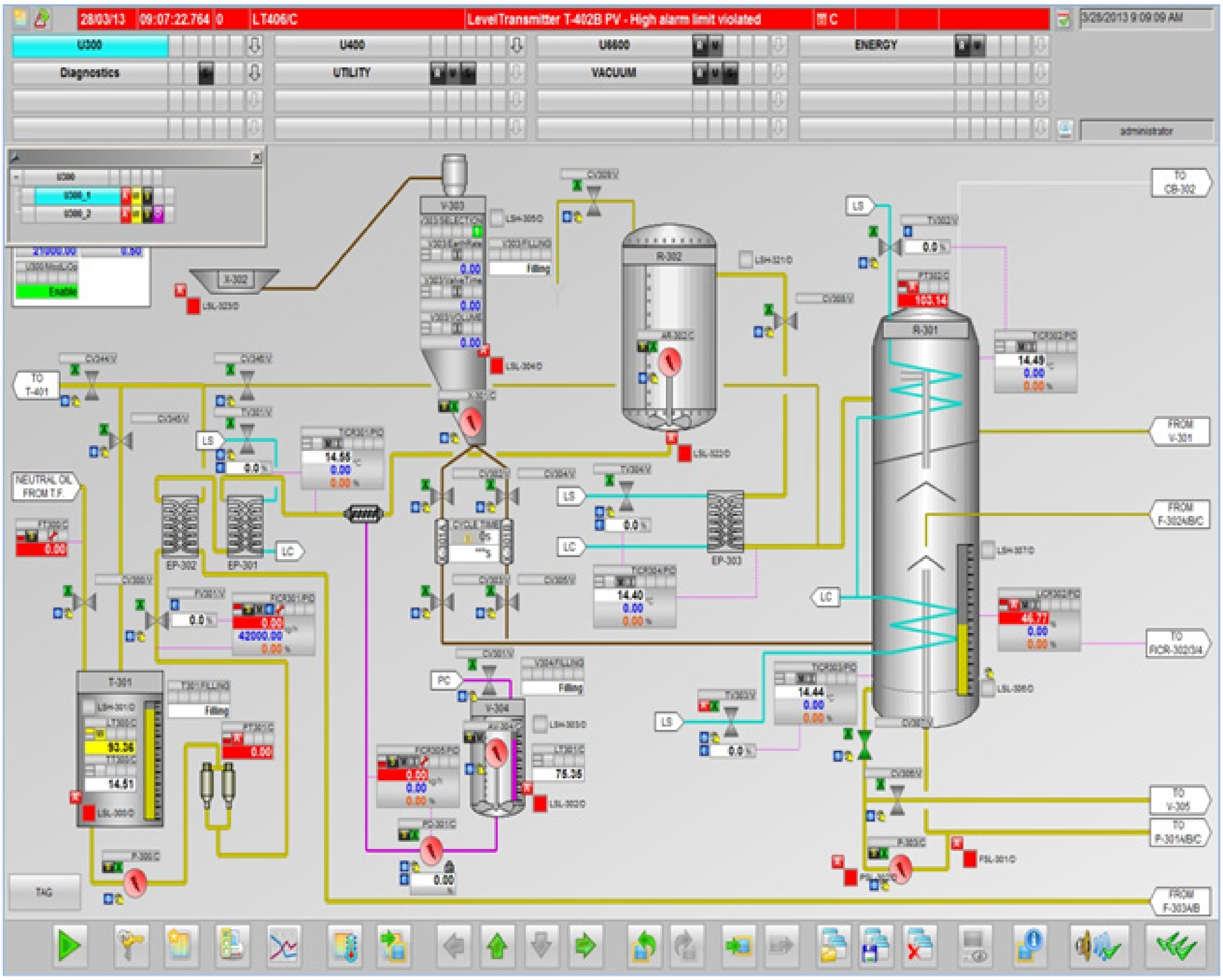
- Since data is continuously recorded, operators do not have to manually read and record meter readings on a daily basis.

- Operators do not have to keep track of hundreds of log sheets since data recorded on the SCADA system can be downloaded and accessed at their convenience.

- SCADA systems can often be accessed remotely through an internet connection on a computer or laptop, and even on a cell phone or a tablet.

- The auto-generated reporting system ensures compliance with regulatory principles and tracking all KPIs.

- Most mid to large scale industries can benefit from a SCADA system which could also have a fully integrated energy metering, and dashboard system as covered in the previous section.



28/03/13 09:07:22.764 0 LT406/C LevelTransmitter T-402B PV - High alarm limit violated

3/28/2013 9:09:09 AM

*Figure 8: SCADA Screen Snapshot*

**Financial Savings**

Significant savings can result from proactively aggregating, monitoring, and analyzing energy data. New and improved software and technologies are available to accomplish this goal.

For example, energy meters provide an enormous wealth of energy data. But since the vast majority of these meters don’t communicate together; most of this data is lost. An easy way to fix this is to establish a communication and visualization system to link these meters, using the existing Ethernet and routers to bring this data to the forefront via an energy management dashboard that allows the user to see where energy is being used, where it’s being wasted, and where efficiency needs to be improved, remotely.

A proper energy management and monitoring system could save 5% going up to more than 35%, depending on the current situation of the facility and the operational profile. The cost of such a system ranges between $10,000 and $50,000 depending on the facility size.

Several indicators are used to estimate the impact of this measure. These indicators include:

- Equipment kWh/ton: defined as the energy required when the optimum amount of equipment is operating at design efficiency.
- System kWh/ton: defined as the energy required when the operator and machine influences are included – this takes into account operational techniques and maintenance practices.
- Actual kWh/ton: Energy use, taking into account any responses of the operators and supervisors to variations and external influences and the time lag in responding.
- The return on investment of an energy management and monitoring system would vary based on the complexity of the system and the effectiveness of systems in place. The payback period would range between one and three years.

**Why look back?**

The energy used by any industry varies as production processes, volumes, and inputs vary. Determining the relationship of energy use to key performance indicators will allow manufacturers to determine:

- Whether their current energy use is better or worse than before;
- Trends in energy consumption that reflect seasonal, weekly, and other operating patterns;
- How much their future energy use is likely to vary if they change aspects of their business;
- Specific areas of wasted energy'
- Comparisons with other businesses with similar characteristics. This "benchmarking" process will provide valuable indications of the effectiveness of the operations as well as the energy use;
- How the business reacted to changes in the past;
- How to develop performance targets for an energy management program.

## 4.3. Power Factor Correction

### Introduction

Power factor correction is often an underestimated aspect of modern industrial operations. In industrial settings, electrical systems are the essence that powers machinery, equipment, and processes. However, not all power is utilized efficiently. Power factor correction aims to optimize the efficiency of electrical systems by improving the relationship between real power (the power used to perform work) and apparent power (the combination of real power and reactive power, which doesn't perform useful work but circulates in the system). This improvement has far-reaching benefits, including reduced energy consumption, lower electricity costs, enhanced equipment lifespan, and reduced stress on electrical infrastructure.

### Application

Power factor correction in industries involves various strategies and technologies to improve the power factor of electrical systems. The goal is to minimize the amount of reactive power in the system and bring the power factor as close to unity (1) as possible. Here are some common methods for power factor correction in industrial settings:

- Capacitor Banks: Installing capacitor banks is one of the most common and effective methods for power factor correction. Capacitors provide reactive power to offset the inductive load of motors and other equipment, thus improving the power factor. Capacitor banks can be automatically controlled based on the load to ensure optimal correction.

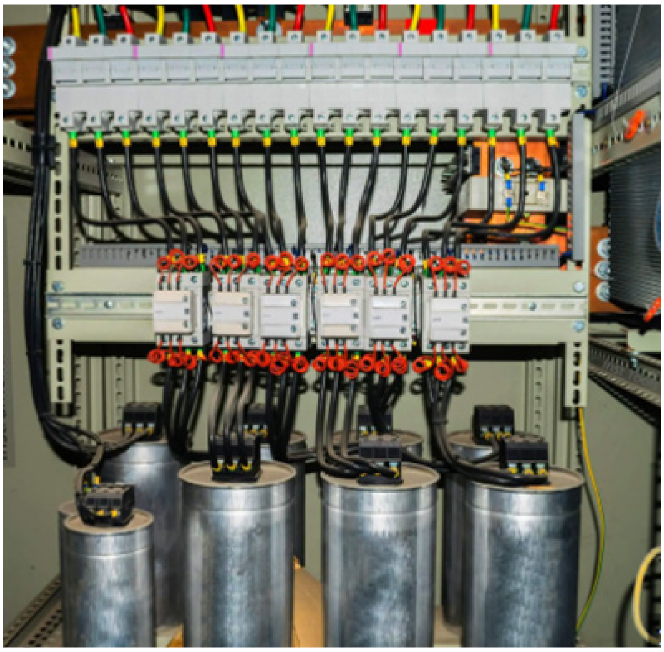


*Figure 9: capacitor bank*

- Static Var Compensators (SVCs): SVCs are devices that use power electronics to control the flow of reactive power into the system. They can quickly adjust to varying loads and are effective in correcting power factor issues.

- Synchronous Condensers: Synchronous condensers are rotating machines that generate reactive power. They can be adjusted to supply or absorb reactive power as needed, making them versatile for power factor correction.

- Transformer Taps: Adjusting the tap settings on transformers can help improve power factor. By changing the voltage ratio, you can reduce the magnetizing current and, in turn, improve the power factor.

- Harmonic Filters: In some cases, harmonic filters may be necessary, especially when harmonic distortion is present. Harmonic filters can mitigate harmonics, which can negatively impact power factor.

*Figure 10: Harmonic Filters*

- Load Management: Properly managing and scheduling equipment usage can help balance the load and reduce the demand for reactive power. This can involve staggered start times for motors or other load-shifting strategies.

- Monitoring and Control Systems: Implementing advanced monitoring and control systems can continuously assess power factor and adjust correction methods accordingly. This ensures optimal correction even in dynamically changing industrial environments.

- Regular Maintenance: Keeping equipment and electrical systems well-maintained is essential for effective power factor correction. This includes checking for loose connections, damaged capacitors, and other issues that can affect correction efforts.

- Power Factor Correction Studies: Conducting a power factor correction study is crucial to assess the specific needs of an industrial facility. This study helps determine the correct size and placement of correction equipment to achieve the desired power factor.

### Application

Power factor correction in industries offers several significant advantages that can positively impact both electrical systems and overall operations:

- **Reduced demand charges:** Most electric utility companies charge for maximum metered demand based on either the highest registered demand in kilowatts (KW meter), or a percentage of the highest registered demand in KVA (KVA meter), whichever is greater. If the power factor is low, the percentage of the measured KVA will be significantly greater than the KW demand. Improving the power factor through power factor correction will therefore lower the demand charge, helping to reduce your electricity bill.

- **Improved voltage:** A lower power factor causes a higher current flow for a given load. As the line current increases, the voltage drop in the conductor increases, which may result in a lower voltage at the equipment. With an improved power factor, the voltage drop in the conductor is reduced, improving the voltage at the equipment.

- **Increased load carrying capabilities in existing circuits:** Loads drawing reactive power also demand reactive current. Installing power factor correction capacitors at the end of existing circuits near the inductive loads reduces the current carried by each circuit. The reduction in current flow resulting from improved power factor may allow the circuit to carry new loads, saving the cost of upgrading the distribution network when extra capacity is required for additional machinery or equipment, saving your company thousands of dollars in unnecessary upgrade costs. In addition, the reduced current flow reduces resistive losses in the circuit.

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- **Reduced power system losses:** Although the financial return from conductor loss reduction alone is seldom sufficient to justify the installation of capacitors, it is sometimes an attractive additional benefit; especially in older plants with long feeders or in field pumping operations. System conductor losses are proportional to the current squared and, since the current is reduced in direct proportion to the power factor improvement, the losses are inversely proportional to the square of the power factor.

- **Increased Equipment Lifespan:** A higher power factor means that motors and other electrical equipment operate more efficiently. This reduced stress on equipment can extend their operational life, reducing the need for costly replacements and maintenance.

- **Enhanced System Capacity:** By reducing the demand for reactive power, power factor correction can free up capacity within the electrical system. This additional capacity can be utilized for future expansions or increased production needs.

- **Environmental Benefits:** Reduced energy consumption and improved efficiency contribute to a smaller carbon footprint and align with sustainability goals, demonstrating environmental responsibility.

- **Improved Power Quality:** Power factor correction can help mitigate voltage flicker and harmonics, which can lead to better power quality and fewer disruptions in industrial processes.

- **Operational Reliability:** A more efficient and stable electrical system enhances overall operational reliability. This is crucial for industries where downtime can result in significant financial losses.

### Financial Savings

The amount of electricity savings achieved through power factor correction depends on various factors, including the initial power factor of the electrical system, the type and size of the correction equipment installed, and the specific industrial processes involved. However, the estimated savings resulting from the PF correction are between 3 and 6%.

# 4.4. Combined heat and Power Generation (CHP)

## 4.4.1. Combined Heat and Power Generation (CHP)

### Introduction

Combined Heat and Power (CHP) refers to the simultaneous utilization of heat and power derived from a single energy source, typically at or near the point of use. An optimal CHP system is designed to fulfill the heat demand of the energy user, whether at the building, industrial, or city-wide level. This approach is cost-effective since it is more economical to transport surplus electricity than surplus heat from a CHP plant. Consequently, CHP is primarily considered a source of heat, with electricity being a by-product.

CHP systems can take various forms and encompass a range of technologies, but they all involve an integrated and efficient system that combines electricity production with heat recovery. By utilizing the heat generated from electricity production for heating or industrial purposes, CHP plants typically convert 75-80% of the fuel source into useful energy. The most modern CHP plants can achieve efficiencies of 90% or higher. Additionally, CHP plants help reduce network losses as they are located close to the end user.

### Application

A typical CHP plant consists of four main elements: a prime mover (such as an engine or drive system), an electric generator, a heat recovery system, and a control system. The prime mover drives the electricity generator and simultaneously produces usable heat, which can be recovered and utilized. The classification of CHP units generally depends on the application, prime mover, and fuel used.

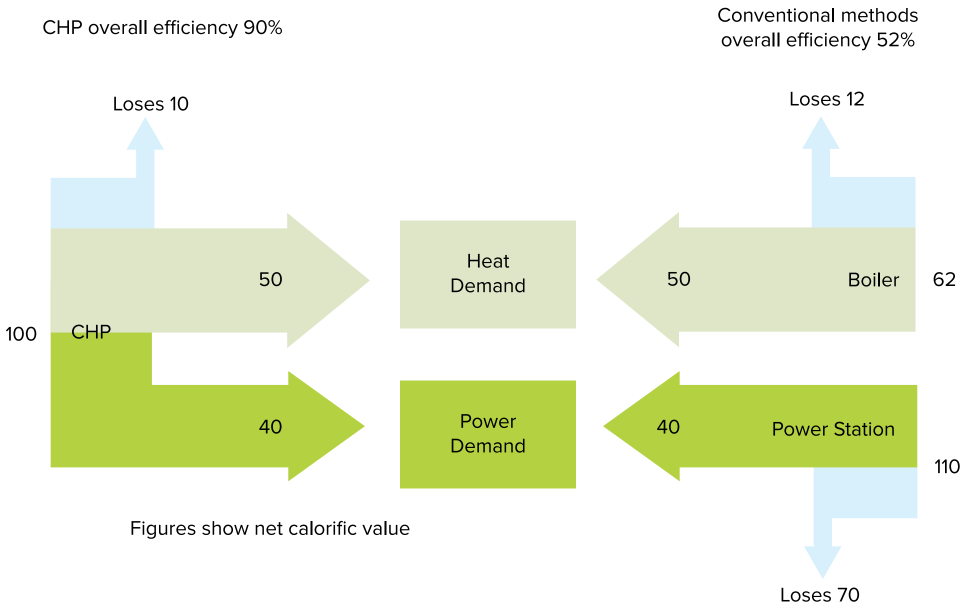


*Figure 11: Cogeneration /CHP diagram vs conventional methods*

### Advantages

CHP systems are typically more suitable for facilities with a consistent and substantial demand for both electricity and heat, such as large manufacturing plants. here are some key advantages of CHP in industrial settings:

- High Energy Efficiency: CHP systems can achieve significantly higher energy efficiency compared to conventional separate power generation and heating systems. By simultaneously producing electricity and capturing waste heat for heating or cooling purposes, CHP systems can reach overall energy efficiencies of 70% to 90%, reducing energy consumption and costs.

- Cost Savings: CHP can lead to substantial cost savings in energy bills, as it reduces the need to purchase electricity from the grid and provides on-site heating or cooling. This can result in a quick return on investment and long-term operational cost reductions.

- Reduced Greenhouse Gas Emissions: CHP systems can lower greenhouse gas emissions by optimizing energy use. By using the waste heat that would otherwise be wasted, CHP helps reduce the carbon footprint of industrial facilities, contributing to sustainability and environmental goals.

- Enhanced Energy Reliability: CHP systems can provide a reliable source of electricity and heat, reducing the risk of downtime due to grid outages. This is especially critical for industries that require continuous and uninterrupted energy supply, such as manufacturing or data centers.

- Grid Support and Energy Resilience: CHP systems can provide grid support during peak demand periods, reducing strain on the electrical grid. Additionally, in the event of a grid failure, some CHP systems can operate independently, enhancing the facility's energy resilience.

- Energy Independence: CHP allows industrial facilities to generate a significant portion of their energy needs on-site, reducing their dependence on external energy suppliers and fluctuations in energy prices.

- Improved Power Quality: CHP systems can enhance power quality by providing a stable and consistent electricity supply, reducing the risk of voltage sags, surges, and other power disturbances.

- Waste Heat Recovery: The captured waste heat from CHP can be used for various industrial processes, space heating, cooling, or even to generate steam for additional power generation, increasing the versatility and utility of the system.

### 4.4.2. Combined Cooling, Heat and Power Generation (CCHP)

**Introduction**

Combined Cooling, Heat and Power (CCHP) - or 'tri-generation' - refers to the process by which the heat produced by a Combined Heat and Power (CHP) unit is used to power an absorption chiller or a direct fired chiller, in order to generate chilled water for applications such as air conditioning or refrigeration, in addition to electricity and heat production.

A slight difference between CCHP and CHP is that thermal or electrical/mechanical energy is further utilized to provide space or process cooling capacity in a CCHP application. CCHP can be defined as a more extensive concept than CHP is. In winter, many CCHP systems can be seen as CHP units, when there is no cooling demand of the facility air-conditioning. In other words, CHP system is CCHP without any thermally activated equipment for generating cooling power, though this difference will change the structure of systems to some extent.

**Application**

CCHP systems are classified into two categories:

1. Traditional large-scale CCHP applications (predominantly CHP systems without cooling options) in centralized power plants or large industries;
2. Relatively small capacity distributed CCHP units with advanced prime mover and thermally activated technologies3 to meet multiple energy demands in commercial, institutional, residential and small industrial sections.

A typical CCHP system is showed in Fig. 10. It is comprised of a gas engine, a generator and an absorption chiller.

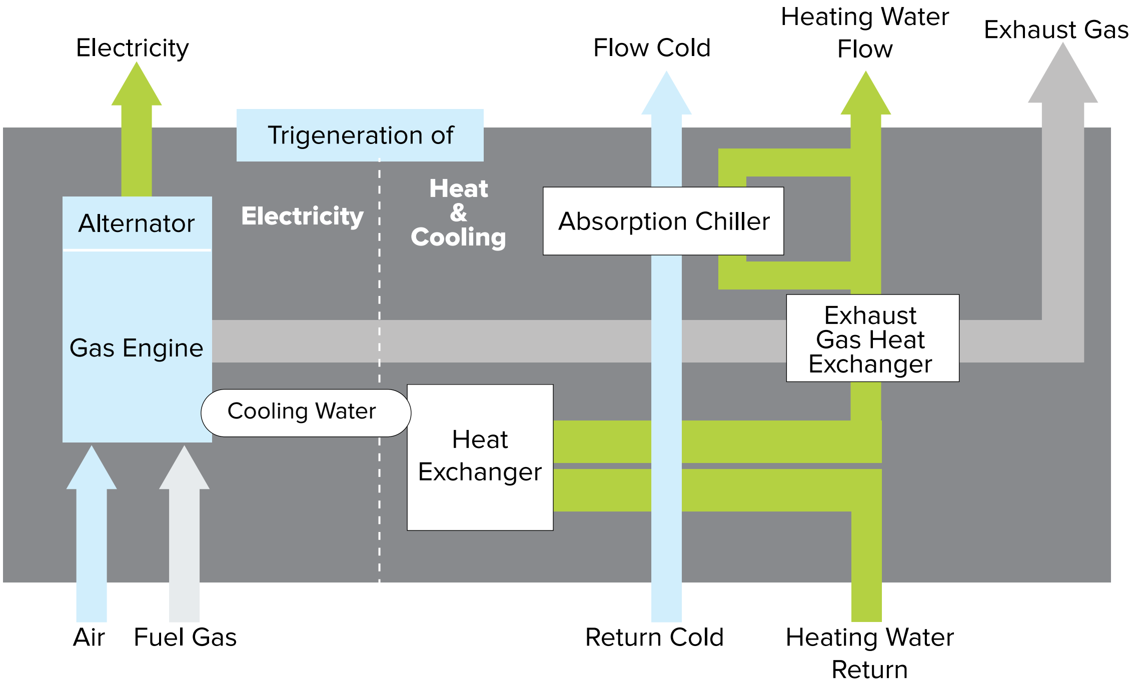


*Figure 12: CCHP system*

CCHP systems begin by generating electricity using a prime mover, such as a gas turbine, reciprocating engine, or microturbine. These devices burn the primary fuel source to produce mechanical energy, which drives an electric generator to produce electricity. One of the key features of CCHP is the efficient capture and utilization of waste heat generated during the power generation process. This waste heat is extracted from the exhaust gases and/or engine cooling systems. The recovered waste heat is used for space heating, water heating, or industrial heating processes, depending on the specific application. This provides a cost-effective and energy-efficient source of thermal energy. the recovered waste heat can also be used in absorption chillers or adsorption chillers to generate cooling or air conditioning. This process utilizes the heat to drive the cooling cycle, providing chilled water for cooling purposes.

### Advantages

CCHP systems are particularly advantageous for applications with simultaneous demands for electricity, heating, and cooling in industrial complexes, and large commercial buildings. Their ability to optimize energy use and reduce operational costs makes them a compelling choice for organizations looking to enhance energy efficiency and sustainability. Some of these advantages are:

1. High efficiency, with overall energy efficiencies typically exceeding 80%. By capturing and utilizing waste heat for heating and cooling, they reduce energy waste compared to separate generation methods.
2. Cost Savings: CCHP can lead to significant cost savings by reducing electricity bills, heating costs, and cooling expenses. The ability to offset or eliminate grid electricity purchases is a major economic advantage.
3. Reliability: CCHP systems can provide a reliable and continuous supply of electricity, heating, and cooling, even during grid outages, enhancing energy resilience for critical facilities.
4. Environmental Benefits: By optimizing energy use and reducing the consumption of fossil fuels, CCHP systems can lower greenhouse gas emissions, contributing to sustainability and environmental goals.
5. Peak Demand Management: CCHP systems can help manage peak electricity demand, potentially reducing demand charges and peak electricity costs.
6. Waste Heat Recovery: CCHP effectively recovers and utilizes waste heat, reducing the need for additional heating and cooling equipment and improving the overall environmental footprint of the facility.

### Financial Analysis

The savings achieved through Combined Heat and Power (CHP) and CCHP generations in industrial applications can be substantial and multifaceted. However, the extent of savings depends on various factors, including the size of the CHP/CCHP system, the specific industrial processes, energy consumption patterns, and most importantly the local energy prices. A 164KW electrical CHP generator usually costs around 760,000 USD.

## 4.5. Compressed Air system

### 4.5.1. System optimization

**Introduction**

Compressed air is often considered as the fourth essential utility, following electricity, water, and gas. However, it can be a costly resource for businesses. Generating compressed air demands more than 10 units of electrical power to produce 1 unit of compressed air. This ratio highlights that even a slight reduction in compressed air usage can lead to substantial electricity savings. The figure below illustrates the primary components of a compressed air plant.

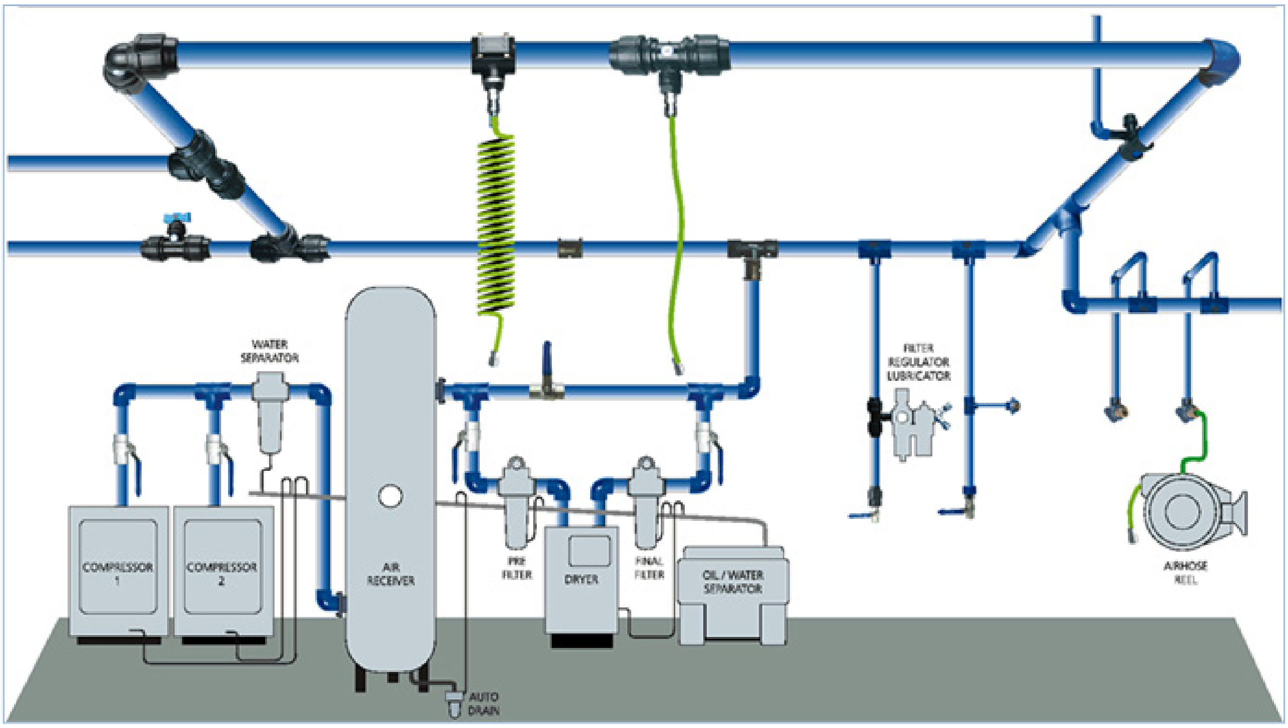


*Figure 13: Typical Compressed Air System components and Network*

Although air is free, the generation and distribution of compressed air is expensive and requires a huge amount of energy. Compressed air is an inefficient medium where around 85% of the electrical energy is used to produce it is converted into heat and only the remainder is converted into pneumatic energy.

### Application

Approximately 75% of the overall expenses of a compressed air system can be attributed to electrical costs, while the remaining 25% comprises capital expenditure and maintenance costs. Although the inherent efficiency of a compressed air production system stands at 10%, the net efficiency of the entire compressed air infrastructure within a plant is typically around 6.5%. This can be observed in the energy flow diagram presented below.

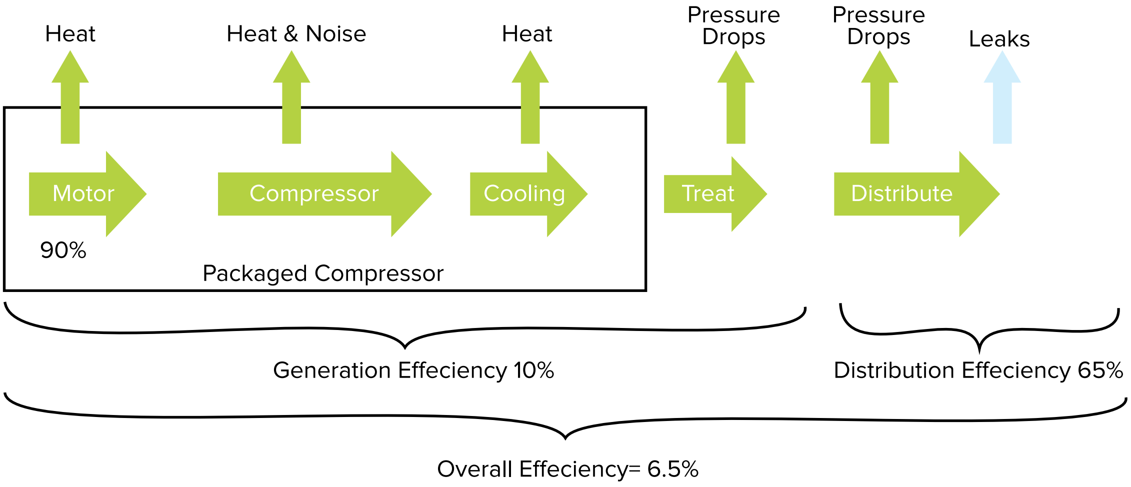


*Figure 14: Compressed air system and network energy flow diagram*

In the above energy flow, the set of losses occur in the following sections and parts:

- Motor Losses- Heat created due to conversion from electric to mechanical power
- Compressor Losses – Thermodynamic inefficiencies of the particular compressor
- Heat rejected from air cooler.
- Losses in treatment – including oil separation, filtration and drying.
- Distribution system pressure drops- Losses related to pressure drops due to elbows, connections and piping.
- Distribution system leaks – Losses die to leaks across all the system from the production point to the end user one.
- End-use pressure drops for low pressure use- Losses introduced by Pressure Reducing valves at end use points.

In order to improve the performance of the compressed air system, the facility operator should follow a phased approach as follows:

#### 1- Maintenance Practices

To ensure maintenance is carried out to the highest standard, it is recommended to conduct a thorough leakage analysis during plant maintenance. There are various methodologies available to detect and identify leaks. For an effective and comprehensive leakage analysis, the implementation of an ultrasonic detector is essential.

Once the leakages are identified and promptly addressed, and maintenance is performed on all components of the compressed air system, it is advisable to monitor the total air and pressure demand of the end-use equipment as well as the compressed air packages. At this stage, it becomes crucial to assess the efficiency ranking (KWh/m2) of the air compressors and establish a cascade control system that considers these findings. This entails placing the most efficient compressors at the forefront of the system to optimize efficiency and performance.

**2- Determine Compressed air needs**

- Check if compressed air is needed for every current end use, and if it can be replaced by another energy form such as simple blowers or cooling.
- Undertake a full inventory of the while compressed air system in terms of:
    - Flow requirement (cfm)
    - Pressure requirement
    - Quality (temperature, moisture content, oil content, etc.)
    - Point(s) in the distribution system
- Undertake a compressed air utilization mapping in terms of end-uses and time of use
- Analyze plant's growth in compressed air usage with plant management in order to validate if the growth is coming from additional needs or from leaks.

**3-Implement low cost/no cost measures**

- Implement an awareness program for compressed air management across the plant
- Eliminate compressed air leaks (discussed further in separate section)
- Eliminate unnecessary uses
- Minimize compressed air production's pressure as much as possible (discussed further in a separate section).
- Minimize/Avoid pressure reduction at point of end-use. Alternatively, segregate large low-pressure uses and provide dedicated low pressure supply
    - – Either a dedicated compressed air unit or high pressure blowers.
- Segregate end-uses based on the appropriate quality requirement (temperature, moisture and oil content, etc.)
- Ensure that controls for treatment (drying) are not set lower than required
- Inspect and ensure that the demand for air is matched by the appropriate online compressor capacity (if not VFD driven)
- Implement compressors' sequencing strategy to ensure that unit with best capacity controls follows the load.
- Ensure that idling compressors shut down promptly.
- Ensure that inlet air temperature is as cool and dry as possible – use outside air during cold seasons

- Ensure that inlet filters are clean with minimal pressure drop
- Ensure that filtration and treatment equipment impose minimal pressure drop.
- Ensure that line sizing is appropriate to flows to minimize pressure drop.
- Ensure good piping practices to avoid excessive pressure drops at T connections, elbows, unions and other fittings.

**4-Implement measures with mid/larger investments**

- Implement a comprehensive compressed air plant's management system including metering and control of all key parameters and sections.
- Install waste heat recovery systems on current air-cooled or water -cooled air compressors
- Retrofit old compressors by new VFD driven ones and potentially with integrated heat recovery.

### Advantages

Implementing improvements to compressed air systems can lead to significant enhancements in energy efficiency. A crucial step in this process is conducting a comprehensive assessment of existing energy usage throughout the entire infrastructure. By enhancing the compressed air system, not only can energy consumption at the facility be reduced, but the need for larger air compressors in the event of increased demand can also be eliminated.

### Financial analysis

The extent of energy savings achieved through system optimization varies depending on the specific compressed air system, its applications, and usage patterns. In some cases, energy savings of up to 10% of the total compressed air energy consumption can be attained. Moreover, the payback period for such optimization efforts is typically less than a year in the majority of scenarios.

Based on the above points, the key problems and their mitigation measures are developed here after.

## 4.5.2. Leakage Prevention

### Introduction

In the majority of installations, there are varying levels of leaks that result in pure losses and should be minimized. Often, these leaks can account for approximately 10-15% of the total compressed air flow produced.

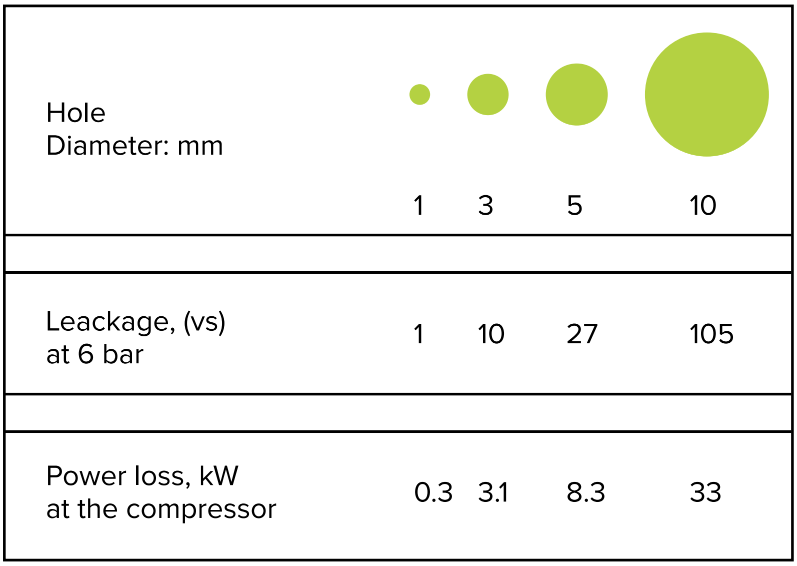
### Application

Typically, leaks can be detected by one of the below methods:

1. Listening – Best done at nighttime or when production is stopped. Make sure the compressor is running normally, walk around the facility's compressed air infrastructure from the production section to the end-uses section and detect leakages by listening to the noises (typically hissing or rasping noise).
2. Using Ultrasonic leak detection equipment that will allow the detection of compressed air leak effectively, even in a noisy environment.

### Advantages

Proactive leak detection and repair can reduce leaks to less than 10% of compressor output. In addition to being a source of wasted energy, leaks can also contribute to other operating losses and is a cause of a drop in system pressure. The figure below shows the effect of leakage on power consumption.



| | | | | |
|---|---|---|---|---|
| Hole Diameter: mm | 1 | 3 | 5 | 10 |
| Leackage, (vs) at 6 bar | 1 | 10 | 27 | 105 |
| Power loss, kW at the compressor | 0.3 | 3.1 | 8.3 | 33 |

*Figure 15: Effect of leakage on power consumption at a system pressure of 6 bar*

### Financial Analysis

By simply reducing the pressure by 0.3 bar, it is possible to achieve a 4% reduction in leakage. For example, in a 100 m3/min installation with a leakage rate of 12%, lowering the pressure by 0.3 bar would result in approximately 3 KW of energy savings.

The investment required for implementing this measure is minimal, but the impact it can have is substantial. The potential savings can exceed 5% of the energy consumption of the air compressor, allowing the invested capital to be recouped within a month or two.

Calculating and quantifying leaks can easily be done on air compressors that use start/stop controls. This method involves starting the compressor when there are no demands on the system (when all the air operated end -use equipment is turned off). A number of measurements are taken to determine the average time it takes to load and unload the compressor. The compressor will load and unload because the air leaks will cause the compressor to cycle on and off as the pressure drops from air escaping through the leaks.

Total leakage (percentage) can be calculated as follows:
**Leakage (%)** = [ **(T x 100) / (T + t)** ]

Where:
T = on - load time (minutes)
t = off - load time (minutes)
Leakage is expressed in percentage of compressor capacity loss. Conventionally, it is considered that the percentage lost due to leakage should be less than 10% to consider the system a well maintained one. In contrast, poorly maintained systems can have losses as high as 20-30%.

## 4.5.3. Temperature Optimization

### Introduction

The location of air compressors and the quality of air drawn have a significant influence on energy consumption. Optimal performance is achieved when the compressor's intake receives cool and relatively clean dry air.

In fact, reducing the inlet air temperature directly reduces the energy required for the compressor's operation. One approach to achieve this is by sourcing the intake air from outside the building, thus taking advantage of cooler external air.

By improving the quality and temperature of the air drawn into the compressor, energy efficiency can be enhanced, leading to potential energy savings and improved compressor performance.

### Application

In typical scenarios, indoor air compressors are often surrounded by warm air, generated by the compressor’s own operation. This warm air is usually drawn in as the compressor’s inlet air source.

To reduce the energy required by the air compressor to achieve the desired conditions, it is beneficial to consider changing the location of the compressor or modifying the inlet air source. One effective approach is installing an extension pipe that allows the intake air to be sourced from the outdoor environment, rather than relying on the warm indoor air.

### Advantages

When considering the location or relocation of air compressors, there are two crucial parameters to consider:

1. Optimize Cool air intake: As a rule of thumb, “Every 4°C rise in inlet air temperature results in a higher energy consumption by 1% to achieve equivalent output” (Rabadia 2015). Hence, cool air intake leads to a more efficient compression.

*Table 1: Effect of intake air temperature on the air compressor consumption (Rabadia 2015)*

| Inlet Temperature (°C) | Relative Air Delivery (%) | PowerSaved (%) |
|---|---|---|
| 10 | 102 | 1.4 |
| 15.5 | 100 | 0 |
| 21.1 | 98.1 | -1.3 |
| 26.6 | 96.3 | -2.5 |
| 32.2 | 94.1 | -4 |
| 37.7 | 92.8 | -5 |
| 43.3 | 91.2 | -5.8 |

2. Ensure Dust free air intake: Dust in suction air causes excessive wear of moving parts and results in malfunctioning of the valves due to abrasion. Suitable air filters should be provided at the suction side. Air filters should have high dust separation capacity, low-pressure drops and robust design to avoid frequent cleaning and replacement.

*Table 2: Air inlet filter pressure from and air compressor consumption (Rabadia 2015)*

| Pressure drop across air filter (mm Water Column) | Increasein power consumption (%) |
|---|---|
| 0 | 0 |
| 200 | 1.6 |
| 400 | 3.2 |
| 600 | 4.7 |
| 800 | 7.0 |

Air filters should be selected based on the compressor type and installed as close to the compressor as possible. As a thumb rule for every 250 mm Water Column improvement in pressure drop values across the suction path due to choked filters etc., the compressor power consumption increases by about 2% for the same output. Hence, it is advisable to clean inlet air filters at regular intervals to minimize pressure drops.

It is also very important to ensure the ventilation of the room is adequately designed and installed.

### Financial Analysis

Relocating the air compressor incurs minimal costs, while adding an inlet pipe extension involves a modest investment. However, both measures have the potential to generate savings ranging from 1% to 3% of the overall compressed air costs, resulting in an immediate or very short payback period.

### 4.5.4. Pressure Reduction

**Introduction**

The energy consumption of compressed air systems increases as the demand for higher pressure rises. However, modifying the compression pressure is not always feasible. Despite the negative economic impact, increasing the compressor pressure is often employed as a solution to address pressure drops caused by undersized piping systems or clogged filters. In installations with multiple filters, particularly those that have been in operation for an extended period without replacement, the pressure drop can be significantly higher, leading to substantial costs if left unaddressed for extended durations. Pressure reduction can be implemented at two locations: the point of usage and the air compressor.

**Application**

Reducing compressed air pressure should only be pursued after conducting a comprehensive analysis of the system requirements and pressure demands specific to the facility. Making sure all leakages are mitigated, pressure reduction can be performed at the following levels:

**1. At point of usage**

A large number of plants use a single common compressed air distribution system to supply their end-use applications. In this case, the total system is designed to maintain a pressure that is high enough to satisfy the diversity of equipment requiring the highest pressure (regardless is the majority of the equipment might require a much lower pressure).

A higher pressure than required would cause unregulated compressed air equipment in the plant to use a higher amount of air. This also increases the power required by the air compressor by 1% for every 0.14 bar in higher pressure.

Usually, most equipment may be operated at a lower pressure than the one used in the identification of new equipment requiring compressed air. It is possible to operate a lower required pressure: minimizing the system pressure requirements in general. It is usually also possible to replace existing equipment for a lower pressure operation by replacing non-optimal components.

For equipment that can’t be optimized, it is possible to segregate equipment into a separate system, so that the most of the compressed air system can be operated at a lower pressure.

The portion requiring a higher pressure could then be supplied by a dedicated- compressor air system, or by a booster compressor drawing air from the lower pressure system.

The pressure drop across air treatment equipment at the end use must also be taken into account and should be monitored to prevent a forced increase in compressor discharge pressure or an unintended decrease in pressure at the points of use. Filters, in particular, should have element pressure drop monitored and changed regularly.

The accuracy of the minimum desired pressure at the point of use should be maintained. Fluctuating system pressure can cause production quality problems such as torque variations of tools and inconsistent paint spray.

Pressures that are higher than necessary can be caused by compressor control problems and can boost end-use air flows by causing artificial demand. Artificial demand occurs because un- regulated end uses will use more air at higher pressure.

### 2. At the air compressors

Real savings will not be realized unless the discharge pressure at the compressors can be reduced. A common rule of thumb for a typical compressed air system is: the energy requirement of the compressors is reduced by 1% for every 0.14 bar decrease in system pressure. In some cases, due to undersized piping, some of these savings may be lost due to increased velocity at the lower pressure, through dryers, filters, and piping.

Some air compressors have to be procured with a pressure rating substantially higher than required at the points of use. Running the compressors at an elevated pressure may compensate for pressure drop across filters and dryers and negate any restriction in the distribution piping and valves, but to save energy the control pressure set points and their operating band should be set as low as is considered practicable, not to the maximum allowable.

The pressure drop across individual components and sections of the distribution system should be measured to determine if they are within acceptable limits. These pressure drops force higher compressor discharge pressures to compensate. Corrective action should be taken where indicated. This corrective action may include changing types or size of pipes, valves, dryers or filters. The pressure drop from the compressor discharge to the points of use should not exceed 10% of the compressor discharge pressure.

### Advantages

The power requirement of a compressed air system is directly influenced by the working pressure. Higher pressure levels correspond to increased energy consumption, with an average power increment of 8% for every 1 bar of pressure rise. Attempting to compensate for pressure drops by increasing the working pressure invariably leads to reduced operating efficiency.

While significant pressure reductions may not be feasible in many installations, the use of modern regulation equipment allows for a realistic reduction of approximately 0.5 bar. This reduction may appear minor, but when considering the overall efficiency enhancement achieved by such a decrease, the actual value of this pressure reduction in terms of tangible savings becomes more apparent.

### Financial Analysis

The figure below shows that excess power requirement is a result of over-pressurizing to compensate for pressure drops. For a 300 l/s compressor, raising the working pressure by 1 bar means 6 KW higher power consumption. At 4,000 operating hours/year this represents 24,000 KWh/year or $7,200/year (at an average of $0.3/KWh).

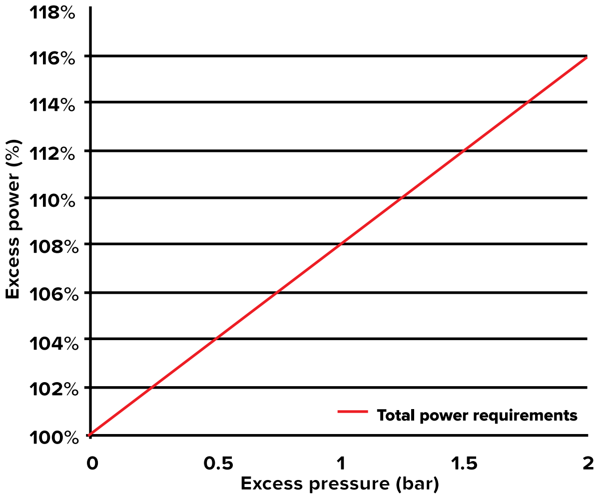


*Figure 16: Relationship between excess pressure and excess power*

Pressure optimization is a low or no cost measure that leads to immediate savings with an immediate or an extremely short payback period.

**Rules of Thumb**

**RELATING DISCHARGE PRESSURE TO ENERGY CONSUMPTION**

For systems in the 6.89 bars range, for every 0.14 bar increase in discharge pressure, energy consumption will increase by approximately 1% at full output flow (check performance curves for centrifugal and two- stage lubricant-injected rotary screw compressors).

There is also another penalty for higher-than-needed pressure. Raising the compressor discharge pressure in- creases the demand of every unregulated usage, including leaks and open blowing. Although it varies by plant, unregulated usage is commonly as high as 30-50% of air demand. For systems in the 6.89 bars range with 30-50% unregulated usage, a 0.14 bar increase in header pressure will increase energy consumption by about another 0.6-1.0% because of the additional unregulated air being consumed (in the worst-case scenario, the extra flow could cause another compressor to start).

The combined effect results in a total increase in energy consumption of about 1.6-2% for every 0.14 bar increase in discharge pressure for a system in the 6.89 bars range with 30-50% unregulated usage.

*Source: Plant Services - 2015*

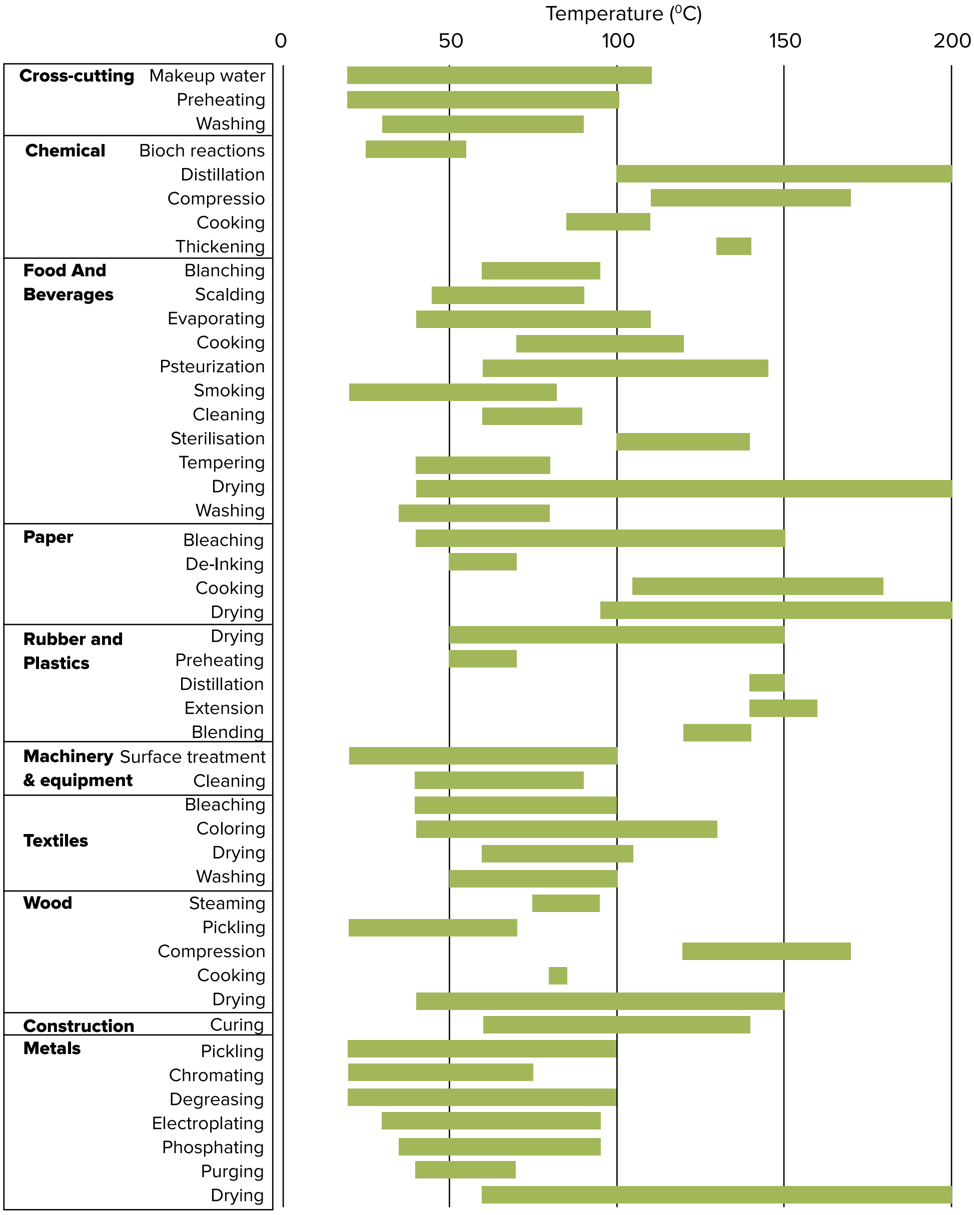
## 4.6. Process Heat Energy Efficiency

### Introduction

Heat represents three quarter of industrial energy demand worldwide and half of it is of low to medium high temperature. Process heat refers to the thermal energy or heat energy that is generated and utilized in various industrial processes. It is distinct from space heating or domestic heating, which is used to maintain comfortable temperatures in buildings. Process heating is a fundamental component in the manufacture of most consumer and industrial products, including those made out of metal, plastic, rubber, concrete, glass, and ceramics.

### Application

Industrial processes that usually involve process heat are paper industry, cement, textile, plastic, tobacco, food , and chemical industries. Process heating systems deliver heat at the temperatures needed to transform materials into manufactured goods. The graph below shows the industrial processes heat based on their temperature requirement.



Depending on the industrial process and the application, process heating is provided by different means.The Key aspects of process heat include:

Heat Sources: Process heat can be generated from various sources, such as combustion of fuels (natural gas, coal, oil), electrical resistance heating, steam, hot water, or renewable energy sources like solar thermal and geothermal energy.

Industrial Applications: Process heat finds applications in a wide range of industries, including but not limited to:

Manufacturing: Heat is used for melting metals, curing materials like plastics or composites, and shaping or annealing various products.

Chemical Industry: Many chemical reactions require specific temperature conditions for synthesis or separation processes.

Food Processing: Heat is essential for cooking, pasteurization, drying, and sterilization in the food industry.

Textile Industry: Dyeing, drying, and finishing processes rely on process heat.

Power Generation: In thermal power plants, high-temperature steam is used to drive turbines and generate electricity.

**Process Heat Categories**

Common industrial process heating systems fall in one of the following categories:

1. Combustion-based process heating systems.
2. Electric process heating systems.
3. Heat recovery and heat exchange systemsThey fall into three categories:
    - Fuel-fired systems can be direct or indirect. In direct fuel-fired systems, burners with open flames place hot combustion gases directly in contact with the material. In indirect fuel-fired systems, flames are enclosed in a sealed chamber with the heated gas running through tubes or panels which radiate the heat to the material, keeping the exhaust gases and material separate.

    - These systems are used in high-temperature processes such as calcining, a critical step in cement making. Direct-fired systems are typically more efficient, have greater temperature control, suitable for smaller equipment, and can be used when fumes containing exhaust gases, water vapor, and particulates (soot) are not detrimental to the material being processed.

      Steam-based systems can efficiently transfer large quantities of latent heat at a constant temperature, which is helpful for many low-temperature processes (less than 100°C). The heat from steam is transferred indirectly through a container wall (such as rollers used in papermaking) or injected directly into water or a product to rapidly transfer heat (such as cooking food).

Steam is used in paper products, chemicals, petroleum refining, food processing, and many other manufacturing industries, accounting for about 30% of all process heat, according to the 2018 Manufacturing Energy and Consumption Survey (2018 MECS). Most steam is generated through the combustion of fuels, although electric boilers are also used to take advantage of low electricity prices.

- Electricity-based systems use electricity to power technologies that apply heat directly to a material or run an electric current to heat a material. For example, resistive electric heating elements take advantage of a material's intrinsic electrical resistivity to convert electricity into heat, which is applied to a target material (similar to an electric coil on a stovetop).

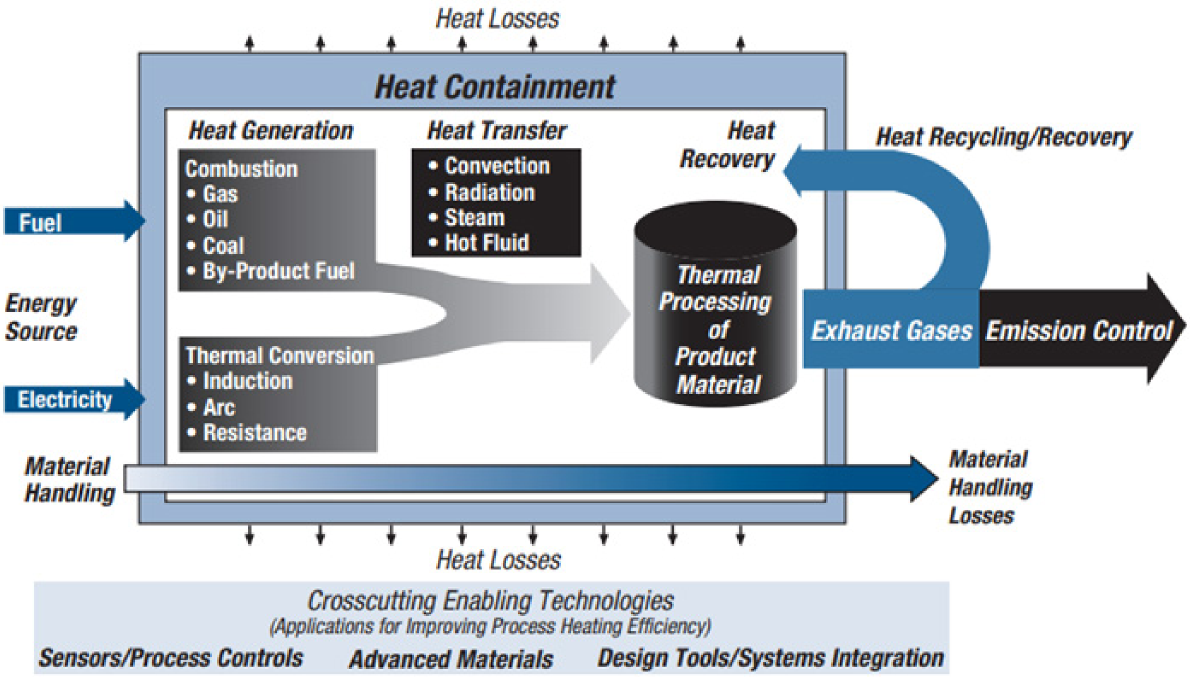


*Figure 17: Key Components of a Process Heating System*

**Savings**

Improving the energy efficiency of process heat systems is crucial for reducing energy consumption, lowering operating costs, and minimizing environmental impact. Here are several options and strategies to enhance the energy efficiency of process heat systems in industrial settings:

### Heat Recovery Systems:

- Waste Heat Recovery: Capture and reuse waste heat generated during industrial processes, such as exhaust gases, to preheat incoming materials or fluids.
- Cogeneration (Combined Heat and Power, CHP): Simultaneously produce electricity and capture waste heat for heating or cooling purposes, maximizing energy utilization.

### Temperature reduction at supply level to avoid excess waste heat production

### Insulation and Heat Loss Reduction:

- High-Quality Insulation: Apply effective insulation materials to equipment, pipes, and vessels to reduce heat loss and minimize temperature fluctuations.
- Sealing and Maintenance: Regularly inspect and maintain equipment to address leaks and ensure that insulation remains intact and functional. Cleaning and maintenance of heat exchangers to maximize heat transfer.

### Efficient Combustion and Burner Management:

- Burner Tuning: Optimize combustion processes by adjusting burner settings for optimal fuel-air ratios, reducing excess air, and minimizing heat losses through flue gases.
- Flue Gas Heat Recovery: Use heat exchangers to recover heat from flue gases before they are vented to the atmosphere.

### Thermal Energy Storage:

- Off-Peak Energy Storage: Store excess thermal energy generated during off-peak hours and use it during peak demand times, reducing the need for continuous high-energy consumption.

### Heat Pump Technology:

- Heat Pump Systems: Implement heat pumps to provide heating or cooling with high energy efficiency, particularly in applications with temperature differences between the source and sink.

### Process Optimization:

- Process Integration: Integrate processes to reduce temperature differences, reuse heat, and improve overall energy efficiency.
- Load Shifting: Shift energy-intensive processes to off-peak hours when energy costs may be lower.

### Use of Renewable Energy Sources:

- Solar Thermal: Install solar thermal collectors to harness sunlight for process heat generation, reducing reliance on fossil fuels.
- Geothermal: Utilize geothermal heat sources for heating and cooling applications where feasible.
- Biomass can be a process heat source for lower temperature application
- Other Renewables can also be used for preheating before using conventional fuel usage – significant reduction in fossil fuel consumption.

### Energy-Efficient Equipment:

- High-Efficiency Boilers: Replace or upgrade old boilers with modern, high-efficiency models that minimize energy consumption.
- Energy-Efficient Heaters: Select and use energy-efficient heaters, such as induction heaters or microwave heaters, for specific industrial applications.

**Advanced Control Systems:**

- Process Control: Implement advanced control systems that can optimize temperature and energy usage in real time.

Process heating energy use and costs can often be reduced 5% to 15% through best practices and system improvements.. As for the investmen cost, these can range from low cost/no cost measures or can require a higher CAPEX depending on the extent of retrofit/improvement.

## 4.7. Refrigeration

### 4.7.1. Refrigeration Free Cooler

**Introduction**

Chillers provide chilled water on a massive number of applications, from general process cooling and commercial air conditioning systems to climate control of critical applications such as data centers and industries. Refrigerant is used to absorb heat from these systems and dissipate it via a condenser. Sometimes the condenser is air cooled by fans mounted on the chiller that vent the heat into the atmosphere.

However, either for efficiency purposes, or often due to the chiller being located where venting the heat to atmosphere is not possible (a basement or plant room), a water cooled chiller is required.

Standard electric vapour compression or absorption chillers pass the heat from the refrigerant to a condenser water loop via a heat exchanger or absorber. At this point an air blast cooler or adiabatic cooler can be positioned outdoors to dissipate the heat.

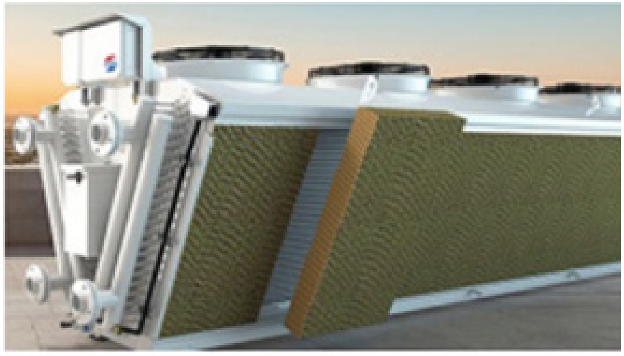
Water cooled absorption chillers are an environmentally friendly way of providing chilled water where a waste heat source at circa. 90°C is available (e.g. water outlet temperature from a gas or diesel fired generating set jacket water circuit or industrial grade hydrogen fuel cell) but often need much lower condenser water temperatures of approximately 30°C.

Free Cooling is an advanced process whereby, the air blast cooler can be used to offload the chiller and provide chilled water temperatures direct onto the process system in the cooler months of the year, thereby reducing system energy usage.

Refrigeration-free cooling processes are gaining traction in various industries as a sustainable and cost-effective solution for temperature control. Unlike traditional refrigeration systems that rely on energy-intensive compression and refrigerants, these innovative cooling methods harness natural processes like evaporative cooling or phase-change materials to achieve desired temperature reductions. In industries, refrigeration-free cooling processes offer advantages such as reduced energy consumption, lower environmental impact, and enhanced operational efficiency. Whether through evaporative cooling systems, thermal energy storage, or other innovative techniques, these approaches are reshaping how industries maintain optimal temperatures while aligning with a growing focus on sustainability and resource conservation.

## Introduction

In industrial settings, the application of refrigeration-free cooling processes has become increasingly prominent due to their efficiency and environmental benefits. Evaporative cooling, for instance, is widely used to regulate temperatures in manufacturing facilities, data centers, and warehouses. The process involves the circulation of hot, dry air through water-saturated media or pads, where the air is cooled through evaporation before being distributed throughout the workspace.



Furthermore, industries are exploring the integration of phase-change materials (PCMs) for temperature control. PCMs absorb and release heat during their phase transitions, making them suitable for maintaining stable temperatures during off-peak hours or peak demand periods. These innovative approaches reduce energy consumption, minimize the carbon footprint, and contribute to sustainable industrial practices while ensuring optimal operating conditions.

## Advantages

The advantages of using refrigeration-free cooling processes in industrial setups are numerous and include:

- Energy Efficiency: Refrigeration-free cooling methods typically consume significantly less energy compared to traditional refrigeration systems. This results in lower operational costs and reduced electricity bills for industrial facilities.

- Environmental Sustainability: These processes are more environmentally friendly as they often eliminate or reduce the use of harmful refrigerants, which can contribute to ozone depletion and climate change. They align with sustainability goals and regulations.
- Cost Savings: Lower energy consumption translates into cost savings for businesses, making refrigeration-free cooling processes a financially attractive option in the long run.
- Maintenance and Reliability: These systems are often simpler and have fewer mechanical components, leading to reduced maintenance requirements and enhanced reliability.
- Adaptability: Refrigeration-free cooling processes can be customized to suit specific industrial needs and conditions, allowing for flexibility in design and application.
- Improved Indoor Air Quality: Evaporative cooling systems, in particular, can increase indoor humidity levels, which can improve air quality by reducing dust and allergen concentrations.

#### Financial Savings

Savings of free cooling can reach up to 50% of the total electrical energy consumption of cooling with a payback period of around 1 year.

### 4.7.2. Refrigeration EER Improvement

#### Introduction

Refrigeration is a crucial process in many industries such as the food industry, pharmaceutical, Supermarkets, and petrochemical industry.

The pursuit of greater energy efficiency has become a concern for industries, driven by both environmental responsibility and economic imperatives. In the realm of industrial cooling and refrigeration, achieving higher levels of energy efficiency is a crucial objective. One of the key metrics is the Energy Efficiency Ratio (EER), which quantifies the cooling output of a refrigeration system relative to the electrical energy input it consumes. Elevating the EER of refrigeration systems in industrial applications represents a pivotal step toward minimizing energy consumption, reducing operational costs, and curbing greenhouse gas emissions.

#### Application

Improving the EER of a refrigeration system is crucial for several reasons, as higher EER values indicate that a system can provide the same level of cooling using less electricity, which translates to reduced energy consumption and lower operating costs. Additionally, more energy efficient refrigeration systems reduce the greenhouse emissions associated with electricity generation, contributing to environmental sustainability.

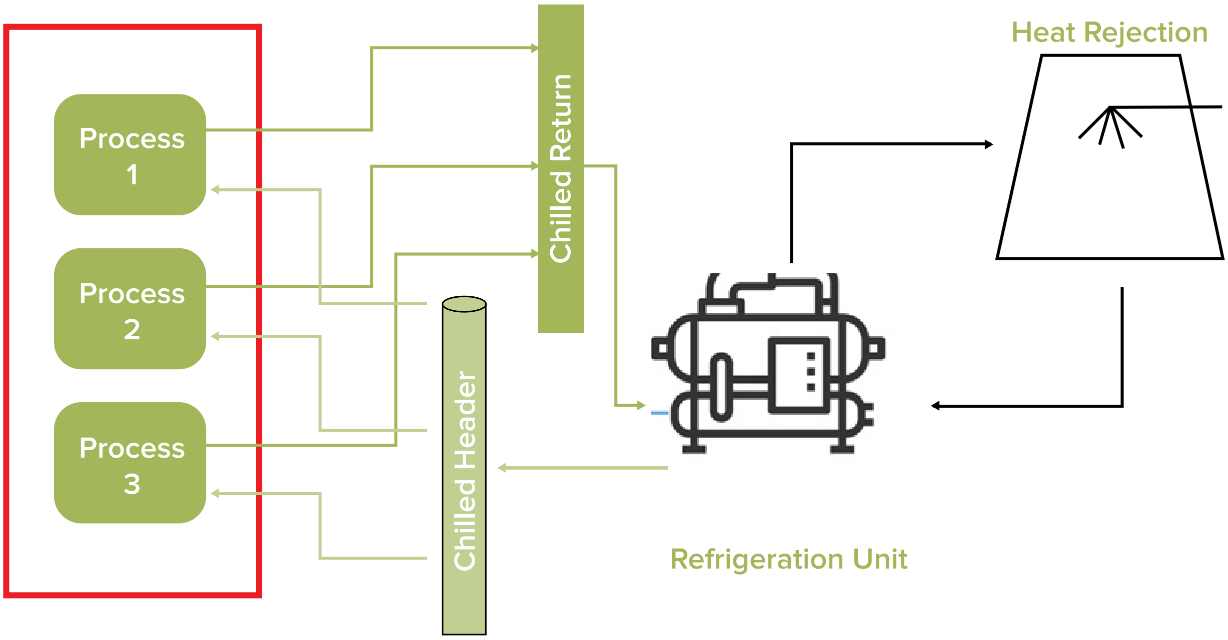


*Figure 18: Refrigeration System schematic*

There are several strategies and technologies to improve the EER of refrigeration systems on all levels:

**On the process level**

- High-Efficiency Components: Using high-efficiency compressors, fans, and motors in the system can boost its overall efficiency.
- Avoid Heat Gains by placing Rubber Sealants
- Improved Refrigerants: Using environmentally friendly refrigerants with lower Global Warming Potential (GWP) can enhance system efficiency.
- Reduce unnecessary openings / install automatic quick shut doors
- Correct Sizing of Cold Rooms
- Night-time ventilation for passive cooling
- Insulation and Air Sealing: Ensuring proper insulation and sealing of ducts and air leaks in the refrigeration system can reduce energy losses and improve EER.

**On the distribution level**

- Insulation of the chilled medium piping
- Correct dimensioning of pipe diameters
- Variable-Speed Technology: Variable-speed compressors and fans can adjust their operation to match the cooling demand, resulting in energy savings and higher EER.
- Avoid overuse of antifreez/coolant where possible
- Evaporative Cooling: using evaporative cooling techniques in conjunction with refrigeration systems can improve overall efficiency.

### On the Refrigeration unit

- Proper Sizing: Installing a correctly sized system that matches the cooling load of the space being conditioned prevents the system from working harder than necessary, improving its EER.
- Upgrading Equipment: Replacing older, inefficient refrigeration systems with modern, energy-efficient models can significantly improve EER.
- Adapt setpoints (highest chilled medium temperature and lowest heat rejection temperature possible

### On the Heat Rejection level

- Cleaning of condenser coils in refrigerators
- Cleaning and Maintenance of cooling towers
- Regular Maintenance: Ensuring that the system is well-maintained, including cleaning coils and filters, can help maintain optimal efficiency.
- Placing units in shaded areas, north side
- VSD for fans

### Advantages

Enhancing EER leads to reduced energy consumption, which not only translates into substantial cost savings but also aligns with sustainability objectives by lowering greenhouse gas emissions. In industries such as food processing, pharmaceuticals, and petrochemicals, where precise temperature control is vital, a higher EER ensures reliable and consistent cooling while minimizing environmental impact. In essence, the advantages of enhancing refrigeration EER encompass economic efficiency, environmental responsibility, and operational reliability, making it a strategic imperative for industrial sectors.

### Financial Savings

Savings resulting from the EER improvement in the refrigeration systems can reach up to 70% of the energy consumed by the system.

**Example retrieved from Train the Trainers slides – UNDP**

Case Study : A bistro for selling Ice Cream and French Fries

**The current situation :**

6 deep freezers, each with 2,000 kWh/a electric load,
each one of them is 20-30 years old
8,760 hours/year utilization (24/7)
Electricity price 0.30 €/kWh
3,600 €/a current costs of electricity
Imputed interest rate 3.0 %
Yearly price increase for electricity 3.0 %

**Solution**

Replace the six deep freezers by one deep freez chamber with an efficient cooling unit, that will be placed outside in the shadow.
Lower surface area, less heat loss
One new, efficient chiller instead of six small inefficient deep freezers
Saving Potential 70 %, 2.520 €/a, 8.400 kWh/a.
Investment 12,000 €

| Savings | Deep Freeze Chamber |
|---|---|
| Savings $CO_2$ | 3.1 to/a |
| Savings End Energy Consumption | 8,400 kWh/a |
| Savings Electricity Cost | 2,530 €/a |
| Expected Lifetime | 30 a |
| Next Present Value | 61,400 €/a |
| Internal Rate of Return | 23.9% |
| Dynamic Payback Time | 4.9 a |
| Static Payback Time | 4.8 a |

## 4.8. Steam System

### Introduction

- Steam systems play a significant role in large-scale applications, particularly in industrial settings, where thermal energy accounts for a substantial portion of total energy consumption, reaching up to 76%. These systems are vital for providing the necessary energy for various purposes, including process heating, pressure control, mechanical drives, component separation, and hot water production for process reactions.

- Effective combustion processes in equipment like boilers rely on achieving an optimal mixture of fuel and air in a carefully calculated ratio to ensure complete combustion. Additionally, an adequate heat transfer area is required to efficiently transfer heat from the hot combustion products to the process fluids.

- The components of a steam system, as illustrated below, encompass steam boilers for generation, distribution components, end-use equipment, and recovery components.

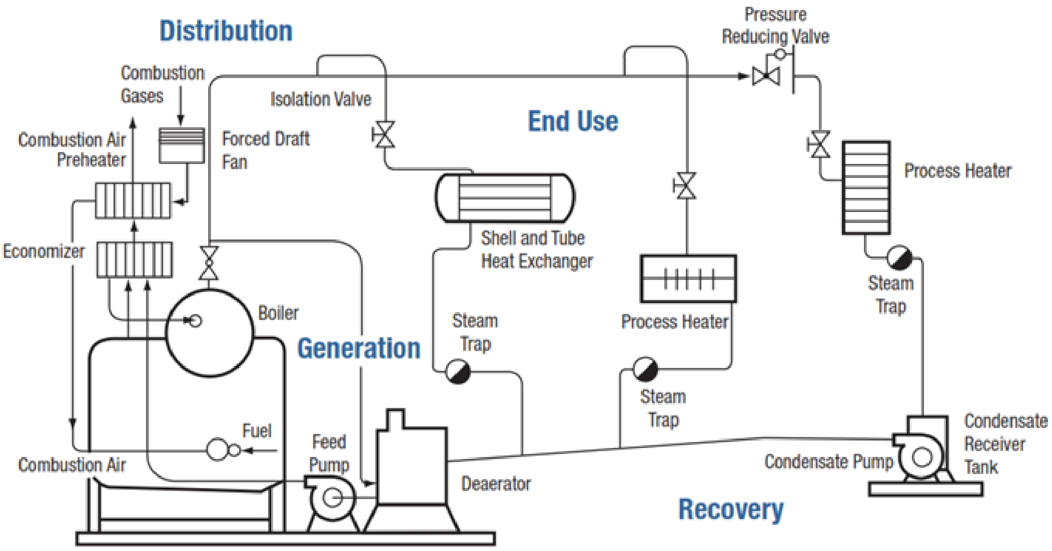


*Figure 19: Typical steam network with recovery*

When steam systems are more efficient, the energy bill could be reduced substantially along with reducing the related environmental emissions. According to the U.S. Department of Energy, a typical industrial facility that conducts a steam system assessment will identify potential steam system energy use and cost savings that range from 10% to 15%.

Considering the large share of thermal energy in many industrial sites, the savings potential would have a substantial impact on their financial and environmental performance.

### Identifying Energy Saving Opportunities

To effectively improve the energy efficiency of steam systems, it is crucial to adopt a systems-level approach that optimizes both the steam demand (end uses) and the steam supply systems.

Furthermore, boilers are typically designed and rated for a specific maximum thermal output. However, in reality, boilers often operate at a fraction of their maximum capacity or at partial load for a significant portion of their lifespan. The efficiency of a boiler varies significantly depending on the load it operates at. Therefore, it is essential to assess the performance and efficiency of boiler plants across the entire range of actual or partial loads they experience.

Energy savings within steam systems can be achieved across various sections of the installations, as summarized in the tables below.

### At Generation level

The boiler energy efficiency measures presented below focus primarily on improved process control reduced heat loss, and improved heat recovery. In addition to the measures below, it is important to note that when new boiler systems are needed, ideally, they should be designed and installed in a custom configuration that meets the needs of a particular plant.

| Efficiency Measure | Impact Description |
|---|---|
| Improve combustion efficiency and minimize excess air | Reduces the amount of heat lost up the stack, allowing more of the fuel energy to be transferred to the steam |
| Clean boiler heat transfer surface | Ensures effective heat transfer from the combustion gases to the steam |
| Maintain high feedwater temperature | High Feedwater temperature drives out dissolved oxygen |
| Size feedwater tank correctly | As a rule of thumb, feedwater tank should be sized to be 1.5 times the peak steam demand |
| Avoid oversizing the boiler | Oversizing leads to frequent On-Off cycles in a boiler which lowers boiler efficiency |
| Monitor the boiler parameters | Continuous monitoring of boiler parameters for optimized boiler efficiency |

| Efficiency Measure | Impact Description |
|---|---|
| Burner retrofit | Typically, after 10 to 15 years of service, a burner loses effectiveness and sees its efficiency plummets |
| Optimize condensate recovery | Recovers thermal energy in the condensate and reduces amount of make-up water, thus saving energy and chemical treatment |
| Use high-pressure condensate to make low pressure steam | Exploits the available energy in the returning condensate |
| Install Heat recovery equipment (feedwater economizers/combustion air preheaters, blowdown heat recovery) | Recovers available heat and transfers it back to the system by preheating feedwater or combustion air. Similarly, apart from controlling blowdown, heat can be recovered from blowdown |

### At Distribution Level

Energy efficiency improvements to steam distribution systems are primarily focused on reducing heat losses throughout the system and recovering useful heat from the system wherever feasible. The following measures are some of the most significant opportunities for saving energy in industrial steam distribution systems.

| Efficiency Measure | Impact Description |
|---|---|
| Eliminate air from steam systems | Eliminate air from steam systems to ensure effective heating and thus fuel savings |
| Adequate drainage of steam lines | To remove condensate for effective heat transfer, avoid water hammer |
| Insulate steam and condensate return piping | Uninsulated steam distribution and condensate return lines are constant source of wasted energy |
| Repair steam leaks | Stop waste, increase savings |
| Isolate steam from unused lines | Minimize avoidable loss of steam due to radiation and leaks |

### At process/ end use equipment

| Efficiency Measure | Impact Description |
|---|---|
| Use steam at lower pressures | Using steam at the lowest possible pressure for indirect heat exchange reduces the steam required |
| Precise Temperature control | Temperature overshoots lead to excess steam consumption |
| Insulate all process tanks | Reduce the energy loss through tank surfaces |
| Ensure quiet operation of steam injector | Control noise level produced by steam injector |
| Drying cylinders | Venting air through drying cylinders can reduce steam consumption. Converting group steam trapping to individual trapping |
| Heat Exchanger efficiency | Proper condensate removal system and flow control of steam based on parameters such as temperature, etc. |
| Increasing heat transfer in coil type heat exchange | Heat emission rate can be increased by forced convection |
| steam load balancing | Steam load can be balanced by either shutting of steam to non-critical applications or the use of steam accumulator |
| Auditing of streamline accessories | Regular energy auditing of streamline accessories will provide aid in taking corrective action in order to minimize steam consumption |
| Correct positioning of steam and condensate connections | Correct positioning of steam inlet and condensate outlet will ensure efficiency of all process equipment |

### 4.8.1. Combustion Optimization

**Introduction**

In practical terms, combustion efficiency is typically defined as the total energy contained in a given volume of fuel minus the energy lost through the hot flue gases discharged from the stack. While combustion efficiency is just one factor in determining overall boiler efficiency, it offers the most effective means of reducing fuel wastage. There are two primary methods for enhancing a boiler's combustion efficiency: adjusting the air-to-fuel ratio and implementing oxygen trimming. Both approaches contribute significantly to improving combustion efficiency and consequently reducing fuel consumption per unit of energy production. These measures lead to substantial improvements in overall energy efficiency and cost savings.

**Application**

1. **Air/Fuel adjustment**

During a combustion process, an excess amount of air is supplied to the combustion chamber. This surplus of air ensures an increased presence of oxygen during combustion. Achieving a perfect balance between the fuel and oxygen from the air results in what is known as stoichiometric combustion. This indicates an optimal air-to-fuel ratio for efficient combustion.

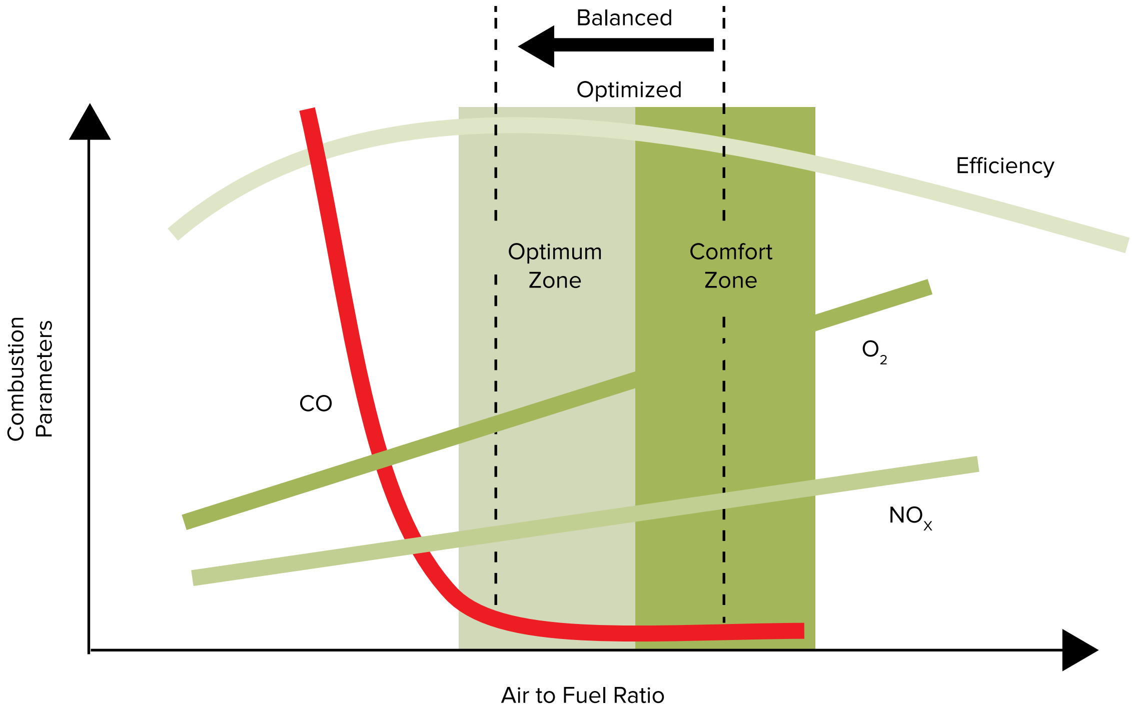


*Figure 20: optimal excess air zone in a combustion process*

There are two ways of optimizing the fuel to air ratio: The first is through manual boiler tune-up, while the second is through the installation of integrated combustion automation or parallel positioning.

### i. Manual Tune Up

A good tune up using precision test equipment can detect and correct excess air losses, smoking unburned fuel losses, fire side fouling, and high stack temperature. Flue gas monitors (portable and continuous) play a crucial role in maintaining the ideal flame temperature and monitoring levels of carbon dioxide (CO2), carbon monoxide (CO), oxygen, and smoke. The oxygen content in the exhaust gas is determined by a combination of excess air and air infiltration. By combining an oxygen monitor with an intake airflow monitor, even minor leaks can be detected.

These findings can be used to restore the boiler in its normal efficiency operating condition. This allows the control system and burner to be adjusted and repaired for optimum performance with immediate feedback on results.

When a tune up is completed, there should be a good record of a boiler's excess air and efficiently across the load range for managing boiler operations.  Periodic check-ups should often be done where boiler efficiency would fall by over 5% within approximately six months.

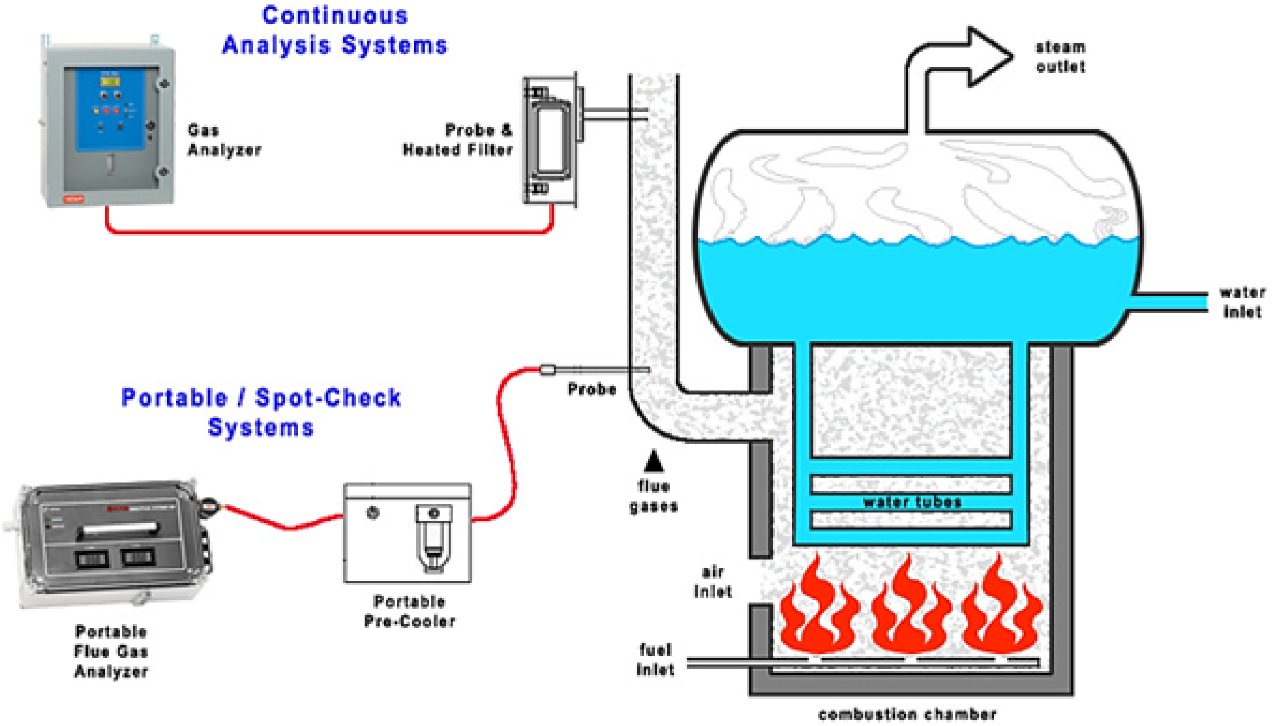


*Figure 21: Continuous & Portable Flue Gas and Emission analyzers*

## II. Integrated Burner Controller

The integrated burner controller is a microprocessor-based flame safeguard. It has a parallel positioning combustion control built into the package. The flame safeguard potion of the control provides the proper burner sequencing, ignition timing, and flame monitoring protection on automatically ignited oil, gas, and combination fuel burners using infra-red, ultra-violet, or ultra-violet self-checking scanners.

Parallel positioning is a control strategy that focuses on optimizing the fuel and air flow rates in combustion processes to achieve efficient and clean combustion. By independently controlling the fuel and air flows and adjusting them in parallel, the system can maintain the optimal fuel-to-air ratio for combustion efficiency across different types of combustion equipment.

Here are some key reasons why parallel positioning is important for energy efficiency:

- **Combustion optimization:** Parallel positioning enables fine-tuning of the fuel and air flow rates independently. By adjusting these parameters, the system can achieve the optimal fuel-to-air ratio, ensuring complete and efficient combustion. This leads to improved energy conversion and reduced fuel consumption.
- **Enhanced turndown ratio:** Turndown ratio refers to the ability of a system to operate efficiently across a range of firing rates. With parallel positioning, the turndown ratio can be significantly improved. This allows the system to modulate its output more accurately based on the demand, avoiding excessive fuel usage during periods of lower load requirements.
- **Minimized emissions:** Efficient combustion achieved through parallel positioning helps minimize harmful emissions. By precisely controlling the fuel and air mixturethe system can achieve more complete combustion, reducing the production of pollutants such as carbon monoxide (CO) and nitrogen oxides (NOx). This contributes to a cleaner and greener operation.
- **Improved system response:** Parallel positioning enables faster and more accurate adjustments to changes in load or environmental conditions. The system can respond promptly to variations in heat demand and maintain optimal combustion conditions, ensuring consistent energy efficiency throughout different operating conditions.

Typically, a control of up to four channels (2 air, 2 fuel) using independent servo-motors allows precise positioning, accurate to 0.1°. The controller provides two fuel profiles per channel, with up to 24 positions per profile. The servo-motors position and speed are checked via feedback potentiometers to verify proper operation.

From the controller, position signals are issued to the air and oil servo motors to obtain the desired firing rate with optimum firing efficiency all along the modulation curve, which induces the significant savings on fuel consumption, The savings can exceed 10%.

## 4.8.2. Oxygen Cutting

Achieving optimal combustion performance requires a carefully optimized volume of oxygen. Both an excessive or insufficient quantity of air can lead to unfavorable outcomes. Too much air results in poor efficiency, while insufficient air leads to the formation of carbon monoxide.

During manual tuning of burners, they are typically adjusted to have around 3% excess oxygen, which corresponds to approximately 15% excess air. From an efficiency standpoint, this excess oxygen indicates an excessive amount of air within the combustion process. This excess air contains moisture, which is heated and subsequently lost through the stack. The extent of excess oxygen directly correlates with the efficiency that is sacrificed. In other words, a 3% excess oxygen level is equivalent to a 3% decrease in efficiency.

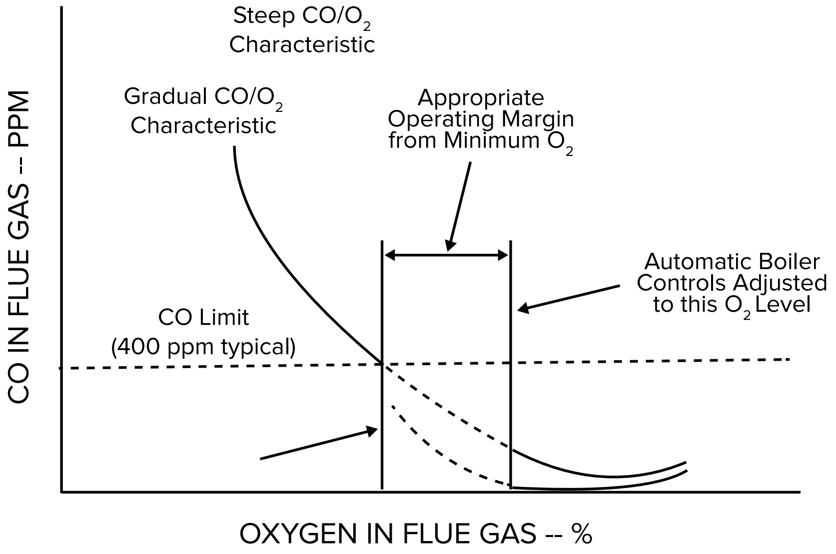


*Figure 20: optimal excess air zone in a combustion process*

While it may be feasible to manually monitor and adjust the burner on a daily basis, it is not a practical approach. A more efficient solution is the utilization of automatic O2 systems, commonly known as “O2 Trim Systems.” These systems continuously monitor the flue gases and regulate the burner’s air supply.

In an Oxygen Trimming system, an electronic sensor is typically installed in the boiler flue, positioned near the boiler and before dampers or any potential sources of air leakage into the boiler or flue. The sensor is connected to a control panel that measures oxygen levels and transmits a signal to a control damper, which in turn adjusts the burner’s air supply.

The following figure shows an Oxygen Trim System installed in Cleveland with an additional SCADA system included in the common control cabinet.

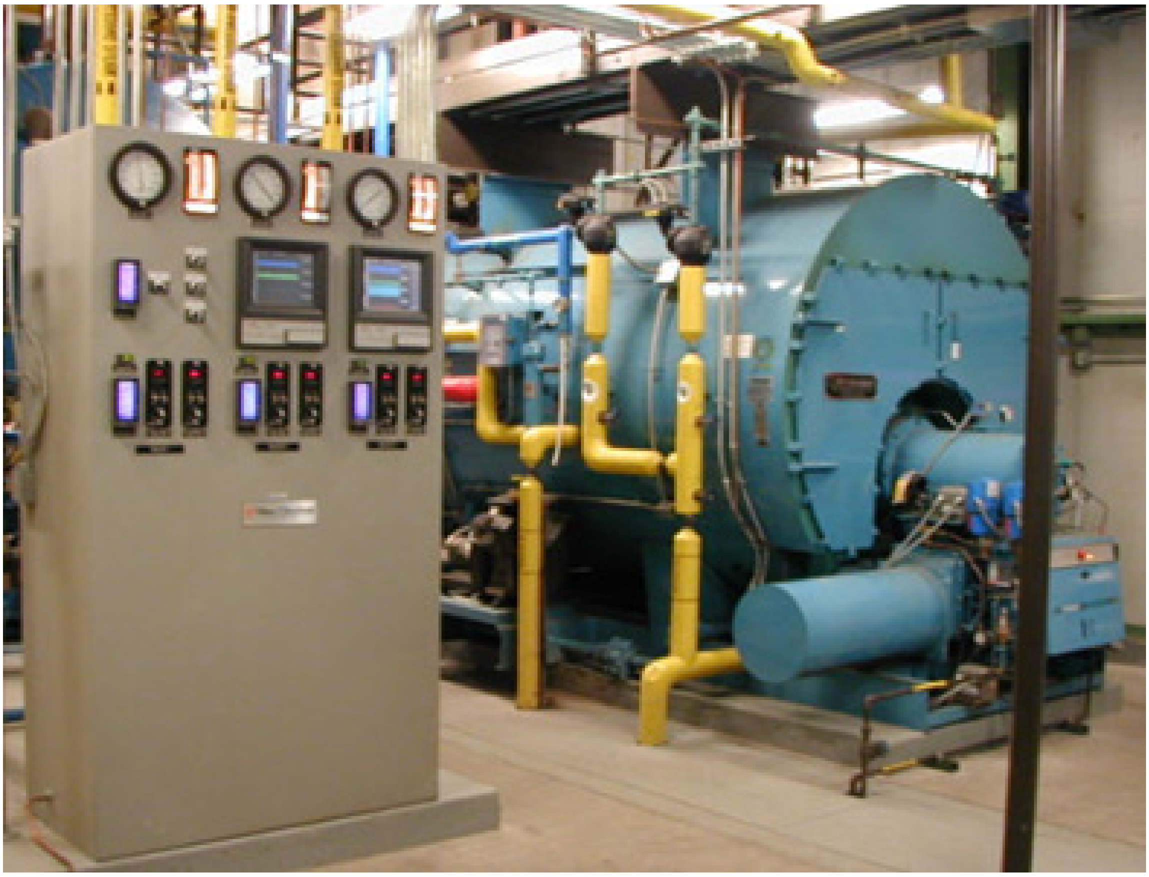


Figure 23: Hays Cleveland's O2 Trim System installed on 2 Boilers

### Advantages

The importance of excess air is, therefore, clear, making it extremely undesirable to operate a burner with less than stoichiometric combustion air. Not only is this likely to result in the release of smoke, but it will significantly reduce the energy released by the fuel.

If a burner is operated with a deficiency of air, carbon monoxide and hydrogen will appear in the products of combustion as a result of incomplete combustion. Anything more than a few hundred parts per million of combustibles in the flue gas indicates inefficient burner operation.

An oxygen Trim System continuously monitors the flue gas and adjusts the burner air supply. It includes an electronic sensor which is normally inserted into the boiler flue, near the boiler, ahead of dampers or other sources of air leakage into the boiler or flue. This sensor is connected to a control panel that measures oxygen and sends a signal to a control damper on the burner air supply.

### Financial Analysis

Combustion efficiency improvement could lead to reduced fuel consumption for the same energy produced, leading to a reduction in thermal energy bills by somewhere between 2% and 5%.

**Estimating Savings from O2 Trim**

Fuel Savings = 1.0 - (Starting Efficiency / Ending Efficiency)

For Example: 4.5% Excess Oxygen reduced to 2.0%

1.0 - (0.7972 / 0.8308) = 0.04044 = 4.04%

**NOTE:**

Because some boilers operate with a very high percentage of excess oxygen, it is common for the first-year savings to be substantially higher than this. However, much of that savings can be attributed to a more reasonable manual tuning of the boiler, and not necessarily from the installation of an automatic O2 control system. Well-tuned boilers can expect savings of 2 - 4%

Source: http://www.cleanboiler.org/Eff_Improve/Efficiency/Oxygen_Control.asp

## 4.8.3. Condensate return – Vented System

### Introduction

Steam consists of two distinct forms of energy: latent and sensible. When steam is utilized in a process application such as a heat exchanger, coil, or tracer, the latent energy within the steam is transferred to the process fluid, causing the steam to condense into liquid condensate. The condensate retains the sensible energy that the steam possessed, and it can contain as much as 16% of the total energy present in the steam vapor.

To maximize the overall energy efficiency of steam installations, Condensate Recovery Systems are specifically designed equipment that aim to recover and capture the condensate generated during steam usage. These systems play a crucial role in extracting the sensible energy contained within the condensate and reusing it within the steam system, thus enhancing the overall energy efficiency of the installation.

### Application

Usuallly condensate return has one of the highest return on investments, not only it saves on the fuel consumption, but it also saves on boiler treatment chemicals, make up water, and sewere system disposals costs.

While condensate return is an obvious measure, many industrial plants are still wasting it or are still losing part of its thermal energy because of un-insulated tanks, condensate pipes, valves and fittings. The best practice for condensate systems is to insulate any device in the condensate system to prevent such losses.

Condensate Recovery Systems equipment are considered to include the following :

- Condensate recovery vessels: These are designed to handle hot condensate, which is commonly returned for use as boiler feed water.
- Steam traps: these are devices that allow the discharge of condensate without the release of steam from steam lines in a steam and condensate system.
- Deaeration Tanks: These tanks remove oxygen and other dissolved gases from steam boiler feed water to reduce corrosion and improve efficiency in the steam system.

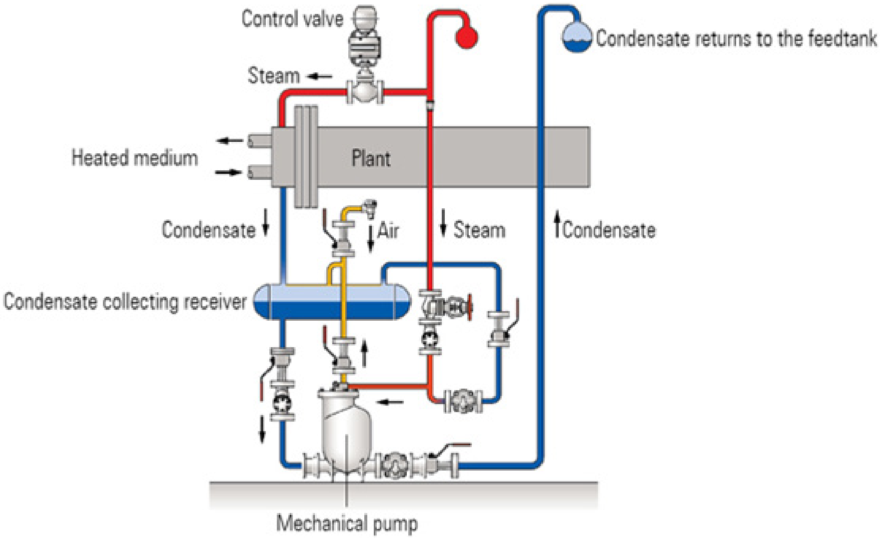


*Figure 24: Condensate Piping connection (Spirac Sarco 2016)*

Due to the velocity at which steam and condensate flows in a steam line, it is important to have the drip leg adequate in size. This is to allow the condensate to flow "into" instead of "over" a drip leg, as its purpose is to remove all condensate in the line. Remember condensate will reduce the quality of the steam in a system. Too small a drip leg is similar to having a golf ball pass "over" the center of the cup due to the speed at which it is traveling.

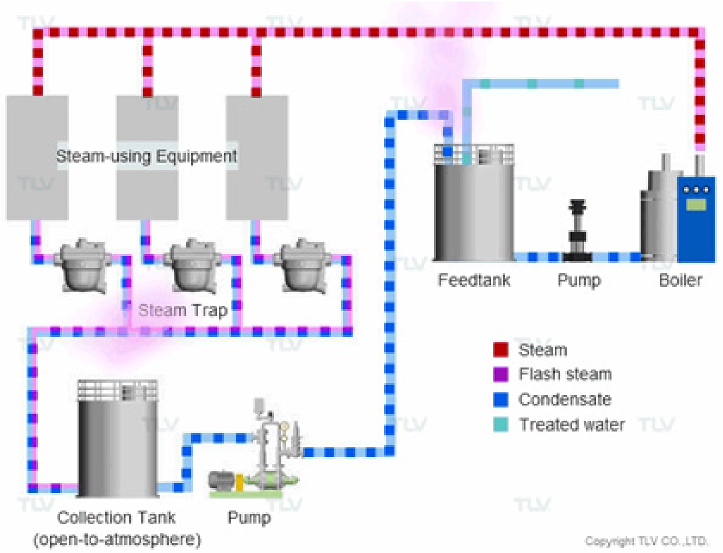


*Figure 25: Condensate Recovery Vented to atmosphere*

Ensure that the condensate piping is adequately sized. Condensate piping has to accommodate two-phase flow B liquid and vapor. The vapor portion of the condensate stream is more voluminous than the liquid portion. In general, condensate piping must be sized to handle the flash and blow-through steam rather than just the liquid portion. Condensate piping that is sized for the liquid portion only will be grossly undersized.

### Advantages

Recycling hot condensate for reuse as boiler feed water is an important way to improve the efficiency of the system. The energy used to heat cold make-up water is a major part of the heat delivered for use by the steam system.

### What Prevents Condensate Return

One must understand the factors that prevent the condensate from being returned to the boiler if the plant wants to establish corrective methods. The first is selecting condensate pumps having the proper net positive suction head (NPSH). A number of condensate pumps handle only condensate temperatures of less than 93°C. Condensate temperatures are close to the atmospheric saturation temperature of 100°C. Therefore, NPSH is a critical variable. Failure to have the proper NPSH rating results in pump cavitation, damaging the seals and impeller in a short period of time.

Steam traps are the next factor. Under sizing and improper installation of steam traps causes the traps to malfunction. Too often, a short solution to the problem is to drain the condensate to sewer. Many steam trap installations have drain valves open to remove the condensate from the process so processes can reach proper temperatures.

Another factor is condensate line corrosion. The condensate system accumulates carbonic acid as a result of excessive carbon dioxide in the system. The highest concentration is in the condensate return lines because carbon dioxide dissolves in cooling condensate. Most condensate lines use Sch 80 steel pipe and threaded connections. Condensate corrodes steel, but the pipe threads typically are more susceptible to deterioration. Using stainless for condensate pipe and valves, and avoiding threaded connections, slows the corrosion.

Figure 26: Steam leaks are a loss of condensate and energy - Left

The fourth factor is condensate system insulation. Steam system components should be insulated to ensure the thermal energy in the condensate isn't lost in transit. Also, insulation protects personnel from contact with hot components, thus improving plant safety. Everything in the condensate system at a temperature above 49°C needs insulation, including:

- Condensate lines
- Condensate tanks
- Valves
- Some steam trap types

The last factor is leaks and flash steam losses /Leaks from malfunctioning components in the steam and condensate system contribute to loss of treated condensate. Tanks that vent to atmosphere also lose condensate.

**Financial Analysis**

Condensate recovery can reach important savings in thermal energy consumption of the facility . Below is an illustration of the potential savings of a 20,000 kg/hr., 10 bars steam system with no condensate returned to the boiler plant.

**Savings Calculation Example**

Below is the basic data for the sample calculation, which represents a typical operating steam system.

| | |
|---|---|
| Average steam flow (kg per hr) | 20,000 |
| Unloaded fuel cost ($ per MBTU) | 15.3 |
| Operation (hr/yr) | 8,760 |
| Operating steam pressure (bars) | 10 |
| Steam temperature (°C) | 186 |
| Steam total energy (hg) BTU/kg | 2,634.75 |
| Makeup water temperature (°C) | 13 |
| Makeup water BTU content (hm) BTU/kg | 50.71 |
| Condensate return temperature (°C) | 100 |
| Returned condensate energy (hc) BTU/kg | 397.56 |
| Benchmark fraction of condensate returned (decimal percent) | 0.90 |

To determine potential energy losses per year, based on zero condensate returned to the boiler point, follow the calculation below:

(hc – hm) = energy loss per kg of condensate

(397.56 – 50.71) = 346.85 BTU per kg of condensate

20,000 kg of steam = 20,000 lbs. of condensate (90% return) = 18,000 kg

18,000 kg x 346.85 BTU per kg = 6,243,200 BTU/hr.

6.243 x $ 15.3 = $95.52/hr.

$95.52 x 8,760 hours per year = $836,737/yr.

The potential savings are based on the energy required to elevate the make-up water to that of the condensate being returned. The calculation doesn't take into account the savings from chemicals, water and sewer costs. It also doesn't consider the effect of bringing condensate back at higher pressures, resulting in greater savings. The above calculation assumes no condensate is being returned to the boiler, but most industrial plants return at least a small percentage of condensate. Each plant should evaluate the cost of failing to return condensate and set forth a roadmap for returning condensate.

## 4.8.4. Condensate return – Pressurized System

### Introduction

In a system with ventilation, the condensate is released to the atmosphere, causing a slight reduction in the maximum temperature at which it can be recovered, just below 100°C. This temperature limitation arises from the flashing that occurs at that specific temperature, as well as the subsequent heat losses in the return piping and equipment. Conversely, in an open-to-atmosphere collection tank, a significant amount of energy is lost when the condensate flashes into the atmosphere. This energy loss can be mitigated by implementing a Pressurized Condensate Recovery System (PCRS).

### Application

In a PCRS, the recovered condensate remains above atmospheric pressure throughout the recovery process and is typically utilized as boiler make-up water. One of the primary distinctions between vented and pressurized systems, apart from the pressure aspect, is the temperature at which condensate can be effectively reclaimed.
In a PCRS, the installation of the below equipment is required:

1. Condensate pump model CP-N / TLV with relevant controls and accessories.
2. Boiler level control with motorized feed water valve.
3. Feed tank return valve: for return water to tank when feed-water level reaches the operating level.
4. Flash Tank and surplus using valve for steam/condensate separation and pressure control. Here after is a drawing showcasing the PCRS installation.

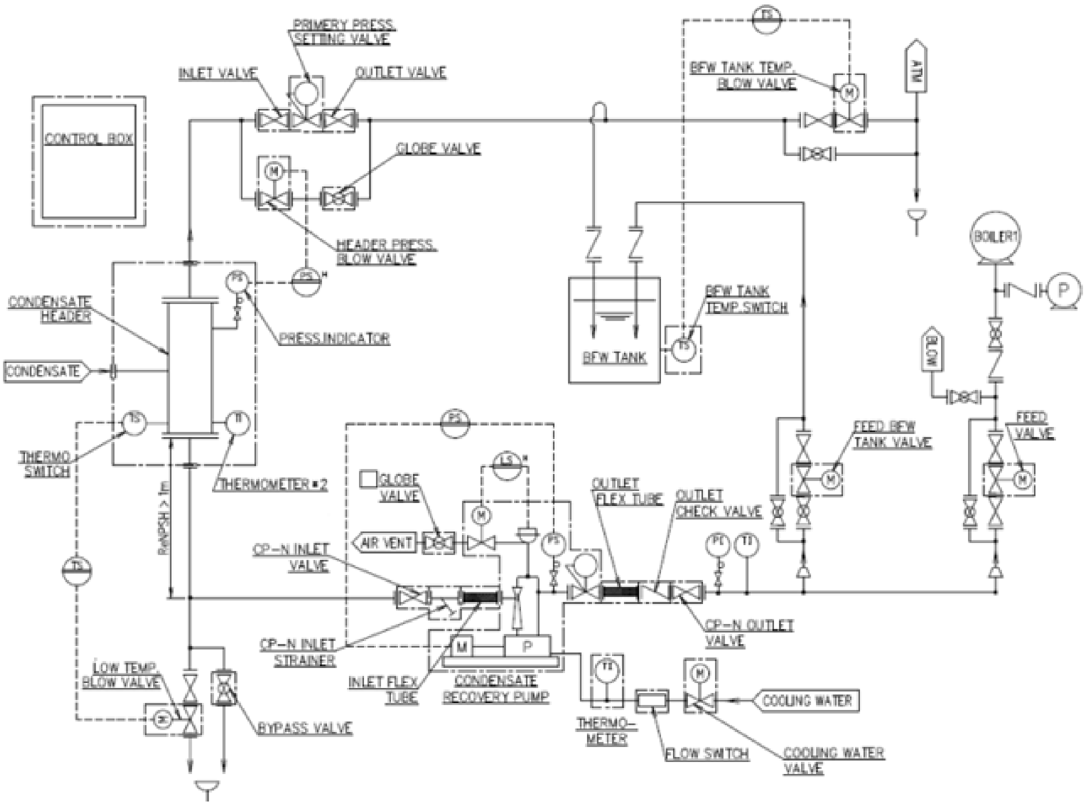


*Figure 27: PCRS system scheme*

### Financial Analysis

PCRS reduces the thermal energy consumed in steam boilers by more than 8%. Additional savings can be achieved from the flash steam recuperation; depending on the PRS operating pressure and the heat load where the flash steam can be used.

The savings calculation for Pressurized Condensate Return Systems (PCRS) is similar to that of vented systems. It serves as an estimate of the potential savings that can be achieved.

However, it’s important to note that actual savings can vary due to factors such as the efficiency of the specific steam system, energy costs, and any operational or maintenance expenses associated with implementing pressurized steam condensate return. These variables can influence the actual amount of savings realized in practice

### Vented vs Pressurized Condensate Recovery

The table below serves as a comparison between the 2 condensate recovery systems.

| | Vented recovery | Pressurized Recovery |
|---|---|---|
| Recovered Condensate Temperature | Up to 100°C [212°F] | Up to 180°C [356°F] |
| System Configuration | Simple | Advanced |
| Initial Costs | Lower | Higher |
| RunningCosts | Varries | Varries |
| Piping Corrosion | Significant (condensate comes into contact with air) | Slight ( no contact with air) |
| Vapor Clouds | Large amount (if condensate tep. is high) | Minimal amount |
| Recovery Applications | Boiler make-up water<br>Pre-heat<br>Water cleaning, etc. | Mainly for direct feed to boiler, and Flash Steam Recovery Applications |

## 4.8.5. Boiler / Burner replacement

Typically, after 10 to 15 years of service, a burner loses effectiveness and sees its efficiency plummets. Replacing a legacy burner with a new one that has a higher turndown capability and advanced controls can yield numerous benefits, including fuel savings, reduced emissions, improved reliability, and increased safety.

Similarly, substantial efficiency gains can often be realized by replacing old boilers with new, higher efficiency models. In particular, when an inefficient boiler is replaced with a higher efficiency model, both boiler fuel costs and emissions of air pollutants can be reduced.

### Boiler / Burner replacement

A simple maintenance program to ensure that all components of a boiler are operating at peak performance can result in substantial savings. In the absence of a good maintenance system, burners and condensate return systems can wear or get out of adjustment. These factors can end up costing a steam system up to 30% of initial efficiency over two to three years (Galitsky et al. 2005a). On average, the energy savings associated with improved boiler maintenance are estimated at 10%. Improved maintenance may also reduce the emission of criteria air pollutants.

Fouling on the fire side of boiler tubes or scaling on the water side of boilers should also be controlled. Fouling and scaling are more of a problem with coal-fed boilers than natural gas or oil-fed boilers (boilers that burn solid fuels like coal should be checked more often as they have a higher fouling tendency than liquid or gas fuel boilers do). Tests reported by CIPEC show that a fire side soot layer of 0.03 inches (0.8 mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5 mm) soot layer reduces heat transfer by 69% (CIPEC 2001). For water side scaling, 0.04 inches (1 mm) of buildup can increase fuel consumption by 2% (CIPEC 2001).

A Meadow Fresh dairy plant in New Zealand hired an energy efficiency consulting company to evaluate its boiler systems. After about 3 hours of the consultant’s work, the resulting boiler system “tune-up” netted the company approximately $45,000 a year in energy savings (EECA 2010).

## 4.8.6. Blowdown Steam Recovery

### Introduction

As process water losses are compensated for by adding make-up water to the boiler, the levels of minerals and chemicals in the boiler drum increase and accumulate over time. In large boilers operating for extended hours with significant make-up water usage, this mineral accumulation can lead to complete boiler clogging in a matter of days.

To combat this mineral build-up, blowdown is commonly employed, which involves releasing a portion of steam energy to remove accumulated contaminants.

Boiler contaminants tend to gather at the bottom of the drum, forming mud, while some float on the water's surface as scum. When blowdown is necessary, one potential measure to reduce energy loss caused by the blowdown process is steam recovery.

### Application

In practice, bottom blowdown is commonly utilized, where steam is used to agitate the bottom mud, followed by opening a valve at the drum's bottom to discharge the muddy water into a drain. Automatic controls can be employed to operate these valve systems by monitoring the drum water conductivity.

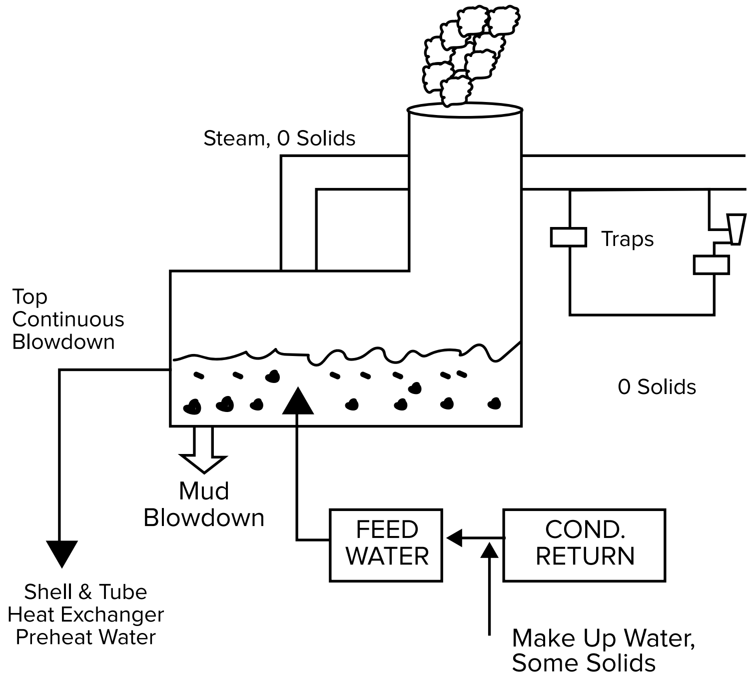


*Figure 28: Boiler Blowdown System*

Regardless of the method of controlling the top and bottom blowdown, considerable energy is lost down the drain when blowdown occurs. Depending on the local water quality, blowdown can be between 1-10% of the total steam production. This percentage is a significant amount of steam and energy since blowdown is essentially live steam and hot water being sent down the drain.

Recovering heat from blowdown is an effective way to reduce energy consumption at the facility. As the blowdown steam and water leave the drum, they pass through a heat exchanger to capture some portion of the thermal energy that would otherwise go to waste. This waste heat can be used to preheat the incoming make-up water. This loop as a feedback loop that brings thermal energy back into the boiler system. By raising the make-up water temperature, direct energy savings will occur due to the avoided fuel consumed to raise the water temperature.

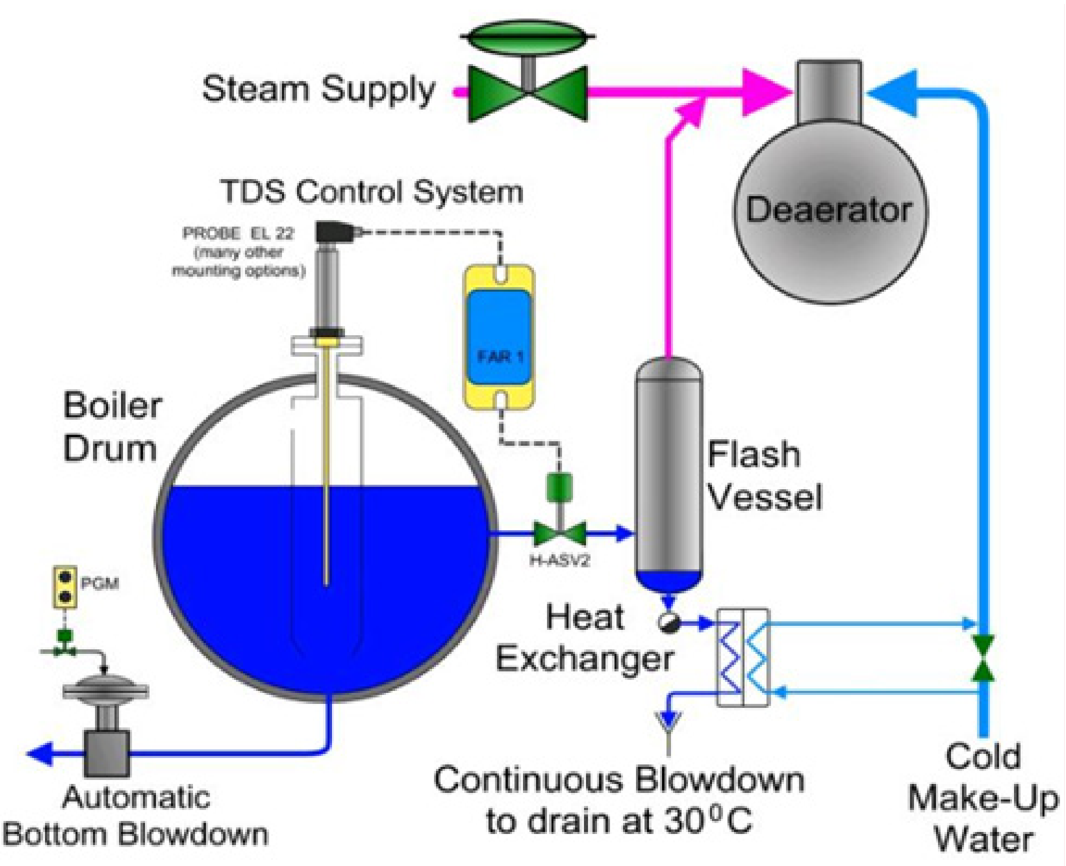


*Figure 29: Blowdown and heat recovery*

**Advantages**

Recovering blowdown steam reduces the demand for heating by reclaiming some of the wasted heat as part of this preventive maintenance action. Recovered energy can be used as a preheating source for make-up water when needed.

**Financial Analysis**

The implementation of a blowdown heat recovery system requires minimal investment. This value varies based on technology details and complexities.

In general, such a system could reduce thermal energy consumption between 2-5%. The primary objective of enhancing energy efficiency in steam distribution systems revolves around minimizing heat losses across the system and capturing valuable heat whenever possible. The measures outlined below represent notable opportunities for conserving energy in industrial steam distribution systems.

## 4.8.7. Thermal Insulation

### Introduction

Un-insulated steam distribution and condensate return lines are a constant source of wasted energy. Insulation can typically reduce energy losses by 90% and help ensure proper steam pressure at plant equipment. Any surface over 45°C should be insulated, including the below:

- Steam lines and hot water pipes
- Condensate return lines and collection vessels
- Boilers
- Deaerator
- Blow down vessels used for heat recovery
- All valves, fittings and controls where practical

### Application

Typically, it is uncommon to encounter pipes without insulation, but it is quite common to come across inadequately insulated pipes and vessels. For insulation to be efficient, it needs to be in good condition. In fact, wet insulation is even less effective than having no insulation at all.

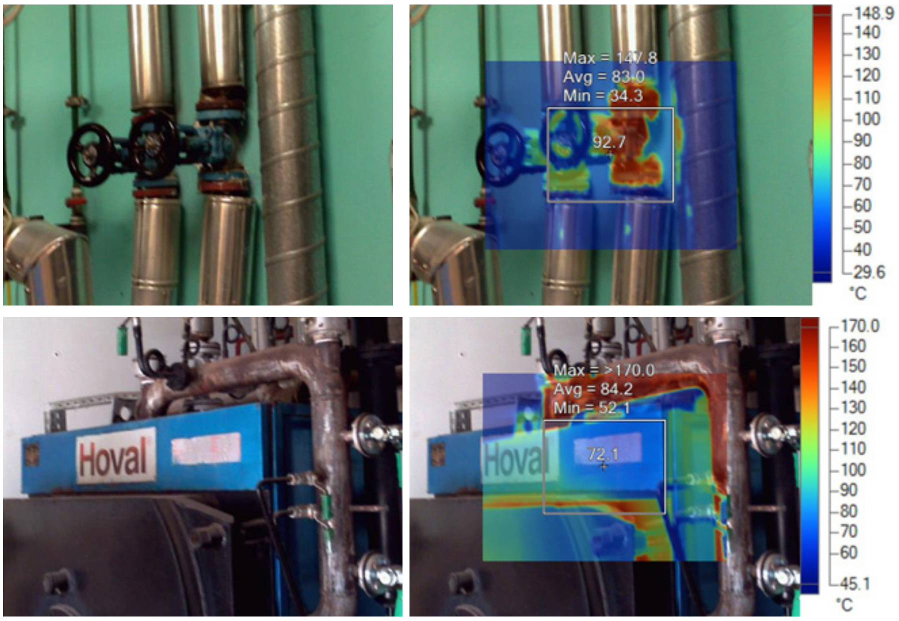


*Figure 30: Example of poor insulation in steam system*

Insulation used for boilers and pipes will be of these general types:

- High density fiberglass shaped for pipes or flat sections
- Blankets or bats of fiberglass or mineral wool
- Molded, fire brick, pre-cast or cast-in-place
- Spray-on ceramic
- Spray-on foam (more common in cold applications than hot)

The insulation is generally covered with some sort of metal, plastic, paper, etc., to protect it from light impact damage, UV exposure and moisture.

*Figure 31: Fiberglass insulation material and well insulated steam systems*

### Insulation maintenance

Insulation frequently becomes damaged or is removed and never replaced during steam system repair. Damaged or wet insulation should be repaired or immediately replaced to avoid compromising the insulating value. Eliminate sources of moisture prior to insulation replacement. Causes of wet insulation include leaking valves, external pipe leaks, tube leaks, or leaks from adjacent equipment.

It is often found that after heat distribution systems have undergone some form of repair, the insulation is not replaced. In addition, some types of insulation can become brittle or rot over time. As a result, a regular inspection and maintenance system for insulation can also save energy. Implementing an insulation maintenance program has given payback periods of less than one year in several industrial plants.

### Advantages

Compared to un-insulated pipes:

- Each un-insulated bare flange is equivalent to 0.3 meter of un-insulated same size pipe.
- Each un-insulated valve is equivalent to 1.5 meters of un-insulated same size pipe.
- From the length and number of flange and valve, the estimation of heat loss from different pipes can be made using the above table.

**Financial Analysis**

Network efficiency is an important factor in thermal energy consumption, especially the insulation, valves and hot surfaces. The heat losses from un-insulated horizontal pipes with ambient temperatures between 10 – 21°C are described in the below table.

| Temp. Diff. Steam to Air °C | 15mm | 20mm | 25mm | 32mm | 40mm | 50mm | 65mm | 80mm | 100mm | 150mm |
|---|---|---|---|---|---|---|---|---|---|---|
| | 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 | 321 | 394 | 464 | 555 | 698 | 969 |
| 139 | 184 | 224 | 272 | 333 | 373 | 458 | 540 | 622 | 815 | 1133 |
| 153 | 210 | 255 | 312 | 382 | 429 | 528 | 623 | 747 | 939 | 1305 |
| 167 | 241 | 292 | 357 | 437 | 489 | 602 | 713 | 838 | 1093 | 1492 |
| 180 | 274 | 329 | 408 | 494 | 556 | 676 | 808 | 959 | 1190 | 1660 |
| 194 | 309 | 372 | 461 | 566 | 634 | 758 | 909 | 1080 | 1303 | 1852 |

*Table 3: Heat losses from Horizontal Pipes with Ambient Temperature*

Proper insulation of the steam network and its components has a very rapid payback period estimated to be less than one year in most cases.

## 4.8.8. Steam traps Management

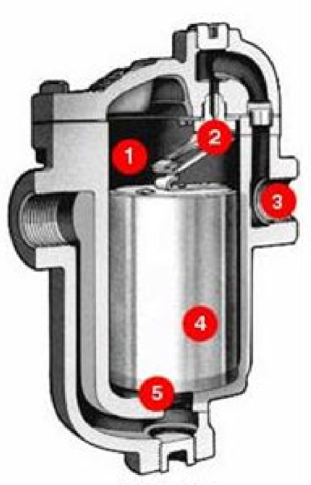
**Introduction**

The purpose of a Steam Trap is to maintain steam within the system while removing condensate and air. Air can negatively impact the heat transfer capacity of steam and cause corrosion. Condensate, on the other hand, significantly reduces heat transfer efficiency and the overall performance of steam devices. A faulty steam trap can result in steam leakage along with the condensate, leading to substantial energy loss. Failed traps not only waste fuel and reduce efficiency but also increase production costs and compromise the integrity of the steam and condensate systems. Consequently, steam trap inspection and repair/replacement programs are essential components of industrial energy audits in plants that use steam.

### Types and Operation of Steam Traps

There are various types of steam traps available from different manufacturers, with the Mechanical Trap being the most common. Mechanical traps operate based on the density difference between steam and condensate. The Inverted Bucket trap is a popular mechanical trap, where a float within the trap detects the weight variation between gas and liquid in the chamber. The condensate enters through the inlet, and the mechanical action drains it through the drain.

Thermostatic traps work by detecting temperature variations between steam and condensate at the same pressure. The sensing device operates the valve in response to changes in condensate temperature and pressure. Thermodynamic traps utilize the volumetric and pressure differences that occur during the state change from water to gas, directly affecting the valve.



## Application

Most trap failures occur in the open mode. When these failures happen, a boiler may have to work harder to generate the necessary energy, creating high back pressure in the condensate system. This back pressure can hinder the discharge capacities of certain traps, exceeding their rating and causing system inefficiencies. While traps can operate with back pressure to some extent, operating beyond their rating affects everything downstream of the failed trap, impacting steam quality and product performance.

Closed traps result in condensate backing up into the steam space, leading to equipment failing to produce the intended heat. For example, if there are four coils in a dryer but only three are operating due to a closed trap, it will take longer to dry the product, negatively affecting production.

Oversizing and dirt are two common causes of trap failure. Oversizing causes traps to work excessively, and in some cases, this overload can result in the blowing of live steam. Sudden pressure changes can cause an inverted bucket trap to lose its prime, leading to the bucket sinking and the valve opening. Dirt is a common issue in steam systems, with excessive build-up causing blockages or preventing valves from closing. Dirt is typically generated from pipe scale or over-treatment of chemicals in a boiler.

When steam traps cause condensate back-up in a steam main, the condensate is carried along with the steam, reducing steam quality and increasing the potential for water hammer. This not only results in wasted energy but can also damage equipment. Before testing a steam trap, it is crucial to understand its function, review different trap types, and be aware of the various pressures within the system. This knowledge helps prevent misdiagnosis and ensures accurate interpretation of trap conditions.

These are three main categories online trap inspection : visual, thermal, and acoustic.

### 1. Visual inspection

VI depends on a release valve situated downstream of certain traps. An inspector opens these valves and looks to see if the trap is discharging condensate or steam. Thermal inspection relies on upstream/downstream temperature variations in a trap. It includes pyrometry, infrared, heat bands (wrapped around a trap, they change color as temperature increases), and heat sticks (which melt at various temperatures).

Acoustic techniques require an inspector to listen to and detect steam trap operations and malfunction. This method included various forms of listening devices such as doctors' stethoscopes, screwdrivers, mechanical stethoscopes and ultrasonic detection instruments.

The ideal listening device will allow users to listen to the sounds of steam trap operations while ignoring most ambient pipe sounds. This is where ultrasonic listening devices excel. Since they are sensitive to high frequency (short wave) signals, they tend to ignore most stray pipe signals. Also, they are very directional in their pick-up. For this reason, they will allow users to hear and see on meters the exact operations of steam traps.

### 2. Ultrasonic detectors

They usually have a stethoscope module, which contains an ultrasonic transducer attached to a metal rod that acts as a “wave guide”. The wave guide is touched on the downstream side of a trap to determine trap condition such as mechanical movements or steam and condensate flow. Most ultrasonic detectors amplify the signals and translate them into the audible range where they are heard through headphones or seen as intensity increments on a meter. Some include frequency tuning to allow users to tune into desired trap sounds.

### 3. Automated Trap Monitoring

When steam traps fail in the open position, they result in a loss of performance and energy. However, the consequences can be even more severe when steam traps fail in the closed position. In such cases, equipment becomes flooded with condensate, causing it to stop functioning. Particularly in cold climates during the winter season, this can lead to equipment freezing. The freezing of coils and equipment can cause damage, such as broken coils and equipment malfunctions.

Manual monitoring of steam traps typically involves periodic inspections. However, even with an active inspection program, each trap may only be checked once or twice per year. The return on investment for replacing failed steam traps is often measured in months. The sooner a failed trap is detected, the faster it can be repaired or replaced. Automated monitoring systems with instant failure reporting minimize the time it takes to identify a failed trap and eliminate the labor required for manual trap inspections.

*Figure 32: Automated Steam Trap system Example (courtesy: Armstrong International)*

**Advantages**

The graph below shows the relationship between steam pressure and steam losses. As mechanical trap sizes increase, the inherent steam losses from fully open traps do not increase in a linear fashion; they increase logarithmically.

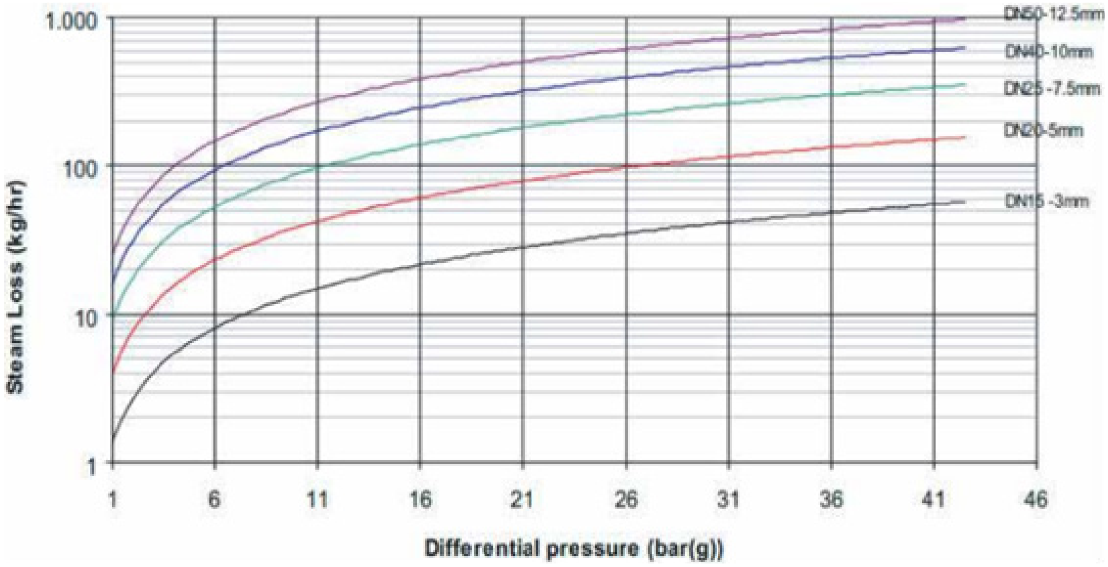


*Figure 33: Relationship between steam pressure and steam losses*

**Financial Analysis**

Steam traps maintenance is a low cost measure that requires regular inspection and cleaning of steam traps. It is rare that this measure required additional investment. Savings caused by proper steam trap maintenance could reach as much as 2% of thermal energy consumption.

## 4.8.9. Steam Leakage repair

### Introduction

Similar to steam traps, steam distribution piping networks often experience leaks that can go unnoticed without a regular inspection and maintenance program. The U.S. Department of Energy (DOE) estimates that repairing leaks in industrial steam distribution systems can result in energy savings ranging from 5% to 10% (U.S. DOE 2006d). For instance, at a Land O'Lakes dairy facility in Tulare, California, the DOE projected potential annual natural gas savings of $18,000 by implementing a steam leak maintenance program (U.S. DOE 2005b). Moreover, regular inspection and timely leak repair can help minimize the occurrence of major system leaks, which can be exceedingly costly to fix.

### Application

Application-wise, repairing leaking components of the steam distribution network involves good housekeeping measures and, in some cases, replacing damaged items. It is crucial to conduct routine checkups on the steam network to ensure that steam is not being wasted.

### Advantages

Steam leaks have various detrimental effects on steam-based plant operations, including energy losses, increased emissions, reduced reliability, production issues, and safety concerns. Steam system leaks can result in significant energy losses within plant operations. Given the high cost associated with these energy losses, rectifying steam leaks offers highly favorable payback potential.

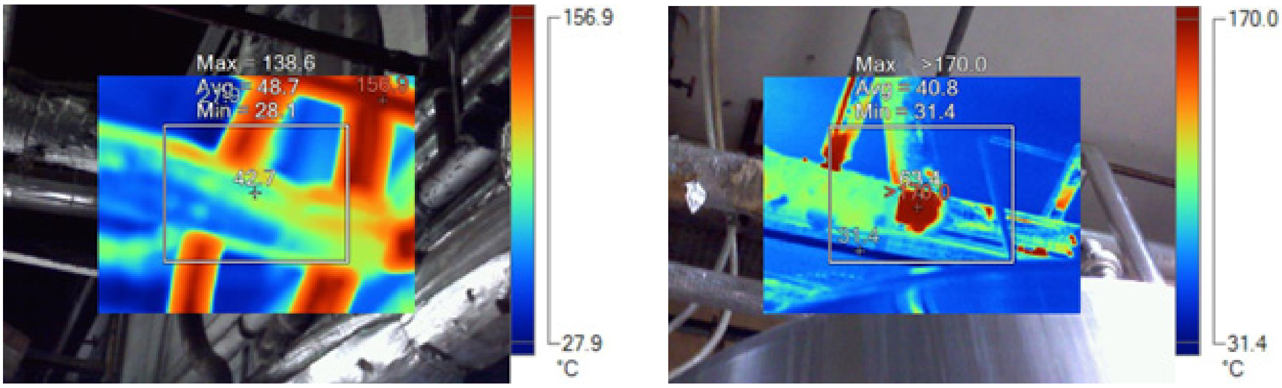


*Figure 34: Steam Leakage Examples*

Figure below shows the steam leakage rate at different steam pressure and different holes sizes.

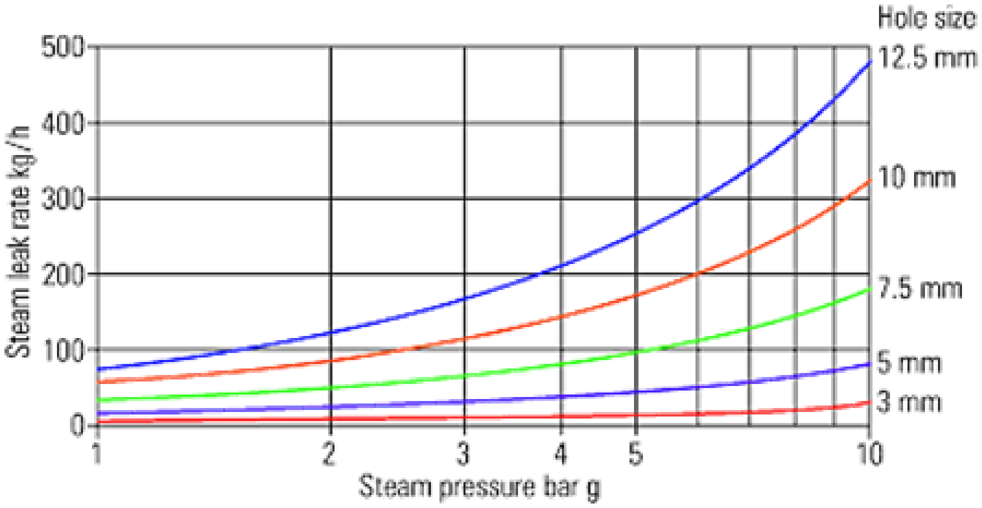


Figure 35: Steam leakage rate

### Financial Analysis

This measure requires no or low investment, with preventive maintenance playing a major role. Thermal Energy Savings from proper steam leakage repair are important which results in attractive payback periods.

## 4.8.10. Flash Steam Recovery

### Introduction

When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. As with flash steam produced by boiler blow down, steam trap flash steam can be recovered and used for low grade facility applications, such as space heating or feed water preheating.

### Application

Flash steam recovery systems typically involve the use of heat exchangers or flash tanks to separate the high-pressure condensate into low-pressure steam and liquid condensate. The recovered steam can then be used for heating or other applications, while the condensate can be returned to the boiler for further energy efficiency.

The flash steam recovery process involves capturing and utilizing the energy from high-pressure flash steam that is generated during industrial processes. Here is a step-by-step overview of the process:

1. Steam Generation: High-pressure steam is generated in a boiler or steam generator as part of an industrial process.
2. Heat Transfer: The high-pressure steam is used to transfer heat to the process, providing the necessary energy for various operations.
3. Condensation: After the steam transfers its heat to the process, it becomes condensate, which is high in heat content
4. Pressure Reduction: The high-pressure condensate is rapidly released or passed through a pressure-reducing valve, causing it to undergo a significant drop in pressure.
5. Flash Steam Generation: The sudden pressure reduction causes a portion of the high-pressure condensate to flash vaporize, forming flash steam. Flash steam is low-pressure steam that contains a considerable amount of thermal energy.
6. Flash Steam Recovery: The flash steam is captured using flash tanks or heat exchangers. These devices separate the flash steam from the remaining liquid condensate.
7. Utilization: The recovered flash steam can be utilized for various purposes, such as preheating boiler feedwater, heating process fluids, or generating additional steam.
8. Condensate Return: The liquid condensate separated from the flash steam can be returned to the boiler or steam generator for further energy efficiency. This helps reduce water and fuel consumption in the steam generation process.

### Advantages

The effectiveness and cost-efficiency of this measure depend on the specific site conditions, particularly the proximity of areas that can utilize low-grade heat to the steam traps. Implementing this measure can be relatively straightforward and yield significant energy savings where feasible.

### Financial Analysis

A study conducted on a food processing facility in the United States demonstrated that the installation of a flash steam recovery system for feed water preheating could lead to annual fuel cost savings of approximately $29,000, with a payback period of less than 1.8 years (Iordanova et al., 2000). Additionally, based on the reduction in boiler fuel consumption, it was estimated that the plant's carbon emissions would be reduced by 173 tons per year.

## 4.9. Heat Recovery

Recovered waste energy can be effectively utilized in various applications, including air compressors, power generators, boilers, and more. The utilization of wasted heat can be applied in two primary ways:

### Heating Air

Air-cooled packaged rotary screw compressors, which are mostly used in Lebanese industries, are very amenable to heat recovery for air heating for any potential hot air uses. Ambient atmospheric air is heated by passing it across the system's after cooler and lubricant cooler, where it extracts heat from both the compressed air and the lubricant that is used to lubricate and cool the compressor.

Since packaged compressors are typically enclosed in cabinets and already include heat exchangers and fans, the only system modifications needed are the addition of ducting and another fan to handle the duct loading and to eliminate any back pressure on the compressor cooling fan. These heat recovery systems can be modulated with a simple thermostatically controlled hinged vent.

Hot air can be used for space heating, industrial drying, preheating aspirated air for oil burners, or any other application requiring warm air.

### Heating Water

One approach involves utilizing a heat exchanger to extract waste heat from the lubricant coolers commonly found in packaged water-cooled reciprocating or rotary screw compressors. This process enables the production of hot water. Depending on the design, heat exchangers can generate either non-potable (gray) or potable water. When there is no requirement for hot water, the lubricant is directed back to the standard lubricant cooler for cooling purposes.

Hot water derived from waste heat can find applications in various sectors, such as central heating or boiler systems, industrial cleaning processes, plating operations, heat pumps, laundries, and other instances where hot water is necessary. Additionally, heat exchangers present an opportunity to produce both hot air and hot water, providing flexibility to adjust the ratio of hot air to hot water as desired by the operator.

## 4.9.1. Heat Recovery from Boiler– Economizer installation

### Introduction

In fuel-driven boilers, approximately 18-22% of the fuel energy is lost through the exhaust stack, presenting a significant opportunity for energy savings. One common approach to capitalize on this potential is by implementing heat recovery from flue gas, where the heat from the flue gas is utilized to preheat the boiler feed water in an economizer. Although this measure is widely adopted in large boilers, there is often additional potential for further heat recovery.

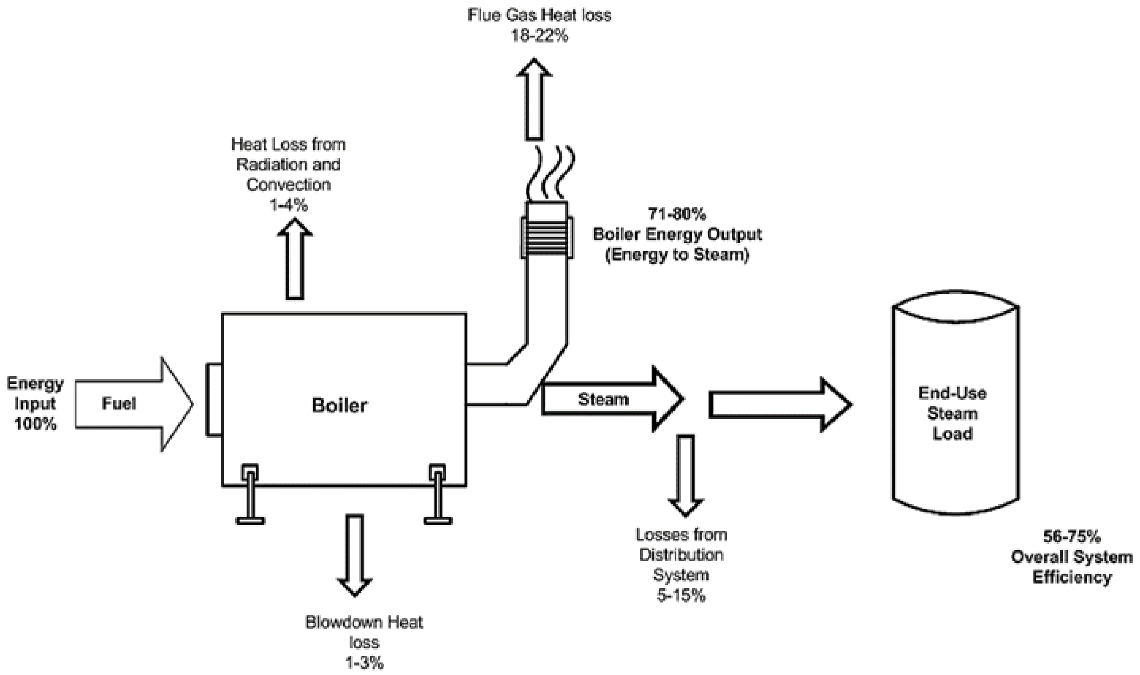


*Figure 36: Steam boiler energy balance scheme*

The limiting factor for flue gas heat recovery is that one must ensure that the economizer wall temperature does not drop below the dew point of acids contained in the flue gas (such as sulfuric acid in sulfur-containing fossil fuels).

### Application

The heat energy contained in the flue gas of a steam boiler can be harnessed through the use of an economizer, a specialized tool designed for this purpose. Stack economizers, which are essentially heat exchangers, are employed in the boiler exhaust gas heat recovery process. They consist of hot flue gas on one side and water on the other, and are strategically sized and installed in the stack, close to the boiler's flue outlet.

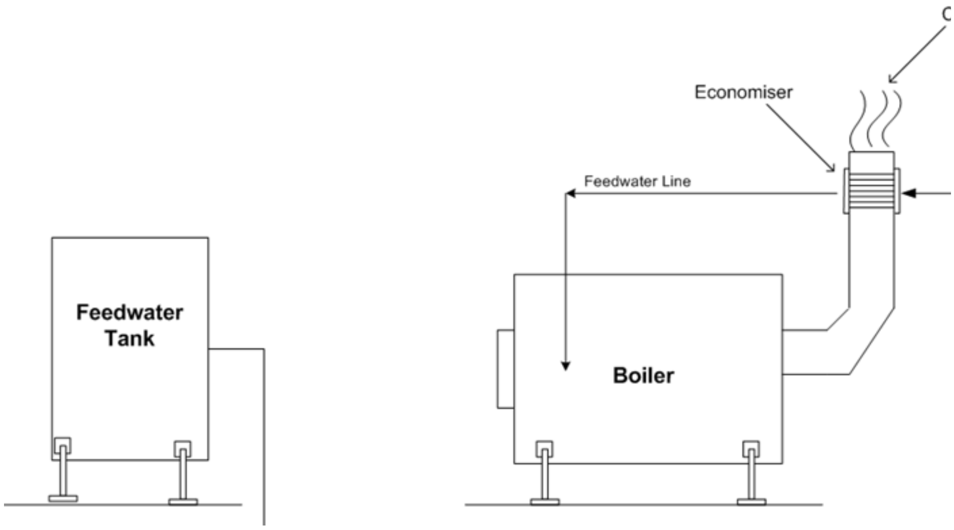


*Figure 37: Boiler stack economizer*

Proper sizing of economizers involves considering factors such as the volume of flue gas, its temperature, the allowable maximum pressure drop in the stack, the type of fuel used in the boiler, and the desired amount of energy to be recovered. It is crucial to ensure that economizers are suitable for the specific application. For example, an economizer designed for natural gas usage may encounter blockages if installed on a coal boiler, while corrosion risks may increase if installed on an oil-fired boiler. Some units are designed to maintain the flue gases above the condensation temperature, and others are constructed with materials resistant to the corrosive effects of condensed flue gases.

### Advantages

Flue gases from large boilers typically range from 220°C to 340°C. By utilizing stack economizers, a portion of this heat can be recovered for pre-heating water. This water is commonly used for boiler make-up or other applications that coincide with boiler operation. Stack economizers should be considered as an efficiency measure in situations where significant amounts of make-up water are required or when there is a simultaneous need for substantial quantities of hot water.

The existing stack temperature provides insights into potential energy savings, the volume of make-up water required, and the operational hours of the system. Economizers are available in a wide range of sizes, ranging from small coil-like units to large waste heat recovery boilers.

### Savings Calculation

Savings potential is a function of recovered heat, based on existing stack temperature, required volume of make-up water, and number of operation hours. A generally accepted rule of thumb is that about 5% of boiler input capacity can be recovered with a properly sized economizer. The lower the amount of condensate return, the higher the volume of make-up water and the higher savings potential.

**Savings Calculation Example:**

Consider a 4,905kW (500 HP) boiler with a diesel input of 5,861.4 kW.

5,861.4 KW x 5% = 293 kW (100% Load Factor)

293 kW / (0.093 kW per liter of 93°C water) = 3,150 liters per Hour

(293kW / 80% efficiency) = ~34m3 x $0.247 per m3 Natural Gas = $8.40 per Hour Value

Savings is reduced by 50% for a 50% Load Factor, etc.

Source: Boiler Consortium 2012

## 4.9.2. Heat Recovery from Generator – Exhaust Gas Boiler

### Introduction

Heat recovery from exhaust gas boilers specifically focuses on capturing and utilizing the waste heat generated by combustion processes in boilers or furnaces. These systems recover heat from the flue gas or exhaust gases leaving the boiler or furnace and use it to preheat incoming combustion air, feedwater, or for other heating purposes. Heat recovery from exhaust gas boilers is commonly applied in industries that rely heavily on boilers for steam production or hot water, such as refineries, chemical plants, and power generation facilities. This technology is effective in improving boiler efficiency and reducing fuel consumption by preheating the inputs, which results in cost savings and reduced emissions.

### Application

Approximately 90% of the energy consumed by a compressor is released as waste heat, and a significant portion of this waste heat can be recovered. The waste heat from compressor cooling is typically low grade but suitable for building services and other applications. Air-cooled compressors can provide hot air up to 80°C, while water-cooled compressors can generate hot water up to 95°C.

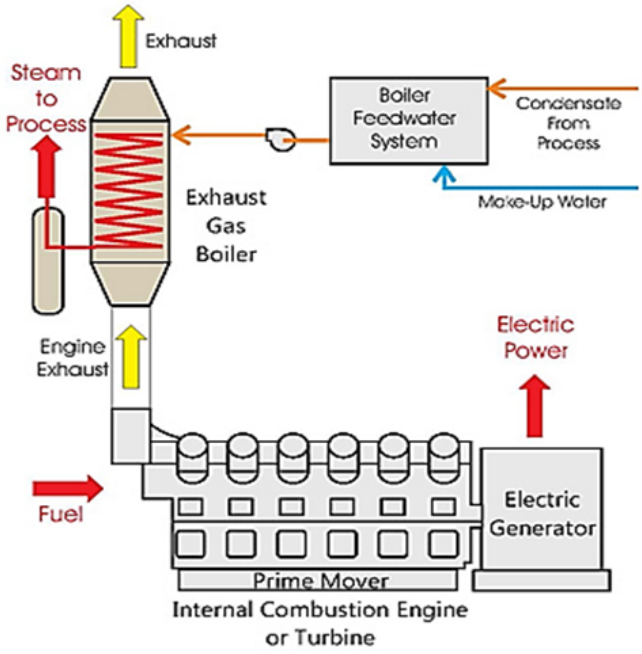


*Figure 38: Exhaust Gas Boiler*

The very common and most applicable design on EGB follows the Clayton Model which has an excellent working efficiency.

The Clayton Model shown in the figure below works as follows: the feed-water for the exhaust gas boiler is prepared in a feed – water tank (hot-well) which can be either atmospheric or pressurized. In the feed-water tank, fresh make-up water and condensate coming back from the installation are blended. The water in the tank is preheated in a controlled way by steam injection in order to drive out oxygen and non-condensate gases. The water preheating temperature is 95 °C. in the same tank chemicals for water treatment are added to the feed-water. A pump takes water from the feed-water tank to the separator accumulator. The separator/accumulator is a vessel under steam pressure with controlled water levels.

The vessel has two basic functions: separation of the steam and water mixture coming from the exhaust gas boiler and preheating of the water going to the exhaust gas boiler. The clayton water pump takes water from the separator/accumulator and feeds it to the exhaust gas boiler. This quantity of recirculation water is about twice the steam production of the exhaust gas boiler at full load. The mixture of steam and water coming out of the exhaust gas boiler is going to the separator/accumulator. A system of fixed vanes mounted inside the vessels takes care of the separation of steam and water. The separated water, however, is at steam saturation temperature and mixes in the vessel with the in-coming water from the feed-water tank. In this wat, the water at the bottom of the accumulation has a temperature in between the steam temperature and the temperature of the water in the feed-water tank. The system assures that the water going to the exhaust gas boiler is well above the acid dew-point of the exhaust gases, thus protecting the boiler tubes against outside corrosion.

The installation of the EGBs requires 70 m2 in the generators area. On the other hand, the system will comprise the EGB and all the auxiliaries for controlling the exhaust gases and steam flows.

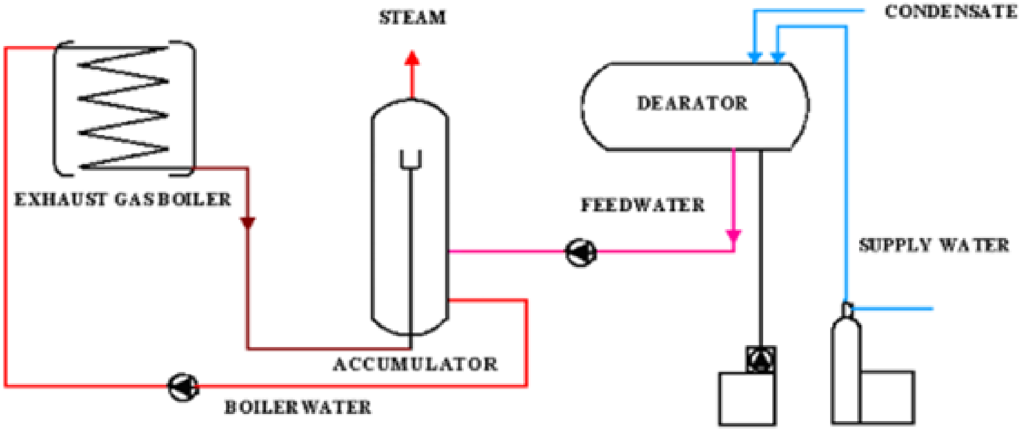


*Figure 39: Clayton R system operational scheme*

## Advantages

EGB allows recovering waste energy and converting it into heat. This process leads to a massive reduction in thermal energy demand and also helps cleaning up stack gas. The exhaust gas boiler is a compact unit that does not required complicated configuration. The boiler is already equipped with an inlet pipe where stack gas enters, and an exhaust where leftovers exit.

### Financial Analysis

The price of an exhaust gas boiler varies depending on the size and application itself, but normally falls in the range between $150,000 and $350,000.

The savings can reach more than 20% of the thermal energy consumption, with a payback period that does not exceed eight years.

Considering a typical application, an EGB designed to work with two generators with a total capacity of 1,300 KVA costs around $250,000 but pays back the investment in less than four years by saving 7.7% of the thermal energy consumption at the facility.

## 4.9.3. Heat Recovery from Generator- Jacket Water

### Introduction

The electrical power generation process in generators typically exhibits an efficiency of only up to 40%. The remaining portion represents pure losses, primarily in the form of exhaust gases and cooling through radiators/jackets. However, the heat contained in these exhaust gases can be effectively recuperated to produce hot water.

One approach to utilizing this waste heat is by installing a heat exchanger on one of the generators. During generator operation, the exhaust gas passes through the heat exchanger and transfers its heat to the water stored in a tank, raising its temperature.

### Application

Application-wise, the engine’s jacket water and radiator offer another opportunity for waste heat recovery, although at a lower recovery gradient compared to the exhaust gases. This particular measure involves installing a heat exchanger on the engine’s jacket water coolant to generate hot water.

By harnessing the heat that is rejected by the coolant from one generator, it becomes possible to produce hot water. The system will include the heat exchanger and all the necessary control auxiliaries.

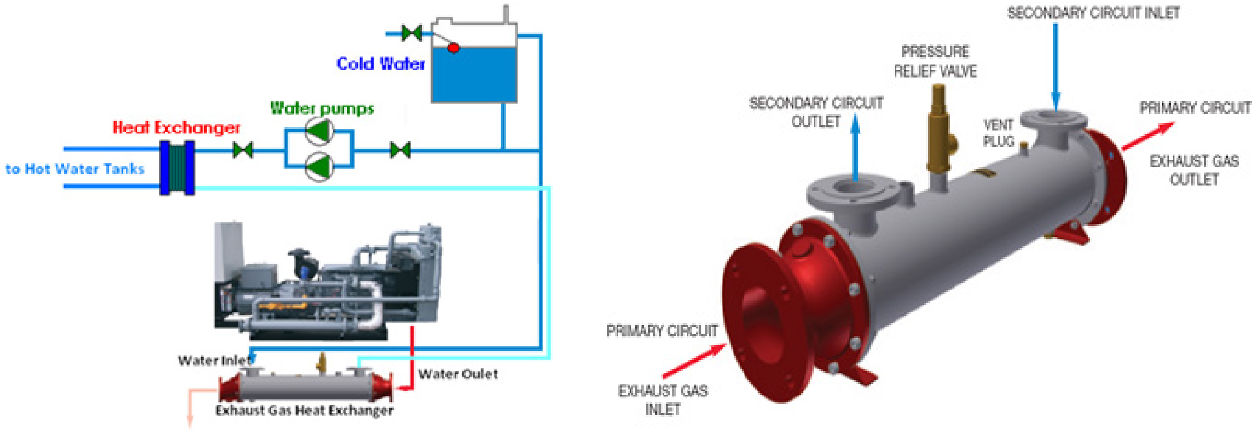


*Figure 40: Heat exchanger network drawing (left), type of heat exchanger (right)*

**The system installation must include**:

- Two Gas/liquid heat exchangers BOWMAN equipped with all necessary accessories (valves, connections, etc...).
- Two heating pumps (1 duty - 1 standby) equipped with all needed valves.
- Water temperature sensors.
- Galvanized steel pipes complete with all connection accessories.
- Fiberglass insulation 25mm thick with a density of 64 Kg/m3.
- Three way valve with temperature controller in order to mix between supply and return.

### Financial Analysis

These savings lead to a very attractive payback period starting at 1.3 years for one site and then going up to 4.63 years in the worst-case scenario. The investment size depends on the system itself and the amount of heat that will be recovered, ranging from $20,000 to around $100,000, saving somewhere between 1% and 13% of the thermal energy consumption at the facility.

## 4.9.4. Heat Recovery from Generator – Absorption Chiller

### Introduction

An absorption refrigeration system distinguishes itself from a vapor compression refrigeration system by utilizing a thermal energy source rather than electrical energy. This system involves the use of two working fluids: a refrigerant and an absorbent. In an absorption refrigeration plant (ARP), ammonia serves as the refrigerant, while water acts as the absorbent. The ARP is capable of providing cooling for industrial applications at temperatures as low as -60°C.

### Application

In a traditional cooling machine, the refrigerant undergoes evaporation at a low temperature and low pressure. The resulting vapor is extracted from the evaporator and then compressed to a higher pressure before being liquefied in the condenser.

In contrast, an absorption refrigeration plant operates differently. It employs a solution circuit that functions as a thermal compressor. A liquid absorbent dissolves the refrigerant vapor, and this liquid is then pumped to a high-pressure level in the de-sorber or generator. In the de-sorber, the refrigerant is separated from the liquid solution. This separation is achieved by heating the solution to its boiling point, causing the refrigerant to evaporate out of the solution. The heating process can be accomplished using waste heat, steam, or a gas/oil burner. The resulting ammonia vapor is subsequently condensed in the condenser. Both the condensation heat and the absorption heat must be dissipated to the surroundings

Overall, an absorption refrigeration plant offers an alternative method for achieving cooling effects, utilizing a thermal energy source and a solution circuit to drive the refrigeration process.

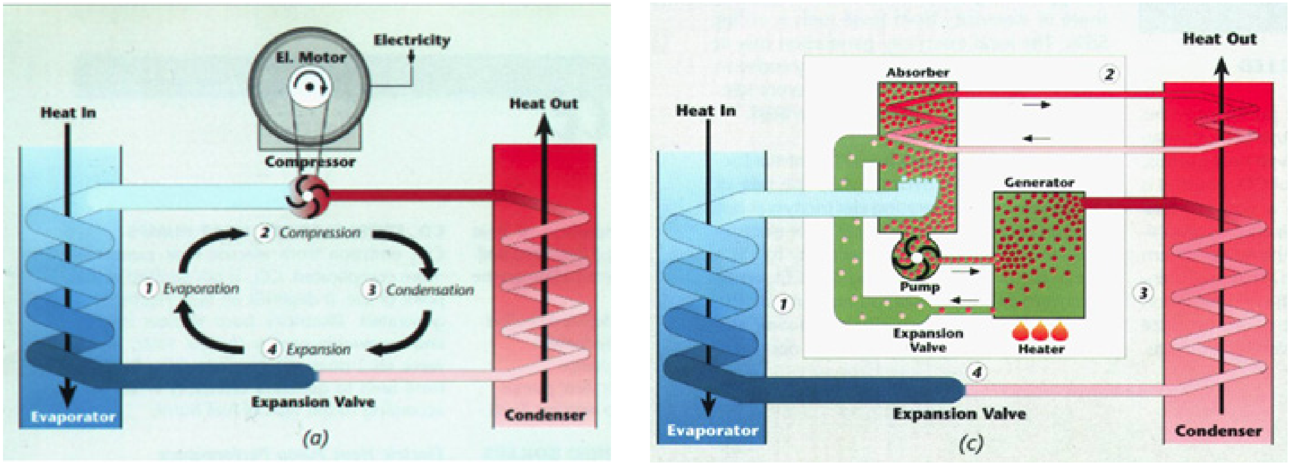


*Figure 41: CROM (left), ARP (right)*

The main difference between a compression and an absorption cycle is that the former needs mechanical energy as a driving energy for the compressor, while the latter needs thermal energy for the de-sorber and only a small amount (2% of the driving energy) of electricity for the liquid pump.

Because most of the components of an ARP are heat exchangers, the plants are very robust and are not susceptible to wear and tear. ARPs need very little maintenance. Only the liquid pumps and the pneumatic valves consist of moving components that are susceptible to wear and tear. Maintenance is an easy task and no specialists are required.

Each 1,000 KVA generator can be equipped with an ARP of a capacity of 150 tons of refrigeration.

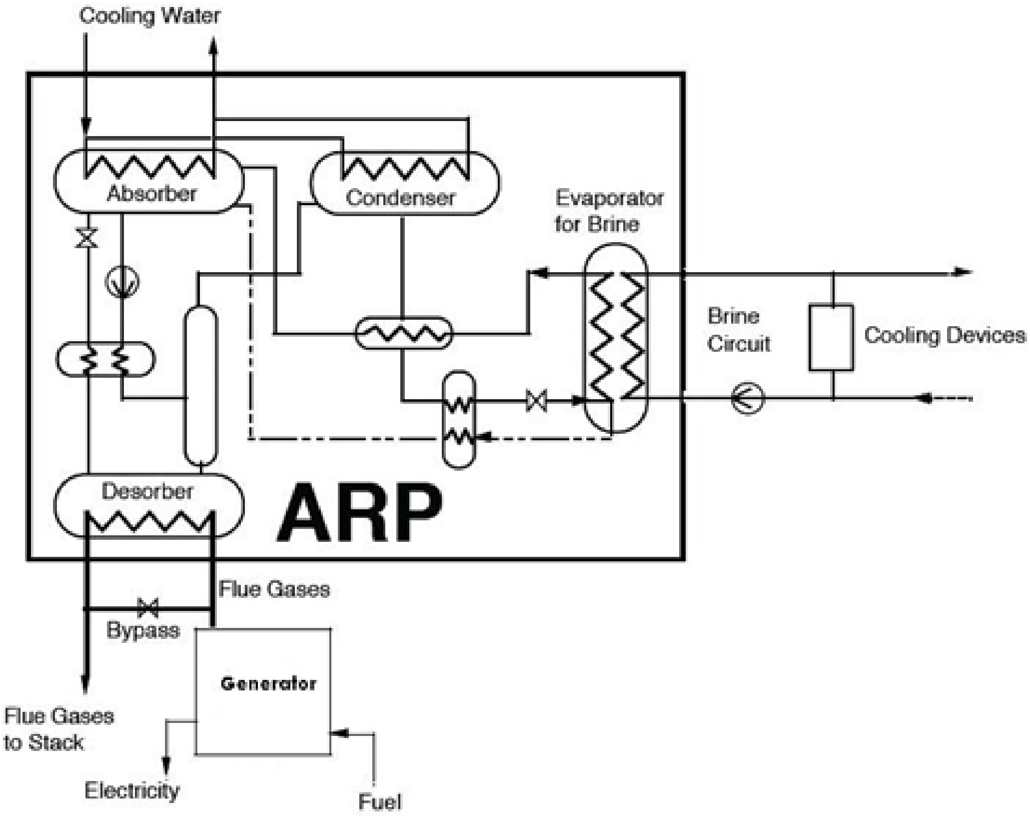


*Figure 42: Sample drawing of an ARP on a 1,000 KVA generator*

### Financial Analysis

Heat recovery absorption chiller system usually result in attractive saving in the range of 10%, with an investment cost of around $400,000.

### 4.9.5. Heat Recovery from Compressed Air

**Introduction**

The generation of compressed air is an energy-intensive process, and it often leads to the generation of substantial waste heat. This excess heat, if not efficiently recovered and utilized, represents an opportunity for improving overall energy efficiency and reducing energy costs within industrial facilities. Compressed air heat recovery is a sustainable and economically beneficial practice that involves capturing and repurposing this waste heat, thereby enhancing the performance and sustainability of compressed air systems.

**Application**

Compressed air waste heat recovery involves the capture and utilization of the waste heat generated during the compression of air in industrial processes. The process generally consists of several steps, from heat capture to its utilization for various purposes.

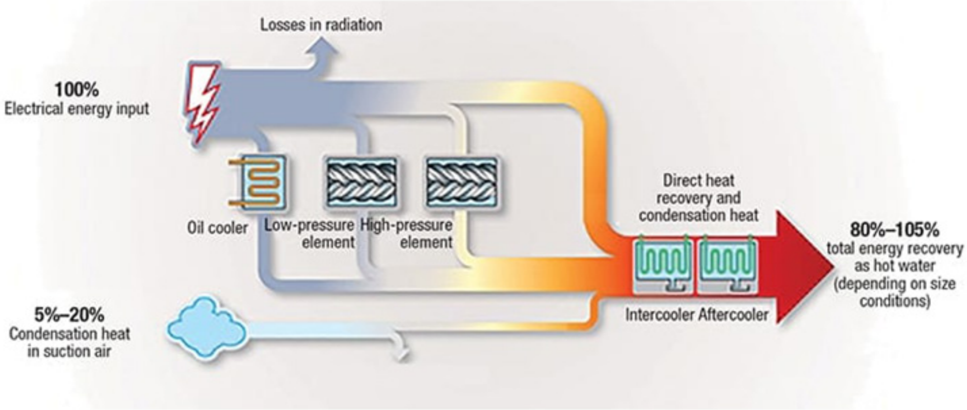


*Figure 43: An energy recovery scheme can help to utilize waste heat for hot water, which can be used in a variety of process applications*

Here's an overview of the compressed air waste heat recovery process:

1. Heat Generation: The first step in the process is the generation of waste heat during the compression of air by an air compressor. This heat is a byproduct of the compression process and is typically expelled into the surrounding environment.
2. Heat Capture: To recover the waste heat, a heat exchanger or heat recovery system is installed within or near the air compressor. This equipment captures the heat from the compressed air or the compressor's cooling system. The type of heat exchanger used depends on the specific design and configuration of the system.
3. Heat Transfer: The captured waste heat is transferred from the compressed air or cooling system to another medium, such as water or air. This transfer typically occurs through a heat exchange surface within the heat exchanger.

4. Heat Utilization: The recovered waste heat can be used for various purposes, depending on the specific needs of the facility. Common applications include:
    - Space Heating: The waste heat can be used to supplement conventional heating systems, reducing the reliance on other heating sources.
    - Water Heating: The heat can be used to preheat water for industrial processes, sanitation, or general facility use, reducing the energy required for water heating.
    - Process Heating: Industries with high-temperature process requirements can use recovered waste heat to preheat air or other process fluids, enhancing energy efficiency.
    - Absorption Cooling: In trigeneration systems, the heat can drive absorption chillers to provide cooling or air conditioning.
    - Steam Generation: Waste heat can be used to generate steam for industrial processes or to drive a steam turbine for electricity generation.

5. Distribution and Control: The recovered heat is distributed to the areas or processes where it is needed. Control systems ensure that the heat is delivered at the appropriate temperature and flow rate to meet the specific requirements of each application.

6. Monitoring and Optimization: Continuous monitoring and control of the waste heat recovery system are essential to optimize its performance, ensuring that heat is captured and utilized efficiently.

7. Maintenance and Safety: Regular maintenance and safety protocols should be established to keep the waste heat recovery system in good working condition and to ensure the safety of personnel.

The specific design and components of a compressed air waste heat recovery system can vary depending on the facility's requirements, the type of air compressors used, and the intended applications for the recovered heat. Proper engineering and system design are essential to maximize the efficiency and benefits of the waste heat recovery process, making it an integral part of overall energy management strategies in many industrial settings.

3 main technologies are used in compressed air heat recovery in industrial applications:

1. Air cooled compressor: which features high volume rate with relatively low temperature available, has a 90%recovery efficiencies, temperature is increased by 5-25 °C. possible of air and has limited application.
2. Water Cooled Lubricant Injected compressorts: whereby water is heated by 50

K up to 70°C. Has a 70% recovery efficiency whereby water can be transported to demand or integrated in hot water system.

3. And finally the Water cooled oil free compressorts whereby temperature can reach up to 90°C.Some manufacturers are offering built in energy recovery systems which circulate cooling water.

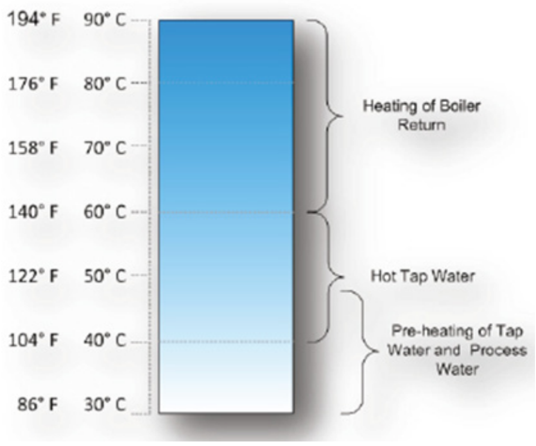


Figure 44: Application of heat

Some challenges rely in the thermal match between the heat recoverable and the demand for heat. In addition to the hourly match between the production and the demand.

### Advantages

Compressed air waste heat recovery offers numerous advantages for industrial facilities, commercial buildings, and other applications that rely on compressed air systems. By capturing and utilizing the waste heat generated during the compression of air, this technology provides several benefits, including :

- Energy Efficiency and Savings wherbey 75% of heat can be recovered
- Improve in the overall energy efficiency. By capturing and repurposing waste heat, the system reduces the energy consumption of the air compression process, resulting in significant energy savings.
- Recovered waste heat can be used to preheat air or other process fluids, improving the efficiency of manufacturing processes. This can lead to higher productivity and product quality.
- Generation of hot water
- Workshop production with hot water application
- Preehating and steam generation
- Cost saving by treplacing electricity, oil, or gas

### Financial Analysis

Waste heat recovery from compressed air typically has moderate to high energy efficiency and the potential for cost savings, all with a moderate initial investment, rendering it an appealing option in the majority of situations.

## 4.10. Installation of VFDs

### Introduction

Variable Frequency Drives (VFDs) have revolutionized the way industrial facilities operate by providing precise control over motor speed and optimizing energy consumption. Variable frequency drives (VFDs) are electronic devices that manipulate electrical current to electric motors to control speed and torque. In industrial settings, VFDs are used to funnel AC power, convert it into DC power, and temporarily store converted current until it is needed.

### Application

VFDs are particularly useful with centrifugal loads, such as pumps and fans. Popular industrial VFD applications include variable-loaded air compressors (typically rotary screw type), boiler and chiller feedwater pump motors, cooling tower fans, air handler supply and return fans, exhaust fans, and more.

#### 1. Air Compressors with VFD

When there are strong variations in load and/or ambient temperatures there will be large swings in compressor load and efficiency. In these cases installing a VFD (Variable Frequency Drive) or retrofitting one of the existing air compressors unit with a VFD driven one may result in attractive payback periods.

VFDs can be used to control the operation of positive displacement air compressors, such as rotary screw and reciprocating machines. These present a constant torque load and VFDs become viable when the average loading is around 75% of capacity or less. The actual level of savings is dependent on the control regime of the compressor plant, for example for a compressor operating at 50% capacity the energy saving would be 38% compared against modulating control and 20% compared against ON-OFF only control. Some existing compressors are not compatible with VFD controls and could be damaged if retrofitted with VFD control; the compressor manufacturer should always be consulted when considering retrofitting VFDs.

Dynamic (centrifugal) compressors use a rotating disk or impeller in a shaped housing to force the gas to the rim of the impeller, increasing the velocity of the gas. The most common way to control the capacity of centrifugal compressors is to modulate inlet guide vanes however this is less efficient at part load; VFDs can be used to successfully control their output with greater efficiency.

#### 2. Pumps with VFD

Centrifugal pumps are used on many industrial applications. Many of these pumps are operated at fixed speeds, but could provide energy savings through variable speed operation. Reviewing the affinity laws for centrifugal pumps and a typical operating cycle for a centrifugal application will show this. VFDs (Variable Frequency Drives) can achieve reduced flow by providing variable speed pump operation. This results in reduced system pressure and operation near the pump's Best Efficiency Point. In addition, maintenance costs might be reduced.

Figure below shows the physical laws of centrifugal pumping applications. The flow is directly proportional to speed; pressure is proportional to the square of the speed; and power is proportional to the cube of the speed. Theoretically, it would be possible to operate at 50% flow with only 13% of the power required at 100% flow. Since the power requirements decrease much faster than the reduction in flow, the potential exists for significant energy reduction at reduced flows.

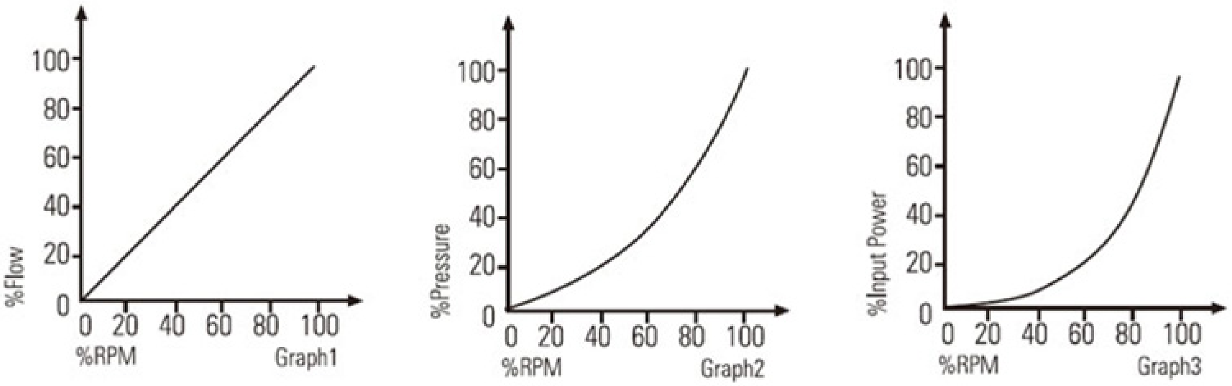


*Figure 45: Centrifugal Pump Affinity Law*

### Advantages

VFDs are an essential part of many industrial operations and provide a number of benefits that reduce the time and resources needed to perform operations, increase the safety of equipment and technicians in the area, reduce electric costs, and extend the life of motors. VFDs are basically a refinery that changes the rough AC voltage into a more stable current. By converting it to DC, it can be refined even further before being sent back out as an AC. This voltage that is sent out is square in shape rather than the traditional sinusoidal form, allowing for a gradual export of current. Some other benefits of VFDs include:

- Reduced energy consumption
- User-friendliness
- High power output
- Torque and speed control
- No soft starter for motor required

### Financial Analysis

VFDs application usually results in attractive savings in the range of 27%-49%. The investment cost varies based on the load of the equipment motor.

## 4.11. Renewable Energy Technologies

### Introduction

The Implementation of renewable energy into industries is an important strategy for reducing greenhouse gas emissions, decreasing energy costs, and increasing the sustainability of industrial operations. This integration can take various forms, depending on the specific needs and characteristics of the industrial facility.

### Application

Here are some key examples of renewable energy projects for industries:
-Solar Power: Installing photovoltaic solar panels on rooftops or open land adjacent to the industrial facility can generate electricity directly from sunlight.

- Wind Power: Wind turbines can be installed on-site to harness wind energy for electricity generation.
- Biomass: Biomass energy can be used to generate heat or electricity, using organic materials such as agricultural waste, wood, or dedicated energy crops.
- Hydropower: Hydroelectric power generates electricity by harnessing the energy from flowing water, typically through dams or water turbines. Large industries located near rivers or water bodies can integrate hydropower into their energy mix.
- Waste-to-Energy: This involves converting organic waste, such as landfill gas or sewage, into biogas or syngas, which can be used for heat or electricity generation in industries.

### Advantages

Using renewable energy in industry offers a wide range of advantages, which contribute to economic, environmental, and social sustainability. Here are some of the key benefits:

- Reduced Greenhouse Gas Emissions: One of the most significant advantages is the substantial reduction in carbon emissions. Using renewable energy sources such as wind, solar, and hydropower significantly lowers a facility's carbon footprint, contributing to global efforts to combat climate change.

- Lower Energy Costs: In many cases, renewable energy sources have lower ongoing operational costs. While the upfront costs of installing renewable energy systems can be significant, they often lead to reduced long-term energy expenses, making industries more financially stable.

- Energy Cost Predictability: Renewable energy sources, such as wind and solar, provide stable and predictable energy costs over time, reducing vulnerability to fluctuations in fossil fuel prices.

- Energy Independence: Industries that generate their own renewable energy become less reliant on external energy sources, increasing energy security and reducing the impact of energy supply disruptions.

- Diversification of Energy Sources: Using multiple renewable energy sources or a combination of renewables and conventional energy sources creates a diversified energy portfolio, reducing risk associated with dependence on a single energy source.

# 05.

# Conclusion

The provided table displays the potential savings associated with different energy efficiency measures.

*Figure 45: Centrifugal Pump Affinity Law Table 4: Energy Efficiency Measures*

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Efficient Lighting | Lighting Retrofit | Retrofit of non LED fixtures to LED | - | 50%-60% | Lighting Electrical Energy | <2 |
| Monitoring And Energy Management | Energy Metering And Control | Energy monitoring system for optimized energy utilization (Enterprise Energy Management, SCADA, etc.) | $ 10,000 - $50,000 | 5%-35% | Total Energy | 2 |
| Power Factor | Power Factor Correction | Power factor correction aims to optimize the efficiency of electrical systems by improving the relationship between real power and apparent power. | N/A | 3%-6% | Electrical Energy | N/A |
| CHP/CCHP | Combined Cooling/ Heat and Power generation | CHP involves an integrated and efficient system that combines electricity production with heat recovery. | $ 760,000 | 30-35% | Electrical Energy | <6 |
| Compressed Air System | System Optimization | Following proper maintenance practices, and properly sizing the system. In addition to implementing of good housekeeping measures | $0-$ 10,000 | Up to 10% | Electrical Energy | <2 |

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Compressed Air System | Leakage Prevention | Avoiding leakages and treatment of damaged pipes, accessories, elbows, and other leaking items that lead to wasting compressed air | $ 0 - $5,000 | Up to 5% | Electrical Energy | <1 |
| | Temperature Optimization | Relocating the air compressor or installing a piping extension that allows the inlet of outdoor air to the air compressor | $0 -$500 | 1%-3% | Electrical Energy | <1 |
| | Pressure Reduction | Reduction of set pressure to the lowest possible value. Could be applied at the point of usage or at the air compressor point | $0 | 1%-3% | Electrical Energy | 0 |
| Process Heat | Process Heat | Improving the energy efficiency of process heat systems crucial for reducing energy consumption, lowering operating costs, and minimizing environmental impact. | 0$ - N/A | 5% - 15% | Thermal Energy | <2 |
| Refrigeration | Refrigeration Free Cooler | Free Cooling is an advanced process whereby, the air blast cooler can be used to offload the chiller and provide chilled water temperatures direct onto the process system in the cooler months of the year, thereby reducing system energy usage | $2,000-$ 10,000 / Piece | 50%-70% | Electrical Energy | <1 |

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Refrigeration | Refrigeration EER Improvement | Elevating the EER of refrigeration systems in industrial applications represents a pivotal step toward minimizing energy consumption, reducing operational costs, and curbing greenhouse gas emissions. | $ 0 | 50% | Electrical Energy | - |
| Steam System | Combustion Optimization | Optimizing combustion efficiency by fuel to air ratio control and oxygen trimming, avoiding losses and reducing fuel consumption | $500-$10,000 | 2%-5% | Thermal energy | <3 |
| | Condensate Return Vented and Pressurized | through a condensate recovery system that recovers condensate from steam installations in order to maximize their overall energy efficiency | $100,000 | 3%-10% | Thermal energy | 3 |
| | Blowdown Steam Recovery | Recovering energy from blowdown steam and reducing energy losses caused by this necessary maintenance measure | $5,000 | 2% | Thermal energy | <3 |
| | Thermal Insulation | Improving insulation conditions to all steam network elements as well as boilers and hot mediums. This improvement also includes proper maintenance practices | $500-$5,000 | 1%-5% | Thermal energy | 1 |

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Steam System | Steam Traps Management | Management of steam traps including maintenance, care, cleaning, and replacement if the item is totally damaged | <$15,000 | 1%-2% | Thermal energy | <1 |
| | Steam Leakage Repair | Avoiding leakages and treatment of damaged pipes, accessories, elbows, and other leaking items that lead to wasting steam | $0-$3,000 | 5%-10% | Thermal energy | <2 |
| Heat Recovery | Economizer | Flue gas heat recovery through the use of an economizer that reuses the exhaust gas boiler that generates thermal energy for water heating | $15,000-$40,000 | 1%-5% | Thermal energy | 3 to 7 |
| | Exhaust Gas Boiler | Heat Recovery from generator exhaust connecting it to a single unit called exhaust gas boiler that generates thermal energy for water heating | $200,000-$500,000 | 5%-15% | Thermal energy | 1 to 5 |
| | Heat Exchanger - Jacket Water | Heat recovery from generator exhaust by the installation of a heat exchanger on the engines jacket water coolant to produce hot water | $20,000-$120,000 | 1-%15% | Thermal energy | 5 |

| CATEGORY | EEM | DESCRIPTION | INVESTMENT RANGE (estimation) | SAVING (%) | | PAYBACK |
|---|---|---|---|---|---|---|
| Heat Recovery | Compressed Air | Compressed air waste heat recovery involves the capture and utilization of the waste heat generated during the compression of air in industrial processes | N/A | 12% | Total Energy | N/A |
| VFDs | Installation of VFDs | installing VFDs on air compressors and centrifugal pumps which leads to reduced speed and increase in energy savings. | $10,000 - $50,000 | 27%-49% | Electrical Energy | <5 |
| Renewable Energy Technologies | Installation of Renewable Energy Sources | Implementation of renewable energy projects to reduce greenhouse gas emissions, decrease energy costs, and increase the sustainability of industrial operations. | N/A | 1%-100% | Electrical Energy | N/A |