Journal of Thermal Engineering
https://jten.yildiz.edu.tr/
https://doi.org/10.47481/jten.0068

RESEARCH ARTICLE

# Energy audits in auto ancillary industries in India: energy, economic and environmental evaluation towards sustainable industry

Hitesh R. Thakare[1,*]

[1]BEE Certified Energy Auditor (EA – 27707), Department of Mechanical Engineering, Shri Vile Parle Kelavani Mandal's Institute of Technology, Dhule, 424 001, Maharashtra, India

## Abstract

Owing to increased consumption and consequent depletion of fossil fuels, it has become imperative to use the available reserves sensibly. Such prudent use contributes to reducing greenhouse gas emissions and mitigating the intensity of the consequences of global warming. The automobile and ancillary industries are major energy consumers in India. However, there stays a significant need for awareness of prudent energy use and practical energy-saving measures in this industry. This is particularly vital for small- and medium-scale industries, which are exempt from mandatory energy audit regulations and are also distant from the appointment of a dedicated energy manager. The present work aims to bridge the gap between the availability of technical ability and the grassroots-level understanding of possible energy-saving avenues in such industries, resulting from the obstacles. The current work presents key insights obtained from plant-wide energy audit of two auto-ancillary industries: a rubber-tube manufacturing plant and a casting and machining industry, carried out by a Certified Energy Auditor in India. Unlike earlier works, this audit has helped find energy-saving potential through electricity-bill analysis, compressor speed control, insulation upgrades for steam systems, and the application of microturbines for electricity generation. The energy-saving potential was assessed through temperature measurements of steam distribution and the hot-water system, with more than 400 observations; leakage testing of the compressor system; electricity-bill analysis for both plants and a techno-economic evaluation of replacing the pressure-reducing valve with a microturbine. It's a novel study proving how energy savings in two distinct industries can be achieved despite variations in their operational characteristics and energy consumption patterns. Insulation upgrade of steam and hot water systems have savings potential of 91.94 MT fuel, 27.3 MWh electricity and 358.72 tCO2 per year. Replacement of the pressure reducing valve in RTM plant has yielded potential savings of 903.702 MWh electricity and 704.89 tCO2 per year. Arresting compressed air leakages in both the plants resulted in annual savings of 97.749 MWh and 76.24 tCO2. Total saving has been 1141 MWh electricity and 1,228.10 tCO2 per year. Notably, analysis of electricity bills has been widely used for energy conservation. This energy audit has found energy savings of 33.13% and 26.71% in the manufacturing and casting plants, respectively. This audit has helped plant management find energy-wastage hotspots and has further supported informed decision-making by prioritizing the implementation of energy-saving measures. In conclusion, energy audits have been recognized as a pragmatic tool for achieving energy conservation.

**Keywords:** Insulation, compressor, power factor, microturbine, energy audit, auto ancillary

**Cite this article as:** Thakare, H. R. (2026). Energy audits in auto ancillary industries in India: energy, economic and environmental evaluation towards sustainable industry. Journal of Thermal Engineering, 12(5), 1814–1836. https://doi.org/10.47481/jten.0068

## 1. Introduction

Over the past two decades, a steady increase in the demand for industrial products, such as automobiles, has been seen in India. This trend can be attributed to the globalization of the Indian economy, increased foreign investment, the availability of diverse car models, and accelerated industrialization. Consequently, these aspects have resulted in increased industrial energy consumption and a later spike in carbon emissions, reaching unprecedented levels. Globally, industrial sector contributes to about 40% of total energy consumed, as per the observations of Internation Energy Agency [1] and Wang et al. [2]. This proportion is expected to increase further as automobile electrification rises. All these factors are major contributors to climate change and global warming. As per recent observation of World Meteorological Organization (WMO)

*Corresponding Author
E-mail Adress: thakare.hitesh@gmail.com

**Submitted:** 16 January 2026; **Accepted:** 1 July 2026

This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkılıç

Published by Yıldız Technical University, İstanbul, Türkiye

based on the data of the past 176 years, average near-surface temperature from January to August of 2025 was reported to be 1.42°C higher than its pre-industrial age value. Such elevated temperatures increase demand for cooling (air conditioning), thereby further intensifying energy consumption. Further, it is poignant to know that about 80% of primary energy of the world is still extracted from fossil fuels, coal in particular, as per Gado et al. [3]. India is a major importer of crude oil from various regions, such as Russia and the Gulf countries. Geopolitical worldwide consistently contributes to fluctuations in crude oil prices. Pertinent to these observations, India, as a developing nation, is highly prone to two major problems, viz., volatility in energy supply and environmental pollution. This possibility is further upsetting, because 60% of primary energy consumed in India is coal-based, as per Energy Statistics of India Report [4]. Moreover, scientists have time and again warned about the devastating consequences of global warming due to greenhouse gases such as $CO_2$. Pertinently, a balanced effort is needed to achieve both aims, i.e. energy security, to ensure & drive industrial growth while curbing the elevated levels of $CO_2$ emissions. These aims can be effectively achieved through improved energy efficiency in the industrial sector. It is noteworthy that, besides reducing the $CO_2$ emissions levels & ensuring energy security, energy efficiency enhancement results in tangible economic benefits to the underlying industry through energy cost reduction, thereby improving industrial competitiveness for them in the global market as reported by Boharb et al. [5] and Oyelaran et al. [6].

Focusing on the Indian energy scenario as per the reports of Bureau of Energy Efficiency BEE [7], substantial rise in electricity demand has been seen, across all the sectors such as residential, commercial, agricultural, railways, industrial and public services. The industrial sector has consistently appeared as the largest consumer of electricity (41.80% of the total consumption), followed by the residential sector (24% of the total consumption). State-wise, Maharashtra is the second-largest consumer of electricity, with industry accounting for 42% of total electricity consumption. Particularly, Small and Medium Enterprises (SMEs), which contribute to 30.1% to the nation's Gross Domestic Product (GDP) as per Ministry of Ministry of Micro, Small and Medium Enterprises (MSME) Annual Report [8], represent a significant share of overall energy consumption. These SMEs are 2$^{nd}$ largest employers for the nation after agriculture and are predominantly affected by the volatility in energy scenario, owing to their dependence on export driven output. Such SMEs have limited pricing power, resulting in diminished profit margins during periods of high interest rates. To sustain the customer base, SMEs are compelled to adopt cost-reduction measures, including workforce reductions. Remarkably, SMEs are a very important piece of the employment puzzle in a developing nation like India, providing employment to 244 million people. In such a volatile scenario, a reduction in energy costs can substantially help such organizations reduce the cost of their products and thereby enhance profitability, without compromising their product quality despite input cost inflation.

Given its critical importance to sustainable development and industrial competitiveness, energy efficiency has been a pivotal topic in many scientific studies. Prominent among such studies that have proved the systematic evaluation of energy aspects in various industries have been reviewed and discussed here to inform further deliberation. Kannan and Boie [9] analyzed the energy scenario of a SME German bakery. Their study emphasized clear preparation of a baking plan to ensure proper loading of the ovens. This measure showed an estimated savings potential of 5%, equivalent to 4200 kWh of electricity and 2500 liters of oil. Preheating of combustion air and the generation of hot water from flue gases were also suggested. Biswas et al. [10] assessed the energy conservation opportunities in sponge iron plants through detailed temperature measurements and process analysis. For a plant with a production capacity of 100 tons per day, a replacement of the kiln's mechanical seal with air-ring sealing was suggested, thereby saving 10 kW of energy per unit area. Perfecting the coal injection facility was expected to yield a saving of 12.5 kW and after reducing the Induced Draft (ID) fan energy consumption by 50 kW. Engin and Ari [11] carried out energy audit of a cement manufacturing plant in Turkey. They reported that approximately 40% of heat was lost through flue gases. The authors reported an energy-saving potential of 2263 kW by using a waste-heat-recovery steam generator running on flue gases. Energy audit of a cement plant conducted by Thirugnanasambandam et al. [12] revealed operation of motors in underloaded condition and suggested the installation of Variable Frequency Drives (VFD). However, financial analysis showed that the installation of capacitors for power factor improvement was not possible. Ghalandari et al. [13] saw that 48% of input heat for the clinker formation in a cement processing plant was lost through radiation, convection and exhaust gases. The authors evaluated the waste-heat recovery potential of 5.2 MWh, with a payback period of 6.7 years. Kaya and Eyidogan [14] carried out detailed flue-gas analysis of an industrial boiler system. Authors reported an energy conservation potential of 1,333.74 kW from avoiding excess air leakage, 742 kW from reducing excess air quantity, 1,576 kW from running the boiler at full load, and 620 kW from reducing flue gas temperature. The audit conducted by Dongellini et al. [15] in a car manufacturing unit in Italy estimated a saving potential of 15% in gas consumption, amounting to about 100,000 € per year.

The study of May et al. [16] used a fishbone diagram and a systematic approach to develop a 7-step method for industry specific performance indicators. These indicator values are not affected by changes in market demand but are influenced by variations in the product mix. Neri et al. [17] carried out energy and exergy analysis of an aluminum casting plant and found that melting furnaces had highest energy consumption. Increasing the inlet temperature to 379 K was estimated to improve the energy and exergy efficiencies by up to 36% and 20%, respectively. The analysis performed by Selim et al. [18] for 20 different industrial sectors in USA resulted in reduction of 100,000 tons of $CO_2$ emissions. The authors focused on various energy-saving avenues, such as electrical demand management, waste management, heat recovery systems, lighting systems, electric motors, and the building envelope. The Cumulative Sum (CUSUM) technique was used by Giacone et al. [19] to analyses and correlate the production output and energy consumption in small and medium sized enterprises. The method successfully tracked changes in energy consumption patterns because of structural changes such as building extensions, the operation of air-conditioning systems, and the operation of new machining systems. The analysis carried out by Kadric et al. [20] found energy saving potential in steam generation system of a bakery. The four energy-saving measures suggested in the areas of boiler replacement and steam distribution system upgrades proved potential energy savings of 6.14%. Thakare and Daspute [21] provided a comprehensive assessment of energy saving avenues in a cold-fired thermal power plant. Their energy audit resulted in an annual savings potential of 12 million kWh of electricity and 25,832 MT of fuel. This also helped in mitigation of 104,243 $tCO_2$/year.

The study by Catrini et al. [22] developed a bottom-up method for generation of cooling load profiles of wine industry. This is particularly important considering the effect of seasonal variation on energy consumption in cooling technologies. The standard seasonal indicators overestimated the energy savings by 56.85% and 83.87% for low- and medium-temperature systems, respectively. Gurturk et al. [23] carried out energy and exergy analysis of a furnace in a plaster plant. The authors calculated the sustainability index as the inverse of the ratio of exergy destroyed to input exergy. The insulation upgrade of the system showed an energy-saving potential of 400 kW. The authors also reported that the excess air coefficient was 1.94, which is higher than the recommended range of 1.05 to 1.1. Kong et al. [24] carried out energy audit of a paper mill and found energy saving potential of 967.8 TJ, which is 14.4% of the total energy consumption of the plant. This also represented reduction of 93,453 tons of $CO_2$ emissions. The Authors suggested energy-saving measures such as retrofitting low-efficiency boilers, implementing anaerobic wastewater treatment, reusing sludge as boiler fuel, and recovering waste heat, among others. Karki and Rao [25] analyzed the effect of water efficiency practices on energy and greenhouse gas emissions in the manufacturing sector of the United States. The authors compiled 75 water-efficiency measures related to cooling towers, boilers, water leaks, etc. The largest savings potential was seen in the paper manufacturing, petroleum, chemical, and primary metals industries. Siddique et al. [26] found various barriers implementing energy management practices in Bangladesh. Most difficulties were met with compressed air systems and Heating, Ventilation and Air Conditioning (HVAC) systems, while they were comparatively lower for electric motors and pumps. Sasanya and Olaifa [27] carried out energy audit of 03 commercial poultry farms in Nigeria. The authors quantified the percentage contributions of various energy streams and recommended recycling poultry waste generated on the farms back into the system to improve sustainability. Momani et al. [28] analyzed a food production industry, finding 18% saving in diesel consumption, accompanied by replacement of old inefficient motors with energy efficient motors. Bosu et al. [29] has audited a SME in Egypt and found energy saving in various areas such as fork-lift, fans, lights and compressors. Moya et al. [30] saw that energy is often regarded as an added expense in industries. Many industries lack knowledge and technical capacity to implement energy management programs and have limited awareness of the benefits of energy audits.

McLaughlin et al. [31] assessed industrial combustion systems for improving their energy efficiency. Authors provide a technical and economic evaluation for various measures, such as trimming boiler excess air, installing burners equipped with variable frequency drives, installing automatic blowdown controls, and converting gas burners to oxy-fuel combustion. This study resulted in identification of saving potential of $185 million in energy costs as well as abatement of 2.3 million metric tons of $CO_2$ emissions, along with possibility of creating 972 jobs. To help the industries to avail the services of Energy Services Companies (ESCOs) in a prudent manner, Cagno et al. [32] provided a characterization framework. The proposed framework was tested on a sample of 8 Italian ESCOs to assess its usefulness. The framework not only adequately mapped the clusters of services, technologies, and markets addressed by ESCOs, but also found future business prospects for ESCOs. A novel characterization framework was also proposed by Hasan et al. [33] to help industrial decision makers during evaluation of energy management services. The framework was confirmed through surveys and interviews with industry experts. A remarkable study conducted by Abdel-Hadi et al. [34] provided analysis of various energy saving aspects such as HVAC systems, lighting, compressors and electric motors, in more than 61 SMEs. The results showed the highest energy-saving potential in the fabricated metal and food-processing industries. Among the energy consumption segments, the HVAC section proved the highest energy-saving potential (44%), while the second-highest savings were obtained in waste heat recovery (21%). The effects and benefits of energy audit are not limited to improved energy efficiency only, but extend to wider arenas such as improvement in staff behavior, development of essential awareness, change in attitude towards energy utilization habits and amendment in process routines, aiding the energy conservation, as per the observations of Kanchiralla et al. [35].

Energy audit can also be effectively used for meeting sustainable development goals as well as benchmarking the performance of an organization with reference to KPIs, as put forth by Kamran et al [36]. Taheri et al. [37] followed a novel approach wherein software was used to simulate the energy scenario of an office building. The software helped find 53.77% energy savings and 21.84% CO2 emission reductions through improvements in Air Handling Units (AHUs), HVAC systems, and other components. Alamin et al. [38] conducted an energy audit of an educational building and proposed a 41% reduction in annual energy consumption. Abd et al. [39] found energy saving opportunities in a wood manufacturing plant in Morocco. The power factor of the plant was proposed to be improved from present value of 0.6 to proposed value of 0.96, prospecting the saving of 403.26 MWh and abatement of 220.58 $tCO_2$. Savings found on the lighting system were 56.79 MWh & 31.06 $tCO_2$. Motion detectors for lighting had saving potential of 1.99 MWh and 1.09 $tCO_2$. Luo et al. [40] found an energy-saving potential of 125 KW in a comprehensive study. This initiative showed a modest payback period of 1.9 years along with estimated $CO_2$ reduction of 35 tons per year. Kassas et al. [41] found energy savings in air conditioning through the application of a VFD, with estimated annual savings of 4,481.484 kWh and a payback period of 6 years and 6 months. Zhu et al. [42] focused on demand side management, thereby augmenting the carbon neutrality. This resulted in electricity savings of 15.1%. These studies have been summarized in Table 1 to enhance readability and comprehension for the intended audience.

**Table 1.** Summary of important research carried out on energy audit

| Sr. No. | Focus Industry/System | Areas found for energy efficiency improvement |
|---|---|---|
| 1. | SME Bakery [9] [20] | • Preheating of combustion air<br>• hot water generation<br>• boiler replacement |
| 2. | Sponge iron plant [10] | • Replacement of mechanical seal of the kiln<br>• Optimization of coal injection facility<br>• ID fan |
| 3. | Cement [11] [12] [13] | • Flue gas loss reduction<br>• waste heat recovery steam generator |
| 4. | Boiler system [14] | • Leakage losses of air<br>• excess air reduction<br>• boiler load optimization |
| 5. | Car manufacturing [15] | • Perfecting the HVAC system |
| 6. | Aluminum casting [17] | • Increase in inlet temperature to furnace |
| 7. | Wine [22] | • Replacement of old inefficient chillers with efficient ones, |
| 8. | Furnace [23] | • Insulation upgrade<br>• reducing excess air for combustion |
| 9. | Paper [24] | • Retrofitting old low efficiency boilers<br>• Reuse of industrial sludge as boiler fuel<br>• waste heat recovery |
| 10. | Paper, petroleum, chemicals, primary metal [25] | • Analysis of water efficiency in relation with energy |
| 11. | Food industry [28] [35] | • Old motors replaced by energy efficient motors<br>• change in behavior and attitude of staff |
| 12. | SME [29] [34] | • Thermal insulation for heating systems<br>• Compressors<br>• Forklift electrification. |
| 13. | Office building [37] [38] | • Use of simulation software<br>• improvement in AHU, HVAC system |
| 14. | Wood manufacturing [39] | • Power factor<br>• lighting system<br>• motion sensors |

## 1.1. Gaps found in the published literature & aims of present study

This comprehensive review clearly finds the following key research gaps in energy audit and management research.

a. Published data about Energy Conservation Measures (ECMs) in SMEs stays scarce, except for some notable works [9,20,29,34], with prominent focus on large-scale industries.
b. A detailed analysis of energy-saving potential in steam systems through insulation upgrades has seldom been reported.
c. Comprehensive techno–economic evaluation of VFD application in compressor stays unexplored.
d. Analysis of the replacement of the Pressure Reducing Valve (PRV) with a microturbine in steam systems has received limited attention.
e. Use of electricity bill analysis as a tool for finding energy savings has not been reported.

As pointed out by [9], SMEs face significant difficulties and lack of motivation for energy assessment, which have been addressed in the present work, such as,

- resentment among the plant operators towards energy audit due to lack of training/awareness
- limited availability of technical manpower, capable of analyzing the diversified energy consumption.
- financial constraints restricting the appointment of dedicated energy managers towards implementation of energy conservation initiatives.
- Absence statutory/regulatory obligation for conducting energy audit of the facility

Thus, the novel contribution of this paper can be summarized as follows:

- Clear description and methodical assessment of ECMs to ease understanding by all plant personnel.
- Demonstration of a novel framework for using the electricity bill analysis of the organization for energy saving and economic benefit.
- Providing a novel technical, energy and economic assessment for replacement of PRV in steam generation with microturbine.
- Emphasis on low-cost and no-cost ECMs to ease decision-making and prioritization for implementation.
- Identification and analysis of ECMs across both thermal and electrical energy domains.
- Evaluation of $CO_2$ abatement potential to aid the industrial sustainability efforts.

This manuscript is structured as follows: Section 1 describes the necessity of an energy audit in the context of Indian SMEs and their role in improving competitive position through cost reduction. Subsequently, a systematic review of essential published work in the domain of energy audit was presented. Consequently, gaps found in the literature review have been presented. Section 2 provides a detailed description of both the industrial sites analyzed in the present study, with a primary focus on outlining the core manufacturing processes and pertinent energy interactions. Section 3 describes the steps taken in the present energy audit. Section 4 presents the detailed technical specifications of the measuring instruments used in the study. Section 5 provides detailed calculations and a discussion of the results for the computation of ECM, as well as a monetary analysis of the necessary investment and the payback period. Section 6 presents an Executive Summary of energy-saving avenues intended to help plant management prioritize the implementation of ECMs. Section 7 presents the concluding remarks.

## 2. Description of industrial sites

### 2.1. Rubber Tube Manufacturing (RTM) Plant

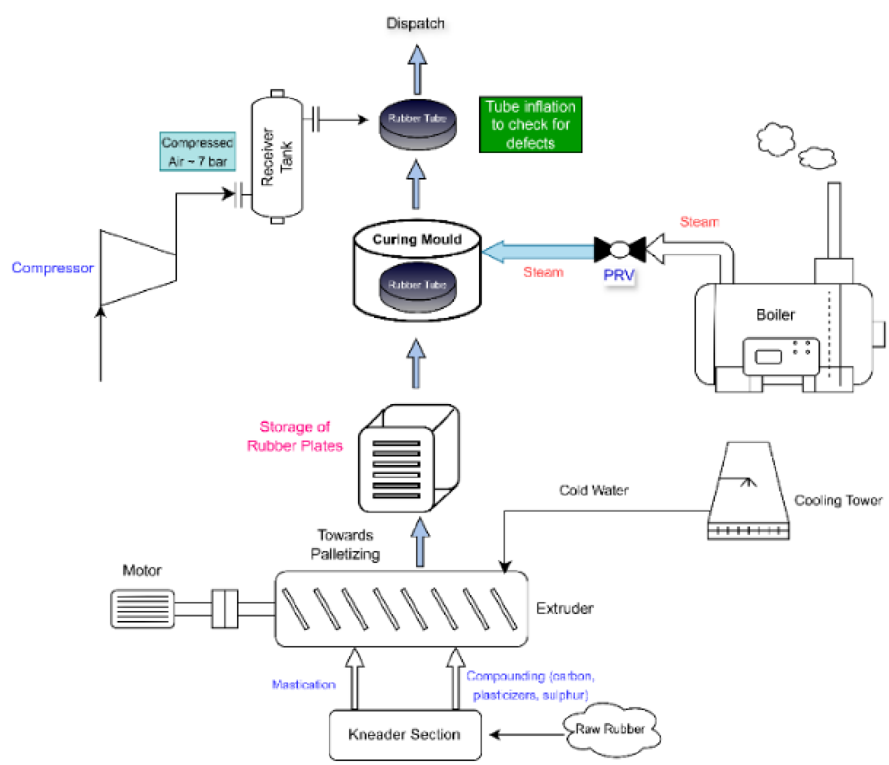


**Figure 1.** Process flow of Rubber Tube Manufacturing (RTM) plant

The first industry under consideration is a rubber tube manufacturing (RTM) plant found in MIDC, Nashik, Maharashtra that supplies its final product to a renowned tyre manufacturer in India. The process layout of the RTM plant is shown in Figure 1. The plant has important utility equipment, such as a boiler, boiler-feedwater pumps, a compressor, a cooling tower, steam distribution piping, and an electrical-energy distribution network. Raw rubber is fed into a kneader, where it undergoes mastication and compounding through the addition of carbon, plasticizers, and sulphur. This process is essential to enhance the plasticity of rubber so that it can be shaped into tubes of the desired size. This is followed by extrusion, during which a rubber billet is produced. The extruded rubber is supplied with cold water from the cooling tower to keep its temperature. These billets are converted into rubber tubes in the curing mould. Steam is produced in a boiler with a capacity of 3 TPH at a generation pressure of 10 bars. The generated steam is passed through the PRV, reducing its pressure to 3 bars. Then, steam is supplied to the curing mould at 3 bar pressure for about 240 seconds. After the curing operation, the rubber tube is removed from the mould and then inflated with compressed air at 6 bar to check for any manufacturing defects, such as leaks. Once the quality of the rubber tube has been ensured, it is dispatched to the customer. The plant runs 24 hours per day in three shifts, with Saturday as the weekly day off. The operational characteristics of the plant result in substantial electrical and thermal energy consumption. The plant management looked to improve its competitive position in the market through tangible savings achieved by virtue of a techno-economic analysis of energy-saving avenues.

### 2.2. Casting Machining Industry (CMI) plant

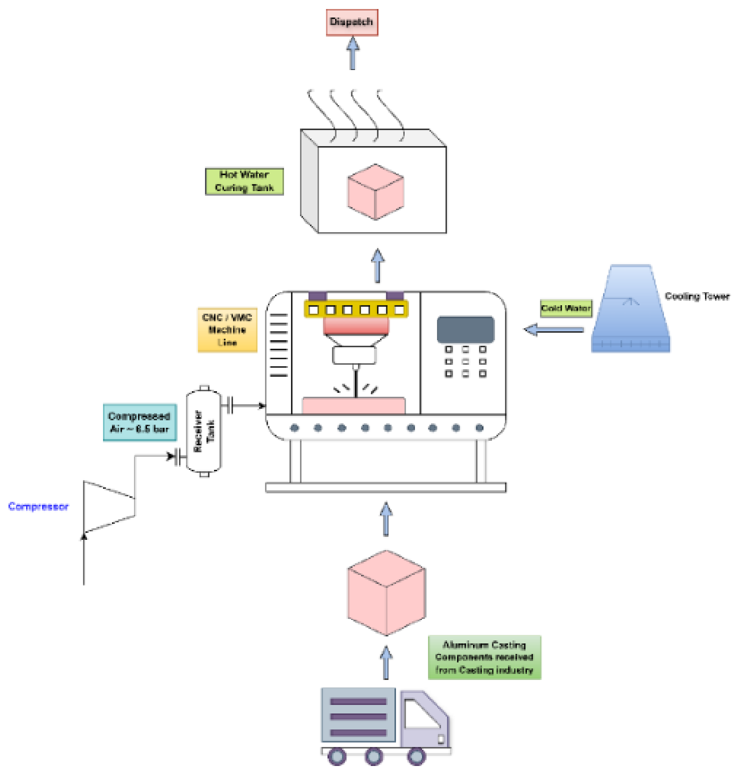


**Figure 2.** Process flow of Casting Machining Industry (CMI) plant

The second audited industry is an aluminum casting and machining industry (CMI) engaged in machining automobile components. The process layout of the CMI plant is shown in Figure 2. The CMI plant is divided into two distinct sections. The first performs the machining operations, while the second performs curing operations. This section receives cast automobile components from a casting facility found 1.5 KM away in MIDC Malegaon, Sinnar, Nashik, and delivers the final machine components to an automobile assembly line in Pune. After machining is completed, it undergoes curing in a hot-water tank. CMI primarily uses electrical energy to run equipment such as Vertical Machining Centers (VMCs), cooling towers, and compressors. A noteworthy observation during the walkthrough audit was that CMI used compressed air at an unnecessarily high operating pressure. Key details pertinent to the energy scenario of both industries are summarized in Table 2.

**Table 2.** Essential operational characteristics of both industrial sites

| Sr. No. | Particular | Value for RTM Plant | Value for CMI Plant |
|---|---|---|---|
| 1. | Type of industry | Rubber tube manufacturing (RTM) plant | Aluminum Casting components Machining Industry (CMI) Plant |
| 2. | Important equipment | Boiler, compressor, cooling tower, steam distribution piping and electrical energy distribution network | VMCs, compressors, cooling tower, curing tank |
| 3. | Essential utilities of the plant's manufacturing system | • Steam<br>• Electricity<br>• Compressed air<br>• Chilled water | • Electricity<br>• Compressed air<br>• Cold water<br>• Hot water |

| | | | |
|---|---|---|---|
| 4. | Source of electricity | Maharashtra State Electricity Distribution Company Ltd. (MSEDCL) | |
| 5. | Source of thermal energy | Coal, wood and briquettes | None |
| 6. | Annual consumption | 2,531,361 kWh | 344,225 kWh |
| 7. | Operating hours/year | 24 | 24 |
| 8. | Operating days/year | 300 | 300 |
| 9. | Present ECMs already implemented | APFC installed along with capacitor bank to keep unity Power Factor (PF). | LED lamps installed in the plant |

Such SMEs provide employment to several people in the vicinity who are from the lower strata of society. Thus, helping this organization achieve energy and monetary savings ultimately provides support to this workforce.

## 3. Energy audit method

The following method was adopted for the present energy audit.

1. A formal meeting with plant personnel was held to raise awareness of energy audits and conservation. This helped the team foster cooperation and obtain essential data on the plant's operational characteristics.
2. Subsequently, measurements of the steam distribution system were undertaken to evaluate the potential for energy savings from insulation.
3. Electrical systems are characterized by the presence of resistive and inductive loads. The combined effect of the monthly operation of all such loads in a plant is reflected in the monthly electricity bill received from MSEDCL. Hence, the analysis of electrical systems began with analysis of the electrical bills themselves.
4. Thereafter, the compressed air generation and distribution system was analyzed.
5. Further, lighting system parameters were measured and recorded.
6. This was followed by detailed measurements and analysis of the PRV system installed on the steam distribution line in the boiler house. Observations and measurements were undertaken based on instantaneous operating conditions and were supplemented by discussions with plant personnel during the audit.

## 4. Instrumentation used for energy audit

Several measuring instruments were used during the present energy audit study, as shown in Table 3, which provides essential details.

**Table 3.** Essential details of measuring instruments used during present energy audit

| Instrument | Make & model | Range | Accuracy | Uncertainty |
|---|---|---|---|---|
| Infrared thermometer | Kusam – Meco IRT550T | -50°C to 550°C | 0.1°C | ±2% |
| Laser distance meter | BOSCH | 100 m | ± 1.5 mm | ± 0.2° |
| Lux meter | Kusam – Meco KM-LUX-200K | 200, 2,000, 20,000, 200,000 Lux. (4 Ranges) | ± 3%rdg | ± 0.5% f.s |
| Clamp meter | Kusam – Meco 2736 | 40.0 A<br>600 V | ± (1.0%rdg + 5dgts)<br>± (0.5%rdg + 5dgts) | ±1% |
| Sling psychrometer | ZEAL, London | -5 to +50°C | 0.5°C | 0.5°C |

## 5. Results and discussion

This section provides succinct details about energy assessment and subsequent financial analysis of ECMs. The ECMs pertain to thermal and electrical energy.

### 5.1. Energy conservation through insulation upgrade

#### 5.1.2. Energy conservation in insulation of steam distribution system of RTM

In the RTM plant, steam produced in the boiler is transported to the curing section through steam distribution pipes. These pipes were seen to be insulated; however, their surface temperatures remained on the higher side, as shown in Figure 3. Elevated temperatures were also seen on boiler surfaces and doors. To evaluate the energy-saving potential of the steam distribution system, the temperature, length, and outer diameter of steam distribution pipes were measured at several locations. In total, more than 400 observations about various insulation parameters were recorded, as summarized in Table 4.

Energy saving by application of insulation on a surface is quantified as per BEE guidelines [43]

Surface heat loss (S) is calculated as

$$S = \left(10 + \frac{Ts - Ta}{20}\right) \times (Ts - Ta) \tag{1}$$

Where, Ts is the surface temperature while Ta is the ambient temperature.

Total heat loss per hour (Hs) from uninsulated surface having surface area A is calculated as,

$$Hs = S \times A \tag{2}$$

Equivalent fuel loss ($H_f$) is calculated as,

$$\text{Equivalent fuel loss}\,(H_f)(kg/yr) = \frac{H_s \times \text{Yearly hours of operation}}{GCV \times \eta_{boiler}} \tag{3}$$

Here, GCV is Gross Calorific Value of the fuel, $\eta_{boiler}$ is the boiler efficiency.

$$\text{Annual heat loss in monetary terms}\,(Rs.) = H_f \times \text{Fuel Cost}\,(Rs./kg) \tag{4}$$

**Figure 3.** Surface temperature of steam distribution pipes in RTM plants at various locations

The Techno–economic evaluation of this ECM, presented in Table 5, shows an annual fuel loss of 119.88 tons due to damage to the existing insulation of the steam distribution system of RTM. After the insulation upgrade, the annual fuel loss will be reduced to 91.94 Tons; this will require an investment of Rs. 32,865/-. The payback period for this investment is modest, i.e., only 1.07 months. Moreover, the service life of the insulation is approximately 3 years. Thus, this ECM is beneficial from both economic and energy conservation perspectives. To help the plant management obtain a section-wise assessment and thereby prioritize the insulation upgrade, Figure 4 depicts heat loss and fuel savings. Heat loss cannot be eliminated in any section of the system. However, it will be reduced substantially due to an insulation upgrade. Figure 4 shows that the greatest savings can be achieved in steam piping outside the boiler house; this category also includes thermal losses associated with the steam pipeline supplying the rubber-tube curing line.

**Table 4.** Observations of steam distribution system recorded in the CMI plant

| Sr. No. | Component/ Location | Ts (°C) | Shape | Dimensions Length / dia. (m) | Width (m) | t (m) | Area (m²) | Heat Loss without insulation, kCal/hr/m² | Op. Hrs | Total Heat loss kCal/day | Fuel loss per day (kg) | Heat loss With insulation, kCal/hr/m² | Heat loss With insulation kCal/day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Boiler house - Observations near PRV section** | | | | | | | | | | | | | |
| 1 | Flange to right of PRV | 180.8 | Circular | 0.16 | | 0.05 | 0.045239 | 2,610.02 | 24 | 2,833.79 | 0.94 | 145.248 | 473.10 |
| 2 | Flange on top of PRV (consider top and 4 side area) | 133.1 | Square | 0.15 | 0.15 | 0.06 | 0.0585 | 1,534.14 | 24 | 2,153.94 | 0.72 | 145.248 | 611.78 |
| 3 | Flange at bottom of PRV | 133.1 | Circular | 0.26 | | 0.08 | 0.118438 | 1,534.14 | 24 | 4,360.84 | 1.45 | 145.248 | 1,238.61 |
| 4 | PRV Main Globe | 193.6 | Spherical | 0.16 | | | 0.080425 | 2,937.44 | 24 | 5,669.85 | 1.89 | 145.248 | 841.07 |
| 5 | Flange to left of PRV | 178.9 | Circular | 0.16 | | 0.05 | 0.045239 | 2,562.81 | 24 | 2,782.54 | 0.93 | 145.248 | 473.10 |
| 6 | Pipe for PRV Connection | 191.55 | Cylindrical | 0.08 | 0.55 | | 0.13823 | 2,883.90 | 24 | 9,567.43 | 3.19 | 145.248 | 1,445.59 |
| 7 | Safety valve flange | 177.6 | Circular | 0.16 | | 0.05 | 0.045239 | 2,530.72 | 24 | 2,747.70 | 0.92 | 145.248 | 473.10 |
| 8 | Safety valve connection pipe | 179.6 | Cylindrical | 0.08 | 0.3 | | 0.075398 | 2,580.16 | 24 | 4,668.96 | 1.56 | 145.248 | 788.51 |
| 9 | Flange 1 below safety valve | 170.9 | Circular | 0.12 | | 0.05 | 0.030159 | 2,368.01 | 24 | 1,714.03 | 0.57 | 145.248 | 315.40 |
| 10 | Flange 2 below safety valve | 160.3 | Circular | 0.12 | | 0.05 | 0.030159 | 2,119.76 | 24 | 1,534.33 | 0.51 | 145.248 | 315.40 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **11** | length of bare pipe, for flange below safety valve | 165.6 | Cylindrical | 0.05 | 0.3 | | 0.047124 | 2,242.48 | 24 | 2,536.19 | 0.85 | 145.248 | 492.82 |
| **13** | 03 Flanges below PRV near ground | 167.2 | Circular | 0.13 | | 0.05 | 0.101081 | 2,280.08 | 24 | 5,531.35 | 1.84 | 145.248 | 1,057.09 |
| **14** | Globe valve for 03 flanges near ground | 167.2 | Spherical | 0.13 | | | 0.053093 | 2,280.08 | 24 | 2,905.36 | 0.97 | 145.248 | 555.24 |
| **15** | Flange below steam header | 123.65 | Circular | 0.16 | | 0.04 | 0.040212 | 1,348.00 | 24 | 1,300.96 | 0.43 | 145.248 | 420.54 |
| **16** | Enlarged pipe section below flange (below steam header) | 105.1 | Cylindrical | 0.12 | 0.22 | | 0.082938 | 1,008.58 | 24 | 2,007.61 | 0.67 | 145.248 | 867.36 |
| **17** | 02 Flanges on extreme right of PRV | 173.1 | Circular | 0.12 | | 0.04 | 0.052779 | 2,420.94 | 24 | 3,066.59 | 1.02 | 145.248 | 551.95 |
| **18** | flange below insulation near PRV | 187.7 | Circular | 0.2 | | 0.05 | 0.062832 | 2,784.48 | 24 | 4,198.91 | 1.40 | 145.248 | 657.09 |
| **Piping outside boiler house** | | | | | | | | | | | | | |
| **1** | Pipe 1 on left side (half inch dia.) | 142.5 | Cylindrical | 0.0127 | 0.75 | | 0.029924 | 1,728.16 | 24 | 1,241.11 | 0.41 | 145.248 | 312.94 |
| | Flange on pipe 1 | 168 | Circular | 0.12 | 0.04 | | 0.01131 | 2,298.98 | 24 | 624.02 | 0.21 | 145.248 | 118.28 |
| **2** | Pipe 2 in middle (1/2 in. dia.) | 157 | Cylindrical | 0.0127 | 0.75 | | 0.029924 | 2,044.77 | 24 | 1,468.49 | 0.49 | 145.248 | 312.94 |
| **3** | Pipe 3 on right (half inch dia.) | 60 | Cylindrical | 0.0127 | 0.6 | | 0.023939 | 326.90 | 24 | 187.81 | 0.06 | 145.248 | 250.35 |
| **4** | Header below pipes | 113.8 | Cylindrical | 0.07 | 0.5 | | 0.109956 | 1,163.49 | 24 | 3,070.38 | 1.02 | 145.248 | 1,149.90 |
| **5** | Steam pipe for curing line | 157.4 | Cylindrical | 0.0762 | 70 | | 16.75729 | 2,053.80 | 24 | 825,987.15 | 275.33 | 145.248 | 175,245.37 |
| **6** | Feed tank connecting pipe 1 | 105.4 | Cylindrical | 0.06 | 12 | | 2.261952 | 1,013.80 | 24 | 55,036.01 | 18.35 | 145.248 | 23,655.17 |
| **Boiler surface observations** | | | | | | | | | | | | | |
| **1** | Flange for boiler cleaning (left side from front) | 118.8 | Circular | 0.16 | | 0.05 | 0.045239 | 1,255.94 | 24 | 1,363.62 | 0.45 | 145.248 | 473.10 |
| **2** | Backdoor of boiler | 179 | Rectangular | 0.52 | 0.41 | | 0.2132 | 2,565.29 | 24 | 13,126.07 | 4.38 | 145.248 | 2,229.61 |
| **3** | Boiler blows down header 1 (left side) | | | | | | | | | | | | 0.00 |
| | Right side face | 79.2 | Rectangular | 0.5 | 0.33 | | 0.165 | 592.24 | 24 | 2,345.28 | 0.78 | 145.248 | 1,725.55 |
| | Left side face | 95 | Rectangular | 0.5 | 0.33 | | 0.165 | 838.25 | 24 | 3,319.46 | 1.11 | 145.248 | 1,725.55 |
| | Top face | 97 | Rectangular | 0.5 | 0.33 | | 0.165 | 871.17 | 24 | 3,449.83 | 1.15 | 145.248 | 1,725.55 |
| | Bottom face | 70.4 | Rectangular | 0.5 | 0.33 | | 0.165 | 466.05 | 24 | 1,845.56 | 0.62 | 145.248 | 1,725.55 |
| **4** | Boiler blowdown header 2 (Right side) | | | | | | | | | | | | 0.00 |
| | Right side face | 87 | Rectangular | 0.5 | 0.33 | | 0.165 | 710.57 | 24 | 2,813.85 | 0.94 | 145.248 | 1,725.55 |
| | Left side face | 82.3 | Rectangular | 0.5 | 0.33 | | 0.165 | 638.54 | 24 | 2,528.62 | 0.84 | 145.248 | 1,725.55 |
| | Top face | 94.6 | Rectangular | 0.5 | 0.33 | | 0.165 | 831.71 | 24 | 3,293.58 | 1.10 | 145.248 | 1,725.55 |
| | Bottom face | 68.5 | Rectangular | 0.5 | 0.33 | | 0.165 | 439.82 | 24 | 1,741.69 | 0.58 | 145.248 | 1,725.55 |
| | Total | | | | | | 21.91 | 57,865.22 | | 983,022.89 | 327.67 | 4,938.43 | 229,129.80 |

**Table 5.** Techno – economic evaluation of insulation of steam distribution system

| Description | Value | Unit |
|---|---|---|
| Fuel lost per day due to absence of insulation | 327.67 | Kg/ Day |
| Considering boiler efficiency = 82 % | 399.60 | Kg/ Day |
| Fuel loss due to damaged insulation 300 working days/year | 119,880 | Kg/ Year |
| Fuel loss due to damaged insulation 300 working days/year | 119.88 | Tons/ Year |
| Fuel price per kg | 4.00 | Rs. /Kg |
| Money lost per day | 1,598.41 | Rs. /Day |
| Money lost per year @ 300 working days/year | 479,523.36 | Rs. /Year |

| | | |
|---|---|---|
| Fuel lost per day after insulation | 76.38 | Kg/ Day |
| Considering boiler efficiency = 82 % | 93.14 | Kg/ Day |
| Fuel saved due to insulation | 306.46 | Kg/ Day |
| Fuel saved due to insulation 300 working days/year | 91,938 | Kg/ Year |
| Fuel saved due to insulation 300 working days/year | 91.94 | Tons/ Year |
| Fuel price per kg | 4.00 | Rs. / Kg |
| Money lost per day | 372.57 | Rs. / Day |
| Money lost per year @ 300 working days/year | 111,770.63 | Rs. / Year |
| Money saved per year | 367,752.73 | Rs. / Year |
| % saving in fuel | 76.69 | % |
| Area of steam system to be insulated | 21.91 | $m^2$ |
| Cost of insulation per unit area (Including labour and cladding charges) | 1,500 | Rs. /$m^2$ |
| Total investment required | 32,865 | Rs. |
| Payback period | 1.07 | Months |

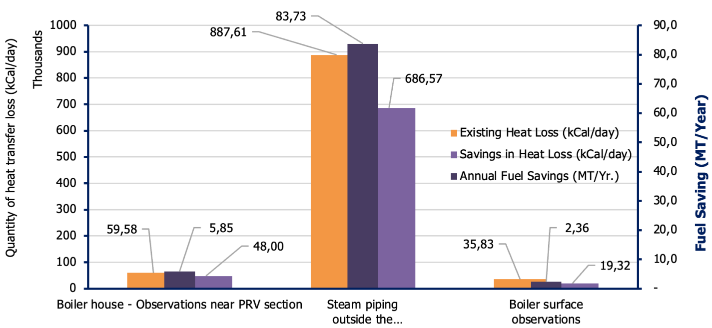


**Figure 4.** Savings on heat lons and fuel consumption due to insulation upgrade for various sections

### 5.1.2. Energy conservation through insulation of curing tank of CMI

In CMI, a hot water tank is used for curing the machined and anodized parts. This hot water is generated at 92°C through electrical heaters installed in the tank. Machine parts are loaded into a bucket and immersed in the hot-water tank, as shown in Figure 5.

**Figure 5.** Photo of hot water curing tank in CMI plant

**Table 6.** Techno – economic evaluation of insulation of hot water curing tank

| Description | Value | Unit |
|---|---|---|
| Without insulation | | |
| Dimensions of the tank | | |
| Length x Width x Height | 1.5 x 1.5 x 1.8 | m |
| Electrical heater efficiency | 100 | % |
| Height | 1.8 | m |
| Total surface area of tank exposed to atmosphere | 13.05 | $m^2$ |
| Average surface temperature of hot water curing tank | 65 | °C |
| Average ambient temperature | 30 | °C |
| Heat loss from uninsulated heated surface | 411.25 | KCal/ hr.$m^2$ |
| Total Heat loss from tank per day | 128,803.5 | KCal/ Day |
| Total Heat loss from tank per year 300 working days/year | 38,641,050 | KCal/ Year |
| Electrical energy loss due from tank 300 working days/year | 44,931.45 | kWh/ Year |
| Electricity rate from bill analysis | 8.25 | Rs. / kWh |
| Monetary loss due to absence of insulation | 370,684.46 | Rs. / Year |
| With insulation | | |
| Surface temperature after insulation | 45 | °C |

| | | |
|---|---|---|
| Heat loss from insulated tank surface | 161.25 | KCal/ hr.m$^2$ |
| Total Heat loss from tank per day | 50,503.5 | KCal/ Day |
| Total Heat loss from tank per year 300 working days/year | 15,151,050 | KCal/ Year |
| Electrical energy loss due from tank 300 working days/year | 17,617.5 | kWh/ Year |
| Monetary loss after application of insulation | 145,344.37 | Rs. / Year |
| Energy saved due to insulation | 27,313.95 | kWh/ Year |
| Economics | | |
| Monetary saving due to insulation | 225,340.09 | Rs. / Year |
| Rate of insulation per unit area (Including labour and cladding charges) | 1,500 | Rs. /m$^2$ |
| Investment required for insulation material | 19,575~20,000 | Rs. |
| Added cost of performance and guarantee from supplier | 5,000 | Rs. |
| Total Investment needed | 25,000 | Rs. |
| Payback period | 0.1109 | Year |
| | 1.33~2 | Months |

It was seen that heat loss occurred from the external hot surface of this tank due to the absence of insulation and direct exposure to the atmosphere. Hence, it is suggested that this tank be properly insulated, given its continuous 24-hour operation. The techno-economic evaluation of this ECM, presented in Table 6, shows that the energy loss due to the absence of insulation can be reduced from 44,931.45 kWh/year to 17,617.5 kWh/year, resulting in annual savings of 27,313.95 kWh. Furthermore, this ECM will help keep stricter process control by reducing temperature fluctuations within the curing tank and preventing corrosion of the curing tank's outer surface.

## 5.2. Energy conservation in steam system through replacement of PRV with microturbine in RTM plant

**Figure 6.** PRV installed in RTM plant for pressure reduction of steam

Presently, RTM plants produce steam at a pressure of 10 kg/cm$^2$. However, the operating pressure for steam supplied to the rubber tube curing mould is 3 kg/cm$^2$. To achieve this pressure reduction, plant management has installed a Pressure Reducing Valve (PRV) as shown in Figure 6. This PRV is of the SPIRAX DP – 143 model, temperature range of up to 300$^o$C and working pressure of up to 26 kg/cm$^2$. The existing PRV serves no function other than reducing steam pressure. Hence, it is suggested that this PRV be replaced with a microturbine-based pressure-reduction system. Such a system would not only reduce steam pressure but also generate electricity through recovery of pressure energy. This will help the plant reduce its dependence on grid electricity and lower the overall electrical demand. The assessment process is as follows:

Fuel consumption with PRV operation is given as,

$$(m_f)_{PRV} = \frac{(m_{f1})_{Steam} \times (h_{steam} - h_{water})}{\eta_{boiler} \times GCV} \tag{5}$$

Where, $m_f$ shows flow rate for respective fluid stream, h shows enthalpy of fluid.

Fuel consumption with microturbine operation is given as,

$$(m_f)_{Turbine} = \frac{(m_{f2})_{Steam} \times (h_{steam} - h_{water})}{\eta_{boiler} \times GCV} \tag{6}$$

Added cost of fuel ($C_{fuel}$) is given as,

$$(C_{fuel})_{additional} = [(m_f)_{Turbine} - (m_f)_{PRV}] \times C_{fuel} \tag{7}$$

Power generated using microturbine ($P_{Turbine}$) is given as,

$$P_{Turbine} = \frac{(m_{f2})_{Steam} \times (h_{steam,i} - h_{steam,o}) \times \eta_{gearbox} \times \eta_{alternator} \times \eta_{mech}}{860} \tag{8}$$

Here, suffix i and o show values of enthalpy at inlet and outlet respectively. $\eta_{gearbox}$ is the gearbox efficiency, $\eta_{alternator}$ is the alternator efficiency and $\eta_{mech}$ is the mechanical efficiency.

Isentropic efficiency of microturbine $(\eta_{isen})_{microturbine}$ is calculated as,

$$(\eta_{isen})_{microturbine} = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{(h_{in} - h_{out})_{actual}}{(h_{in} - h_{out})_{isen}} \tag{9}$$

Where, $h_{in}$ shows the enthalpy of steam at the inlet to microturbine, $h_{out}$ indicates the enthalpy of steam at the outlet to microturbine, suffix actual and isen correspond to actual enthalpy drop and isentropic enthalpy drop, respectively.

The techno-economic analysis of this ECM is presented in Table 7. This dataset is also depicted in Figure 7 to ease understanding. The operation of the microturbine and the generation of electricity entail added costs. Added steam may be needed for this operation. However, the benefit gained from electricity generation will be greater than that from steam consumption. The Application of a microturbine could generate 903,702.41 kWh/year, which, when compared to the plant's annual consumption (i.e., 3,101,625 kWh/year), is a potential savings of 29.14%. Figure 8 depicts this comparison for clarity.

**Table 7.** Techno economics of replacement of PRV with microturbine in RTM plant

| Particular | Values for RTM Plant | Unit |
|---|---|---|
| **Present Condition – with PRV** | | |
| Steam generation pressure | 9.806 | Bar |
| Reduced pressure of steam | 2.942 | Bar |
| Mass flow rate of steam | 2,500 | kg/hr |
| Operating hours per year | 7,200 | Hrs/year |
| Calorific Value of Fuel | 3,500 | kCal/kg |
| Cost of fuel | 7,000 | Rs. /tonne |
| Cost of Electricity | 7.61 | Rs. /kWh |
| Boiler efficiency | 82 | % |
| Enthalpy of steam at inlet of PRV | 663.07 | kCal/kg |
| Enthalpy of steam at outlet of PRV | 663.07 | kCal/kg |
| Enthalpy of Steam at inlet to condenser | 90 | kCal/kg |
| Enthalpy of steam at outlet of microturbine - actual | 620 | kCal/kg |
| Enthalpy of steam at outlet of microturbine – isentropic | 599.62 | kCal/kg |
| Proposed condition – Microturbine | | |
| Gear Box efficiency | 98 | % |
| Alternator efficiency | 98 | % |
| Mechanical Efficiency of turbine | 97 | % |
| Mass flow rate of steam | 2,690.25 | kg/hr |
| Fuel consumption with PRV Operation | 499.19 | kg/hr |
| Fuel consumption with steam turbine | 537.18 | kg/hr |
| Additional cost of fuel | 265.92 | Rs. /hr |
| Power generated | 125.51 | kW |
| Annual electricity generation | 903,702.41 | kWh/year |
| Grid Electricity savings | 955 | Rs. /hr |
| Net savings | 689.24 | Rs. /hr |
| Net annual savings | 4,962,562 | Rs. /Year |
| Investment | 5,500,000 | Rs. |
| Payback Period | 1.11 | Years |
| Annual Electricity consumption | 3,101,625.4 | kWh/ Year |
| % Electricity generated out of annual consumption | 29.14 | % |
| Isentropic efficiency of microturbine | 67.85 | % |

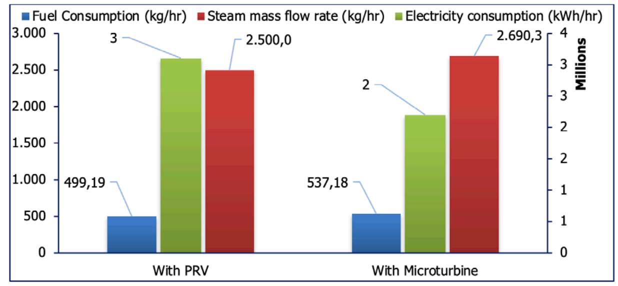


**Figure 7.** Comparison of electricity, fuel and steam consumption with PRV and microturbine

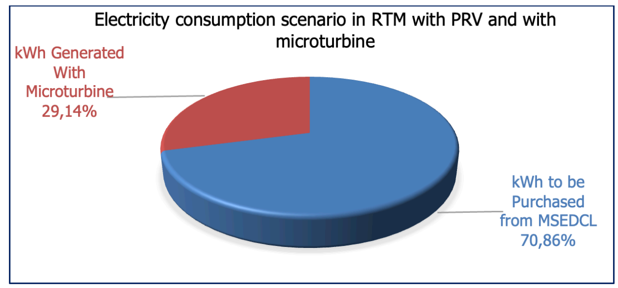


**Figure 8.** Electricity consumption scenario in RTM with PRV and with microturbine

This ECM will need an investment of Rs. 5,500,000 with annual savings of Rs. 4,962,562. Thus, the payback period of this ECM is 1.11 years (13.30 months). The steam at the exhaust of the microturbine can be supplied directly for processing heating and for curing the rubber tubes in the mould.

## 5.2. Energy conservation in electrical systems of RTM and CMI

The Electrical energy consumption of RTM was studied for 16 months, and that of CMI for 11 months. The Electricity bill analysis for RTM was prepared using 416 data points, while the analysis for CMI used 286 data points. Such an extensive dataset helps to compensate for the effects of variations in weather conditions and operational characteristics on the energy consumption of the plant. As the resulting tables were extensive, the findings are presented graphically to enhance visualization and interpretation.

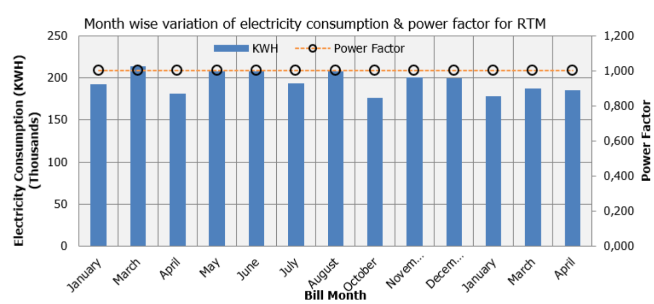


**Figure 9.** Monthly variation of PF and kWh consumption in RTM Industry

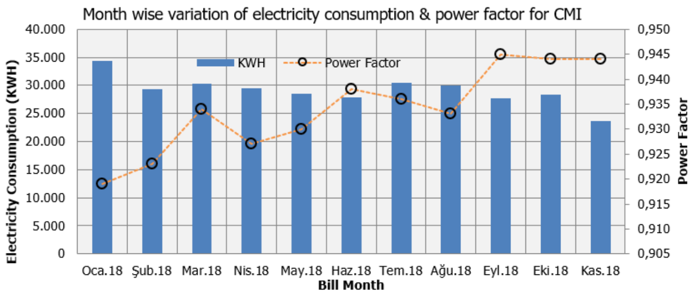


**Figure 10.** Monthly variation of PF and kWh consumption in CMI

The electrical energy consumption in both RTM and CMI are characterized by

a. Apparent power received from MSEDCL in kVA
b. Active power used in the facility in kW
c. Reactive power consumed in the facility in kVAr

Mathematically, Power Factor (PF)is expressed as,

$$PF = \cos\varphi = \frac{\text{Active Power}}{\text{Apparent Power}} = \frac{kW}{kVA} \quad (9)$$

Here, φ is the phase angle between voltage and current in an alternating current (AC) circuit.

If the PF of an industry is less than 1.00, then it can be improved by installing capacitor banks providing reactive power $P_R$, calculated as follows [44]:

Reactive power (kVAr) needed for Active Power (kW) consumed in the plant

$$kVAr = kW \times (\tan\varphi_1 - \tan\varphi_2) \quad (10)$$

$$kVAr = kW \times (\tan(\cos^{-1} PF_1) - \tan(\cos^{-1} PF_2)) \quad (11)$$

Here, $PF_1$ is the existing power factor of the plant, while $PF_2$ is the targeted power factor. An improvement in PF will also lead to a reduction in clear power obtained by industry from MSEDCL, thereby reducing demand charges. Figure 9 depicts electricity consumption and power factor variation for RTM, while Figure 10 presents the corresponding data for CMI. The power factor of RTM is kept close to unity due to the installation of a power factor correction capacitor bank. However, for CMI, the value of PF is well below 0.950, the threshold prescribed by MSEDCL to avail the incentive for higher power factor. According to MERC regulations, the industry could avail itself of a 7% incentive for keeping the PF at unity. A higher PF helps avoid energy losses in the plant's electrical network. Therefore, it is recommended that CMI consider the installation and maintenance of an Automatic Power Factor Controller (APFC), which will automatically switch the capacitor banks and so keep unity PF. The techno–economic evaluation of this prospect, as depicted in Table 8, shows that reactive power capacitors of 24 kVAr should be provided for CMI, resulting in a short payback period of about 1 month. These results suggest that, regardless of the sector of operation, analysis of electricity bills can help find energy-saving avenues without substantial investment.

**Table 8.** Savings due to PF improvement in CMI

| Parameter | Formula / notation | Value for CMI | Unit |
|---|---|---|---|
| Contract demand | CD | 98 | kVA |
| Lowest PF | PF1 | 0.919 | - |
| Highest kVA demand in the last 12 months | BD | 58 | kVA |
| Expected PF | PF2 | 1.000 | - |
| Highest kW Demand for lowest PF | kW = BD × PF1 | 53.302 ~ 54 | kW |
| Total Capacity of kVAr needed for unity PF | kW × [(tan ($\cos^{-1} PF_1$) – tan ($\cos^{-1} PF_2$))] | 23.16 ~ 24 | kVAr |
| Cost of capacitors per kVAr | $C_{capacitor}$ | 500 | Rs. /kVAr |
| Total investment needed | $I_{total} = C_{capacitor} \times kVAr$ | 12,000/- | Rs. |
| Demand after unity PF | KVA = KW | 54 | kVA |
| Reduction in kVA demand due to unity PF | BD – KW | 58 – 54 = 4 | kVA |
| Saving in demand charges for 12 months | = Bd x Rs. /kVA months | 13,440/- | Rs. /Year |
| Saving through PF incentive from MSEDCL | 7% of electricity charges | 175,125.05 | Rs. / Year |
| Total savings by PF improvement to unity | Demand charges +PF incentive | 188,565.05 | Rs. / Year |
| Payback period | Investment / annual saving | 0.0636 | Years |
| | | 0.763 ~ 1.0 | Months |

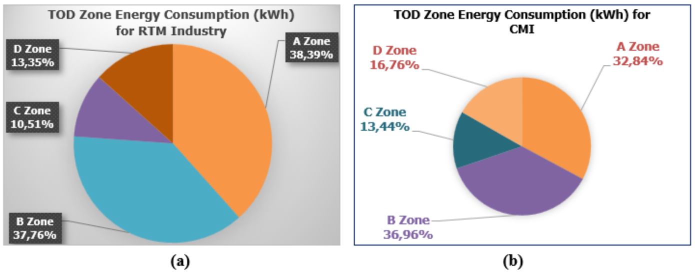


**Figure 11.** TOD Zone wise Electrical energy consumption of **(a)** RTM for 13 months **(b)** CMI for 11 months

**Table 9.** TOD Tariff structure of MSEDCL for different operational time zones

| Sr. No. | TOD Zone | Timing | Rate (Rs. / kWh) |
|---|---|---|---|
| 1 | A | 0000 Hrs – 0600 Hrs | – 1.50 |
| 2 | B | 0600 Hrs – 0900 Hrs & 1200 Hrs – 1800 Hrs | 0.00 |
| 3 | C | 0900 Hrs – 1200 Hrs | 0.80 |
| 4 | D | 1800 Hrs – 2200 Hrs | 1.10 |

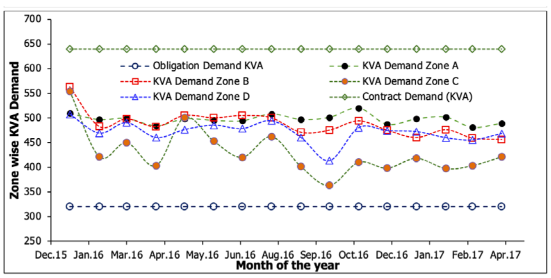


**Figure 12.** kVA demands consumption of RTM for various operational zones

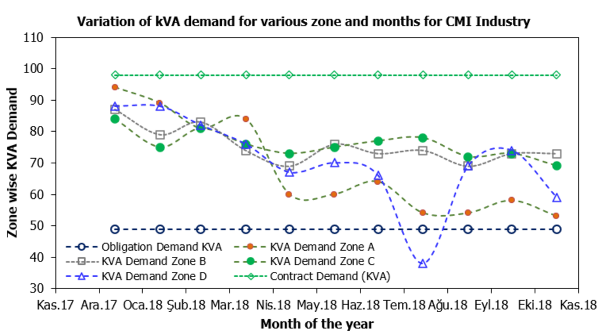


**Figure 13.** kVA demands consumption of CMI for various operational zones

Zone-wise Time-of-Day (TOD) energy consumption for RTM and CMI is depicted in Figure 11. According to MSEDCL's TOD regulations, electricity consumption in Zones C and D is subject to added charges because of the greater burden on the electrical grid, while consumption in Zone A is subject to a discount, as shown in Table 9. Both RTM and CMI exhibit significant energy consumption in zones A and B (totaling 76.15% for RTM and 69.8% for CMI). Consequently, both plants are recommended to reschedule suitable operations for Zone A to obtain a further discount.

The kVA demand of RTM and CMI for various TOD zones over several months is depicted in Figures 12 and 13. It also shows the contract demand and percentage obligations related to kVA consumption imposed on both industries by MSEDCL. This percentage obligation is revised by MSEDCL each year, effective from April. At the time of the audit, this percentage obligation was 50%. It is noteworthy that both RTM and CMI have consumed a kVA demand higher than the prescribed obligation in any month of operation, except for CMI in August. The highest demand consumption of RTM was 563 kVA in January in Zone B, while the highest for CMI was 94 KVA in January in Zone A. Because each plant's contract demand is being effectively used, neither plant currently needs to reduce its contract demand. Thus, these observations about PF improvement, TOD tariff analysis, the relative contribution of kVA/kWh charges, and revision of contract demand have helped find opportunities to perfect electrical energy consumption costs.

### 5.3. Energy conservation in compressed air system

In RTM, compressed air is generated and used to inflate the rubber tubes after curing in the moulds is completed. Inflating tubes are necessary to check for defects such as holes or cracks. This compressed air is also used in the mixing section to homogenize the ingredients for tube manufacturing. Additionally, this compressed air is used to clean the machines during their maintenance, removing small debris particles. In CMI, compressed air is needed to clean the machine parts and remove residual particles. Details of the compressed-air generation systems at both plants are presented in Table 10.

**Table 10.** Essential details of compressed air system in both the plants

| Parameter | Value for RTM | Value for CMI | Unit |
|---|---|---|---|
| Make & Model Compressor #1 | KAESER ASD 37 | Chicago Pneumatic CPM 7 | - |
| Motor Power Compressor #1 | 22 | 5.5 | kW |
| Operational status | Working | Working | - |
| Make & Model Compressor #2 | Atlas Copco GA 37 | Chicago Pneumatic CPA 20 D | - |
| Motor Power Compressor #1 | 22 | 15 | kW |
| Operational status | Working | Standby | - |
| Capacity | 70 | 70 | CFM |
| Operating pressure | 10 | 7 | bar |
| Operating Hours / days | 24 / 300 | 24 / 300 | - |

Since the pipeline transmitting compressed air in the plant is aging, it is likely to develop holes and cracks from long-term exposure to moisture, which ultimately results in corrosion of the pipeline. A significant amount of compressed air at high pressure leaks into the atmosphere through these cracks, thereby severely affecting the economics of compressor operation. Hence, leakage tests were conducted on the compressed air systems to quantify the leakage percentage and evaluate the potential for energy savings. Table 11 presents the leak-test results for the Kaeser compressor in RTM; Table 12 presents the leak-test results for the Atlas Copco compressor in RTM; and Table 13 presents the leak-test results for the CPM7 compressor in CMI, together with the corresponding techno–economic evaluation.

### 5.3.1. Energy conservation through leakage arrest in compressed air system of RTM and CMI

Procedure for leakage test of compressed air system:

- Shut off the equipment run by compressed air. Run the compressor until the system reaches the set operating pressure.
- Note the later time taken for 'Load' and 'Unload' cycles of the compressors. For accuracy, record ON and OFF times for 8 – 10 cycles consecutively.
- The system leakage is calculated as [44]:

$$\%\text{Leakage} = \frac{T}{T+t} \times 100 \quad (12)$$

$$\text{AirLeakage}(m^3/\text{minute}) = Q \times \frac{T}{T+t} \quad (13)$$

Where, Q = Actual free air supplied, ($m^3$/min), T = Time on load(min), t = Time on unload (min)

**Table 11.** Results from leak test conducted on Kaeser Compressor in RTM

| Sr. No. | Parameter | Value | Unit |
|---|---|---|---|
| 1. | Average Load Time (T) | 43.33 | Sec |
| 2. | Average Unload Time (t) | 40.67 | Sec |
| 3. | % of Leakage | 51.59 | % |
| 4. | Leakage volume | 2.49 | $m^3$/min |
| 5. | Specific Power Consumption | 0.033 | kWh/$m^3$ |
| 6. | Energy lost due to leakage per day | 119.31 | kWh/ Day |
| 7. | Loss Rs. 8/kWh & 300 days / year | 286,347.89 | Rs. /Year |
| 8. | Electricity savings due to leakage arrest | 35,793 | kWh/Year |
| 9. | Monetary saving due to leakage arrest | 272,385 | Rs. / Year |
| 10. | Investment needed | 8,000 | Rs. |
| | | 0.029 | Years |
| 11. | Payback period | 0.348 | Months |
| | | 10.44 | Days |

**Table 12.** Results from leak test conducted on Atlas Copco Compressor in RTM

| Sr. No. | Parameter | Value | Unit |
|---|---|---|---|
| 1. | Average Load Time (T) | 35.20 | Sec |
| 2. | Average Unload Time (t) | 55.75 | Sec |
| 3. | % of Leakage | 38.70 | % |
| 4. | Leakage volume | 2.67 | $m^3$/min |
| 5. | Specific Power Consumption | 0.0291 | kWh/$m^3$ |
| 6. | Energy lost due to leakage per day | 111.93 | kWh/ Day |
| 7. | Loss in 300 days / year Rs. 8/kWh | 279,371.97 | Rs. /Year |
| 8. | Electricity savings due to leakage arrest | 33,579 | kWh/ Year |
| 9. | Cost of electricity | 7.61 | Rs. / kWh |
| 10. | Monetary saving due to leakage arrest | 255,536.19 | Rs. / Year |
| 11. | Investment needed | 13,000 | Rs. |
| 12. | Payback period | 0.0508 | Years |
| 13. | | 18.30 | Days |

**Table 13.** Results from leak test conducted on CPM 7 Compressor in CMI

| Sr. No. | Parameter | Value | Unit |
|---|---|---|---|
| 1. | Average Load Time (T) | 25.516 | Sec |
| 2. | Average Unload Time (t) | 42.108 | Sec |
| 3. | % of Leakage | 37.73 | % |
| 4. | Leakage volume | 0.757 | $m^3$/min |
| 5. | Specific Power Consumption | 0.0867 | kWh/$m^3$ |
| 6. | Energy lost due to leakage per day | 94.59 | kWh/day |
| 7. | Loss in 300 days / year Rs. 8.25/kWh | 243,474.66 | Rs. /Year |
| 8. | Electricity savings due to leakage arrest | 28,377 | kWh/ Year |
| 9. | Cost of electricity | 8.25 | Rs. /kWh |
| 10. | Monetary saving due to leakage arrest | 234,110.25 | Rs. / Year |
| 11. | Investment needed | 9,000 | Rs. |
| 12. | Payback period | 0.0384 | Years |
| 13. | | 13.83 | Days |

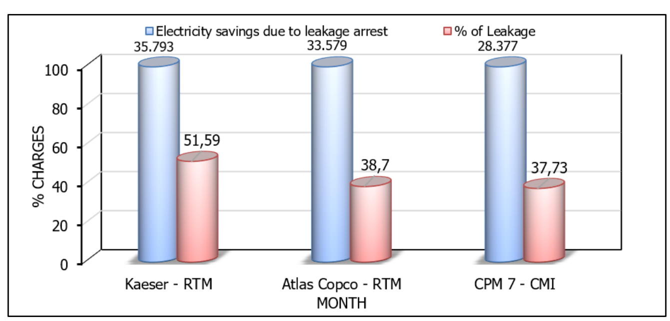


**Figure 14.** kWh savings in RTM and CMI plant due to compressed air leakage arrest

Thus, arresting air leakages in compressed air systems in both RTM and CMI can help conserve a substantial amount of electricity, as saw in Figure 14. For RTM, the total electricity-saving potential is 69,372 kWh/year, while it is 28,377 kWh/year for the CMI plant. The investments needed to achieve these savings are Rs. 8,000/-, Rs. 13,000/-, and Rs. 9,000/- for the KAESER, Atlas Copco, and CPM 7 compressor lines, respectively, resulting in payback periods of 10.44 days, 18.30 days, and 13.83 days.

### 5.3.2. Energy conservation through VFD applications in compressor of RTM and CMI

The compressor runs under unloaded conditions for a significant portion of its operating cycle. The compressor motor still consumes 30% of its power in unload mode. Hence, it is recommended that these compressors be fitted with Variable Frequency Drive (VFD) to control motor speed based on feedback from a pressure transducer installed on the compressed-air receiver tank, thereby completely avoiding unload power consumption. Energy savings due to VFD application are calculated as:

$$\text{Energy saved(kWh/day)} = (\text{unload kW}) \times \frac{t}{T+t} \times 100 \times 24 \tag{14}$$

The techno–economic evaluation of this ECM is presented in Table 14 for all compressors. Its graphical representation is also shown in Figure 15. This analysis showed that VFD installation can result in total annual electricity savings of 25,822.02 kWh/year for RTM and 20,809.12 kWh/year for CMI.

**Table 14.** Techno – economic evaluation of application of VFD in compressor in RTM & CMI

| Sr. No. | Parameter | Value for RTM Kaeser | Value for RTM Atlas Copco | Value for CMI CPM 7 | Unit |
|---|---|---|---|---|---|
| 1 | Loading power consumption | 6.06 | 11.93 | 10.45 | kW |
| 2 | Unloading power consumption | 2.12 | 4.18 | 6.1 | kW |
| 3 | Average Load Time (T) | 43.33 | 35.20 | 39.66 | Sec |
| 4 | Average Unload Time (t) | 40.67 | 55.75 | 35.71 | Sec |
| 5 | Savings with VFD installation per day | 24.65 | 61.43 | 69.36 | kWh/ Day |
| 6 | Savings with VFD installation per year | 7,393.81 | 18,428.21 | 20,809.12 | kWh/ Year |
| 7 | Cost of Electricity | 8.00 | 8.00 | 8.25 | Rs. /kWh |
| 8 | Monetary saving per year | 59,150.45 | 147,425.68 | 171,723.25 | Rs. /Year |
| 9 | Investment required | 100,000 | 200,000 | 220,000 | Rs. |
| 10 | Payback period | 1.69 | 1.36 | 1.28 | Years |

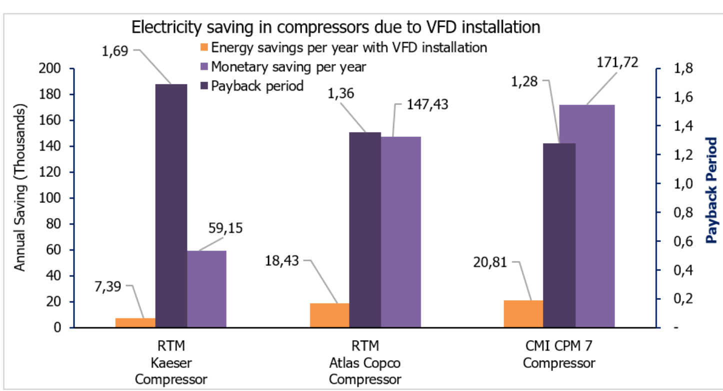


**Figure 15.** Electricity saving in compressors due to VFD installation

### 5.3.3. Energy saving due to operating pressure reduction of compressors

During normal operating conditions in RTM, both compressors operate simultaneously to meet the air requirement of the curing line. In CMI, one compressor is running and another one is on standby. In both RTM & CMI, the compressors' load pressure is 6.0 Bar. This is common industrial practice in which the pressure is usually set at a higher level due to limited awareness of its impact on compressor energy consumption. Workers also tend to use compressed air at higher pressures for minor operations, such as cleaning burrs from machined parts. However, during the present audit, it was found that the maximum pressure requirement for pneumatic applications does not exceed 5.0 bar in RTM and 4.0 bar in CMI. Hence, it was suggested that the discharge pressure of the compressors be reduced from 6.0 bar to 5.0 bar and 4.0 bar for the RTM and CMI plants, respectively. As a rule of thumb, every 0.5-bar reduction in pressure reduces power consumption by 3-4%. Table 15 presents the cost-benefit analysis for this ECM, which shows annual electricity savings of 7,772 kWh for RTM and 9,029 kWh for CMI, with no required investment, thereby providing an immediate payback period.

**Table 15.** Cost benefit analysis to reduce discharge pressure for air compressors

| Description | Unit | RTM KAESER Compressor | RTM Atlas Copco Compressor | CMI CPM 7 Compressor |
|---|---|---|---|---|
| Power consumption by Compressor | KW | 6.06 | 11.93 | 10.45 |
| Annual operating hours | Hours | 7200 | 7200 | 7200 |
| Annual energy consumption | KWh/Yr. | 43,632 | 85,896 | 75,240 |
| Operating pressure (present) | bar | 6 | 6 | 6 |
| Operating pressure (proposed) | bar | 5 | 5 | 4 |
| Total reduction in pressure | bar | 1 | 1 | 2 |
| % energy saving possible 3% for every 0.5 bar pressure reduction | % | 6 | 6 | 12 |
| Expected energy saving | KWh/Yr. | 2,618 | 5,154 | 9,029 |
| Cost of Electricity | Rs/KWh | 8 | 8 | 8.25 |
| Estimated Annual Cost Savings | Rs. | 20,943.36 | 41,230.08 | 74,487.6 |
| Investment | Rs. | NIL | NIL | NIL |
| Payback period | Month | Immediate | Immediate | Immediate |

Compressor pressure reduction and leakage arrest will need certain potential operational challenges or maintenance requirements, outlined as follows:

Pressure reduction: Adjustment of pressure regulators, Recalibration of flow rates following pressure reduction, Resetting of compressor controls as per reduced pressure settings.

Leakage arrest: Line isolation to identify and distinguish between true leakage and functional air utilization, Difficulty in identifying small sized leaks in the noisy manufacturing environment, Use of Ultrasonic Leak Detectors instead of relying on manual detection to ensure adequate leakage identification, Tagging the identified leakage locations, preferably color coded as per the size of leakage hole, and maintaining the documented log report of identified and arrested leakages.

### 5.4. Energy conservation in lighting system

Presently, most sections of the RTM plant use CFL lamps due to their relatively low first cost. However, the techno-economic benefits of adopting LED lamps have not yet been realized. Hence, a detailed survey of the plant's lighting system was carried out as part of the present audit, covering various sections such as the boiler house, mixing section, production line, carbon area, parking area, main office, and compressor room. The collected data are presented in Table 16, with the necessary details. Figure 16 depicts the distribution of lighting energy consumption by section within the plant.

Savings gained due to replacement of old CFL lamps with energy efficient LED lamps is given as,

$$\text{kW saving} = [(\text{kW})_{CFL} - (\text{kW})_{LED}] \text{ x operating hours} \quad (15)$$

Here, $(\text{kW})_{CFL}$ indicates power consumption by CFLs while $(\text{kW})_{LED}$ shows power consumption by LEDs.

Table 16 shows that total savings of 65.72 kWh/day are achievable for the lighting system. The cost-benefit analysis of this ECM, in Table 17, shows annual electricity savings of 20,904 kWh, being 42.11% of the annual consumption, with payback period of 0.615 years or approximately 8 months.

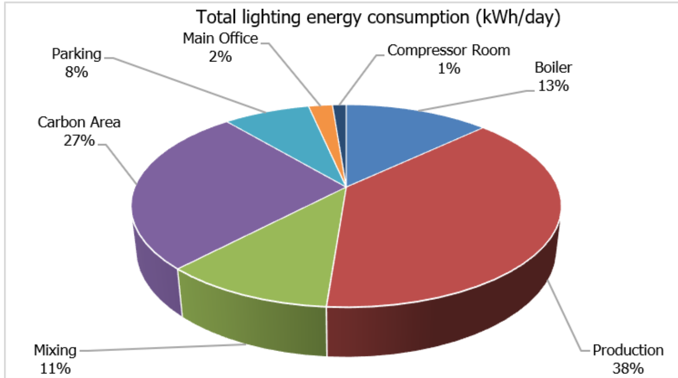


**Figure 16.** Section-wise distribution of lighting energy consumption in RTM plant

**Table 16.** Details of Installed Lighting system in RTM plant

| Section No | Sr. No | Location of Dept. | TYPES | Qty. | Watt | Total Wattage | Ope. Hrs. | Total consumption (kWh/day) | Lumen (present) | Lumen/W (proposed) | Rating of New Lamp | Lamp consumption after replacement (W) | Total consumption (kWh/day) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | | **Boiler** | | | | | | | | | | | |
| | 1.1 | Entry Gate | CFL | 1 | 85 | 85 | 12 | 1.02 | 5,100 | 100 | 51 | 51 | 0.612 |
| | 1.2 | Fuel Storage | CFL | 4 | 85 | 340 | 12 | 4.08 | 5,100 | 100 | 51 | 204 | 2.448 |
| | 1.3 | Below Water Tank | CFL | 1 | 85 | 85 | 12 | 1.02 | 5,100 | 100 | 51 | 51 | 0.612 |
| | 1.4 | Boiler House | CFL | 9 | 85 | 765 | 12 | 9.18 | 5,100 | 100 | 51 | 459 | 5.508 |
| | 1.5 | Staircase | Tubelight | 1 | 48 | 48 | 12 | 0.576 | 2,880 | 100 | 28.8 | 28.8 | 0.346 |
| | | | Tubelight | 1 | 48 | 48 | 12 | 0.576 | 2,880 | 100 | 28.8 | 28.8 | 0.346 |
| | 1.6 | Softener Salt Storage | Tubelight | 3 | 48 | 144 | 12 | 1.728 | 2,880 | 100 | 28.8 | 86.4 | 1.037 |
| | 1.7 | Chimney Area | Tubelight | 4 | 48 | 192 | 12 | 2.304 | 2,880 | 100 | 28.8 | 115.2 | 1.382 |
| | | | CFL | 1 | 85 | 85 | 12 | 1.02 | 5,100 | 100 | 51 | 51 | 0.612 |
| **2** | | **Production** | | | | | | | | | | | |
| | 2.1 | Curing line | CFL | 24 | 85 | 2,040 | 12 | 24.48 | 5,100 | 100 | 51 | 1,224 | 14.688 |
| | | | CFL | 1 | 60 | 60 | 12 | 0.72 | 3,600 | 100 | 36 | 36 | 0.432 |
| | | | Tubelight | 1 | 48 | 48 | 12 | 0.576 | 2,880 | 100 | 28.8 | 28.8 | 0.346 |
| | 2.2 | Tube Packing | Tubelight | 6 | 36 | 216 | 12 | 2.592 | 2,160 | 100 | 21.6 | 129.6 | 1.555 |
| | | | CFL | 3 | 85 | 255 | 12 | 3.06 | 5,100 | 100 | 51 | 153 | 1.836 |
| | 2.3 | Maintenance | CFL | 7 | 85 | 595 | 12 | 7.14 | 5,100 | 100 | 51 | 357 | 4.284 |
| | | | CFL | 1 | 45 | 45 | 12 | 0.54 | 2,700 | 100 | 27 | 27 | 0.324 |
| | | | CFL | 3 | 60 | 180 | 12 | 2.16 | 3,600 | 100 | 36 | 108 | 1.296 |
| | | | Tubelight | 3 | 48 | 144 | 12 | 1.728 | 2,880 | 100 | 28.8 | 86.4 | 1.037 |
| | 2.4 | Intermediate | CFL | 12 | 85 | 1,020 | 12 | 12.24 | 5,100 | 100 | 51 | 612 | 7.344 |
| | | | CFL | 3 | 45 | 135 | 12 | 1.62 | 2,700 | 100 | 27 | 81 | 0.972 |
| | | | Tubelight | 1 | 48 | 48 | 12 | 0.576 | 2,880 | 100 | 28.8 | 28.8 | 0.346 |
| | 2.5 | Tube Solutioning | Tubelight | 2 | 36 | 72 | 12 | 0.864 | 2,160 | 100 | 21.6 | 43.2 | 0.518 |
| | | | Tubelight | 1 | 48 | 48 | 12 | 0.576 | 2,880 | 100 | 28.8 | 28.8 | 0.346 |
| | | | CFL | 1 | 85 | 85 | 12 | 1.02 | 5,100 | 100 | 51 | 51 | 0.612 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.6 | Electrical Dept. | Tubelight | 1 | 40 | 40 | 12 | 0.48 | 2,400 | 100 | 24 | 24 | 0.288 |
| | 2.7 | Tea Room | Tubelight | 1 | 40 | 40 | 12 | 0.48 | 2,400 | 100 | 24 | 24 | 0.288 |
| | 2.8 | Valve Solutioning | Tubelight | 4 | 40 | 160 | 12 | 1.92 | 2,400 | 100 | 24 | 96 | 1.152 |
| | 2.9 | Washroom 1 | Tubelight | 1 | 40 | 40 | 12 | 0.48 | 2,400 | 100 | 24 | 24 | 0.288 |
| **3** | | **Mixing** | | | | | | | | | | | |
| | 3.1 | Kneader 3 | CFL | 4 | 85 | 340 | 24 | 8.16 | 5,100 | 100 | 51 | 204 | 4.896 |
| | 3.2 | Kneader 2 | CFL | 2 | 85 | 170 | 24 | 4.08 | 5,100 | 100 | 51 | 102 | 2.448 |
| | | | CFL | 1 | 60 | 60 | 24 | 1.44 | 3,600 | 100 | 36 | 36 | 0.864 |
| | | | CFL | 1 | 45 | 45 | 24 | 1.08 | 2,700 | 100 | 27 | 27 | 0.648 |
| | 3.3 | Kneader 1 | CFL | 3 | 45 | 135 | 24 | 3.24 | 2,700 | 100 | 27 | 81 | 1.944 |
| **4** | | **Carbon Area** | | | | | | | | | | | |
| | 4.1 | C.Weighing Area | CFL | 1 | 85 | 85 | 24 | 2.04 | 5,100 | 100 | 51 | 51 | 1.224 |
| | | | CFL | 1 | 45 | 45 | 24 | 1.08 | 2,700 | 100 | 27 | 27 | 0.648 |
| | 4.2 | Carbon N660 | Tubelight | 1 | 48 | 48 | 24 | 1.152 | 2,880 | 100 | 28.8 | 28.8 | 0.691 |
| | 4.3 | Store | Tubelight | 1 | 48 | 48 | 24 | 1.152 | 2,880 | 100 | 28.8 | 28.8 | 0.691 |
| | | | CFL | 1 | 45 | 45 | 24 | 1.08 | 2,700 | 100 | 27 | 27 | 0.648 |
| | | | CFL | 1 | 85 | 85 | 24 | 2.04 | 5,100 | 100 | 51 | 51 | 1.224 |
| | 4.3 | Reclam R306 | CFL | 1 | 85 | 85 | 24 | 2.04 | 5,100 | 100 | 51 | 51 | 1.224 |
| | 4.4 | Washroom 2 | Tubelight | 1 | 40 | 40 | 24 | 0.96 | 2,400 | 100 | 24 | 24 | 0.576 |
| | | | Tubelight | 1 | 36 | 36 | 24 | 0.864 | 2,160 | 100 | 21.6 | 21.6 | 0.518 |
| | 4.5 | Process aid R6316 | Tubelight | 2 | 40 | 80 | 24 | 1.92 | 2,400 | 100 | 24 | 48 | 1.152 |
| | | | CFL | 1 | 85 | 85 | 24 | 2.04 | 5,100 | 100 | 51 | 51 | 1.224 |
| | 4.6 | EPDM R2200 | CFL | 1 | 85 | 85 | 24 | 2.04 | 5,100 | 100 | 51 | 51 | 1.224 |
| | 4.7 | Changing Room | Tubelight | 2 | 36 | 72 | 24 | 1.728 | 2,160 | 100 | 21.6 | 43.2 | 1.037 |
| | 4.8 | Receiving Shed | CFL | 3 | 85 | 255 | 24 | 6.12 | 5,100 | 100 | 51 | 153 | 3.672 |
| | | | Tubelight | 1 | 36 | 36 | 24 | 0.864 | 2,160 | 100 | 21.6 | 21.6 | 0.518 |
| | 4.9 | Warehouse | Tubelight | 1 | 36 | 36 | 24 | 0.864 | 2,160 | 100 | 21.6 | 21.6 | 0.518 |
| | | | CFL | 2 | 85 | 170 | 24 | 4.08 | 5,100 | 100 | 51 | 102 | 2.448 |
| | 4.1 | BR760 | Tubelight | 1 | 48 | 48 | 24 | 1.152 | 2,880 | 100 | 28.8 | 28.8 | 0.691 |
| | | | Tubelight | 1 | 40 | 40 | 24 | 0.96 | 2,400 | 100 | 24 | 24 | 0.576 |
| | | | CFL | 1 | 85 | 85 | 24 | 2.04 | 5,100 | 100 | 51 | 51 | 1.224 |
| | 4.11 | Storeroom | Tubelight | 7 | 48 | 336 | 24 | 8.064 | 2,880 | 100 | 28.8 | 201.6 | 4.838 |
| **5** | | **Parking** | | | | | | | | | | | |
| | 5.1 | P 1 | Tubelight | 3 | 48 | 144 | 12 | 1.728 | 2,880 | 100 | 28.8 | 86.4 | 1.037 |
| | 5.2 | Washroom 3 | Tubelight | 2 | 28 | 56 | 12 | 0.672 | 1,680 | 100 | 16.8 | 33.6 | 0.403 |
| | 5.3 | Lunchroom | Tubelight | 4 | 40 | 160 | 12 | 1.92 | 2,400 | 100 | 24 | 96 | 1.152 |
| | 5.4 | DTR | CFL | 1 | 85 | 85 | 12 | 1.02 | 5,100 | 100 | 51 | 51 | 0.612 |
| | 5.5 | H.T.L.T Room | Tubelight | 1 | 40 | 40 | 12 | 0.48 | 2,400 | 100 | 24 | 24 | 0.288 |
| | | | Tubelight | 1 | 40 | 40 | 12 | 0.48 | 2,400 | 100 | 24 | 24 | 0.288 |
| | 5.6 | Administrative Office | Tubelight | 4 | 48 | 192 | 12 | 2.304 | 2,880 | 100 | 28.8 | 115.2 | 1.382 |
| | 5.7 | Security cabin | Tubelight | 1 | 40 | 40 | 12 | 0.48 | 2,400 | 100 | 24 | 24 | 0.288 |
| | | | Tubelight | 1 | 18 | 18 | 12 | 0.216 | 1,080 | 100 | 10.8 | 10.8 | 0.130 |
| | 5.8 | Parking (Back side) | Tubelight | 2 | 40 | 80 | 12 | 0.96 | 2,400 | 100 | 24 | 48 | 0.576 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5.9 | Main Gate | Tubelight | 2 | 40 | 80 | 12 | 0.96 | 2,400 | 100 | 24 | 48 | 0.576 |
| | 5.1 | Washroom 4 | CFL | 1 | 60 | 60 | 12 | 0.72 | 3,600 | 100 | 36 | 36 | 0.432 |
| | | | Tubelight | 1 | 28 | 28 | 12 | 0.336 | 1,680 | 100 | 16.8 | 16.8 | 0.202 |
| | 5.11 | Meter Unit 1 | Tubelight | 1 | 48 | 48 | 12 | 0.576 | 2,880 | 100 | 28.8 | 28.8 | 0.346 |
| 6 | | **Main Office** | | | | | | | | | | | |
| | 6.1 | Office lab | Tubelight | 5 | 48 | 240 | 12 | 2.88 | 2,880 | 100 | 28.8 | 144 | 1.728 |
| | | | Tubelight | 2 | 28 | 56 | 12 | 0.672 | 1,680 | 100 | 16.8 | 33.6 | 0.403 |
| 7 | | **Compressor Room** | | | | | | | | | | | |
| | 7.1 | Operating room | CFL | 2 | 85 | 170 | 12 | 2.04 | 5,100 | 100 | 51 | 102 | 1.224 |
| | | | | | | | **Total kWh/ day (before)** | **165.48** | | | | **Total kWh/ day (After)** | **99.28** |

**Table 17.** Cost benefit analysis of replacement of conventional lighting with LED lamps

| Description | Unit | Value |
|---|---|---|
| **Present condition** | | |
| No of Lamps functioning in plant | - | 178 |
| Total wattage of Lamps | W | 11,195 |
| Total consumption per day | kWh/Day | 165.48 |
| Annual working days | Days/Year | 300 |
| Annual electricity consumption | kWh/Year | 49,644 |
| **Proposed condition** | | |
| Total wattage of Lamps | W | 6,481.32 |
| Total consumption per day | kWh/Day | 95.80 |
| Annual electricity consumption | kWh/Year | 28,740 |
| **Annual electricity saving** | kWh/Year | 20,904 |
| % electricity saving | % | 42.11 |
| Electricity rate | Rs. /kWh | 7.61 |
| Annual Monetary saving | Rs. /Year | 159,079.44 |
| Cost of lamp | Rs. /Lamp | 550 |
| Investment required | Rs. | 97,900 |
| Payback period | Years | 0.615 |
| | Months | 7.38 |

## 6. Executive summary

An executive summary of all the ECMs proposed during the present study, by standardized energy audit practice in India is presented in Table 18 along with the corresponding $CO_2$ emission reduction due to energy saving. Such a summary is helpful for the plant management during decision-making and prioritization of the ECMs in the implementation phase. This table clearly shows that the ECM related to compressed-air leakage arrest and compressor pressure reduction can be implemented at once without substantial investment, thereby providing a shorter payback period. These measures can be followed by upgrading the insulation and improving the system's power factor. An ECM for the application of VFD to compressors can be implemented once monetary savings from earlier ECMs have gained, thereby reducing the need for added internal capital allocation. For improved visualization, this analysis is also shown Figure 17 graphically. In this figure, a higher proportion of green color shows a more favorable ECM from an implementation–prioritization perspective. Thus, ECMs #2 and #9 should be considered at a later stage due to their relatively high capital investment requirements. Nonetheless, the payback periods for these ECMs are close to one year. In India, guidelines are published by Central Electricity Authority, Ministry of Power, Government of India, for calculation of $CO_2$ baseline database for Indian power sector which give correlation as 0.78 $tCO_2$/MWh of electricity consumed and 3.67 kg of $CO_2$/kg of coal.

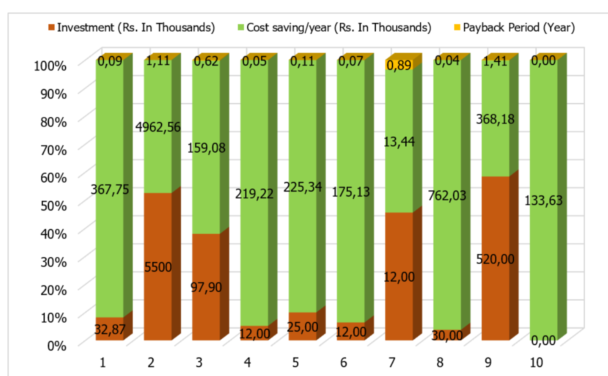


**Figure 17.** Graphical representation of executive summary to ease decision making

**Table 18.** Executive summary for various ECMs found during present project

| ECM No. | ECM Description | Investment (Rs.) | Energy Savings | Cost saving (Rs. / Year) | Payback Period (Year) | CO2 saved (Tons/ Year) |
|---|---|---|---|---|---|---|
| | | | **RTM Plant** | | | |
| 1. | Insulation of steam system | 32,865 | 91.94 MT Coal/ Year | 367,752.73 | 0.09 | 337.42 |
| 2. | Replacement of PRV with microturbine | 5,500,000 | 903,702.41 kWh/ Year | 4,962,562.48 | 1.11 | 704.89 |
| 3. | Saving - lighting system | 97,900 | 20,904.00 kWh/ Year | 159,079.44 | 0.62 | 16.31 |
| | | | **CMI Plant** | | | |
| 4. | PF improvement | 12,000 | 28,800.00 kWh/ Year | 219,223.36 | 0.05 | 22.46 |
| 5. | Insulation of curing tank | 25,000 | 27,313.95 kWh/ Year | 225,340.09 | 0.11 | 21.30 |
| 6. | PF improvement and MSEDCL incentive | 12,000 | 0.00 | 175,125.05 | 0.07 | 0.00 |
| 7. | Demand reduction | 12,000 | 0.00 | 13,440.00 | 0.89 | 0.00 |
| | | | **Compressors** | | | |
| 8. | Leakage arrest | 30,000 | 97,749 kWh/ Year | 762,031.17 | 0.04 | 76.24 |
| 9. | VFD | 520,000 | 46,631.14 kWh/ Year | 368,180.81 | 1.41 | 36.37 |
| 10. | Pressure reduction | NIL | 16,801.00 kWh/ Year | 133,634.17 | Immediate | 13.10 |
| | **Total** | **6,211,765** | **1,141,901** | **7,386,369** | - | **1,228.10** |

## 7. Conclusion

An Energy audit method was deployed as a pragmatic tool for energy savings in two auto-ancillary industries in Nashik, Maharashtra, India. The Following are important conclusions drawn from this study:

- The novelty of the present work lies in finding energy-saving potential through electricity bill analysis, compressor speed control, insulation upgrades for steam systems, and the application of a microturbine for electricity generation.
- Analysis of electricity bills proved effective in finding no- and low-cost practical energy-saving opportunities.
- The application of a microturbine to reduce the pressure of generated steam used for processing heating has an annual energy-saving potential of 903,702.41 kWh/year.
- Optimization of the compressed-air system has an energy-saving potential of 161,181.14 kWh/year, with a modest payback period.
- This energy audit found total annual savings of 1,141,901.50 kWh and 1,228.10 $tCO_2$.

The findings of this study prove the efficacy of plant-level energy audits across diverse industrial sectors in practice.

## 8. General energy saving recommendations

1. Correct the PF to at least 0.950 and preferably 1.000, to reduce energy losses and improve voltage at motor terminals.
2. Use energy efficient motors, following a detailed economic evaluation.
3. Provide adequate ventilation for electric motors and often inspect the motor–coupling alignment.
4. Evaluate the potential for on-site electricity generation or cogeneration.
5. Compressor intercoolers should be periodically inspected to ensure proper functioning.
6. The waste heat from a large compressor can be used as a source of heat for a vapor absorption chiller or for preheating the process or utility feed.
7. The Application of variable-speed drives to compressors reduces pressure fluctuations, energy consumption, and wear and tear on compressor components.
8. Replace the decades-old, galvanized iron (GI) compressed-air distribution pipes with smoother CPVC pipes to reduce pressure loss.
9. Relocate the compressors closer to the point of application. If possible, divide the compressor output section-wise.
10. Wherever possible, reduce the use of compressed air by using blowers for applications requiring airflow rather than pressured air, and adopt electronic controls to replace pneumatic controls.
11. Evaluate the feasibility of getting the utilities from neighboring industries, particularly during the peak-demand periods.

## 9. Future scope

An energy audit is a methodical and rational approach to achieving energy conservation in a pragmatic manner. In the context of the current global energy crisis and sustainability challenges, its importance in supporting the energy security of any nation is becoming more pronounced. The following endeavors can be undertaken to enhance energy efficiency.

1. Internet of Things (IOT) based sensors deployed across the plant systems to enable real-time monitoring and traction of energy consumption.
2. Data collected from such sensors can be used to develop machine learning models to predict future energy consumption of equipment and process systems.
3. Computational Fluid Dynamics (CFD) analysis of thermal systems can also be undertaken to offer improved insights into the flow physics and heat transfer mechanisms of the plant systems.

## Author contributions statement

Hitesh Thakare – Conceptualization, method, software, formal analysis, writing – original draft, writing – review & editing, supervision.

## Declaration of interests

The author declares he does not have any competing financial or personal interests or conflict of interests related to this work.

## Data availability

The data may be provided by the author upon request.

## Declaration of generative AI and AI-assisted technologies in the writing process

The author hereby declares that no generative AI or AI-assisted technologies were used in the writing process. The entire manuscript is manually typed by the author, using conventional writing tools such as Microsoft Word, Math type, and Mendeley. The tables and visualization graphs were prepared using Microsoft Excel.

## References

[1] World Energy Outlook, International Energy Agency (IEA),2021.
[2] Y. Wang, C. Chen, Y. Tao, Z. Wen, B. Chen, H. Zhang, A many-objective optimization of industrial environmental management using NSGA-III: A case of China' s iron and steel industry, Appl. Energy 242 (2019) 46–56.
[3] M.G. Gado, S. Nada, S. Ookawara, H. Hassan, Energy management of standalone cascaded adsorption-compression refrigeration system using hybrid biomass-solar-wind energies, Energy Convers. Manag. 258 (2022) 115387.
[4] Government of India, Ministry of Statistics and Programme Implementation, Energy Statistics India, 2025.
[5] A. Boharb, A. Allouhi, R. Saidur, T. Kousksou, A. Jamil, Energy conservation potential of an energy audit within the pulp and paper industry in Morocco, J. Clean. Prod. 149 (2017) 569–581.
[6] O.A. Oyelaran, Y.Y. Twada, O.M. Sanusi, Energy Audit of an Industry: A Case Study of Fabrication Company Energy Audit of an Industry: A Case Study of Fabrication Company, Aceh Int. J. Sci. Technol. 5 (2016) 45–53.
[7] Indian Energy Scenario for the year 2023-24, Bureau of Energy Efficiency (BEE), Ministry of Power, (2024).
[8] Government of India, MSME Annual Report, 2025.
[9] R. Kannan, W. Boie, Energy management practices in SME - Case study of a bakery in Germany, Energy Convers. Manag. 44 (2003) 945 – 959.
[10] D.K. Biswas, S.R. Asthana, V.G. Rau, Some studies on energy savings in sponge iron plants, J. Energy Resour. Technol. Trans. ASME 125 (2003) 228–237.
[11] T. Engin, V. Ari, Energy auditing and recovery for dry type cement rotary kiln systems - A case study, Energy Convers. Manag. 46 (2005) 551 – 562.
[12] M. Thirugnanasambandam, M. Hasanuzzaman, R. Saidur, M.B. Ali, S. Rajakarunakaran, D. Devaraj, N.A. Rahim, Analysis of electrical motors load factors and energy savings in an Indian cement industry, Energy 36 (2011) 4307 – 4314.
[13] V. Ghalandari, M.M. Majd, A. Golestanian, Energy audit for pyro-processing unit of a new generation cement plant and feasibility study for recovering waste heat: A case study, Energy 173 (2019) 833–843.
[14] D. Kaya, M. Eyidogan, Energy conservation opportunity in boiler systems, J. Energy Resour. Technol. Trans. ASME 131 (2009) 0324011–0324014.
[15] M. Dongellini, C. Marinosci, G.L. Morini, Energy audit of an industrial site: A case study, Energy Procedia 45 (2014) 424–433.
[16] G. May, I. Barletta, B. Stahl, M. Taisch, Energy management in production: A novel method to develop key performance indicators for improving energy efficiency, Appl. Energy 149 (2015) 46–61.
[17] M. Neri, A.M. Lezzi, G.P. Beretta, M. Pilotelli, Energy- and Exergy-Based Analysis for Reducing Energy Demand in Heat Processes for Aluminum Casting, J. Energy Resour. Technol. Trans. ASME 141 (2019) 1–10.
[18] O.M. Selim, M. Abousabae, A. Hasan, R.S. Amano, Analysis of energy savings and CO2 emission reduction contribution for industrial facilities in USA, J. Energy Resour. Technol. Trans. ASME 143 (2021).
[19] E. Giacone, S. Mancò, P. Gabriele, Energy management techniques for small- and medium-sized companies (ESDA2006-95808), J. Energy Resour. Technol. Trans. ASME 130 (2008) 0120021–0120027.
[20] D. Kadric, N. Delalic, B. Delalic-Gurda, M. Kotur, A. Skulj, Reduction of Energy use in Industrial Facility, J. Therm. Eng. 7 (2021) 54–65.

[21] H.R. Thakare, P. Daspute, Enhancing energy conservation in power generation in a coal fired thermal power plant through comprehensive energy audit, Energy 301 (2024) 131661.

[22] P. Catrini, D. Panno, F. Cardona, A. Piacentino, Characterization of cooling loads in the wine industry and novel seasonal indicator for reliable assessment of energy saving through retrofit of chillers, Appl. Energy 266 (2020) 114856.

[23] M. Gürtürk, H.F. Oztop, A. Hepbasli, Energy and exergy assessments of a perlite expansion furnace in a plaster plant, Energy Convers. Manag. 75 (2013) 488–497.

[24] L. Kong, L. Price, A. Hasanbeigi, H. Liu, J. Li, Potential for reducing paper mill energy use and carbon dioxide emissions through plant-wide energy audits: A case study in China, Appl. Energy 102 (2013) 1334–1342.

[25] U. Karki, P. Rao, Techno-economic analysis of the water, energy, and greenhouse gas emissions impacts from the adoption of water efficiency practices in the U.S. manufacturing sector, Resour. Conserv. Recycl. 196 (2023) 107054.

[26] M.N.I. Siddique, A.S.M.M. Hasan, M.A. Kabir, F.Z. Prottasha, A.M. Samin, S.S. Soumik, A. Trianni, Energy management practices, barriers, and drivers in Bangladesh: An exploratory insight from pulp and paper industry, Energy Sustain. Dev. 70 (2022) 115–132.

[27] B.F. Sasanya, O. Olaifa, Analysis of energy consumption in poultry management for table egg production in Nigeria, Heliyon 8 (2022) e10053.

[28] D. Al Momani, Y. Al Turk, M.I. Abuashour, H.M. Khalid, S.M. Muyeen, T.O. Sweidan, Z. Said, M. Hasanuzzaman, Energy saving potential analysis applying factory scale energy audit – A case study of food production, Heliyon 9 (2023) e14216.

[29] I. Bosu, H. Mahmoud, H. Hassan, Energy audit and management of an industrial site based on energy efficiency, economic, and environmental analysis, Appl. Energy 333 (2023) 120619.

[30] D. Moya, R. Torres, S. Stegen, Analysis of the Ecuadorian energy audit practices: A review of energy efficiency promotion, Renew. Sustain. Energy Rev. 62 (2016) 289–296.

[31] E. McLaughlin, J.K. Choi, K. Kissock, Techno-Economic Impact Assessments of Energy Efficiency Improvements in the Industrial Combustion Systems, J. Energy Resour. Technol. Trans. ASME 144 (2022).

[32] E. Cagno, S. Franzo, E. Storoni, A. Trianni, A characterisation framework of energy services offered by energy service companies, Appl. Energy 324 (2022) 119674.

[33] A.S.M.M. Hasan, A. Trianni, N. Shukla, M. Katic, A novel characterization-based framework to incorporate industrial energy management services, Appl. Energy 313 (2022) 118891.

[34] A. Abdel-Hadi, A.R. Salem, A.I. Abbas, M. Qandil, R.S. Amano, Study of energy saving analysis for different industries, J. Energy Resour. Technol. Trans. ASME 143 (2021) 1–9.

[35] F.M. Kanchiralla, N. Jalo, P. Thollander, M. Andersson, S. Johnsson, Energy use categorization with performance indicators for the food industry and a conceptual energy planning framework, Appl. Energy 304 (2021) 117788.

[36] M. Kamran, M. Turzy, H. Shams, Strategic energy audit and system assessment, Innovative Energy Management, 2026, pp. 37–83, Elsevier Publication.

[37] S. Taheri, E. Norouzijajarm, A. Amiri, Energy for Sustainable Development Technical, economic, and environmental assessment of energy audit and optimization in the mechanical room of an office building, Energy Sustain. Dev. 87 (2025) 101717.

[38] E. Alamin, A pragmatic retrofitting approach to enhancing the thermal, energy and economic performance of an educational building: a case study in Malaysia, Clean Energy, 7 (2023) 1282–1299.

[39] C.N. Abd, A. El Fadar, O.B. Achkari, Energy for Sustainable Development Energy efficiency improvement of a wood-manufacturing plant in Morocco through energy audit, Energy Sustain. Dev. 85(2025)101669.

[40] Y. Luo, E. Woolley, S. Rahimifard, A. Simeone, Improving energy efficiency within manufacturing by recovering waste heat energy, J. Therm. Eng. 1 (2015) 337–344.

[41] M. Kassas, W.M. Hamanah, A. Sahin, B.S. Yilbas, C.B. Ahmed, Operation of HVAC System for energy savings and economic analysis, J. Therm. Eng. 5 (2019) 181–197.

[42] Y. Zhu, Y. Wang, S. Hou, Y. Chen, L. Zhang, Enhancing carbon neutrality through renewable energy and demand-side management, J. Therm. Eng. 11(2025)1540–1551.

[43] M. of P. Bureau of Energy Efficiency (BEE), Book 2 - Energy Efficiency in Thermal Utilities, (2015) 296.

[44] M. of P. Bureau of Energy Efficiency (BEE), Book 3 - Energy Efficiency in Electrical Utilities, (n.d.).