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Increasing Energy Efficiency Based on the Kaizen Approach

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Abstract: The energy crisis, an increasing concern of the industrial sector, is characterized by increased energy costs and low energy availability. As part of an effort to increase energy efficiency, the present study assessed the impact of applying lean tools on the energy consumption of a manufacturing organization. Using the Kaizen approach, the organization's processes were analyzed to identify the main vulnerabilities and make the required changes to increase consumption performance. Several technical improvements were performed to reach increased energy efficiency. Results showed an energy efficiency increase; consumption was reduced by up to 7.5% in the production line, 3.5% in the extruder stage, and up to 20% for the injection stage of the manufacturing process. The results suggest that the organization's energy reduction targets have been achieved. Standardization of procedures was useful in the development of Kaizen projects which could be applied with certain limitations. The implications of these results for understanding energy consumption reduction are discussed.

Keywords: energy efficiency; manufacturing; Kaizen; continuous improvement

Citation: Androniceanu, A.; Enache, I.-C.; Valter, E.-N.; Raduica, F.-F. Increasing Energy Efficiency Based on the Kaizen Approach. *Energies* **2023**, *16*, 1930. https://doi.org/10.3390/en16041930

Academic Editor: Piotr Borowski

Received: 29 December 2022
Revised: 9 February 2023
Accepted: 10 February 2023
Published: 15 February 2023

1. Introduction

Technological advance and the development of society are based on the use of energy, from which derives the importance of increasing energy efficiency in organizations. It is obvious that productivity is influenced by the increase in energy costs [1], so there is an incentive to find solutions that lead to efficiency of consumption [2,3]. The decrease in energy consumption and the reduction of energy costs for a manufacturing process can be determined by a detailed analysis of the energy flows [4,5]. The manufacturing process is a complex one and requires the involvement of the human factor through the workforce efforts, of the equipment and of the technologies necessary for manufacturing the final product [6]. In the current conditions, increasing energy efficiency is a priority for all organizations and a strategic objective by which an organization becomes more competitive in the sector and can win the competition with other organizations. The common framework for promoting energy efficiency in the European Union is established according to Energy Efficiency Directive 2012/27/EU (EED) and Directives 2018/2002/EU and aims to reduce energy consumption by 32.5% by 2030 [7,8]. According to the data published by EUROSTAT for 2020 in Europe, energy consumption in the industrial sector represents 26.1% of the total consumption [9,10]. The analysis of the data provided by EUROSTAT [9] for the 27 Member States of the European Union shows that between 2015 and 2020 the energy consumption in the industrial sector had a slight increase, as can be seen in Table 1.

The increase in prices for energy and raw materials influences inflation, so low energy consumption will generate positive macroeconomic effects [11]. In other words, a reduction in the cost of consuming energy for a given process can lead to the redirection of saved revenues to other services, goods, and processes that use energy. Energy efficiency by reducing energy consumption can have notable effects on production costs but also on the environment, as part of the transition to a carbon-neutral economy [12]. In 2021, CO_2 emissions from energy combustion and industrial processes accounted for almost 89% of greenhouse gas emissions in the energy sector [13]. The objectives of an energy efficiency organization can be achieved by using new technologies or upgrading existing ones. Kaizen is an approach centered on process, product, people, and the environment. According to this approach, each component in the chain of conception, production, and sale can be improved [14]. Kaizen is a tool used by organizations around the world, which aims at continuous improvement achieved through small steps and by eliminating losses and which can adapt to the specific needs of each organization. The main reasons for which we used Kaizen are the following: identifying losses, reducing energy consumption, replacing and improving equipment with high energy consumption, and increasing the organization's profit and investments. The case study is conducted for an organization that is a market leader in home appliances. They seek to reduce waste in their production processes by applying lean tools and investing in improving the technology used. Different models of refrigerators are assembled on the five production lines of the organization. Some of the parts used in the assembly process are made internally. The work is structured as follows. Section 2 includes aspects regarding energy efficiency and the Kaizen approach developed in the literature. Section 3 contains the research methodology by which the implementation of the Kaizen approach is achieved, and Sections 4 and 5 describe the steps for the implementation of the Kaizen approach to increase energy efficiency within an organization. Section 6 suggests future research that derives from the limitations of the case studies presented, whilst the last chapter includes the conclusions of the current work.

Table 1. Energy consumption in the last 5 years in Europe [9].

Europe Energy Consumption	2015	2016	2017	2018	2019	2020
Final consumption—total energy used (terajoules)	909,447	927,747	940,587	942,623	937,857	885,764
Industry sector (terajoules)	233,689	237,994	240,289	242,693	239,416	231,211
Percentage (%)	25.7	25.7	25.5	25.7	25.5	26.1

2. Literature Review

2.1. Energy Efficiency

Organizations need to implement energy management strategies for better efficiency to minimize different costs [15–17]. To identify the potential for energy efficiency, a reference point must be established. It is necessary for choosing a method by which to determine energy efficiency. Boyd, G.A. in the paper "Comparing the statistical distributions of energy efficiency in manufacturing: a meta-analysis of 24 Case studies to develop industry-specific energy performance indicators (EPI)" presents the measures and methods by which one can identify the reference point [18]. In order to calculate the reference point, the parameters influencing the energy consumption must be kept constant. The first way to determine the reference point is by measuring the energy intensity, which represents the ratio between energy consumption and activity or can be identified as the energy inputs and outputs from an organization over a certain period of time [19]. It is a useful physical value to measure energy consumption or energy performance. The energy efficiency of an industrial process will increase if the energy consumption is reduced or if for the same amount of energy consumed the level of production or the productivity of the labor force increases [12,19]. The values of energy intensity can be compared across time or between several organizations or at the sector level to which they belong, based on specific parameters. The issue with establishing measures regarding energy consumption is the lack of data within organizations on energy management techniques [15]. The monitoring and analysis of energy consumption for manufacturing systems are essential for the application of consumption reduction methods [20]. Energy efficiency measures (EE) can refer to a physical approach by optimizing process parameters or to a theoretical optimization of process parameters that may have practical limitations due to high calculation costs and the accuracy of results [21]. Another improvement measure consists in investments, which is based on identifying economic factors and barriers [22]. The factors that influence energy efficiency from the point of view of the production process are related to the equipment runtime [23,24]. Avoiding idling, using the equipment optimally, the existence of an operational plan but also the use of new technologies can reduce energy consumption [25–27]. It was found that for the systems operated by electric motors (EMDS), the highest consumption is recorded for the electric motor [28]. The consumption of electric motors and the systems they engage within is estimated to be between 43–46% of global energy consumption [29]. Globally there are regulations on the efficiency of electric motors and the replacement of low-efficiency motors with motors of a higher efficiency class and with low costs [30]. IEC 60034-30 and NEMA MG 1-2014 standards present the classes of "international efficiency"—IE of electric motors [30,31]. Table 2 contains an extract from the IEC and NEMEA standards showing the level of efficiency depending on the energy class.

Table 2. Electrical motors efficiency classes [30,31].

Energy Classes		Efficiency Levels
IEC (International)	**NEMEA (USA)**	
IE 1	-	Standard
IE2	Energy Efficient EPACT	High
IE3	Premium	Premium
IE4	Super-Premium	Super-Premium
IE5	Ultra-Premium	Ultra-Premium

The European Commission through its regulation 2019/1781 of 1 October 2019 presents the calendar of energy efficiency requirements for motors and electricity consumption up to 2030 [32].

2.2. Kaizen

In a competitive market environment, the application of modern process management approaches can contribute to the improvement of performance on the productivity of an organization [33]. The improved productivity of an organization will also be positively reflected in the energy efficiency of the entire organization. This efficiency can be achieved with minimal costs if the management of the respective organization applies the principles and tools offered by quality engineering. For example, lean tools are applied to increase the economic productivity of organizations and eliminate waste [34–36]. Several methods can be applied to reduce or eliminate losses and to achieve a certain level of productivity [37,38], which can be applied depending on the size of the organization and its needs. Some of the commonly used methods are the following:

- Kaizen—5S (Sort, Set in order, Shine, Standardize, Sustain) [39]
- Benchmarking [40]
- Kaizen—Continuous Improvement [41]
- Kaizen—Just in Time [42]
- Pull-principle and Kanban [43]
- Visual Management in Production [44]
- Zero waste [45]
- Value Stream Mapping [46]

- Efficient and ergonomic workstations [47]
- Poka Yoke [48]
- Six Sigma [49]

The Kaizen method is part of the plethora of lean tools offered in the literature and can be used by organizations to achieve the organization's objectives, to increase profit, to reduce losses called Muda, and to reduce expenses through the involvement of each employee [50].

The Kaizen method was developed by Iami in 1986 and was first applied in the automotive company Toyota to improve the company's efficiency, productivity, and competitiveness [51]. It was then applied to boost the productivity of other organizations by reducing costs [52–54]. Currently, this method is applied in various fields both in large enterprises and also in small and medium-sized enterprises [55].

The Kaizen method is used to eliminate and reduce losses or Muda. Muda in production is associated with any activity or process that consumes resources without creating value. In the literature [14] there are 7 losses—Muda that once detected and treated properly allow the organization to be more competitive and to have greater efficiency in the processes specific to that organization. These Muda are [14]: waste from overproducing, waste of time (waiting), waste from transporting, waste from over-processing, waste of inventory, waste of motion, and waste caused by defects and reworking.

There are many empirical studies [41,56–59] related to the implementation of Kaizen in different fields of activity, but only some of these focus on improving the process by making energy consumption more efficient. In the pharmaceutical industry, the Kaizen method was used to show how the involvement of operators and managers in the operations of the production process created a circle of positive ecological improvement [56]. In the custom furniture processing industry, the Kaizen method has been used to improve quality and productivity [57]. The Kaizen method has been successfully used both in the automotive industry [58] and in the food service industry [59]. Niranjana Sundararajan in her paper presents a case study through which the elimination of losses and the improvement of productivity in the production of fasteners were obtained through small and systematic improvements and the application of Lean-Kaizen Manufacturing Techniques [41]. There are some limitations to Kaizen implementation:

- reduced employee motivation [60];
- poor cooperation between employees and management (management) [61];
- limited ability to manage continuous improvement [62];
- poor definition of purpose [63];
- the structure of the organization must align with Kaizen principles [64];
- lack of organizational culture with values necessary for this approach [65].

In order to achieve a certain level of performance and the organization's objectives, several managerial actions are applied. In a company, there are many options [56] but the strategic actions applied should lead to benefits in the simplest way with the lowest cost [66]. Applying the Kaizen methodology involves nine steps that can be adapted depending on the study conducted in a particular organization.

1. Select the target process
2. Create a team
3. Set project goals and plans
4. Observe the process
5. Analyze the process
6. Create an improvement plan
7. Implementation
8. Presentation
9. Standardize and monitor

Kaizen methodology is used in various fields. A study based on Online Radio Frequency Identification-based Facility Performance Monitoring System (ORFPM) [67] by a company that remanufactures agricultural clutch discs, water pumps, torque amplifiers, and other industrial equipment has collected data to improve process efficiency. In the disc department, the challenge was that long transportation time led to few good results of parts flow between departments. The proposed framework used RFID, lean strategy, and Kaizen. As a result, the team improved the value stream map (VSM) and overall material flow.

The authors of [68] describe the improvement of operational and sustainability performance using lean management specifically Gemba Kaizen. The team found that the cutting process was incorrectly done and led to waste. New routines were put in place to reduce loss. This resulted in the reduction of shrinkage from 4.4% to 2.4% which led to reduced food waste by 50% and as a secondary outcome the stocks index was reduced by 33% in a cold meat section of a hypermarket store.

A case study [69] that took place in a metalworking company that designs and develops fluid flow valves shows that through lean leadership (LL) and lean tools (LTs) quick wins can be achieved. Daily Kaizen meetings involving the workforce to generate ideas cause rapid improvement over a small period after implementation. A six-dimensional survey revealed that by applying 70% of proposed ideas the quality awareness increased from average to good.

In [70], the authors present the results of a data rich systematic review focusing on improving performance in public hospital emergency departments. Among challenges that can be overcome using Kaizen and lean concepts are patient flow, high waiting time, high length of hospital stays, health safety and cost reduction. For example, waiting time reduction is the most important benefit because it impacts the mortality rate. The high patient flow is reduced with Kaizen events using health information systems (HIS). Implementing tools such as Kaizen events and lean healthcare improve care capacity by an average of 30% and reduce patient waiting time by 50% on average.

In [71], the authors describe a framework developed in the ambulatory healthcare clinic setting. The goal was to improve patient throughput. Identifying problems in this context was done through Kaizen and lean healthcare methodology. Maps were created to improve patient flow. Kaizen events were held to increase access to ambulatory clinics. The Heijunka approach was used to establish a better patient scheduling strategy. Flow-time efficiency was increased. Inventory was reduced using Just in Time (JIT) principles. The results highlighted an improvement of the overall quality of service.

In [72], the authors describe applying leadership and Kaizen principles in education. The results conclude that transformational leadership and regular Kaizen meetings improve clinical research performance in the laboratory and encourage volunteers to contribute to the research effort.

In this paper, we present two case studies for increasing energy efficiency by studying and treating losses (Muda) in the energy system of an organization. We have chosen to apply the Kaizen methodology because it is useful in identifying losses by using the internal resources of the organization and can be adapted to its needs.

The Kaizen approach used here followed the standard applicability steps adapted to the analyzed areas, as presented in Section 3.

3. Research Methodology and Kaizen

The implementation of the Kaizen approach depends on the setting of objectives at the organizational level. The strategic objective of the organization where the case study presented in this paper was performed was to reduce energy consumption without changing the technological process. To achieve this objective, we proposed the use of the Kaizen method.

The steps we follow to increase energy efficiency based on the Kaizen approach are the following:

Step 1: Determining the energy consumption in the organization and develop maps/graphs that reflect the total consumption on each production line.

Step 2: Analysis of the area of the organization with the highest consumption and determination of losses (Muda).

Step 3: Analysis of a process for which energy distribution solutions are investigated.

Step 4: Identifying and implementing solutions that can be applied to reduce energy consumption—eliminating Muda previously detected.

Step 5: Checking the implemented solutions.

To have a necessary reference point in identifying the economic potential, the amount of energy consumed at the level of the organization is measured and a complete map of the energy consumption is made.

From an economic or technological point of view, it is necessary to formulate certain scenarios to improve energy consumption.

As a strategy in the Kaizen approach, we propose to identify the process and, respectively, the machine tools or the area in the organization where the case study is carried out, which have the highest energy consumption [73]. We aim to detect the Muda that are responsible for reducing energy efficiency.

We establish a set of specific indicators that measure energy consumption, then we perform a quick and reliable analysis to determine the factors that influence energy consumption. Such an analysis is oriented toward identifying the largest consumers of energy. The identification of the existing potential must also be analyzed from the point of view of the improvement barriers [74]. In order to achieve the objectives assumed in the case study, we have gone through the next six steps of the Kaizen approach [56].

1. Process selection and detection of «Muda» losses.
2. Setting goals by prioritizing the most important Muda.
3. Analysis of the initial situation.
4. Establishing an action plan and finding solutions to eliminate or mitigate Muda losses detected.
5. Application of the solutions proposed by our team.
6. Checking solutions and standardizing them at the organizational level.

The aim is to eliminate or diminish areas of inefficiency and turn them into opportunities for the organization through the Kaizen approach. After the first step of the Kaizen methodology, in which the highest consumers in the organization are identified, it will be determined which other areas to focus on to reduce energy consumption. The organization establishes strategic actions according to the assumed objectives. By defining the strategic actions, we identify the competitive advantages of the organization having as limitations the associated risks and the existing or potential obstacles. In the medium and long term, the energy efficiency strategy establishes the general objectives of the organization and defines the way in which the organization can act to achieve them.

4. Case Study Based on the Kaizen Approach

In this case study, we use the Kaizen approach to reduce electricity consumption within an organization that produces refrigerating appliances. The strategic objectives of the organization are increasing profit, producing competitive products, reducing losses and reducing electricity expenses. The objective we pursue using the Kaizen approach is to reduce electricity consumption by 5%. We recommend the Kaizen approach because this methodology allows the identification of losses and the increase of the organization's profit by reducing electricity expenses, but also the production of competitive products. The case study focuses on identifying Muda which is responsible for wasting electricity without a precise purpose. It analyzes from an engineering and application point of view the energy consumption necessary for carrying out the activities in the organization. The production process is analyzed in smaller specialized groups to outline the ideas that can lead to the reduction of electricity consumption and to the identification of solutions that can be adopted.

Creating and understanding a hierarchical structure on strategic energy-saving goals is important in the Kaizen process for establishing an action plan and engaging employees at all levels of the organization.

Monitoring energy consumption is necessary to analyze the use of energy and to identify the largest consumers.

Analysis of the use of energy–loss identification (Muda) is carried out by:

- Engineering analysis that requires:
  - Determination of cumulated electricity consumption in different areas of the organization
  - Comparing electricity consumption for different areas of the organization
- The actual analysis of the process that requires:
  - Identifying the area and the process with the highest electricity consumption
  - Determining critical places
  - Analysis of energy consumption
  - Value analysis by formulating solutions that can be applied to reduce electricity consumption.

The operational objectives of the organization for the electricity-saving activities are related to the energy efficiency of the processes and equipment and the energy efficiency of the products. In this case study, we have focused on increasing the energy efficiency of processes and equipment. Figure 1 shows a graphic that highlights the operational objectives of the organization related to their energy efficiency.

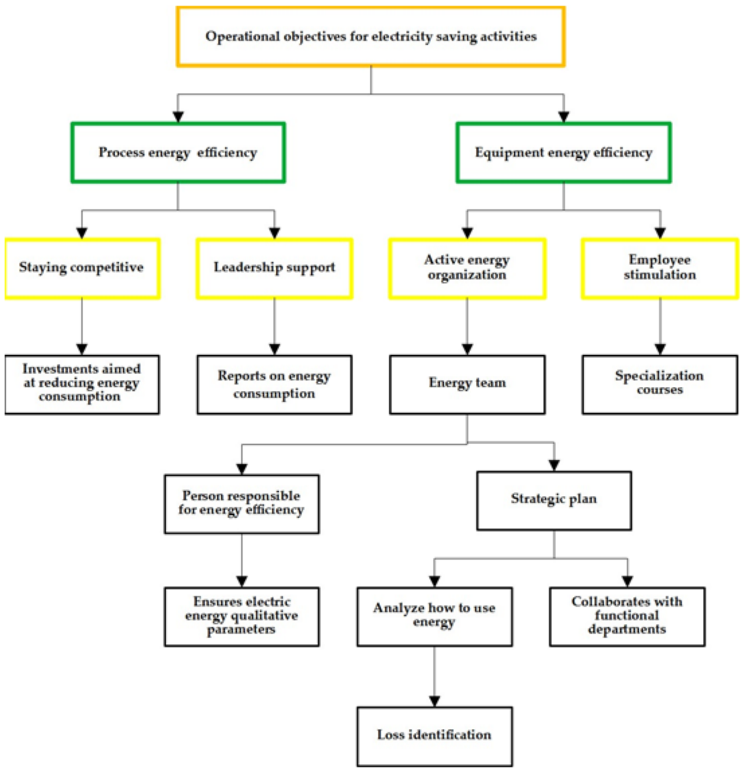

Figure 1. Operational objectives for energy-saving activities.

Operational objectives related to the energy efficiency of products will be the objective of another case study.

The organization wants to remain competitive in the market and this objective can be achieved by supporting investments in new technologies and equipment aimed at reducing energy consumption. Investments regarding energy consumption can be approved by the organization's management following reports on the energy efficiency of the organization.

The reports to the management of the organization are elaborated by a team that monitors the energy consumption and identifies the losses that in the case of our study represent Muda. To identify the losses, it is necessary to involve the employees who can be stimulated by attending specialization courses.

4.1. Step 1: Determining the Energy Consumption in the Organization

To obtain the necessary data for the analysis, the electricity consumption was monitored over a period of one year for 44 points in the organization. In Table 3 we find the energy consumption per day and the arithmetic average of the measurements taken over one week specific to Production Line 1.

Table 3. Consumer monitoring on Production Line 1.

	Day Consumption (MWh)	Weekly Average Consumption (MWh)
Production Line 1	5.701	5.114
Consumer 1	0.12	0.15
Consumer 2	1.578	1.532
Consumer 3	1.785	1.122
Consumer 4	0.109	0.161
Consumer 5	0.622	0.653
Consumer 6	0.381	0.308
Consumer 7	0.006	0.005
Consumer 8	0.023	0.016
Consumer 9	0.118	0.095
Consumer 10	0.081	0.063
Consumer 11	0.102	0.087
Consumer 12	0.084	0.086
Consumer 13	0.09	0.1
Consumer 14	0.109	0.203
Consumer 15	0.493	0.533

As a result of the monitoring carried out, a map (Figure 2) resulted in which the main consumers of electricity are marked. This map gives us a clear picture of each work area in the enterprise. Figures 2 and 3 show that there are five production lines and nine areas serving the production lines in the organization.

The situation of the electricity consumers is highlighted in Figure 3 from which it appears that for the production lines the highest consumption is recorded on Line 1 and for the areas serving the production lines the highest consumption is recorded in the maintenance area.

Our case study will focus on reducing energy consumption in Production Line 1.

The electricity consumption on Production Line 1 is influenced by the number and energy class of the existing electric motors.

In Table 4 for each area of the organization is indicated the number and energy class to which the existing motors larger than 5.5 kW belong. In the organization, there are 405 motors divided into 4 different classes of efficiency: IE3, IE2, IE1, and smaller than IE1. Table 4 shows that 20% of the engines in operation are smaller than IE1, 60% of the engines have the efficiency class IE1, 16% have the efficiency class IE2 and only 2% of the flat motors in operation have the energy class IE3.

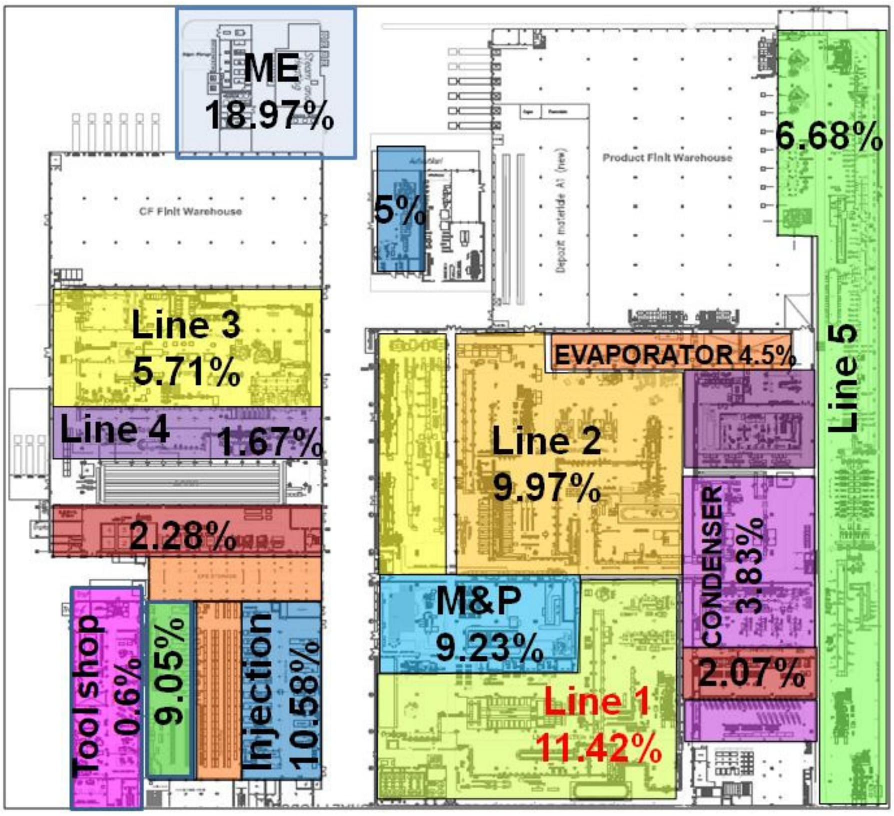

Figure 2. Electricity consumers map. ME—Maintenance Equipment. EPS—Expanded Polystyrene area. M&P—Mechanical and Painting area.

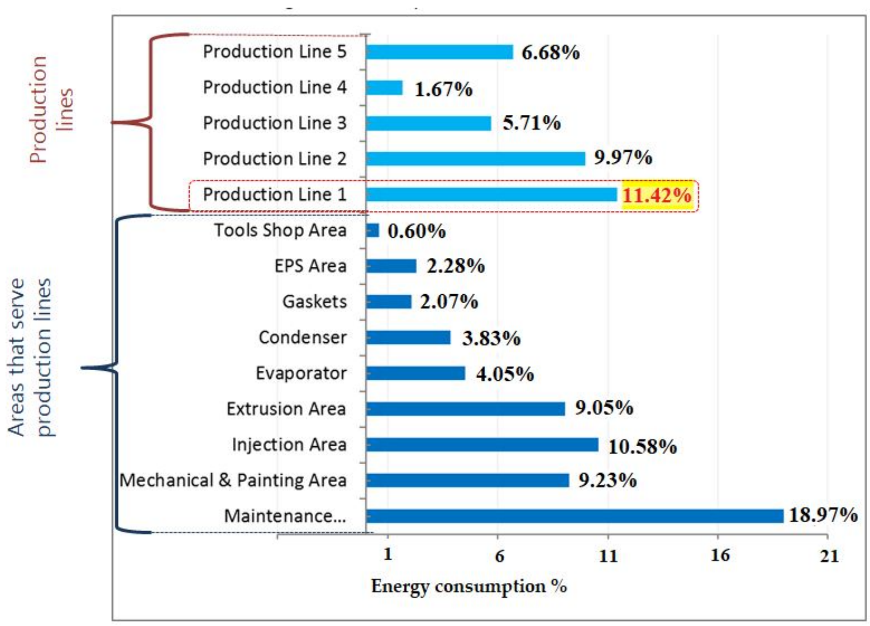

Figure 3. Energy consumption for different areas of the organization.

Table 4. Existing engines.

	Motor Energy Efficiency Class				
	<IE1	**IE1**	**IE2**	**IE3**	**Total Engines**
Efficiency Levels		Standard	High	Premium	
Line 1	3	25	14	2	
Line 2	17	33	-	-	
Line 3	10	19	3	-	
Line 4	-	-	4	-	
Line 5	-	-	28	1	
Total production lines	30	77	43	3	153
Tool shop area	9	5	-	-	
EPS area	14	24	-	-	
Condenser	-	8	-	-	
Evaporator	-	18	-	-	
Injection and Extrusion area	18	49	10	2	
Mechanical and Painting area	12	42	9	-	
Maintenance	-	20	7	5	
Total components by areas	53	166	26	7	252
TOTAL	83	243	69	10	405

Having a clear situation of the electricity consumers presented in Figure 3, together with the data from Table 4 where the types and number of motors existing in the factory are highlighted, will lead to the identification of the process that needs to be improved from an energy point of view. The results show that the highest energy consumption is achieved by Production Line 1.

4.2. Step 2: Analysis of the Area of the Organization with the Highest Consumption

On Production Line 1, two foaming processes are performed for different components of the refrigeration unit and a thermoforming process. Motors of energy efficiency classes IE1, IE2 and IE3 can be found on this production line. Table 5 contains the existing motors on Production Line 1 for the identified processes.

The monitoring of energy consumption for Production Line 1 resulted in a different consumption for each process identified in Figure 4. The consumption for foaming component 1 represents 57% of the total consumption recorded on Production Line 1 so this process must be analyzed thoroughly to identify solutions that can lead to the reduction of energy consumption.

Table 5. Main consumers of energy of choice for Line 1.

	Process	Equipment	Motor	Power [kW]	rpm	No.	Efficiency Class
Production LINE 1	Foaming component 1	2 Composite foaming installations 1	Confirmatory spindle training	5.5	725	16	IE1
				7.5	960	4	IE1
			Polyol	30	1475	2	IE2
			Isocyanate	22	732	2	IE2
			Hydraulic	11	1470	2	IE3
			Ventilator	11	1440	4	IE2
	Foaming component 2	2 Foaming installations component 2	Polyol	5.5	1440	1	IE2
			Isocyanate	5.5	1440	1	IE2
			Hydraulic	5.5	1440	2	IE2
			Ventilator	5.5	1440	1	IE2
			Shaft drive motors	22	3000	1	<IE1
	Thermoforming	Equipment 1	Hydraulic	22	1465	1	IE1
			Vacuum pump	7.5	1440	1	IE1
		Equipment 2	Hydraulic	22	1465	1	IE1
			Vacuum pump	7.5	1440	1	IE1
		Thermoforming equipment 1	Hydraulic	5.5	1450	1	IE1
			Vacuum pump	11	1455	1	IE2
		Thermoforming equipment 2	Vacuum pump	5.5	1440	1	<IE1
		Thermoforming equipment 3	Vacuum pump	5.5	1450	1	<IE1

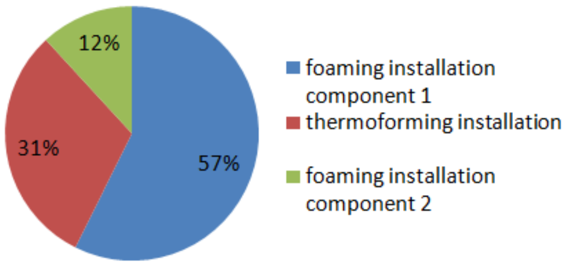

Figure 4. Energy consumption on Production Line 1.

4.3. Step 3: Analysis of a Process for Which Energy Reduction Solutions Are Investigated

Setting a target is essential in the development of the Kaizen project. On component 1 foaming installations, there are 5 categories of monitored motors: isocyanate pumps, polyol pumps, hydraulic motors, motors used for ventilation, and motors used to drive shafts (Table 6). To identify the losses, it is necessary to analyze the consumption for each category of motors separately. Using the data from the energy consumption monitoring program from Table 6, it appears that the largest losses are due to isocyanate pumps and polyol pumps for which consumption of 10.42 MWh was recorded for each category, which means that for Production Line 1, the electricity consumption for the two categories of motors represents 74% of the amount of energy recorded as being consumed.

Table 6. Motors consumption for foaming installation component 1.

No.	Motors	Real Consumption MWh	Consumption Percentage
1	Isocyanate pumps	10.42	37%
2	Polyol pumps	10.42	37%
3	Hydraulic motors	3.71	13%
4	Fan motors	1.7	6%
5	Shaft drive motors	2.1	7%

The objective of the organization is to reduce energy consumption by 5%. To achieve this objective, we proposed to reduce consumption for foaming installation component 1 by 5%. A decrease of 5% means a decrease in electricity consumption from 28.34 MWh to 26.93 MWh. A 5% reduction in consumption for foaming installation component 1 can be achieved if we reduce the consumption for each motor by 5%, Figure 5.

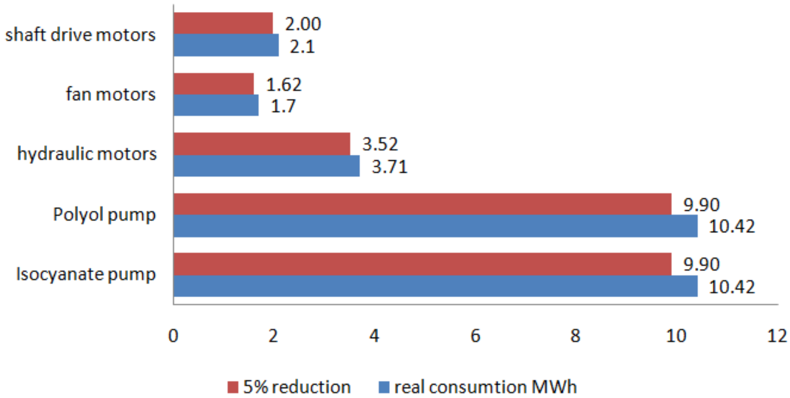

Figure 5. Proposed target for reducing energy consumption at foaming installation component 1.

Identifying solutions to reduce energy consumption requires detailed knowledge of the foaming process for component 1.

The component 1 foaming process is carried out with the help of 20 foaming plants positioned in parallel on two branches A and B that work simultaneously (Figure 6). Each foaming installation has mounted a motor that has the role of lowering and raising the conformers (Figure 7). In total, we have 20 spindle conformer drive motors of IE1 energy class. For the same process, 2 isocyanate motors and 2 polyol motors were identified, both having the IE2 energy class. The area formed by the 20 conformers will be analyzed to improve the foaming process.

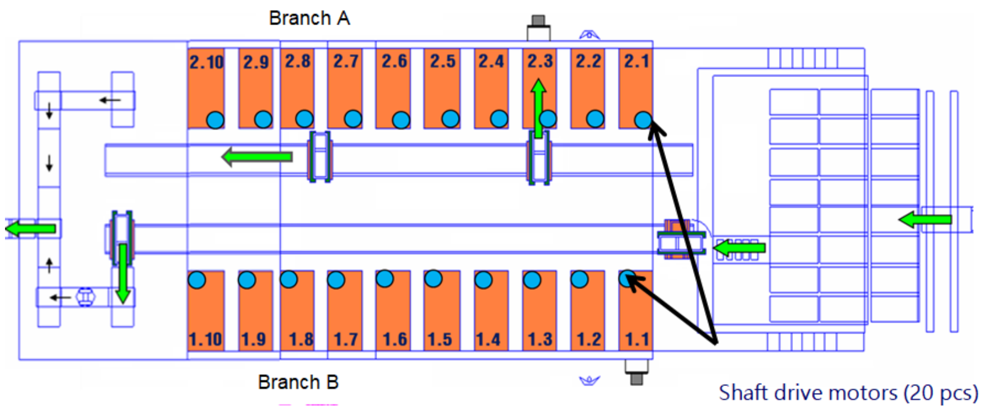

Figure 6. Conformer layout.

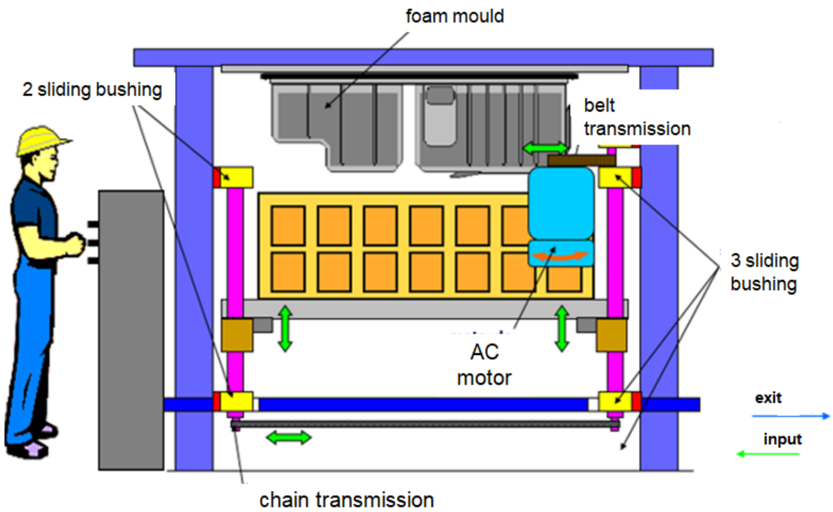

Figure 7. The operation mode of the conformer.

In the foaming process, the motor engages 2 shafts located in parallel (Figure 6). A shaft is engaged directly by the motor through a belt drive. The rotational movement of the shaft is also transmitted to the secondary shaft using a chain transmission. An operator drives the motor that by the transmitted movement raises or lowers the conformers to the foam mold Figure 7.

The motors that drive the shafts have 2 revs and run-in alternating current.

We can calculate the motor speed using Equation (1)

$$n = \frac{60 \cdot f}{P} \quad (1)$$

where:

n = synchronous motor speed [rpm]
f = frequency of the supply voltage [Hz]
P = number of motor pole pairs

For the motor, the frequency of the supply voltage is 50 Hz and uses at low speed 4 pairs of poles, and at high speed 42 pairs of poles. To calculate the speed, we have replaced in Equation (1) the given values.

$$\text{Slow speed}: \quad n_{lenta} = \frac{60 \cdot 50}{4} = 750 \text{ rpm} \quad (2)$$

$$\text{Fast speed}: \quad n_{rapida} = \frac{60 \cdot 50}{42} = 1500 \text{ rpm} \quad (3)$$

From Equations (2) and (3) it follows that the motor can run at a slow speed of 750 rpm (rotations per minute) and a fast speed of 1500 rpm. The motor helps to raise and lower the conformer which can be in the closed or open position. The open position is where the product is fed and foamed and the open position is where the foamed product is discharged. The conformer ascent is done in 3 steps.

Step 1—the conformer ascends slowly (the necessary settings are made to prepare for the fast ascent of the conformer).

Step 2—the conformer ascends quickly until near the closing area of the conformer.

Step 3—the conformer ascends slowly to the closing position.

As shown in Figure 8, the slow to fast speed receding from slow to fast and vice versa is done at an interval of about 0.5 s, suddenly by changing the engine winding. Removing the conformer from the stand for lifting or lowering is done by direct start with contactors. Monitoring of the motor's operation shows that the transition from one step to another is achieved with large jumps in current intensity. It can also be observed that the current intensity does not keep the same value during a step, which can lead to certain operating errors. The 20 motors used to drive the shafts recorded a consumption of 1704 kWh.

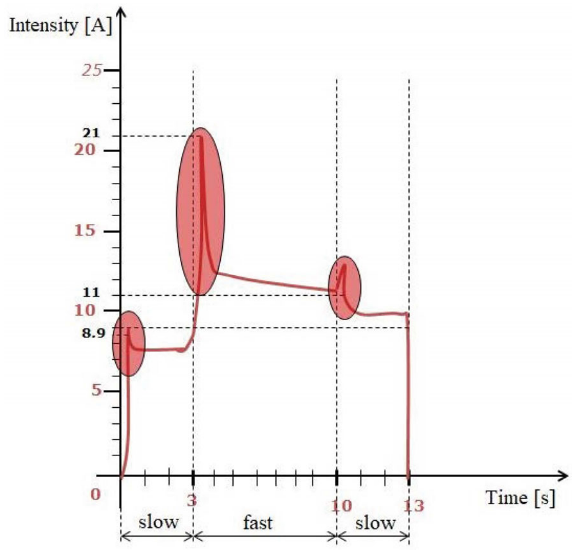

Figure 8. Engine intensity measured over time.

4.4. Step 4: Identifying Solutions That Can Be Applied to Reduce Energy Consumption

The high energy consumption for the component 1 foaming installation is influenced by the consumption of the motor entraining conformer shafts, polyol pumps, and isocyanate pumps. Each case was analyzed to find a suitable solution. The motors that operate the polyol and isocyanate pumps are of the IE2 energy class (Table 4). A solution to this problem is to invest in more advanced motors of the IE3 energy class in which speed cab be varied. Conformation shaft drive motors are of energy class IE1 (Table 4) and a viable solution would be to replace them with motors of energy class IE3/IE4. Another problem related to the energy consumption for these motors refers to the fact that the removal of the conformer from rest is done by starting directly with capacitors. For this problem, there are two solutions. The first solution would be to use hydraulic pumps for operating the conformer, but this solution leads to very high costs. A second solution consists in installing a speed adjustment system that from an economic point of view is preferable compared to the first solution proposed. The scheme in Figure 9 shows an overview of the proposed solutions.

Following the analysis of the solutions in Figure 9, we proposed and piloted three major changes to reduce the electricity consumption of Production Line 1, which had the highest energy consumption.

The first change we proposed to reduce energy consumption was to install Altivar 71 [75] speed dimmers that were designed to generate significant energy savings in industrial processes. The speed adjustment system was replaced by installing speed dimmers resulting in the reduction of energy losses at variable loads. This system offers the possibility of increasing the frequency from 50 to 80 Hz, and implicitly the progressive increase of the speed from 0 to speeds higher than 1500 rpm as well as the leveling of the absorbed current.

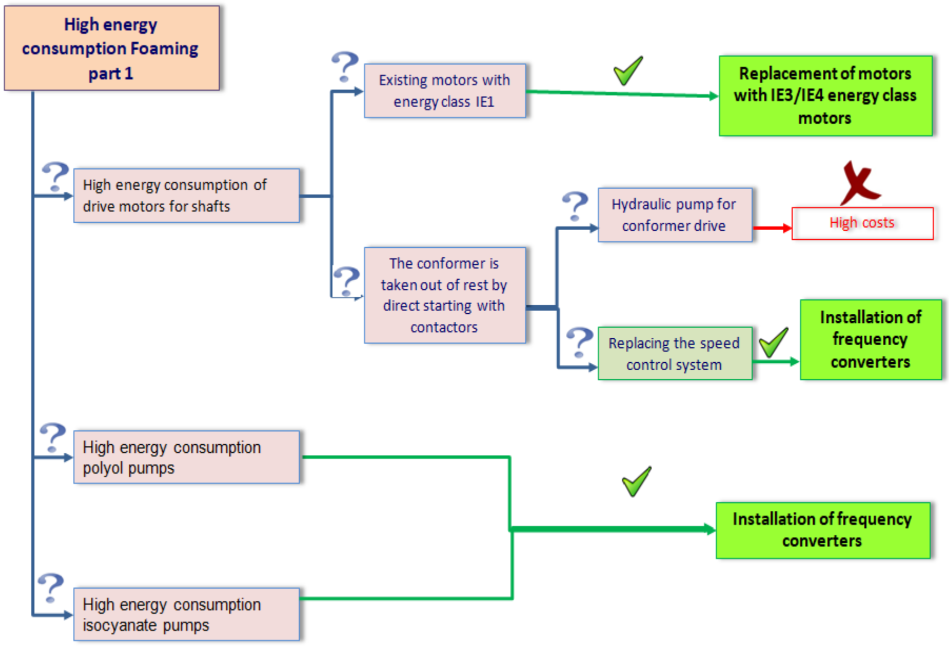

Figure 9. Solution analysis.

After the implementation of the system, a new set of measurements was made to make a comparison between the initial and the current mode of operation (Figure 10). Such before and after comparisons are frequently used in Kaizen projects [41,76].

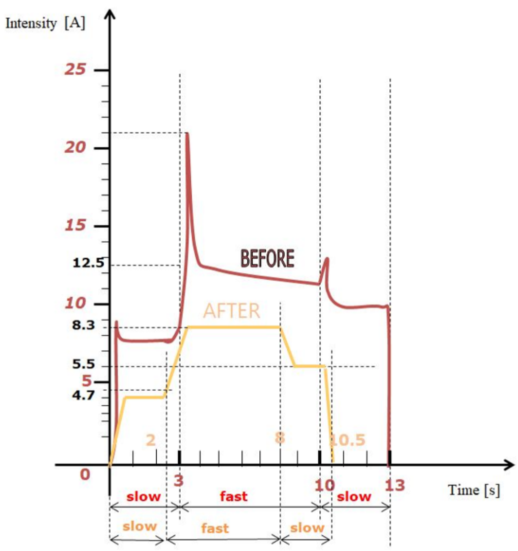

Figure 10. Engine intensity measured over time after improvement.

The improvements obtained from the installation of the speed variators are the following:

1. Removal from rest for ascent or descent of the conformer occurs progressively from 0 to 30 Hz, with an acceleration of 0.4 s.
2. The transition from slow to fast speed occurs progressively with acceleration from 30 Hz to 60 Hz in 0.4 s.
3. The transition from fast to slow speed occurs in 0.4 s from 60 Hz to 30 Hz.
4. The conformer shutdown takes place in 0.4 s from 30 Hz to 0 Hz.
5. Speed increase in a shorter time from 13 s to 10.5 s.

To these improvements we can add:

1. It has a safety function to ensure that the motor stops and prevents accidental restarts.
2. Protects bearings, bearings, and shafts.
3. Contactors are no longer replaced.
4. A single-speed motor can be used.

The second change proposed was to replace the old motor of the efficiency class IE1 (Table 4) with a new motor from the energy efficiency class IE3. A before/after comparison reveals that there are no problems with the installation of the new motor (Figure 11). The motors have the following characteristics: they can develop a power of 5.5 KW, at a frequency of 60 Hz resulting in a speed of 1500 rpm if we replace them in Equation (1).

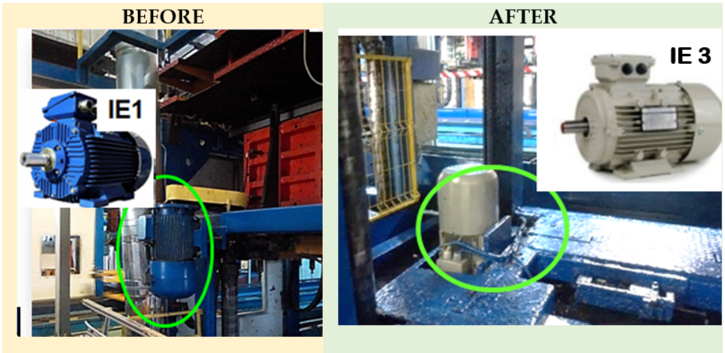

Figure 11. Engine positioning before and after applying the Kaizen approach.

The advantages of using IE3 motors are:

- Saving energy and reducing CO_2 emissions
- Extra performance
- Low maintenance costs
- Comfort of use

The third change proposed was to replace the polyol and isocyanate pumps for branch A and branch B, with 2 IE3 motors with frequency converters with lower energy consumption.

4.5. Verification of Implemented Solutions

A new set of measurements regarding energy consumption was made after the implementation of the solutions. The solutions adopted are focused on replacing motors that have low efficiency with motors from higher efficiency classes. The acquisition costs are substantial but can be compensated by the decrease in electricity consumption. Instability in electricity prices [77] is a factor influencing production.

The new set of measurements regarding the energy consumption compared to the initial situation leads to a result that exceeds the proposed target. The graph in Figure 12 is a histogram that presents a comparison of the initial situation, the proposed target, and the current situation for each type of motor and pump.

With the new improvements, a saving of 7.5% was reached, from an initial consumption of 28.34 MWh to 26.22 MWh, a decrease that led to a saving of 20,630 € annually for the organization. Reducing energy consumption has a positive impact on the organization's energy costs.

In the first stage, the research was carried out only for Production Line 1. It was then extended to other production lines or areas that serve the production lines. By replacing the motors that had low energy efficiency, the organization managed with a total investment of 15,480 € to reach an annual profit of 194,853 €. This profit is due to annual energy savings that reached −1.139 MWh.

The organization's profits will be used for other projects mainly aimed at reducing energy consumption. In the next section, we present the application of Kaizen methodologies in other areas.

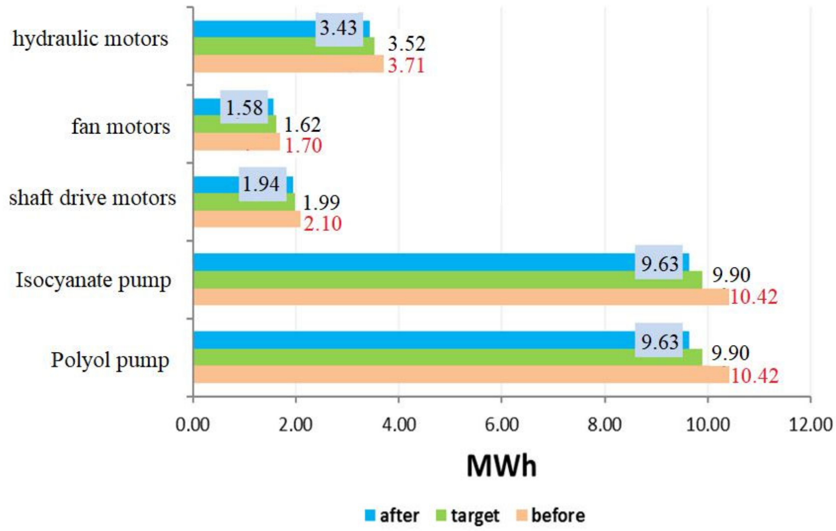

Figure 12. Energy consumption frame.

5. Application of Kaizen Methodology in Other Areas

The steps presented in the description of the Kaizen methodology are followed. This case study is dedicated to areas serving production lines and focuses on eliminating energy losses in the injection and extrusion areas.

5.1. Step 1: Determine the Next Project for Increasing Energy Consumption

In step 1 the energy consumption in the organization was determined for different areas. Figure 3 shows that the maintenance area is a high energy consumer. This area has the particularity of serving the whole organization. In order to apply the Kaizen methodology in the maintenance area, the management teams responsible for certain areas of the organization must cooperate. In this context, we have not yet been able to develop a plan whereby the managers responsible for the areas of the organization develop a project in which the Kaizen methodology can be applied. We can apply the Kaizen methodology to reduce energy consumption in the areas of injection and extrusion.

5.2. Step 2: Analysis of the Injection and Extrusion Area

In these areas, various parts are made that will be used in the assembly process for refrigerators. In these areas, we have 31 injection machines and 4 extruder machines. Table 7 shows the measurements for 3 injection machines and 3 extruders on 5 different days and the average consumption.

Table 7. Electricity consumption from different periods.

Machine	Day 1	Day 2	Day 3	Day 4	Day 5	Average
	kWh/Day					
Extruder 1	6602.17	6629.01	6656.46	6650.05	6643.26	6636.19
Extruder 2	2953.20	2969.47	2954.96	2860.56	2877.88	2923.21
Extruder 3	4557.50	4558.75	4548.42	4698.68	4674.21	4607.51
Injection 1	5163.63	5166.37	5073.52	4901.25	4840.20	5028.99
Injection 2	6103.74	5992.69	6163.59	5993.93	5665.92	5983.97
Injection 3	3016.12	3781.03	3981.64	3364.52	3331.28	3494.92

The highest energy consumption in the injection and extrusion processes has been identified in the regions where the machine heats the material (Figure 13).

Figure 13. Material heating zone on the injection machine.

5.3. Step 3: Identifying and Implementing Solutions

The material that will be injected/extruded must have a certain temperature. In the heating zone of the material, there are large temperature losses during the process which influence energy consumption. Hence, material heaters will be installed to reduce heat loss and will collect and heat the material to the required temperature. The material heaters are equipped with heaters and thermocouples that indicate the temperature of the heated material. The addition of insulation jackets increases the heating efficiency of the material by keeping it at the required temperature (Figure 14). To make this solution applicable for injection and extrusion machines, insulation jackets must be modular.

Figure 14. Insulation jackets for an extrusion machine.

5.4. Step 4: Check the Implemented Solutions

The aim is to save a significant percentage of electricity, with shorter cylinder heating times and maintaining a constant temperature of the material. With a budget of 24,500 €, the solution was initially applied to the 3 injection machines and 3 extruders. For this example, a new set of energy consumption measurements is performed (Table 8).

Comparing the average values obtained from the initial measurements with the ones obtained after the implementation of insulation jackets, a significant reduction in energy consumption is noted (Table 9).

In one year, by eliminating heat losses, a saving of 89,965.22 € will be made on electricity consumption. In view of the large reduction in energy consumption, this system will be implemented on all injection and extrusion machines.

Table 8. Electricity consumption from different periods after insulation jackets implementation.

Machine	Day 1	Day 2	Day 3	Average
	kWh/Day			
Extruder 1	6580.95	6530.10	6503.58	6538.21
Extruder 2	2861.73	2832.67	2855.62	2850.01
Extruder 3	4457.83	4444.87	4443.33	4448.68
Injection 1	4990.98	4992.11	4992.17	4991.75
Injection 2	5332.85	5357.66	5312.25	5334.25
Injection 3	2844.87	2803.20	2811.97	2820.01

Table 9. Average electricity consumption trends.

Machine	Before	After	Saving
	kWh/Day		
Extruder 1	6636.19	6503.58	132.61
Extruder 2	2923.21	2855.62	67.59
Extruder 3	4607.51	4443.33	164.18
Injection 1	5028.99	4992.17	36.82
Injection 2	5983.97	5312.25	671.72
Injection 3	3494.92	2811.97	682.95
	Total saved		1755.88

Energy consumption will be reduced by 400 MWh/year during the 228 working days. The greenhouse gas emission factor specific to the electricity grid in Romania is 0.26184 kgCO_2e/kWh and was used to determine CO_2 emissions [78]. Based on this it has been estimated that the CO_2 emissions for the organization is 126,5630 tonnes.

In the next section, we make a brief presentation of the projects that can be carried out in the organization.

6. Future Research

The case studies show the use of the Kaizen approach to reduce energy consumption in 3 areas of an organization that produces refrigerating appliances. Kaizen's approach can be applied to other production lines and to the areas that serve the production lines. The research team is in discussion with the organization's management about developing new energy efficiency projects.

The organization is interested to develop Kaizen projects because there is already a culture in terms of application methodology. Based on the study already carried out, it was identified from the first step (Figure 3) that in the maintenance area, there is very high energy consumption. A proposal would be to carry out a Kaizen-type project on lighting in the organization. The aim is to create an interior lighting installation suitable for the production area, with LED lighting, in which the luminous flux is harmoniously distributed and ensures a special climate of comfort. With an investment of 270,000 € in such a project it is expected a reduction of energy consumption of 2,130,344 kWh per year. The lighting levels were calculated according to the regulations in force, by using lamps with higher or lower intensity, the circuits being dimensioned accordingly to allow this. Depending on the service area and the height of the room, projector type lighting will be used for very high heights (over 6 m) and linear lighting for heights below 6 m.

Increasing lighting efficiency in the organization will bring a profit of €167,535, with a payback time of 2 years and 6 months.

Investments in lighting can be made by replacing old lighting spans with the sun tracker mirror system. With an investment of 20,500 €, the annual energy consumption can be reduced by 344,461 kWh. This can lead to an annual financial efficiency of 7628 €/Year.

The objective of the organization is to continue reducing costs. We suggest to apply the Kaizen approach to analyze and discover the technical and technological changes needed to reduce other expenses such as the labor force, the product costs, or the costs of another production line.

In the future, we propose to develop research with the objective of reducing CO_2 emissions as a result of the technological changes proposed in all the production sectors of the analyzed organization. Thus, the total reduction of CO_2 at the organization level could be determined, as a result of the changes discovered and implemented with the help of the Kaizen methodology.

The changes identified and operationalized using Kaizen can be completed with the digitalization of organizational production and administrative processes [79,80]. These changes require extensive and in-depth research in advance to identify the appropriate solutions and the financial resources needed for their implementation as part of an extensive and systematic digital transformation process. Therefore, in future research, we propose to approach organizational digitalization and the increase of energy efficiency as real and necessary strategic options for a modern organization.

7. Conclusions

At the global level, in the current conditions related to energy shortage, but especially regarding the exponential increase of the energy price, we consider that steps are needed for organizations to find solutions to increase the energy efficiency of their production lines. Therefore, to remain in the market, increasing energy efficiency has become a strategic objective for any organization. Worldwide, this strategic organizational objective can lead to other beneficial effects for mankind, such as the reduction of pollution [81] and the decrease of the prices for the products obtained from the production processes carried out.

Kaizen is a process-centric approach towards people and the environment and has developed over time as a managerial strategic option, through which, with small steps and without high additional costs, a systematic analysis of a process can be made to achieve efficiency by detecting the losses (Muda) and by detecting the inefficient use of resources on the targeted production chain.

In this respect, the authors have systematically approached this problem, following the steps already established in the specialized literature of the Kaizen methodology.

By applying the Kaizen methodology in the organization, several areas could be identified for energy improvement. Our attention was focused on the areas with the highest energy consumption and the solutions identified for each studied area led to a reduction in energy consumption. Kaizen is a methodology that can be applied systematically and has led to the identification of losses and the most efficient solutions. The internal resources of the organization were used to implement the Kaizen methodology. Once a routine is established it is standardized and can be applied several times in the organization.

Kaizen methodology has not been applied in the maintenance area because it requires the involvement of managers responsible for all areas of the organization and at this moment there is no well-developed Kaizen culture.

We believe that the method used by us has achieved its intended goal of energy consumption in the organization where we made these case studies.

The use of the Kaizen methodology has a positive impact on the organization. It is a method that can be applied systematically and that can be adapted to the organization's needs.

The application of the Kaizen methodology in these case studies led to the identification of major energy losses and to quick and efficient solutions. The organization needs to ensure that investments made to reduce energy consumption will be recovered in a short period of time so that profits can be reinvested. In these case studies, applying the Kaizen methodology, we started from a general problem to find specific solutions. We can use Kaizen because it is a method for improving processes in an organization, available to everyone, that can be applied with internal resources and minimal costs.

The Kaizen approach can be successfully applied in other organizations to help them eliminate production line losses, product manufacturing process losses, or human resource time losses. Once these losses are eliminated, the total expenses are reduced and the profits of the organizations can increase.

The authors decided to publish this study in the context of the current energy crisis at the global level, to support organizations that want to increase their energy efficiency with minimal costs and pollution [82,83]. The price of the product is given by the production costs, and the customer should pay for costs that add value to the product, not for avoidable expenditures or losses.

Author Contributions: Conceptualization, A.A. and I.-C.E.; methodology, A.A. and E.-N.V.; validation, A.A., I.-C.E., E.-N.V. and F.-F.R.; formal analysis, A.A., I.-C.E., E.-N.V. and F.-F.R.; investigation, I.-C.E.; data curation, A.A., I.-C.E., E.-N.V. and F.-F.R.; writing—original draft preparation, A.A., I.-C.E., E.-N.V. and F.-F.R.; writing—review and editing, A.A., I.-C.E., E.-N.V. and F.-F.R.; supervision, A.A.; funding acquisition, A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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