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Identification of Savings Opportunities in a Steel Manufacturing Industry

Victor A. Alcalá Abraham[1], Elkin D. Alemán Causil[2], Vladimir Sousa Santos[2]*, Eliana Noriega Angarita[2], Julio R. Gómez Sarduy[3]

[1]Electrical Engineering Student, Universidad de la Costa, Barranquilla, Colombia, [2]Department of Energy, Universidad de la Costa, Barranquilla, Colombia, [3]Center of Energy and Environmental Studies, Universidad de Cienfuegos, Cuba.
*Email: vsousa1@cuc.edu.co

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ABSTRACT

This paper aims to present a procedure that allows identifying savings opportunities in a steel manufacturing company. The procedure based on the ISO 50001, 50004, and 50006 standards comprise the use of tools such as energy baselines, the goal line, energy performance indicators, the Pareto chart, and an energy review. As a result of the implementation of the procedure, it was possible to obtain the baseline, the goal line, and energy performance indicators that allow the control of energy consumption and efficiency of the company in general and of the area with the highest electricity consumption. It was possible to identify that there is a potential savings of up to 6% throughout the company and up to 13% in the area with the highest electrical energy consumption. From an energy review carried out in the area with the highest consumption, motors operating with low load and idle for long periods were identified, as well as a lack of maintenance. Besides, the replacement of traditional technology lamps by LED technology lamps was proposed. The procedure can be generalized in steel industries with similar characteristics, which is one of the sectors that consume the most energy worldwide.

Keywords: Electricity, Energy, Energy Efficiency, Energy Saving, Energy Performance Indicator, Steel Industry
JEL Classifications: Q4, L610

1. INTRODUCTION

The industrial sector consumes 29% of the world's energy demand and has an energy-saving potential of 20% equivalent to 974 million tons of oil equivalent (Morejón et al., 2019), (Eras et al., 2019), (Fawkes et al., 2016). This sector is also characterized by the intensive use of technology and complex processes, which require knowledge and a structure based on organizational management practices. In this context, programs have been developed to promote energy management systems in industries, promoting energy savings, the reduction of greenhouse gases, and the benefits of productivity, through management practices and technological changes (Sola and Mota, 2020), (IEA, 2018). The main policies adopted in these programs can be mandatory or regulatory, with incentives or support.

The concepts of energy management and energy management systems have been highlighted by specialists as follows:

- Activities include the control, monitoring, and improvement of energy efficiency in the production area (Bunse et al., 2011)
- Understands strategy/planning, implementation/operation, control, organization, and culture (Schulze et al., 2016)
- Energy management implies the systematic monitoring, analysis, and planning of energy use including energy management activities, practices, and processes (IIP, 2012)
- Energy management involves procedures through which a company works strategically on energy, while an energy management system is a tool to implement these procedures (Thollander and Palm, 2015)
- A systematic approach is required for continuous improvement of energy performance, including energy efficiency (ISO, 2011).

Improving energy efficiency is an important strategy to address energy supply security, climate change, and competitiveness, and can be achieved through technological changes or better organizational management or behavior changes (WEC, 2010). Despite public policies in many countries (IEA, 2018), actions to improve energy efficiency have encountered barriers within organizations. Such barriers are economic (Arens et al., 2017), and also behavioral (Trianni et al., 2017), or lack of knowledge and awareness about energy-efficient technologies (Hochman and Timilsina, 2017).

Both energy efficiency and energy management are implemented at different levels in manufacturing plants, namely: factory, production line, machine, and process, although the energy used in the processes is only a small fraction of the total consumption (Gutiérrez et al., 2018), (Apostolos et al., 2013). Monitoring energy use is a fundamental pillar to support the decision-making process about energy efficiency measures. This is based on the definition of key performance indicators (KPIs) (Bunse et al., 2011), which are energy performance indicators (EnPI) when developed for energy management (Rossiter and Jones, 2015). Although several EnPIs have been developed for manufacturing plants and processes, this varies too much to establish a single EnPI, that is, appropriate IDEs must be developed for each case (Bunse et al., 2011).

The implementation of energy management in the industry shows good results in several countries (Hens et al., 2017); (Sola and Mota, 2020); (Hossain et al., 2020); (Cai et al., 2017); (Tesema and Worrell, 2015); (Gandoman et al., 2018); (Sarduy et al., 2018). Until 2017, around 22,870 ISO 50001 certifications were issued worldwide, only 15 of them were issued in Colombia (Morejón et al., 2019). However (Weinert et al., 2011) emphasized the importance of developing new energy monitoring methods, to further support decision-making towards more efficient use of energy in production systems.

In Colombia, around 70% of the electrical energy that is generated is hydraulic. Although this is a renewable energy source (Henao et al., 2020), it is important to take saving measures, since its stability can be put at risk by environmental phenomena such as "El Niño" (Perez and Garcia-Rendon, 2021); (Reyes-Calle and Grimaldo-Guerrero, 2020). On the other hand, 46% of the electrical energy generated in the country is demanded by the industrial sector (UPME, 2018) with annual demand growth of around 3.4% (Rodríguez-Urrego and Rodríguez-Urrego, 2018); (Vélez-Henao et al., 2020). In this sense, several studies have been developed on the implementation of energy management in various companies (Montoya et al., 2016); (Manrique et al., 2018); (Alcántara et al., 2018); (Yáñez et al., 2018); (Angarita et al., 2019); (Eras et al., 2020) however, none have been developed in the steel manufacturing industry.

This study is important at a national and global level because within the industrial sector (Johansson, 2016), the iron and steel industry are the second-largest consumer of energy with an energy intensity of 20 GJ per ton of crude steel and CO_2 emission intensity of 1.9 t per ton of crude steel (Sun et al., 2020). Improving energy efficiency or conserving energy are the most controllable factors influencing energy consumption and emissions from the iron and steel industry, and climate change and rising energy prices are increasing, even more, its importance (Rojas-Cardenas et al., 2017); (Johansson, 2015). However, the opportunity to achieve energy savings is getting narrower after decades of hard work by the steel community (He and Wang, 2017).

This article proposes a procedure for identifying savings opportunities in a steel manufacturing company. The procedure is based on the ISO 50001, 50004, and 50006 standards and comprises one methodological step that include the quantitative estimation of electrical energy savings throughout the company and in the area with the highest energy consumption. In the procedure, the energy baseline is obtained, the goal line and energy performance indicators are identified. Additionally, an energy review is carried out in the area with the highest energy consumption and savings opportunities are identified. The proposed method could be applied in other steel manufacturing companies with similar characteristics.

2. MATERIALS AND METHODS

The ISO 50001, 50004, and 50006 standards (ISO, 2011); (ISO, 2014a); (ISO, 2014b) establish guidelines for the implementation of the different stages of an energy management system through the use of tools such as Energy baselines and energy performance indicators. Based on these standards, the following steps were applied to identify the area with the highest consumption, the determination of energy performance indicators, the main energy-consuming equipment, and the energy-saving proposals of the company under study.

The step sequence of the applied method is as follows:

1. Collection of general data
   In this step, the monthly data of processed steel and total electricity consumption of the company and by areas were collected in 2 years (2018 and 2019). The total electrical energy consumption data and by areas was obtained with electrical energy meters installed by the company and the production data was provided by the company's production area.
2. Obtaining the baseline and the energy performance indicator of the company
   The energy baseline is performed by obtaining a linear regression model from the data on electrical energy consumption and production. The determination index R^2 is evaluated, and it is greater than 0.6 it can be concluded that there is a significant dependence between the production and consumption of electrical energy, therefore the energy performance indicator is valid for its use (Eras et al., 2016). The energy performance indicator is shown in equation 1.

$$\mathrm{EnPI} = \frac{\mathrm{EC}}{\mathrm{P}} \tag{1}$$

where EC is the electrical energy consumption in MWh and P the production in terms of processed steel in t.

3. Obtaining the company's goal line
   A goal-line is a tool that allows the company to estimate the energy-saving potential and establish its energy-saving objectives from the points of best energy performance. This line is obtained with a linear regression model with the points that are below the baseline.
4. Estimation of the electricity-saving potential of the company
   The energy-saving potential is analytically estimated as the difference between the areas under the baseline and the goal line curves. In this study, this procedure was performed mathematically by integrating the mathematical models of the two lines. As limits of the integral, the minimum and maximum production values registered by the company were used. Equations (2), (3), and (4) present the solution of the integrals corresponding to the energy baselines and the energy goal line, with which the area under the lines is obtained. The energy-saving power is calculated with equation (5).

$$A_{uc} = \int_{P_i}^{P_s} \left(A \cdot P + B \right) dP \qquad (2)$$

$$A_{uc} = \frac{A \cdot P^2}{2} + B \cdot P \qquad (3)$$

$$A_{uc} = \left(\frac{A \cdot P_s^{\,2}}{2} + B \cdot P_s \right) - \left(\frac{A \cdot P_i^{\,2}}{2} + B \cdot P_i \right) \qquad (4)$$

$$E_{sp} = 100 \cdot \frac{A_{uc(bl)} - A_{uc(gl)}}{A_{uc(bl)}} \qquad (5)$$

where P_i and P_s is the minimum and maximum production respectively, A and B is the slope and intercept on the y axis of the baseline and goal lines respectively, E_{sp} is the area under the curve, $A_{uc(bl)}$ and $A_{uc(gl)}$ are the areas under the baseline and goal line, respectively.

5. Identification of the area with the highest electricity consumption of the company
   This step was made with the monthly electricity consumption in all areas registered in 2019 with the help of the Pareto diagram.
6. Obtaining the baseline and the energy performance indicator of the area with the highest electricity consumption
   This step is carried out with the same methodology as step 2, but with the production and consumption data for each area.
7. Obtaining the goal line of the area with the highest consumption
   This step is carried out with the same methodology as step 3 but with the production and consumption data for each area.
8. Estimation of the electrical energy saving potential of the area with the highest electrical energy consumption
   This step is done in a similar way to step 4.
9. Energy review of the area with the highest electricity consumption of the company
   For the energy review in the area with the highest consumption, the nominal data of the equipment with the highest energy consumption (i.e., electric motors) were collected, a survey was conducted with the technical staff on the use of the equipment and instantaneous measurements were made.
10. Energy-saving proposals in the area with the highest electrical energy consumption
    From the energy review, opportunities for saving electricity were identified focused on avoiding bad operating practices and improving technology from the point of view of efficiency.
11. Presentation of the results

In this step, the results are organized and presented.
Figure 1 show the sequence of steps of the method described for the energy review of the company.

2.1. Company Characteristics

The company under study belongs to the steel industry and is in Colombia. This company is dedicated to the transformation of steel through the manufacture of different products such as pipes, mezzanine profiles, cuts of sheets for machines, roof covers, rods for electro-welded mesh, profiles for ceilings as well as partitions and ceiling panels. The company has 13 areas, nine production areas, and four production support areas. Table 1 shows the areas, main functions, and type (i.e., production, production support).

3. RESULTS AND DISCUSSIONS

Table 2 shows the monthly records of the tons of steel processed and the total electricity consumption of the company during 2018 and 2019. Table 3 shows the annual data.

Figure 1: Method flow chart based on ISO 50001, ISO 50004, and ISO 50006 standards

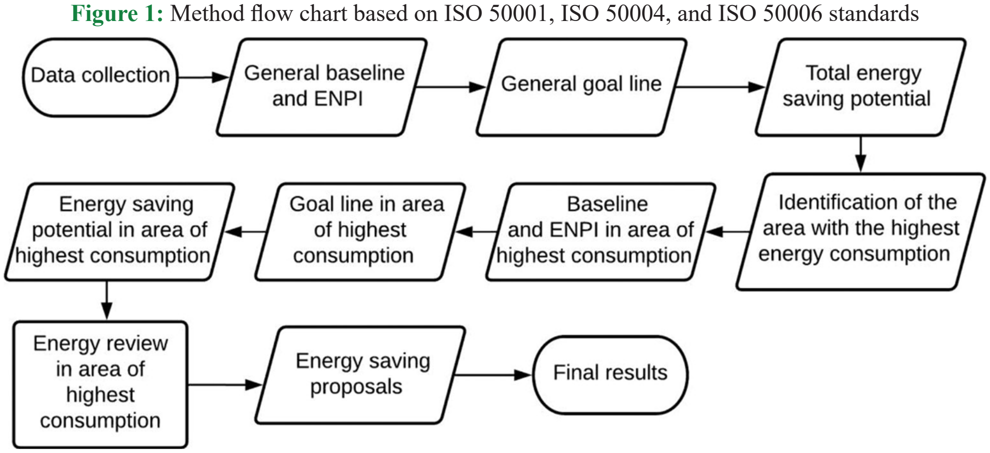


Table 1: Description of the company's areas

Name	Function	Type
Mckay	The production line that manufactures furniture type, structural, square, and rectangular pipes of different diameters	Production
Human resources office, security rooms, and maintenance workshop	Management of human resources, security, and industrial maintenance	Production support
Etna	The production line that manufactures furniture type, structural, square, and rectangular pipes of different diameters	Production
Promostar	The production line that manufactures rebar for an electro-welded mesh of different thicknesses	Production
Bridges crane	Transportation of heavy equipment between the areas of the company	Production support
Asc2	The production line that manufactures structural profiles of three types	Production
Asc	The production line that manufactures structural profiles of three types	Production
Samshin	The production line that manufactures steel deck type sheets for ceiling panels	Production
Mertform	The production line that manufactures easy plate-type profiles for ceilings	Production
Comec	The production line that manufactures roofing sheets	Production
Formtek	The production line that manufactures profiles for ceilings	Production
Recovery workshop	Maintenance of the tools that make up the manufacturing equipment	Production support
Administrative office	Administrative management of the company	Production support

Figure 2a shows the company's baseline including the model equation and determination index, obtained through a linear regression model from the data in Table 2. Figure 2b shows the energy baseline and the goal line.

As shown in Figure 2a, the correlation index obtained was higher than 0.6, which shows that there is a statistically significant relationship between the processed steel and energy consumption. This implies that the energy performance index and the mathematical model can be used to evaluate the energy performance of the company, also to estimate energy consumption and energy savings.

The energy-saving potential was estimated by the difference of the areas below the baseline and the goal line shown in Figure 2b. The area under the two lines was obtained by applying equations (2), (3), and (4) and estimating savings with equation (5). Table 4 shows the baseline and goal parameters, production limits, and calculated savings potential.

As shown in the table, the company's energy-saving potential is 6%. This expectation is achievable without making additional investments as it is obtained from the best records in energy performance that the company has had. In this sense, it is proposed to identify and systematize the practices that made it possible to obtain these results, as well as to avoid the practices that produced poor energy performance.

Table 2: Production and monthly energy consumption of the company

Date	P (t)	EC (MWh/month)
January-2018	2,006	227.2
February-2018	2,123	212.3
March-2018	2,315	242.9
April-2018	1,976	206.6
May-2018	2,016	230.4
June-2018	1,736	212.3
July-2018	1,613	206.5
August-2018	2,032	225.3
September-2018	2,534	253.4
October-2018	2,824	239.7
November-2018	3,031	297.8
December-2018	1,810	201.6
January-2019	2,800	251.3
February-2019	2,564	225.9
March-2019	2,299	252.2
April-2019	3,133	277.7
May-2019	2,370	237.5
June-2019	1,556	182.7
July-2019	2,461	220.2
August-2019	2,821	244.2
September-2019	1,822	180.5
October-2019	2,919	246.2
November-2019	2,551	216.9
December-2019	2,897	227.0

Table 3: Annual energy production and consumption of the company in 2018 and 2019

Year	P (t)	EC (MWh/month)
2018	26,016	2,756
2019	30,194	2,762

Figure 3 represents the Pareto diagram with the energy consumption of the areas of the company with the data for electricity consumption and production for the year 2019. The area number corresponds to the areas described in Table 1.

According to the figure, the area with the highest electrical energy consumption is identified as "Mckay". For the year 2019, this area consumed 590 MWh/year, representing 21.3% of the electricity consumption of the company. Efforts to identify opportunities for saving electricity were focused on this area.

Table 5 shows the monthly production and consumption data for the area with the highest energy consumption.

Figure 4 shows (a) the baseline and (b) the baseline and the goal line. In this case, to reach the correlation index of 0.6, non-representative data were filtered using the "Hampel" method (Lin et al., 2007).

Table 6 shows the baseline and goal parameters, production limits, and the calculated savings potential applied in equations (2), (3),

Figure 2: (a) Baseline and (b) baseline and goal line of the company

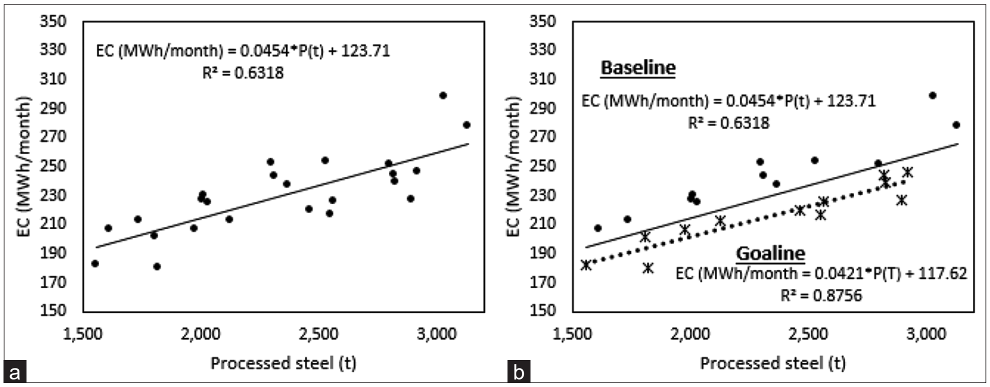
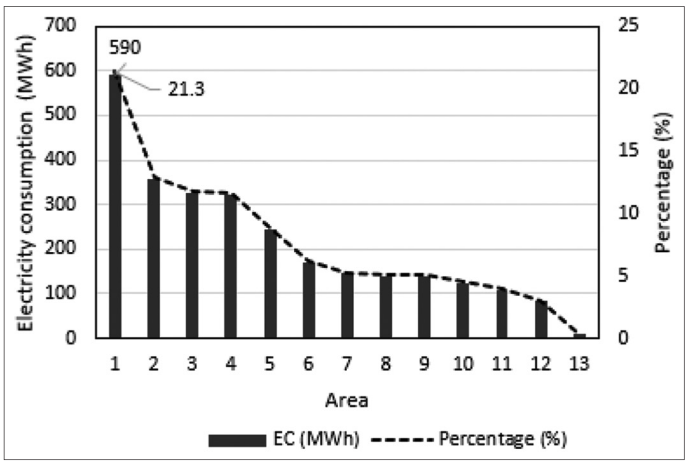


Figure 3: Pareto chart



(4), and (5). The baseline and goal models obtained can be used by the company to monitor and plan energy consumption and performance in the area.

According to the results, there is a potential for energy savings that can reach up to 13% only by standardizing the good practices that allowed obtaining the best energy performance.

As a result of the energy review in the "Mckay" area, 73 motors of 26 different types and 20 lamps were evaluated. Table 7 shows the nominal characteristics of this equipment and the approximate operating time.

Figure 5 shows the Pareto diagram of the "Mckay" area equipment with the energy consumption of each equipment and the accumulated consumption. It is also pointed out the equipment where 79% of the energy consumption is reached.

According to the Pareto diagram, six motors account for 79% of electrical energy consumption. As a result of the energy review, the following savings opportunities were identified that can contribute to improving the energy performance of the Mckey area:

- Most of the motors are working with a load factor of less than 50% which implies that they are operating in the low-efficiency zone (Santos et al., 2019) and a good part of the motors are not of premium efficiency (IE3). Taking this into account, it is proposed to evaluate the substitution for motors with a lower capacity and a higher level of efficiency
- The lamps in the area can be replaced by LED technology, which can mean energy savings of more than 30% (Liu et al., 2019)
- The idle operation of motors for long periods was identified, which implies a waste of energy. According to this the

Table 4: Parameters for calculating the energy-saving potential of the company

Line	A	B	P_i (t)	P_s (t)	E_{sp} (%)
Baseline	0.0454	123.71	1556	3133	6
Goal-line	0.0421	117.62			

Table 5: Monthly production and electricity consumption of the area "Mckay"

Date	P (t)	EC (MWh/month)
January-2018	325	52.8
February-2018	317	60.1
March-2018	727	63.2
April-2018	624	59.0
May-2018	603	59.6
June-2018	330	43.3
July-2018	420	50.9
August-2018	360	44.8
September-2018	862	57.6
October-2018	826	57.1
November-2018	887	67.9
December-2018	168	40.4
January-2019	735	49.0
February-2019	594	38.9
March-2019	980	64.9
April-2019	1095	122.9
May-2019	613	46.2
June-2019	392	34.0
July-2019	665	44.6
August-2019	644	30.0
September-2019	182	14.4
October-2019	534	49.5
November-2019	795	48.4
December-2019	527	46.8

Table 6: Parameters for calculating the energy-saving potential of the area "Mckay"

Line	A	B	P_i (t)	P_s (t)	E_{sp} (%)
Baseline	0.0457	21.426	168	1095	13
Goal-line	0.0591	6.2605			

Figure 4: (a) Baseline and (b) baseline and goal line of the area "Mckay"

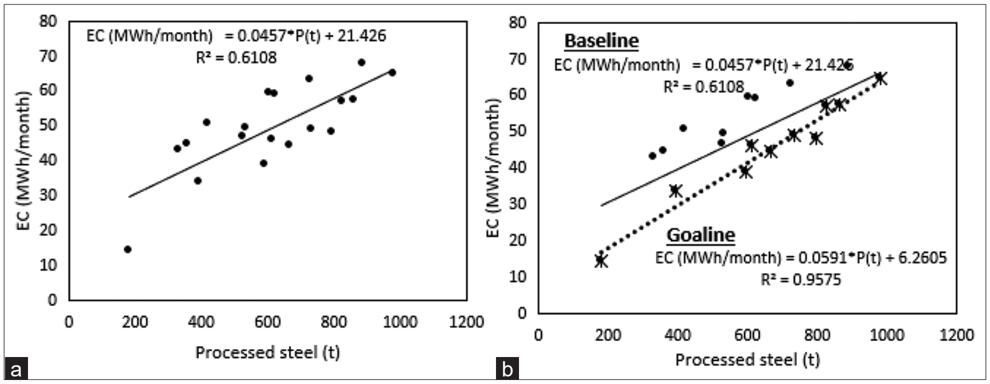


Figure 5: Pareto diagram in the "Mckay" area

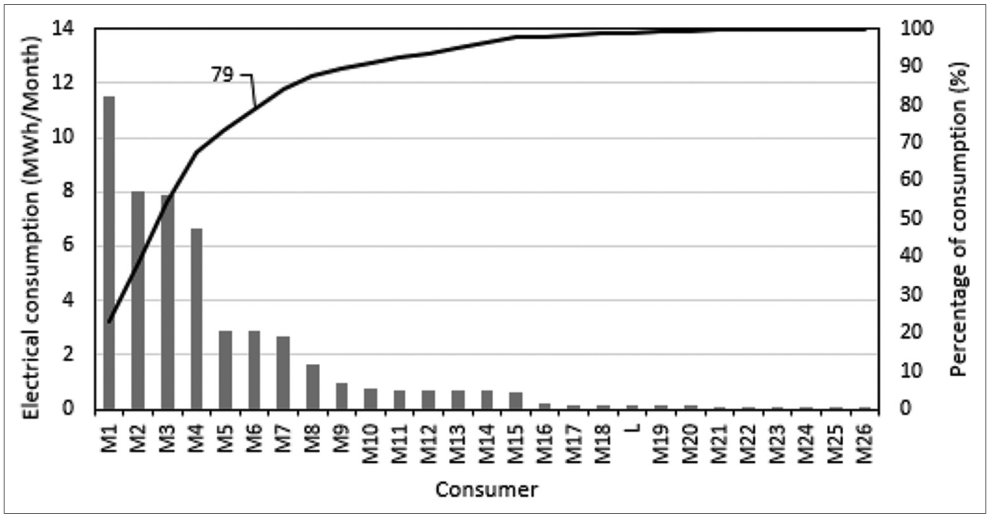


Table 7: Nominal and operating data of the "Mckay" area equipment

Cons.	Qty	P_{mec} (kW)	Voltage (V)	Current (A)	Speed (RPM)	η (%)	P_{elc} (kW)	Oper. time (h/month)
M1	2	93	460	143	1785	95	68.5	168
M2	1	110	460	170	1780	95.8	57.4	140
M3	1	75	440	118.2	1780	95.7	47.0	168
M4	2	75	460	113	1780	94.5	47.6	140
M5	1	38	460	61.9	1770	92.5	20.5	140
M6	1	18.5	760	18.2	1740	91	10.2	280
M7	1	37	412	70	2000	95.8	19.3	140
M8	1	22	440	37.6	1760	91.5	16.8	98
M9	1	11	440	18.6	1765	83	6.6	140
M10	3	9	440	17	3230	95.8	5.6	134
M11	1	9	440	17	1745	88.1	5.1	140
M12	15	7.5	440	15.5	1730	74.7	5.0	140
M13	1	5.5	460	9.5	3470	86.9	4.4	157
M14	1	9.2	440	16.5	1755	95.8	4.8	140
M15	3	5.5	440	9.55	3500	86.9	3.8	168
M16	6	1.27	440	2.85	1675	78.1	1.1	196
M17	1	11	440	18.9	1760	90	8.6	20
M18	1	2.2	440	4.09	1730	86.5	1.3	112
L	20	N/A	220	N/A	N/A	N/A	0.4	336
M19	1	0.55	440	1.7	1600	60.6	0.6	196
M20	6	1.73	460	3.55	1675	80.4	1.1	112
M21	1	0.55	115	10	1725	68	0.6	157
M22	1	0.55	440	1.29	1728	74	0.4	168
M23	1	2.2	440	4.09	1730	86.5	1.5	34
M24	3	0.65	400	2.1	4560	95.8	0.3	112
M25	15	0.09	440	0.31	3100	58.6	0.1	168
M26	2	0.18	440	0.56	1655	68.5	0.1	7

where: Cons. is consumer, M is electric motor, L is the lamp, Qty is the quantity of equipment, P_{mec} is mechanical power, η is the efficiency, P_{elc} is electric power, and Oper. Time is the operating time

installation of automatic disconnects or the training of personnel is proposed to avoid this bad practice
- In some electric motors and equipment, lack of maintenance is evident, which leads to mechanical failures and inefficient operation. In this sense, the development of a comprehensive maintenance system based on energy efficiency is proposed.

4. CONCLUSIONS

The study presented demonstrates the possibility provided by the ISO 50001, 50004, and 50006 standards to implement tools of little complexity without the need for investment and that can significantly impact the control of energy consumption and the identification of energy-saving opportunities of a company.

In the case study presented, it was possible to obtain the baseline and goal lines and valid energy performance indicators that allow the control of energy consumption and energy efficiency of the company in general and of the areas. Also, it was possible to identify from mathematical and statistical tools that there is a saving potential of up to 6% throughout the company and up to 13% in the area with the highest electrical energy consumption that can only be achieved by standardized good operating practices.

As a result of an energy review, it was possible to identify the operation of motors working with low load and no-load for long periods, as well as lack of maintenance. Besides, the replacement of traditional technology lamps by LED technology lamps was proposed.

The applied procedure can be generalized in steel manufacturing industries with similar characteristics, which can have a positive impact on this sector, which is one of the most energy-consuming globally.

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