Energy Efficiency Promotion in an Industrial Sanitary Systems Production Unit

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Abstract

This dissertation was made based on a challenge proposed by the company OLI – Sistemas Sanitários, regarding its futurist vision and environmental concerns, who proposed the fulfilment of an energetic analysis of its main industrial area, a study of possible investments and improvement actions aiming the reduction of its energy consumption and associated costs.

In order to do this academic work, it was necessary to start by making a primary macro analysis to the consumption patterns of the factory and concluded that the building consumes about **8494,6** MWh/year. It was also estimated that the unit as a base consumption of **64,9** MWh/month, which isn't related to the raw material injected. The other part of the consumption has to do with the raw material, and it is **1,47** kWh/kg of injected plastic.

It was studied many energetic improvements and efficiency proposals and was estimated that the investment on a photovoltaic energy production unit for self-consumption allows to obtain a **112.748 €** savings on the first year. The lighting system could be improved, resulting in an estimated reduction of **3.500 €** per year. The current motor's replacement for higher efficiency ones, and the investment on variable speed drives to the motors allows the reduction of the electrical bill in **5.857 €** and **7.570 €** per year respectively. It was also proposed the substitution of the injection hydraulic machines for electrical ones which are more efficient, resulting in savings about **8.675 €**/year on the studied machine.

Concerning operational improvements, it was made a list of good habits that together allows energy reductions of about **17.153** €/year.

Key Words: **Energy Efficiency, Energy Auditing, Improvement Actions, Photovoltaic Energy Production Unit, Good Operating Habits, Injection Moulding.**

I. Introduction

The European Union (EU) has been implementing measures to reduce the environmental impact resulting from the energy production. It is therefore extremely important to increase energy efficiency in different sectors in order to reduce energy consumption in various areas leading to increased competitiveness of the world economy and reduction of Greenhouse Gases (GHG), contributing to environmental improvement.

Over the last 2 decades, several protocols and agreements have been established to preserve the environment. Some of these examples are the Kyoto Protocol and the Copenhagen, Durban and Paris Agreements. More recently, the European Commission comes up with the 20-20-20 initiative, which has three objectives by the year 2020. They are:

(1) Reduce GHG emissions by 20% compared to 1990;

(2) Achieve that 20% of consumption in Europe comes from renewable sources;

(3) Increase energy efficiency by 20%.

These targets were set by EU leaders in 2007 and enacted in 2009 [1].

The first target set for GHG was reached before the deadline set. By 2015, these emissions had been reduced by 22% compared to 1990, which exceeds the set target of a 20% reduction by 2020.

As for the remaining 2020 targets, it appears that the targets will be met by some margin. Still, an update of these goals for 2030 and 2050 has recently been made and will not be achieved if the path taken to date is maintained.

A steeper slope of developments is required to achieve these targets [2].

As can be seen from Figure 1, as mentioned above, it is found that by maintaining the trajectory traveled until recently, the targets for 2030 and 2050 will not be met.

It is therefore important to take measures that reduce GHGs sharply, further increase energy consumption from renewable sources and increase energy efficiency [3].

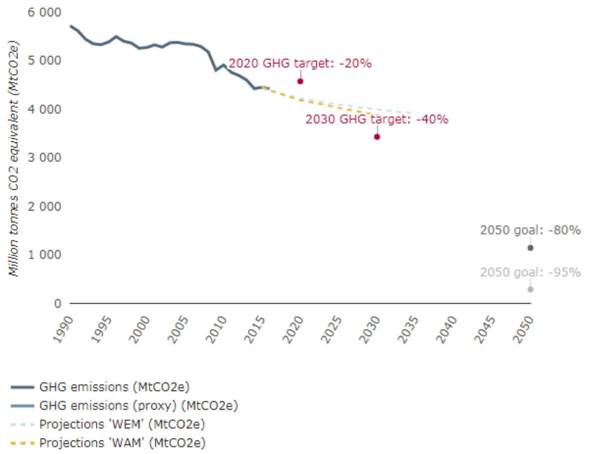


Figure 1. Evolution of Targets 20-20-20, from [3]

II. State of the Art

2.1. Energy Management

Energy performance evaluation in an industrial unit is directly linked to its energy efficiency allowing to quantify the impact of possible improvement policies, programs or mechanisms. In addition, it allows identifying the areas of the installation with more necessity in what concerns intervention and, can also serve as a motivation for the adoption of new measures [4].

In order to improve the energy efficiency of a facility, after an audit, Energy Rationalization Plans (PREn) are presented, which consist of a manual of measures or recommendations that will continuously improve the energy efficiency of the site [5].

With the purpose of having rationalization plans and energy savings, it is crucial to make an energy assessment for the plant concerned. Each industrial unit has unique characteristics and it is important to make a specific analysis of the unit concerned. For this, according to Kent & Cheater [6], it is necessary to answer four questions regarding the use of energy and, subsequently, it is important to analyze the obtained data. The first thoughts on the energy analysis of an industrial unit are as follows:

(1) Where energy is being used;
(2) When in used;
(3) Why it is being used;
(4) How much is being spent.

Several authors suggest energy audits to answer the above questions [7].

Abdelaziz et al. [8] state that energy management, investment in new technologies, and the implementation of energy policies and regulations are the three possible approaches to improving energy efficiency in industry and achieve energy savings.

Audits are the key to access the energy performance of an industrial unit, and the detailed steps to pursue in this process generally include the following procedures [9]:

(1) Preparation and planning;
(2) Data collection and review;
(3) Plant survey and system measurements;
(4) Observation and review of operating practices;
(5) Documentation and data analysis;
(6) Reporting of data and recommendations;
(7) Preparation of actions and implementation plans and implement them.

Energy audits aim to characterize energy consumption, enabling the identification of potential energy saving measures for subsequent elaboration of rationalization plans that lead to reductions in the energy bill. Energy rationalization plans can be equipment improvements or operating procedures that lead to energy rationalization [10].

Generally, audits are divided into 3 types depending on their level of detail. More recently, some authors present more detailed divisions, or add levels to the existing three [11]–[13]. The main types of audit distinctions mentioned by the authors are as follows:

- Level 1: Walk-through assessment;
- Level 2: Energy Survey and Analysis;
- Level 3: Capital Intensive modifications and computer simulation.

Although, as noted above, the authors make different divisions between levels of complexity, the main tasks, procedures, and their purpose are common.

The sensible and efficient use of energy in order to minimize costs and increase the company's competitiveness is called energy management. This management has as main objectives [14]:

(1) Save energy;
(2) Minimize energy costs;
(3) Minimize energy waste;
(4) Minimize environmental effects.

According to Papadopoulou [15], in order to achieve the above objectives, it is important to define the following principles and operations:

(1) Adopt and implement energy rationalization policies;
(2) Acquire all possible energy at the lowest price;
(3) Manage energy use as efficiently as possible;
(4) Reuse and recycle the energy in cascade;
(5) Use the most appropriate technologies;
(6) Reduce avoidable losses;
(7) Strong environmental concern from companies.

According to Hasan et al. [16] in the industrial sector, energy management is the most viable and economically efficient approach to improving energy efficiency.

With the aim of improving energy management, reducing costs, consumption and supporting a long-term strategy, Energy Management Systems (EMS) have emerged, that provide a framework for developing an energy policy, setting goals and targets, measuring results, use graphics to support decisions, and encourage continuous improvement [17].

Then several energy management systems came, and in June 2011, the International Standard Organization (ISO) arrives with a global standard - ISO 50001.

This International Standard is an energy management system that encourages and provides continually improving for the energy performance of organizations. This system specifies an energy management methodology that organizations can adopt to improve their energy competitiveness.

Several authors have studied the impact of implementing this system and found that good results are obtained in improving energy performance indicators and in the competitiveness of companies. They also point out that this type of result motivates them to implement this system, as it is possible to obtain considerable energy and economic savings [12], [18]. Still, for the realization of this system is important the investment in the development and implementation of energy policies, definition of goals, objectives and action plans.

As noted, this standard is based on a Plan-Do-Check-Act (PDCA) continuous improvement framework, the structure of which is shown in Figure 2, and encourages daily energy management [19].

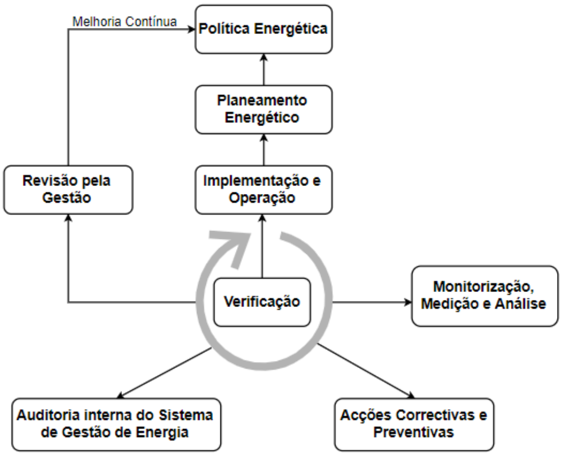


Figure 2. Plan-Do-Check-Act Cycle, adapted from [19]

PDCA is a procedure that can be defined in energy terms as follows [20]:

• Plan - Conduct an energy review to establish a consumption baseline, energy performance indicators, objectives, goals and action plans.

• Do - Implement the energy management action plans.

• Check - Measure and monitor production processes to detect energy irregularities.

• Act - Take continuous improvement actions to increase energy performance and energy management system.

Figure 3 shows how energy audits are inserted into the ISO 50001 energy management system.

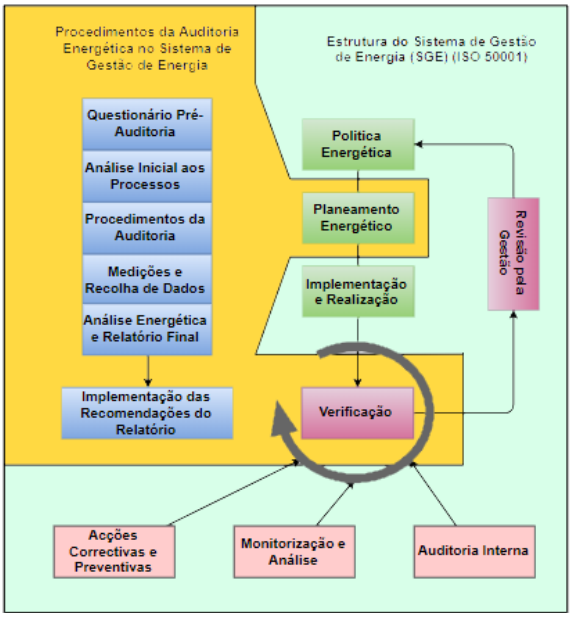


Figure 3. Structure of na Energy Audit Inserted in Energy Management System, ISO 50001, adapted from [21]

2.2. *Energy Performance Indicators*

The main feature of a good energy management system, from a monitoring point of view, are the energy performance indicators required for continuous improvement of a facility.

These are defined as reference points from which comparisons can be made. Its main objectives are: to improve understanding of the energy consumption of installations, to increase their energy efficiency and to reduce their carbon intensity [22].

According to Bunse et al. [23] the three most relevant indicators are as follows:

- Energy Intensity (EI):

$$EI = \frac{Total\ Energy\ Consumption}{Gross\ Value\ Added}$$

- Specific Energy Consumption (SEC):

$$SEC = \frac{Total\ Energy\ Consumption}{Production\ Volume}$$

- Carbon Intensity (CI):

$$CI = \frac{Quantity\ of\ Gaseous\ Emissions}{Total\ Energy\ Consumption}$$

III. Methodology

The sources of data collection for the company's energy characterization and for production data are as follows:

- Energy audit data performed at OLI in 2015;
- Fourth hourly energy consumption data of transformation stations made available online by the energy distributor;
- Records of the production management system;
- Measurements:
  - Energy monitoring software (Method A);
  - Fluke 1735 Energy Analyzer (Method B).

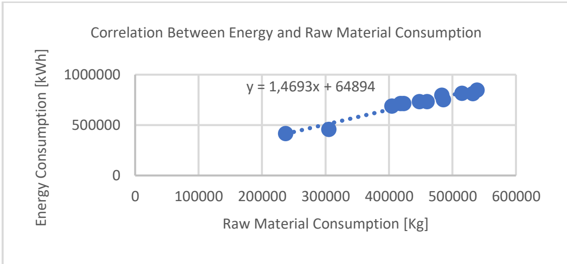


Figure 4. Correlation Between Energy and Raw Material Consumption

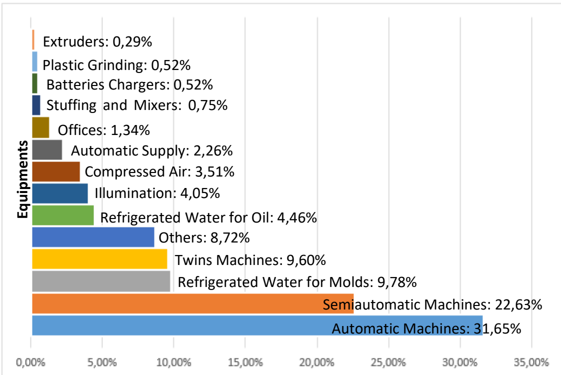


Figure 5. Energy Consumption Distribution

The injection machines were divide into different types depending on the product they produce. The following hourly consumptions were obtain for the different machines.

Table 1 presents the results of the measurements of machines hourly energy consumptions.

Table 1. Average Energy consumptions Hours per Product and Machine Type

Machines	Injection	Exterior	Interior	Plaques	Average
Energy Average Consumption of Hydraulics Machines [kWh/h]	10,8	31,7	31,9	22,8	19,9
Energy Average Consumption of Electric Machines [kWh/h]	5,2	0	0	9,3	6,2
Energy Average Consumption of Hybrid Machines [kWh/h]	0	0	24,5	0	24,5
Total Average	9,9	31,7	30,4	19,4	18,4

The proposed technological and operational improvements differed.

At the technological level, the following improvements were studied: Implementation of a photovoltaic system for self-consumption energy production, replacement of the current lighting system by a more efficient one, replacement of hydraulic injection machines by more efficient electric ones, replacement of current motors by more efficient motors and application of electric speed drives, as well as the implementation of an energy management software for consumption monitoring.

Operational measures include changing some habits and practices in order to reduce energy waste. Setups should be performed to minimize wastage of resources such as time, raw materials and energy consumption.

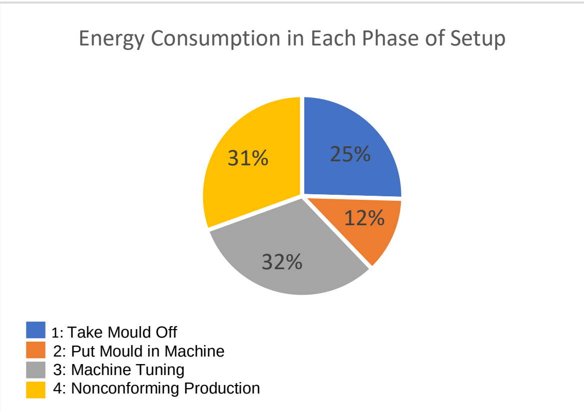


Figure 6. Distribution of Energy Consumption Spent in Setup

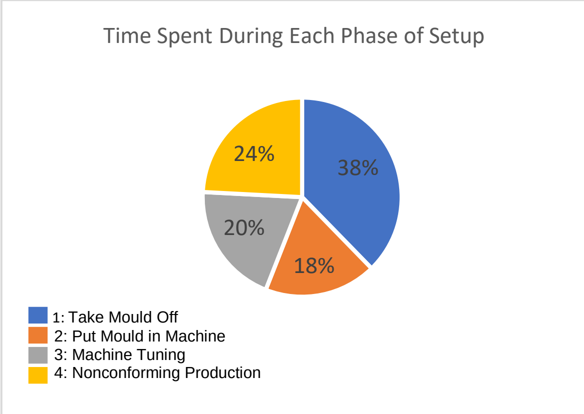
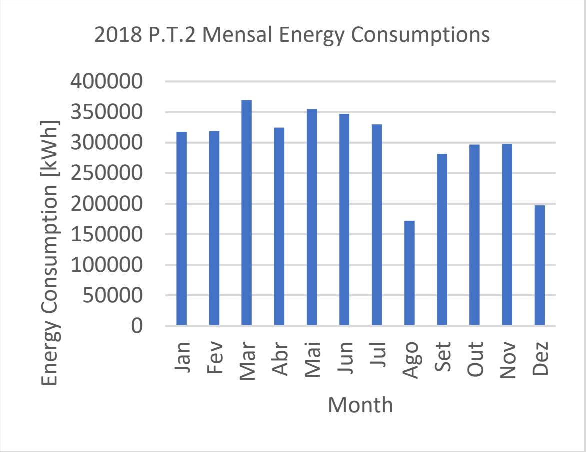


Figure 7. Distribution of Time Spent in Setup

The SMED procedure is used for mould replacement, but it can be improved. In setups, can also be changed the timing of mould cleaning which may lead to reduced consumption of changes. Given production planning, machines sometimes remain idle so that they can be used without heating time, when new production needs to start. We study the impact of shutting down machines or keeping them idle in order to optimize energy consumption. In addition to the consumption of machines, their peripherals also have a significant influence on the overall consumption of the industrial unit. The importance of turning off machine peripherals at appropriate stops is also studied to understand the impact of this measure. Given the energy contracts established with the distributors, other factors such as peak loads and energy consumption time also influence the monthly amount of the energy bill. The impact of changing the charging times of factory transport equipment, to times with lower energy tariffs was studied too, as well as the influence of having a constant energy consumption reducing peak load.



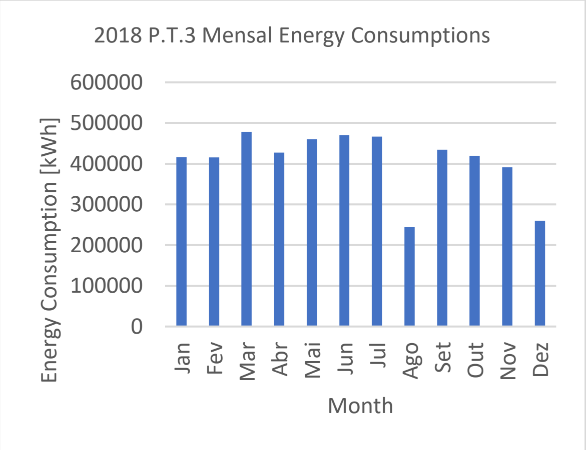


Figure 8. Monthly Consumptions of Transformations Stations 2 and 3 in 2018

IV. Results and Discussion

4.1. Photovoltaic System

Three hypothesis for photovoltaic systems were studied to implement.

The results are shown in the Table 2.

Table 2. Forecast of Energy use after Photovoltaic System Implementation

Results	Energy Produced [kWh]	Sold to Grid [kWh]	Purchased from the grid [kWh]	Autoconsumption [kWh]
Hypothesis 1	946037	62263	7610880	883773
Hypothesis 2	1216667	91315	7369301	1125353
Hypothesis 3	1621444	153422	7026631	1621444

4.2. Illumination

Illumination system was evaluated and, it was identified one solution that can replace the actual system by another one more efficient and that could provide energy savings.

Table 3. Characteristics of Actual and Proposed Illumination Systems

Solution	Actual	1
Reference	OSRAM L36W/765	T8 Advanced Universal Gen 8
Power [Watts]	36	14
Luminous Flux [Lummens]	2500	2100
Efficiency	69,4	150
Lengths [mm]	1200	1200
Color [K]	6500	4000
Lifetime [h]	13000	50000
Cost [€]	2	29

4.3. Injection Moulding Machines

For this study, two automatic machines were used, one hydraulic (Machine 65) and the other electric (Machine 117), in order to compare the energy consumption of both. These machines have similar closing forces, machine 65 having 80 tones and machine 117, 130 tones, allowing a more accurate comparative analysis. To perform this analysis, was evaluated the consumption of machines in production with similar moulds and injecting the same raw material. The properties of both machines and productions are shown in Table 4 as well as the hourly consumption obtained in both measurements.

Table 4. Hydraulic and Electric Machines Compare

Machines Proprieties	Machine 65 (Hydraulic)	Machine 117 (Electric)
Closing Force [Tones]	80	130
Robot	No	Yes
VSD	No	Yes
Mould	ML1099	ML1010
Cycle Time [Sec.]	25	38
Raw Material	ABS	ABS
Piece Weight [Kg]	0,0141	0,0665
Hourly Consumption [kWh/h]	12,81	3,41

4.4. SMED

After analyzing the setups, the SMED procedure used by the company was verified. This analysis was performed simultaneously with the measurement of energy consumption in order to be able to identify in more detail the impact of the various tasks of the SMED procedure and the respective energy consumptions.

In total, seven analyzes were performed at different setups. For each one, the non-value-added times were identified in the setup and three different types of non-value-added times were verified. Thus, the average results obtained are shown in Table 5.

Table 5. Average Non-Value-Added Times Spent During Setup

Tempos	Tempo de Espera [min]	Tempo de Transporte [min]	Tempo de Organização [min]
Tempo médio por Setup	7,3	2,3	0,3
% Tempo do Setup	12,5%	2,6%	0,4%

4.5. Idle

To plan a machine shutdown that results in energy savings, a study was carried out for both semiautomatic and automatic machines to find out how long that shutdown has a positive impact on energy consumption.

To do this, power consumption was measured at startup, and during standby of a semi-automatic machine (Machine 121) and an automatic machine (Machine 63). The results of both measures are shown in Table 6.

Table 6. Values of Energy Consumption during Startup and Standby

Energy Consumption	Hourly Energy Consumption [kWh/h]		Duration [Horas]	Energy Consumption [kWh]
	Startup	Standby	Startup	Startup
Semiautomatic Machine	21,7	1,7	0,65	14,1
Automatic Machine	5,9	1,0	0,4	2,4

4.6. Peripherals

The influence of some machine components and peripherals on their total energy consumption was investigated.

Figure 9, Figure 10 and Figure 11 shows the impact of shutting down the controller box, hydraulic pump and thermoregulator respectively.

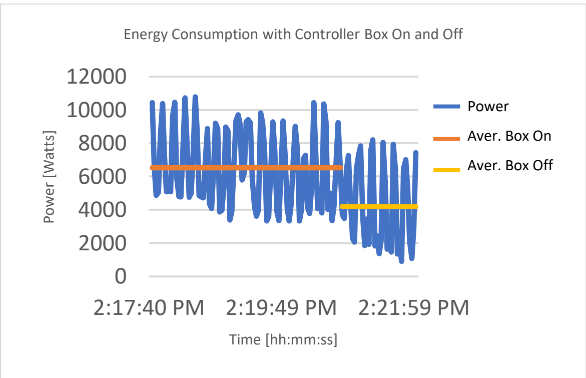


Figure 9. Load Diagram of Machine 107 with Controller Box On and Off

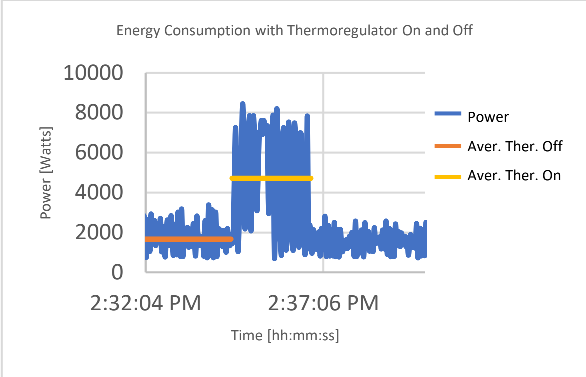


Figure 10. Load Diagram of Machine 107 with Thermoregulator On and Off

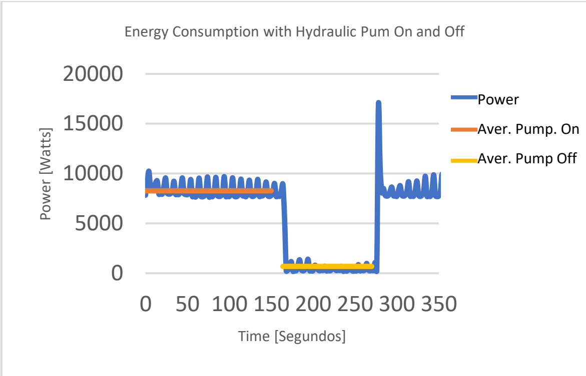


Figure 11. Load Diagram of Machine 50 with Hydraulic Pump On and Off

The consumption reductions are 2,31 kWh/h, 3,0 kWh/h and 7,58 kWh/h for the controller box, thermoregulator and hydraulic pump respectively.

4.7. Final Results and Good Practice Guide

For operational or behavioural improvements, a set of good practices was suggested, in order to change some habits of the company's employees and thus reduce energy waste.

Energy performance indicators should be improved with the implementation of the proposed improvements. Thus, based on the analyses performed above, the final values of the indicators obtained from the proposals made were estimated.

These proposals are expected to have a positive impact, is this to reduce both specific energy consumption as well as energy intensity and carbon intensity.

The following table shows the expected values and calculated values of 2018 of the three energy indicators before and after the implementation of the proposed improvements.

Table 7. Energy Indicators Results after Implementations of Proposed Improvements

Energy Indicators	2018 Values	Expected Values After Proposed Improvements Implementation
Energy Intensity [kgep/€]	0,085	0,082
Specific Energy Consumption [kgep/ton]	347,774	335,956
Carbon Intensity [tCO_2/tep]	2,186	1,936

It can be seen that the three energy indicators evaluated have reductions resulting from the proposals made, implying a positive result in them. In the first two, energy intensity and specific energy consumption account for the energy consumption reductions achieved through the proposed improvements with the exception of the photovoltaic power generation system. The implementation of the photovoltaic system has no impact on these indicators. However, in carbon intensity, the positive result obtained from the implementation of the clean energy production system reduces CO2 emissions, reducing the third indicator. Table 3 presents the main results obtained for the different proposals.

Table 8. Resume of Proposed Improvements

Improv.		Savings [kWh]	Savings [€/year]	Inv. [€]	PRI [Years]
Tech.	P.V. System	1.125.353	112.748	458.635	4,7
	II.	4.007	3.506	4.190	1,2
	Inj. Mach. [1 Mach.]	78.866	8.675	90.000	10,4
	Motors and VSD	122.064	13.427	68.440	5,1
	Software	-----------	-----------	-----------	-----------
	Total	**1.330.290**	**138.356**	**621.265**	**4,5**
Oper.	SMED	6.136	675	-----------	-----------
	Setups	2.627	289	-----------	-----------
	Idle [Auto Mach.]	1.873	206	-----------	-----------
	Peripherals	73.091	8.040	-----------	-----------
	Bat. Charg.	-----------	1.001	-----------	-----------
	Peak Red.	-----------	6.942	-----------	-----------
	Total	**83.727**	**17.153**	**-----------**	**-----------**
Total		**1.414.017**	**155.509**	**621.265**	**4,0**

Suggested best practices for operational improvements are as follows:

- Improve SMED procedure to eliminate the following non-value-added times:
  - Waiting Times;
  - Transportation Times;
  - Organizational Times.
- Cleaning of the mould in detail in the 2nd phase of the setup, avoiding its cleaning repeatedly in the 4th phase;
- Semi-Automatic Machines:
  - Keep the machines in standby whenever the duration of their idle is less than 8 hours.
- Automatic Machines:
  - Perform a Shutdown whenever these idles last for more than 2 hours and 20 minutes;
  - Keep the machines in standby whenever the duration of their idle time is less than 2 hours and 20 minutes.
- Switch off the controller box whenever production ends, and when it is not necessary to preheat the next mould;
- Disconnect the hydraulic pump from the injection machine whenever the machine is not in production, and the pump is not required for machine interventions;
- Turn off the thermoregulator whenever the machine is stopped.
- During the 5 working days of the week:
  - Charge equipment batteries from 00 hours to 7 hours;
  - Allow full charging of batteries;
  - In battery exchange equipment, always change between 00 hours and 3 hours, since the battery charge time is about 4 hours.
- On Saturdays:
  - Charging should be done between 00h and 09h.
- On Sundays:
  - Charging can be done all day long.

- Staged start-up of the machines on Monday is this, starting the semiautomatic machines early, thus preventing the coincidence of the machine starting peaks;
- Production planning taking into account the energy costs of each machine, based on the hourly consumption history of each machine.

V. Conclusion

Throughout the monitoring of the consumptions and the several analyses carried out, improvements were identified as much at the operational level as technological. Improvements were identified mainly at the behavioural and operational level, and the company is already well developed at the technological level. Even so, with the increasing technological evolution, it was verified that some investments in more efficient equipments allow to obtain significant consumption reductions.

It was proposed to invest in a self-consumption photovoltaic production unit with an installed power of 900 kWp, which will save 112.748 € after the first year of implementation. This measure makes it possible to sustain self-consumption in the first year of 1.125.353 kWh.

The “fish market” lighting system can be replaced by a more efficient lighting system and this results in a reduction of 4.007 kWh in annual consumption, which translates into 3.506 € per year. It is also proposed to replace the hydraulic injection machines by more efficient electric machines and it has been found that this improvement allows a reduction of 78.866 kWh per year in a machine that runs 8.390 hours per year, saving € 8.675 annually. It was also concluded that the replacement of some current motors by more efficient motors, as well as the implementation of variable speed drives coupled to their motors, can lead to reductions of 122.064 kWh per year, which means a saving of 13.427 €/year. It is also suggested the implementation of an energy management software, which allows the monitoring of consumption and contributes to the continuous improvement of energy management in the company.

With regard to operational improvements, it was concluded that these, while having a less significant impact on reducing energy consumption, do not require as high an investment as technological improvements. It is suggested, therefore, the improvement of the SMED procedure currently used in the factory, which allows the reduction of 6.136 kWh/year, the rigorous cleaning of the moulds that allows reducing the energy consumption by 2.627 kWh per year, the shutdown to the automatic injection machines reduces 1.873 kWh/year, shutting down machines peripherals when not in use, reduces 73.091 kWh/year, and changing the charging time of the factory transport equipments, and reducing load peaks may result in a cost savings of 1.001 € and 6.942 € per year respectively.

As a result, technological improvements together lead to a saving of 1.330.290 kWh/year resulting in an annual savings of 138.356 €. At the operational and behavioural level, even though they have a lower impact on reducing energy consumption, they generate savings of 17.153 €/year and, a priori, do not imply financial investment.

With regard to energy performance indicators, the implementation of the proposed improvements is expected to result in a reduction of 3.5% in energy intensity, 3.4% in specific energy consumption and 11.4% in carbon intensity.

It can be concluded that energy management, constant investment in more efficient technologies and the creation of energy habits and policies make it possible to increase the efficiency of installations and production processes. It is important to adopt energy practices with the objective of reducing waste, allowing companies to increase their competitiveness and improve their energy efficiency, contributing to global sustainability.

In the future, it is suggested to carry out a detailed analysis of energy consumption in the various plant sectors. In addition, it is important to carry out a detailed study of the impact of replacement of transport equipment batteries and to carry out charging planning to enable charging at the lowest power hours. A detailed study should also be carried out on the raw material drying greenhouses, assessing the feasibility of replacing the current system with more efficient systems, as well as the study of the possibility of using other energy sources for drying the material. Finally, it is suggested to conduct a feasibility study and to select possible energy management software to determine the impact of its implementation in reducing energy consumption.

Acronyms

EU – European Union

GHG – Greenhouse Gases

PREN – Energy Rationalization Plans

EMS – Energy Management System

ISO – International Standard Organization

PDCA – Plan-Do-Check-Act

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