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Analysis of energy saving measures in a production company

Análisis de medidas de ahorro de energía en una empresa de producción

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Abstract

This work analyzes possible measures of energy saving in a production company, with the purpose of establishing recommendations that contribute to the efficient use of energy. This research is descriptive-documentary, based on fieldwork, where the different production processes and industrial services were analyzed. Using data supplied from working hours, an estimate of monthly consumption was made to determine the impact of processes on electricity billing. The analysis was restricted to the calculation of consumption index (Ton/kWh), which allows the use of the most efficient equipment to be prioritized over others performing the same functions. The analysis of the consumption characteristic yields optimum consumption points which allow establishing a graph of Energy vs Production called Goal. The result is that by applying all the proposed actions, the monthly consumption would decrease by 138,024.84 kWh, representing an energy saving of around 25% with respect to the current average consumption.

Keywords: Energy Saving, Characterization, Goal, Production

Resumen

Este trabajo analiza las medidas de ahorro de energía posibles en una empresa de producción, con la finalidad de establecer recomendaciones que contribuyan al uso eficiente de la energía. Esta investigación es de tipo descriptivo-documental, sustentada en un trabajo de campo, en donde se analizan los diferentes procesos de producción y servicios industriales. Utilizando datos suministrados de horas de trabajo, se realiza una estimación del consumo mensual para determinar el impacto de los procesos en la facturación de electricidad; el análisis se restringe al cálculo de índices de consumo (t/kWh) con lo que se puede priorizar el uso de los equipos más eficientes sobre otros que realicen las mismas funciones. El análisis de la característica de consumo arroja puntos óptimos de consumo con los cuales se establece un gráfico de energía *vs.* producción llamado meta. Se obtiene como resultado que aplicando todas las acciones propuestas, el consumo mensual disminuiría en 138 024,84 kWh, lo que representa un ahorro de energía del orden del 25 % respecto con el consumo promedio actual.

Palabras clave: ahorro de energía, caracterización, meta, producción.

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1. Introduction

The evolution of man on Earth has been, to a great extent, made possible by the development of technologies that make day-to-day life much easier. Human beings went from using their muscular strength and that of domesticated animals, to the use of diverse energy sources such as wind, water, fire, steam, among others, reaching the current energy scheme, where the burning of fossil fuels plays a preponderant role. It should be noted that this energy source is finite and highly contaminating.

Many electricity generating plants use it as a driving force to supply the electric demand. This implies a high emission of gases into the Earth's atmosphere that affect the ecosystem. In addition to pollution, it must be borne in mind that oil shortages in the future will represent a major global energy problem, which is why decreasing electricity consumption implies savings of this important source of energy.

For humanity, the beginning of the third millennium represents a crossroads of a new energy choice, in face of the depletion of fossil fuels on the one hand, but above all, due to the threat of an ecological catastrophe, where the limits of the planet's capacity to as-similate their impact is exceeded [1].

In general, Venezuelan society has not been characterized by having a culture of energy saving, since in the past the country's great energy wealth has supported an offer well above the national demand in terms of electricity services. However, in recent years, the appearance of long periods of drought has directly affected the main source of electricity generation in the country, which is hydraulic (Figure 1).

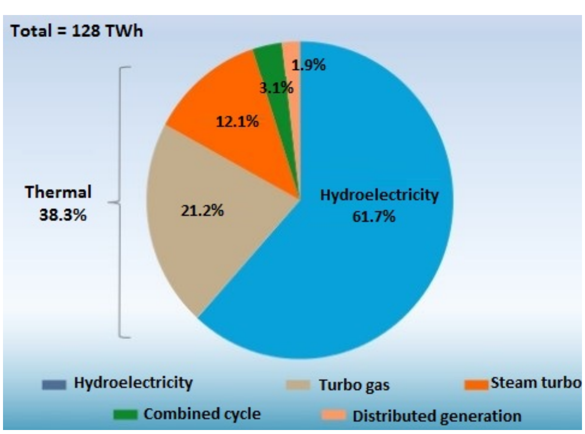

Figure 1. Energy balance in Venezuela by type of plant, estimates for 2015 [2].

In addition, the exponential growth of the population and of the various industrial and commercial sectors brings, therefore, an increase in the demand for electricity (Figure 2). Both factors have taken a turn, not only regarding the energy situation, but also the resulting environmental impact and the reduction of oil reserves.

Nowadays, there is no capacity to generate enough electrical power to supply the entire population if the traditional consumption level is maintained. This is why the need arises to implement awareness plans regarding the efficient use of energy, with the purpose of reducing unnecessary consumption.

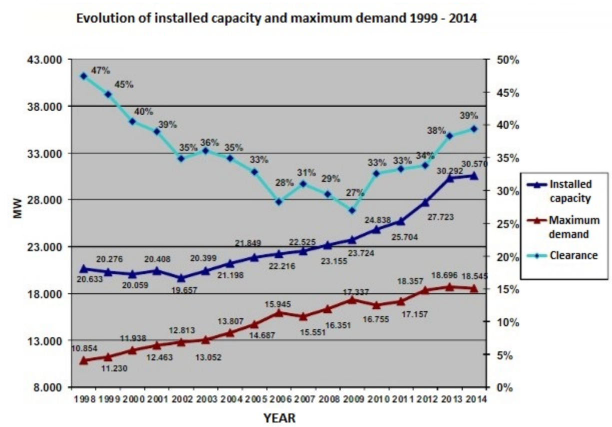

Figure 2. Average power demand of the National Electricity System (Sistema Eléctrico Nacional, SEN) 1999-2014 period [2].

The company that is the subject of this study, Mon-tana Gráfica, a subsidiary of the Corimon Pintura Group, C.A., is dedicated to the manufacture of flexible labels and packaging for various high consumption products such as food, beverages, candies, among others. It is located in Mariara, Carabobo state, Vene-zuela, and has about 30 000 m^2 of construction.

It is powered by a three-phase 13.8 kV line supplied by the national electricity service company Corporación Eléctrica (Corpoelec), which is connected to three internal substations, equipped with a total of seven three-phase transformers with a rated power of 6590 kVA. These reduce the voltage to 460 V, 440 V or 220 V, depending on the unit, according to the one-line diagram shown in Figure 3.

The plant has an average monthly consumption of about 637 000 kWh, and its contracted demand is 1860 kVA. It is classified as a high consumer, as it invoices above 30 000 kWh/month [3]. It is a factory with considerable energy consumption in active systems, such as high consumption lighting and equipment that is relatively inefficient compared to new technologies. The decisions and strategies that man-agement has taken regarding the optimization of consumption have not been as effective as expected. Therefore, this study has been commissioned to achieve a significant effect in terms of efficient use of energy.

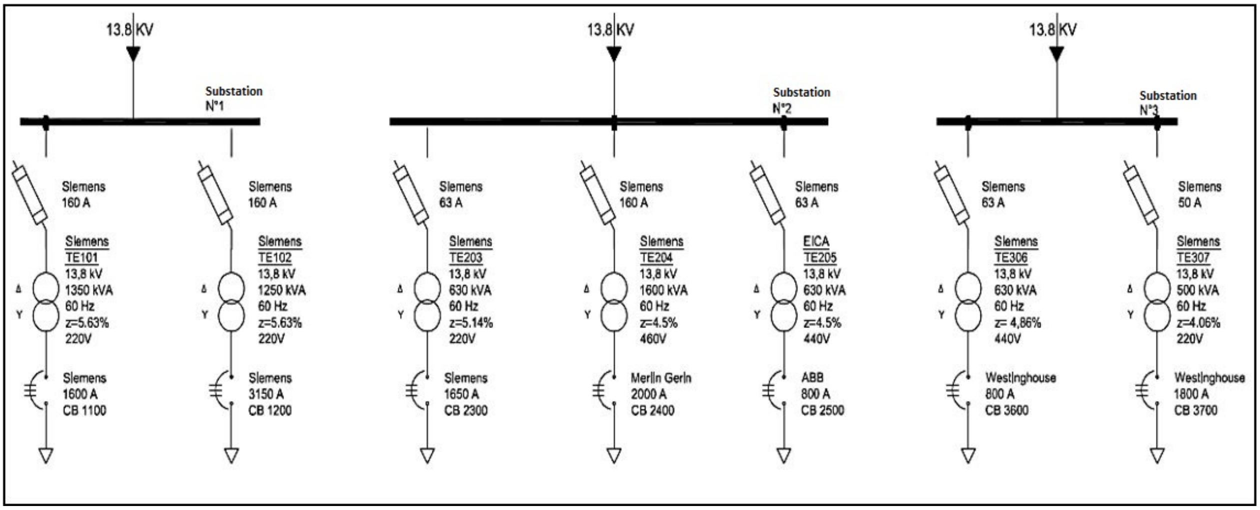

Figure 3. General single line diagram [3].

2. Development and method

The consumption and the availability of energy are preponderant factors in production costs. For this reason, the need to carefully manage energy to increase competitiveness is evident in the manufacturing and services sector [4].

Energy efficiency can be defined as the capacity of a use, equipment, installation or process to perform its function with the lowest possible energy consumption. Likewise, energy savings can be understood as the reduction of primary energy consumption of an a center through the implementation of technical or non-technical measures [4]. The implementation of these concepts in a company's energy management increases its productivity and competitiveness.

This has made it necessary for companies to create their own energy "management models" in order to motivate and encourage the development of a new organizational culture for the efficient use of energy.

By design, this is a documentary, descriptive and field research defined by activities framed in the collection of information that enable the energy characterization of the company Montana Gráfica, a subsidi-ary of the Corimon Pintura Group C.A., through the application of management tools that are part of the procedures presented in the International Standard ISO 50001. This energy review determines the performance of the organization based on data and other information, aimed at identifying opportunities for improvement contemplated in one of the ISO 50001 core requirements, energy planning, which involves a re-view of the company's activities that may affect ener-gy performance [5] for the implementation of an energy management system.

To carry out the energy characterization of the company, the following activities were carried out To carry out the energy characterization of the company, the following activities were carried out [5]:

1. Define the productive energy diagram: flow chart of the main production processes.
2. Carry out the load census: consumption by ar-eas and representative teams.
3. Calculate the Pareto diagram and stratification: 20% of equipment and areas that consume approximately 80% of electric power.
4. Propose control diagrams: simultaneous variation of energy consumption with production carried out over time, for areas and equipment. These include the elaboration of a control graph, energy production vs. time graph, energy vs. produc-tion graph, goal vs. production graph, and consumption index vs. production graph.

The development of these activities is presented below.

2.1. Productive energy diagram

It is very important to know the areas of the plant and the different processes that take place in it, as well as the equipment and raw materials involved. This provides a clear idea of how the company creates its final product, identifies which processes have the greatest impact on monthly electricity billing, determines percentages of automatization in the plant by analyzing different processes, among other characteristics. Identifying the processes will also allow the work to be broken down, so that it is easier to collect and analyze the results.

2.1.1. Identification of areas

The different processes carried out in the company are:

Cylinder preparations

In this process, images are recorded in several copper cylinders, which will then be inserted in the rotogravure machines for the printing of the image that the client wishes for their product.

Ink preparation

In this process, mixtures of base inks are created to achieve the desired color. Sometimes the inks are mixed with gold or varnish so they adhere more easily to some types of printing materials.

Rotogravure

In this process, the rotogravure machines print the image that the client requires at high speed, on their product and in the material they request.

Laminating

In this process, two layers of different materials adhere according to what the client requires for their product. They can be made with different adhesive materials such as hot wax, adhesives with solvents or without solvents. The materials that normally come together are paper and plastics of different natures.

Metallizing

This process is unique and scarcely done by the company, but, when carried out, it causes a very significant energy consumption, which is why it was preferable to separate it from the laminating process although its objective is basically the same: to join a layer of some kind of metal to a layer of some kind of plastic material.

Cutting and finishing

In this process the printing rolls delivered by the rotogravure process, after passing through the laminating or metallizing area when required, are cut according to the client's requirements (rolls or sheets).

2.1.2. Process flowcharts

Flowcharts of the different processes in the plant were drawn to illustrate the knowledge regarding procedures followed for the elaboration of the company's final product.

Figures 4 to 9 present the respective flow diagrams for each process

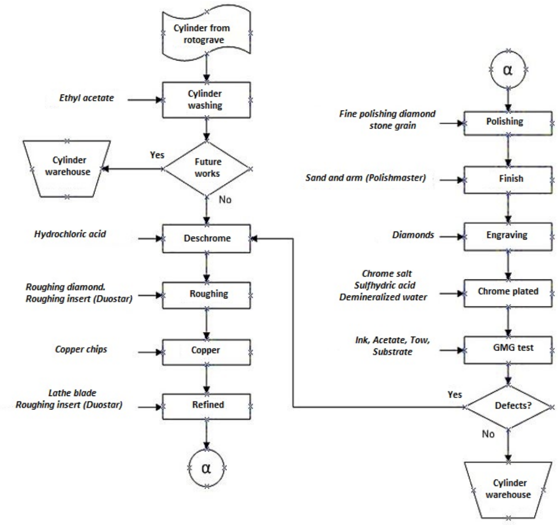

Figure 4. Flowchart for the cylinders area process.

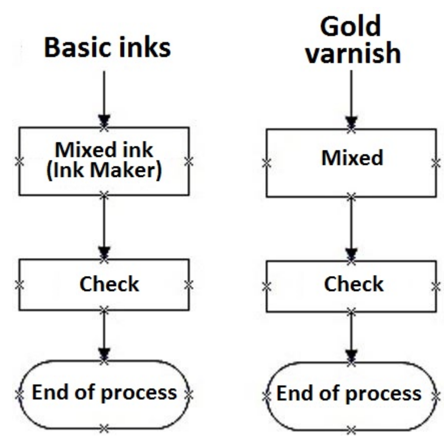

Figure 5. Flowchart for the Ink area process.

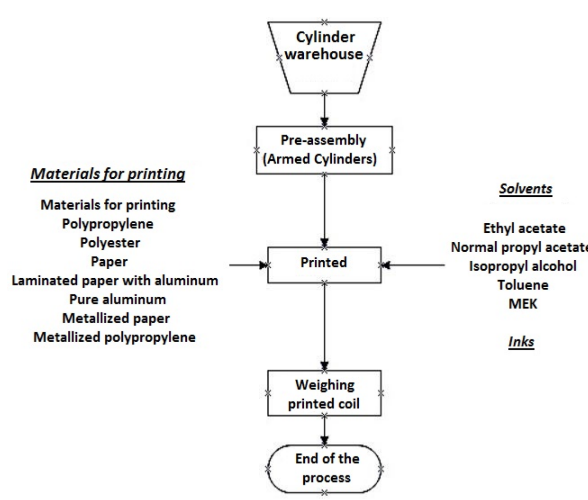

Figure 6. Flowchart for the cylinders area process.

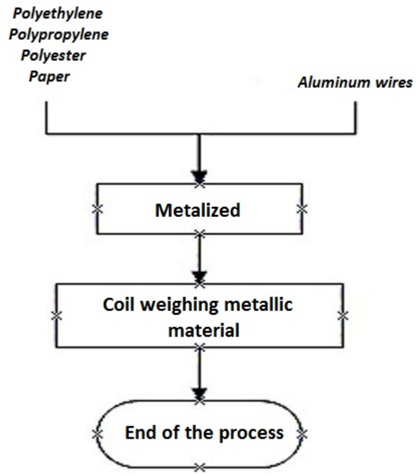

Figure 7. Flowchart for the Metallizing area process.

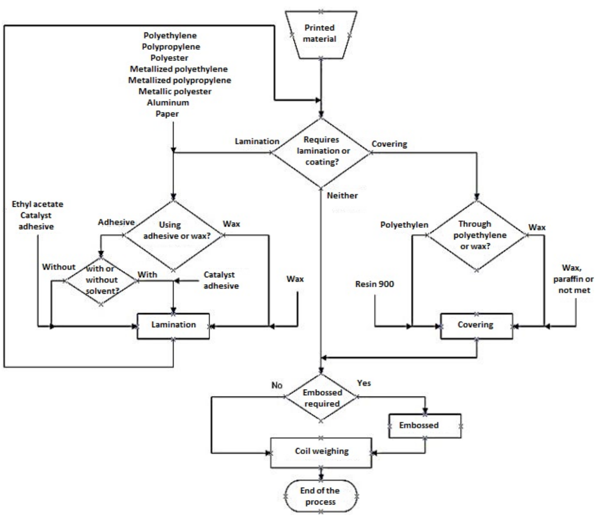

Figure 8. Flowchart for the Laminating process.

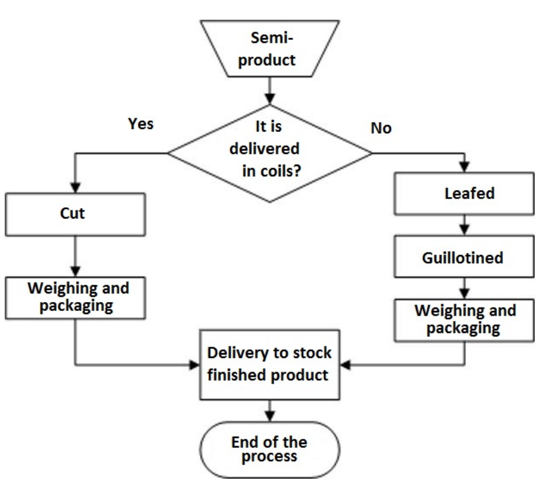

Figure 9. Flowchart of the Cutting and Finishing Process.

2.2. Load census

In the load census, a total of 56 machines composed of motors and various elements were identified; approximately fifty independent engines in the six areas described above, plus office equipment in a total of 45 work areas (offices, workshops, warehouses, etc.), for a total of 5946.35 kVA connected load.

Table 1 presents the independent motors with the highest consumption at the plant.

Table 1. Load estimation of a cooling unit, Chiller 2 – Westing-house – 460 V

Description	P (HP)	Vn (V)	In (A)	kVA
Compressor	20	460	32,5	25,89
Compressor	25	460	40	31,87
Compressor	20	460	32,5	25,89
Compressor	25	460	40	31,87
Fan	2	460	3,3	2,63
Fan	2	460	3,3	2,63
Fan	2	460	3,3	2,63
Approximate power of the machine (kVA)				**123,4**

2.3. Pareto diagram and stratification

Once the load census of the plant has been completed and the load data connected to it is known, the machines, equipment and motors involved are separated for each process carried out in the plant, in order to identify potential savings. Savings potentials were identified using a Pareto diagram.

Figure 10 presents the Pareto diagram of general processes, where the percentage (%) of process load is presented.

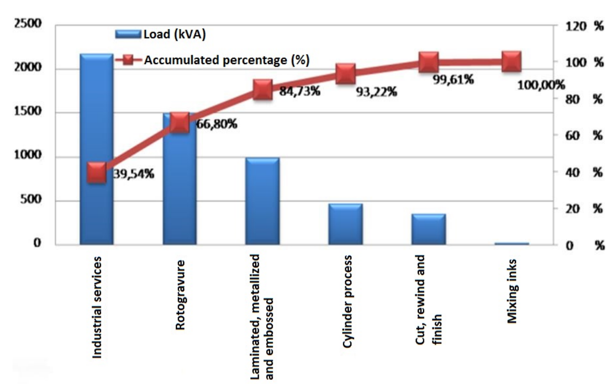

Figure 10. Pareto diagram of general processes.

It is very important to identify the elements that can have a significant impact on the plant's general energy consumption, since these represent possible savings points. Therefore, these devices were measured for real energy consumption.

Low consumption elements have little importance in terms of analysis, since any measurement or recommendation taken will not have a significant impact on the desired energy saving totals.

Figure 10 indicates that there are three processes and one area that represent almost 85% of the plant's total load: metal rolling and winding process, rotogravure and the industrial services area.

– Metallized rolling and winding process:

Dos equipos consumen en conjunto 15 884 kWh al mes, representando un 72 % del consumo mensual estimado de este proceso. Uno de los equipos sobresale por su consumo debido a su operación continua durante el mes y el otro equipo por su elevado consumo puntual.

– Rotogravure:

Three pieces of equipment have an equal production, two of them with the same technology, whose production is superior to the third piece of equipment. The equipments with the same technology consume altogether 105 440 kWh per month, almost 89% of the total monthly energy of this process, and the third piece of equipment consumes only 13 830 kWh.

– Industrial services:

The equipments that consume the most energy monthly are air conditioning equipment and chillers; together they represent 135,000 kWh per month, almost 45% of the monthly consumption in this area.

2.4. Control diagrams

With the data of the last two years of the monthly elec-tricity billing, plus the monthly production data, graphs were made to show the information on the variation of energy consumption based on the plant's production, consumption not associated with production, optimal points of production, establishments of goals, among others.

2.4.1. Control chart

Control charts are linear diagrams that illustrate the behavior of a variable according to certain established limits. They are used as instruments of self-control and are very useful as a complement to the cause and effect diagrams to detect phases of the analyzed process in which the alterations occur.

This graph is used to discard the points located outside the established limits ($\pm 3\sigma$), since these represent abnormal values and, if included in this study, they would give incongruent results. In addition, it allows for the identification of points that come remarkably close to the limits, and find the causes of this deviation. To make this graph, payment records to the electricity service company from the last two years were used. Figure 11 shows the control chart generated for the company. No point of monthly con-sumption exceeds the established limits, so all points are valid for this study.

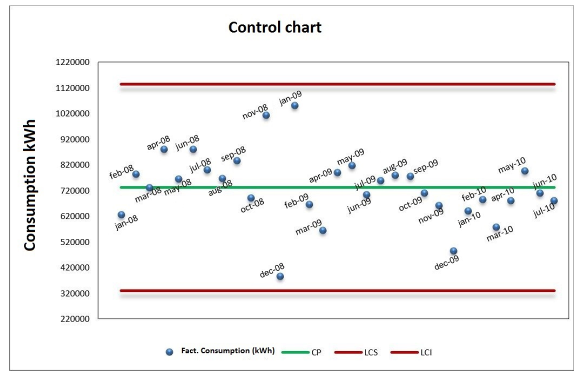

Figure 11. Control chart

2.4.2. Energy production vs. time graph

This graph, presented in Figure 12, simultaneously shows energy consumption and production over time, which illustrates the independent variation of the electrical energy consumed (kWh) and the amount of production (Ton) over time in order to identify any abnormal behavior in a period (month) and the reasons that produce such abnormal behavior [6].

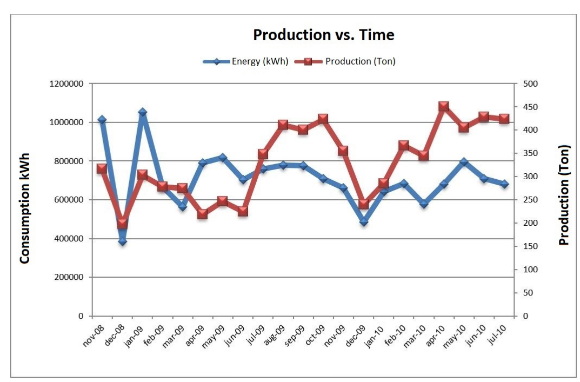

Figure 12. Electric power – Production vs. time graph.

The energy production vs. time graph shows that there is no uniform behavior in the November 2008 to June 2009 period, as well as the existence of a notable change in the relationship between production and electric power billed from July 2009 onwards, due to changes in high consumption equipment, when the production of the company increased significantly.

2.4.3. Energy vs. production graph

The purpose of this graph is to establish the trend that exists between production and energy consumption, and thus quantitatively define the value of energy not associated with production. For industrial and service companies, making a scatter diagram of the energy used in a given time with respect to the production carried out or the services provided during that same period reveals important information about the pro-cess, since when performing the line of characteriza-tion of consumption vs. production, energy consump-tion not associated with production can be established [6].

In the case of the company under study, as shown in Figure 12, two very different energy consumption trends were presented, due to two fundamental reasons: the first is the incorporation of more efficient machines and the second is the regulations published in November of 2009 in the Official Gazette of the Bolivarian Republic of Venezuela Number 39.298 [7], ordering a 20% reduction in electricity consumption, in order not to be subject to penalizations in the form of cuts in the electric supply.

For this reason, individual graphics were made for both trends, one for the period between November 2008 (date from which production data are available) and August 2009, Figure 13, and another for the peri-od from September 2009 to July 2010, Figure 14.

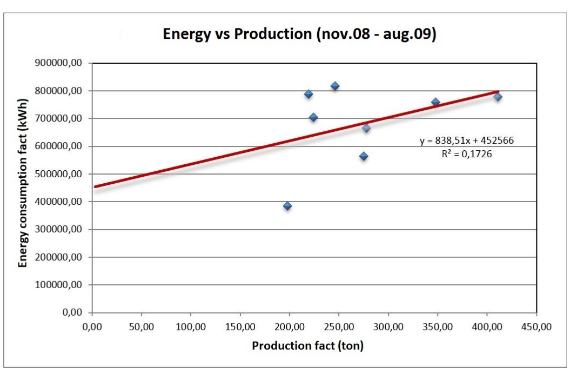

Figure 13. Energy graph vs. production (Nov. 08 - Aug. 09).

Before September 2009, Figure 13, consumption not associated with production was 452 566 kWh. After September 2009, Figure 14, consumption not associ-ated with production was 300 054 kWh (66% of what it was before). This is due to the order to reduce con-sumption, since the company adopted energy sav-ing measures such as replacing luminaires, switching off lighting circuits, shutting off large pressurizers, ac-quisition of a more efficient air compressor, among others.

Figure 13 shows a very low point correlation for various reasons that only the company is aware of (confidential information). There is no proportionality between what is produced and what is consumed. It is also noteworthy that November 2008 and January 2009 were the two months of greatest consumption in the plant and no specific cause for this increase was found, since the production of this period does not justify this fact. It is important to note that these two points further reduce the existing correlation between the plotted data, which indicates the existence of an irregular event in the plant during those months, or an error in the measurement-estimate made by the electric power service company.

Figure 14 shows a correlation of 57% between the graphed data, which indicates their greater reliability, thus the energy consumption study will be made based on this period (September 2009 - July 2010).

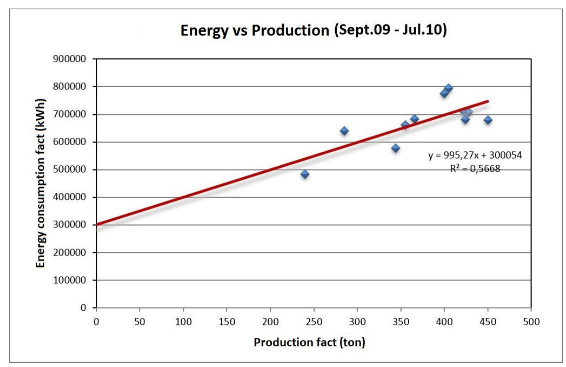

Figure 14. Energy vs. production graph (Sept. 09 - Jul. 10).

2.4.4. Establishment of the goal vs. production graph

Once the energy vs. production graphics are completed, the consumption goals are established.

In order to establish the goals and make them achievable, the months of the plant's best work efficiency were initially selected, that is, those that are below the line drawn in Figure 14. Through these selected points a new consumption trend it is established, which is defined as the goal trend, shown in Figure 15.

In Figure 15 the established goal trend is parallel to the current trend, but vertically displaced downward. This new trend indicates what the consumption of electrical energy for each production value should be so the plant works more efficiently. Consumption not associated with production of the goal trend is 213 871 kWh, while that of the current trend is 300 054 kWh, this implies that if the plant manages to maintain its production within the goal trend, it will achieve 29% energy savings.

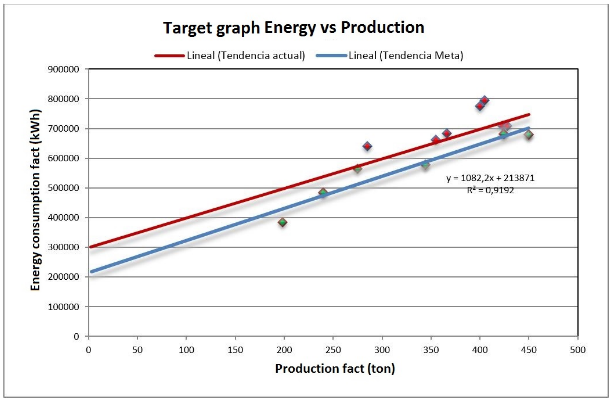

Figure 15. Goal - energy vs. production graph.

It should be noted that the previously established goal was set based on real values that the plant has already reached, so if the plant works to implement new savings systems, the results can be even more efficient.

2.4.5. Consumption index vs. production graph

With the values of the current consumption trend and the goal consumption trend, and dividing these by the production, a graph for the consumption index vs. production is obtained as shown in Figure 16, which indicates the energy needed to produce a ton for a given production value.

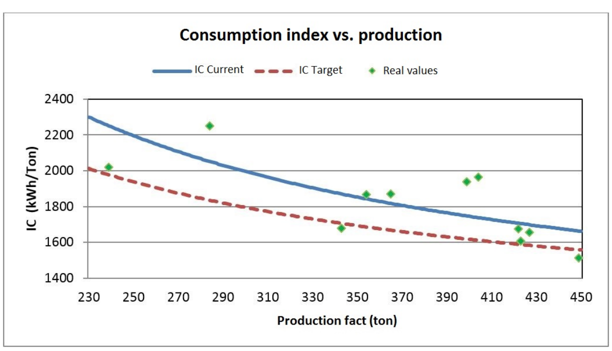

Figure 16. Consumption index vs. production graph.

As can be seen in Figure 16, the greater the production in the plant, the lower the impact of electric power on the cost of a ton of production. Due to this fact, it is important that production in the company is maintained at a high level, in order to reduce the amount of kWh per ton produced. In addition, two theoretical consumption index curves can be observed, one for the current consumption trend and another for the goal consumption trend.

The analysis of the consumption index, summarized in Table 2, indicates that in addition to maintaining high production, it is necessary to meet the established goals to significantly reduce the impact of energy per ton of product.

Table 2. Analysis of the consumption index chart

Tonne	IC current kWh/t	IC goal kWh/t
250	2196,0	1937,0
350	1852,0	1693,0
450	1662,0	1557,0

2.4.6. Measures proposed on the basis of the energy goal vs. production graph

Once the value of electric power (kWh) that can be saved monthly through the application of the proposed measures is quantified, change of luminaires, switching off of luminaires during resting hours, reduction of 20% plant and exterior lighting, change of motors, shutdown of air conditioning and office equipment during resting hours and use of the new compressor 100% of the time; the established goal consumption trend will undergo a modification, since this graph was initially formed by the best values actually achieved by the plant in its operation.

Afterwards, two new goal graphs are established, one considering only the measures that do not require monetary investment in machinery and equipment, and another that includes all energy saving proposals. To lay the foundations of economic analysis, both cases will result in a trend parallel to the previous goal but displaced downwards, that is, with consumption not associated with lower production.

In the establishment of the new goal graphs, factors were applied to the energy saving values for lighting, office equipment and air conditioning in order to give more realism to the results, since in some areas measures such as turning off the lights and computers in resting hours are already applied, and the air conditioning equipment does not work at 100% capacity during its entire work period. These factors are the following:

1) A factor of 0.6 was applied to the value obtained by saving when the luminaires were turned off.

2) A factor of 0.8 was applied to the value obtained through savings when office equipment was turned off.

3) A factor of 0.9 was used at the nominal consumption of air conditioning.

These factors were defined by observing the habits of the company's personnel; Tables 3 and 4 summarize the monthly energy values saved (kWh) as a result of each proposal.

Table 3. Analysis of the consumption index chart

Proposal	Monthly savings kWh
Lighting of luminaires during rest hours	1992,42
20% reduction in floor and exterior lighting	6163,20
Shutdown of A / C during rest hours	4303,28
Shutdown of office equipment during rest hours	155,20
Use of the new compressor 100% of the time	7148,00
TOTAL	**19 762,10**

Table 4. Monthly electricity savings for all the proposed measures

Proposal	Monthly savings kWh
Changing luminaires from 4 × 40 W to 3 × 32 W	2647,04
Lighting of luminaires during rest hours	1765,40
20% reduction of floor and exterior lighting	6163,20
Change of engines (decrease losses)	30 778,73
Shutdown of A / C during rest hours	4303,28
Shutdown of office equipment during rest hours	155,20
Use of the new compressor 100% of the time	7148,00
TOTAL	**52 960,85**

Figures 17 and 18 show the new energy goal vs. production graphs respectively for the measures with-out investment and for all the proposed measures.

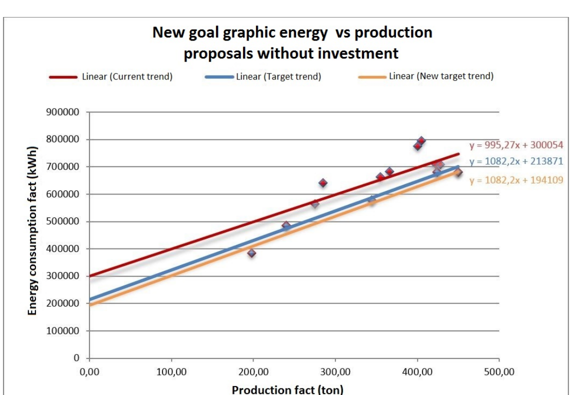

Figure 17. New goal graph – energy vs. production – proposals without investment.

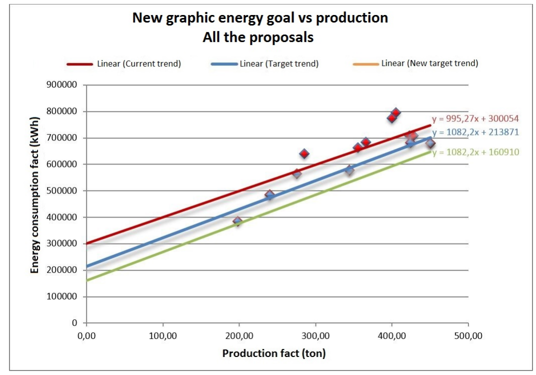

Figure 18. New goal graph – energy vs. production – all proposed measures.

Figures 17 and 18 show the plant's current trend, where consumption not associated to production is 300 054 kWh per month, in red, and the goal trend established for the plant without including changes, whose value is not associated to the production is 213 871 kWh per month, in blue.

Figure 17 shows, in orange, the new goal trend established on the basis of the implementation of savings measures without investment, whose value associated with non-production is 194 109 kWh per month. This represents 35% compared to the current trend and 9% with respect to the established goal trend, Figure 8.

Figure 18 shows, in green, the new goal trend established in accordance with the implementation of all the proposed measures, which yields a consumption value not associated with the production of 160 910,00 kWh per month, representing 46% of current consumption not associated with production, and 25% additional savings compared to the previously established goal.

By way of comparison, Table 5 shows the amount of residences that could be supplied for with the ener-gy savings obtained by implementing the measures proposed for the Montana Gráfica company, subsidiary of the Corimon Pintura Group C.A., taking as average a normal house-hold monthly consumption of 500 kWh per month, the minimum rate for general residential service, typified according to a tariff scheme as Rate 02: General resi-dential service, present in Article 9 point 9.2, published on April 3, 2002 in the Official Gazette of the Bolivar-ian Republic of Venezuela Number 37.415 [8], taking legal rates into consideration. It is possible to supply energy for 40 houses by launching the proposals with-out monetary investment in equipment and machinery, 106 houses if all proposals for energy savings are con-sidered, and, in an ideal case where the company man-ages to operate at optimal points of consumption in accordance with production, besides the implementa-tion of all the actions proposed in this work, it would be possible to supply up to 278 residences with the energy that would no longer be wasted.

Table 5. Number of housing units that could be supplied for with the energy saved

Actions to implement	Energy saved per month (kWh)	N.° of houses
Proposals without investment	19 762,10	40
All the proposals	52 960,85	106
New goal (all proposals)	139 144,00	278

3. Monitoring and control

This section presents an evaluation of the project based on the results obtained due to the implementation of the proposed saving measures, in addition to the company being able to maintain itself in the optimum points of goal consumption established.

The Executive branch introduced a policy for reduction of consumption in 2009 due to the national energy crisis. The management of the Corimon Group, of which the company Montana Gráfica is a subsidi-ary, has since implemented a series of measures, Figure 19, to reduce energy consumption in the different plants that conform it.

Generators were purchased to supply energy to crit-ical processes during interruptions or rationing.

Situations such as sub-loaded engines, imbalances in the power network, operation at reduced voltage and harmonic content introduced by non-linear loads that impact energy consumption were solved.

A study was carried out on the operation of the most important machines that presented the highest consumption in the processes according to the Pareto diagram.

The energy savings obtained range between 18% and 26% according to the conditions, the policies of the company and the level of commitment reached by the staff.

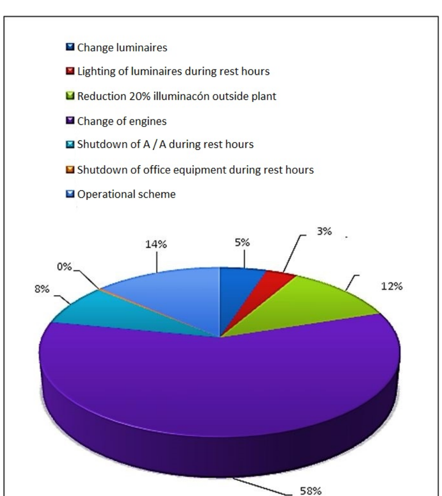

Figure 19. Average percentage of distribution of savings of the proposed measures.

From the constant characterization of the company we can intuit the possibility of improving energy sav-ing goals as new measures are analyzed and implemented.

The economic feasibility of the project was obtained on the assumption that the company operates under optimal conditions in terms of consumption vs. production (goal trend), in addition to the proposed measures without investment over a period of 7 years (short and medium-term measures). The minimum rate of return was considered constant at 17% during the study period.

For the first year (t = 0) only the cost of the project was estimated as monetary flow. For subsequent years, the annual savings obtained through the pro-posals without investment and operation of the plant under the goal consumption vs. production trend are considered as net flows, but increasing as the measures were implemented. The electric rate is con-sidered constant throughout the study period.

The income exceeds the costs, Table 6, so that economically, in 7 years the benefit is higher than the minimum required according to the analysis of the project (2009-2016).

4. Conclusions

This paper presents a methodology to quantify the energy savings possible in an industry, through a procedure based on control charts that allows for the sys-tematization of the calculation of possible energy sav-ings, which is a way to help solve the current energy problem.

The systematic study of possible savings based on the method allows for the improvement of results ob-tained previously with non-systematic changes.

The proposals made according to the presented method achieved monthly savings in terms of the electricity generation system of a total of 138,024.84 kWh, on average. Additionally, the company managed to operate at optimal points of consumption according to production. In addition to the implementation of measures, the savings are equivalent to the electric power needed to power up to 278 residences with the energy that is no longer wasted. The generalized appli-cation of the proposed methodology would allow for the reduction of the national energy problem in a sys-tematic way, eliminating waste of energy without af-fecting levels of industrial production.

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Table 6. Interpretation of the project's value 2009-2016

Year	Investment to recover at the beginning	Net flow	Minimum performance	Recovered invertment	Invertment to recover
1	98 104,00	12 230,25	16 677,68	-4447,43	102 551,43
2	102 551,43	24 460,50	17 433,74	7026,76	95 524,67
3	95 524,67	36 690,75	16 239,19	20 451,56	75 073,12
4	75 073,12	48 921,24	12 762,43	36 158,81	38 914,31
5	38 914,31	48 921,24	6 615,43	42 305,81	-3 391,5
6	30 582,87	65 228,64	5 199,08	74 797,60	-1 757,98
7	15 852,69	65 228,64	2 694,95	87 513,19	-153,21
8	12 458,67	86 971,94	2 117,96	154 725,23	-79,41

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