Energy 154 (2018) 544–552

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Energy audit model based on a performance evaluation system

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ARTICLE INFO

Article history:
Received 8 September 2017
Received in revised form
20 April 2018
Accepted 28 April 2018
Available online 30 April 2018

Keywords:
Energy efficiency
Energy management
Energy conservation
Competitiveness
Evaluation of organizational performance
Performance Indicators

ABSTRACT

Brazil has one of the highest electricity costs in the world, aggravating one of the lowest rates of development in energy efficiency. This context impairs the competitiveness of the Brazilian industrial sector, which consumes approximately one-third of all electricity generated in the country. The researchers aimed to propose a model to diagnose the level of energy performance in companies of the industrial sector, using concepts of evaluation of organizational performance and multicriteria approach to decision support. The model was developed based on Key Performance Indicators, organized in a hierarchical structure. Six Fundamental Points of View were listed, which were deployed in 58 Critical Success Factors, selected from the recurrences identified in the theoretical framework. The influence level of each indicator in the analysis was performed through the Analytic Hierarchy Process prioritization. In order to evaluate the interaction of performance indicators indices in the modeling, software for data processing and reporting was developed. The modeling was submitted to tests in an industry, returning in its evaluation phase an index that represents its energy performance, thus allowing the discussion of the results obtained. Subsequently, adequacy actions were proposed to simulate the possible gains of performance obtained through the adoption of strategic actions.

1. Introduction

An increase in energy consumption in developing countries, especially China and India, accounted for the bulk of global energy consumption growth in recent years, at a rate of 11.37% per year in the last 20 years [1–3]. Although in other proportions, Brazil also contributes to this growth, since the consumption of electrical energy has grown in the last two decades at a rate of 3.3% per year, according to the Brazilian Energy Research Office [4].

Currently, industry is the sector with the highest demand for energy in Brazil, corresponding to approximately 33% of all energy produced in the country. Energy consumption in other sectors, such as residential (21.2%), commercial (14.5%), public (5%) and agricultural (4.3%) also represent significant demands for energy in the country [5].

Due to this growth, several infrastructure changes were made regarding the generation and distribution of energy. However, those changes were not enough to reduce energy costs, especially for the industrial sector, which had 48.2% of growth in tariffs between 2013 and 2016 [5,6].

A recent study published by the Federation of Industries of the State of Rio de Janeiro [5] shows that the average cost of the energy tariff for industries that consume energy in the Regulated Contracting Environment (RCA) in Brazil in 2016 was approximately US$ 160.00 per MW/h. It represents a decrease of 10.7% compared to 2015, when Brazil obtained the first position in the survey on the tariff value of electrical energy that compared it to other 27 countries [7]. This cost, directly impacts the production cost of the Brazilian industry, causing loss of competitiveness in the international market, aggravated with each passing year [8,9].

According to data released by Brazilian National Confederation of Industry (CNI), although Brazil stands out in availability of electric power among 10 other countries [10], with the seventh largest production of electricity and Gross Domestic Product (GDP), it is in the last position in the energy infrastructure sub-sector. This result reflects the high cost of electricity for industrial clients, compared to the cost in other countries evaluated in this research [10].

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https://doi.org/10.1016/j.energy.2018.04.179

In this context, energy efficiency emerges as a solution for the Brazilian industrial sector, considering that the results of energy conservation measures reflect both the costs reduction [11,12] and the optimization of energy consumption [13]. However, according to data published by Ref. [14], through the report of the American Council for an Energy-Efficient Economy (ACEEE), Brazil has presented one of the worst indices of energy efficiency development for the industrial sector among the cited countries. For the second consecutive year, Brazil ranked second to last in this report, which analyzed the 23 largest economies in the world from the point of view of energy efficiency from four main topics: national efforts, buildings, industry, and transportation. The economies evaluated represent 81% of the GDP and 71% of the global energy consumption [14,15].

Considering that the current Brazilian energy scenario for the industries is one of high cost of electrical energy, falling competitiveness and low rates of development in energy efficiency, it is essential to develop methods that help industries in the control and use of energy. Those methods can facilitate the targeting of investments that reduce the impacts of such indices by generating indicators that point to the factors that directly affect the cost and consumption indices of the energy resources [16].

Many studies on the development and application of energy audit methods can be found in the existing literature. Examples, in this sense, are the recent studies published by Refs. [17–19]. In addition, studies that performed energy performance assessments using the Key Performance Indicators were presented by Refs. [20,21]. In turn, the relevance of the application of such approaches in the industrial sector were highlighted by studies published by Refs. [22–24].

However, there are many obstacles to the systematic adoption of energy efficiency measures in the day to day of a company or organization, making the use of management tools for this purpose indispensable. This is because those tools can assist companies in the identification, measurement and analysis of the factors that compromise their energy performance, directing them to investments that will increase their level of competitiveness [25–27].

In this sense, we highlight the energy audit, which has the purpose of directing energy conservation and reducing the impact of its costs on industrial operations through the identification of negative consumption trends [15,28].

2. Fundamental Points of View (FPV)

Several perspectives of analysis can be carried out to prospect for opportunities of improvement in energy efficiency based on the identification of the factors that compose an energy audit. The factors presented here are the most recurrent among analyzes in literature and were thus organized in order to compose the energy efficiency index of the presented model. Therefore, the theoretical deepening of these factors is essential to understand and validate the practical approach carried out in this work.

2.1. Administrative actions (ADMA)

Technical actions related to energy efficiency measures are aimed at reducing consumption, while administrative actions involve contractual aspects, changes in habits and internal procedures in order to reduce the cost of energy [29]. Among the administrative actions aimed at the elimination of waste, we highlight in particular the contracting of energy with the distributors. In this way, understanding the tariff structure and the regulatory concepts that involve the electric sector is fundamental for a correct decision-making process within the energy management proposal [30].

After assessing the tariff structure, it is necessary to elucidate the contracting options for energy, so that it can be managed. Both for customers that fit into the profile for contracting under the Free Contracting Environment (FCE) and companies that have their energy contracts governed by the rules of the Regulated Contracting Environment (RCE), the correct definition of the consumption profile with the contracting of the adequate energy supply to this profile is fundamental in reducing energy costs. Therefore, those consumers should have access to contracted demand, reactive power and tariff framework [31].

2.2. Electric motors (EM)

Electric motors are responsible for the transformation of electrical energy into mechanical energy, being widely applied and of great importance in industrial processes [32,33]. The efficiency of the machine/engine assembly depends, in particular, on the correct design of the engine for the type of drive it is intended for [34]. In addition to the correct sizing of electric motors, the replacement of standard motors by high-performance ones is an important alternative for energy saving in drive systems. The main characteristic of those engines is the improvement in vital points where the majority of the losses are concentrated [35].

Finally, it is necessary to maintain the motors. The proper maintenance of an electric motor and the machines it drives can represent significant energy savings. A program of rational use of electric energy is based on the implementation and the fulfillment of programs of corrective and preventive maintenance applied to every electric motor and the machines that it drives [36].

2.3. Electrical Systems (ES)

The elements used to conduct, transform, condition and control energy are called electrical systems, widely found in industry, and may also present opportunities for improvement in effect to reduce energy waste [37]. From the moment the energy is supplied by the utility to the moment it is used in an engine, light bulb, resistor or other electrical appliance, it goes through several systems and equipment that need to be equally efficient [34].

In this sense, one of the electrical systems that can present significant opportunities for improvement is the transformers. They are indispensable pieces in the field of the use of electric energy, considering that they allow to raise and to reduce tensions, with simplicity and high yield. The importance of improvements in power factor and voltage profile is also highlighted, with consequent efficient operation of equipment, reduction of harmonic distortions and prevention of equipment malfunction, avoiding loss of production [38].

2.4. Lighting (LT)

A lighting system is defined as all the components necessary to meet the lighting requirements. The good performance of this system is directly related to the electrical design, which should involve information on luminaires, usage profile and type of activity to be performed [39]. In order to achieve the required efficiency in a lighting project, the following aspects must be met [40]: