Energy Efficiency in Maquiladoras of Electronic Components: A Cleaner Production Approach

VELAZQUEZ, L. [a*], ESQUER, J. [a], GARCIA, R. [a], VARGAS, N [a]. VELDERRAIN, R. [a]

a. Universidad de Sonora, Hermosillo

**Corresponding author, luis_velazquez@industrial.uson.mx*

Abstract

Estimates by the International Energy Agency show that the world's demand for energy will increase 1.6% annually until 2030; this is mostly due to the rapid growth in the economies of developing countries. Currently, almost two thirds of the world's energy resources are used in production lines; therefore, not only is energy management an operational and administrative priority for entrepreneurs, but has also become a matter of public and governmental concern.

Given the fact that the manufacturing industry is a powerful energy consumer, energy efficiency has become a key element to maintaining competitiveness and core advantages, since not only it does contribute to cut costs and reduce the emission of greenhouse gasses (GHG), but it also aids maquiladoras in their efforts to build an image of prestige and repute in the eyes of the competitors, the employees and other stakeholders. It also helps them developing strong policies to grow as a socially responsible company and paves the way to true sustainable development.

Despite the obvious economic and social benefits that efficient energy management means for companies and entrepreneurs, the manufacturing industry in developing countries still lacks strong energy policies. It is usually the international corporation that adopts and adapts energy conservation measures in host countries; if only as an extension of similarly built management techniques used by the parent company in the countries of origin.

Energy audits in Mexican maquiladoras have shown diverse results, this is mostly due to lax regulations and lack of rigor in compliance, poor employee training and significant differences in infrastructure and in the size of the plants. Nonetheless, opportunities for improvements have been identified in all maquiladoras audited and could, potentially, greatly reduce energy costs and GHS emissions.

Keywords: *energy audits, maquiladora, energy efficiency, energy management systems, cleaner production.*

1. Introduction

Estimates by the International Energy Agency show that the world's demand for energy will increase 1.6% annually until 2030 (International Energy Agency 2008); this is mostly due to the rapid growth in the economies of developing countries; currently, almost two thirds of the world's energy resources are used in production lines; therefore, not only is energy management an operational and administrative priority for entrepreneurs, but has also become a matter of public and governmental concern (Al-Shehri 2000)

In México, specifically, the manufacturing and maquiladora industries are the second highest energy consumer and, as is the case with other productive sectors, its demand for energy increased during the period of 2010-2014; this increase follows similar patterns observed in other developing countries, in which energy consumption is directly linked to greater production (Beltrán Rodriguez et al. 2013)

Given the fact that the manufacturing industry is a powerful energy consumer, energy efficiency has become a key element to maintaining competitiveness (Apostolos et al. 2013) since not only it does contribute to cut costs and reduce the emission of greenhouse gasses, but it also aids maquiladoras in their efforts to build an image of prestige and repute in the eyes of the competitors, the employees and other stakeholders. It also helps them develop strong policies to grow as a socially responsible company (Buitelaar & Pérez 2000; Cartes 2011). Despite the obvious economic benefits, it is for the most part the international corporations that are inclined to adopting sustainable energy measures, perhaps if only as an extension of similar policies in place in their countries of origin (Flores et al. 2004).

Despite the obvious economic benefits, it is imperative to highlight that energy savings should not be the only stimulus in the decision making process for a manufacturing company, but that energy management must be a central part of an integral benefit structure derived from an energy audit and not be the sole purpose of the plan (Hadjimarcou et al. 2013; Sudhakara Reddy 2013). In other words, an energy audit should be an important tool in the management of maquiladoras besides the economic benefits it can provide because energy optimization usage has impact in many other areas such as the working environment, overall environmental performance, product and job quality and because its implementation can unveil improving potentials in the facility; improvements that might not be directly related to energy inputs (Tanaka 2011; Water, Whatley & Berry 2008).

In regards to energy audits, their results should be used to generate recommendations directed at strengthening and encouraging energy efficiency over energy conservation; even when the latter has a shorter payback period and a direct influence on reduction of production costs, energy efficiency is a more solid alternative to maintain the sustainable growth and performance of maquiladoras due to its systemic approach (Ruiz, Rodríguez-Padilla & Martínez 2008; Sardianou 2008).

The market in which maquiladoras for electronic components operate is slightly specialized and therefore not very price-sensitive, thus the strategy of low production costs is not entirely justifiable or advisable; on the contrary, maquiladoras with strong sustainable energy policies show more growth and overall better industrial performance (Sandberg & Söderström 2003; Song et al. 2014; Zhao et al. 2014).

The inclusion of energy audits is essential in the management of maquiladoras, to the extent that energy efficiency and energy conservation become part of the vision and is integrated in the structure of companies. The sustainable growth and development of a maquiladora should consider the economic benefits in the use of energy inputs, but also the implementation of permanent energy policies directed to optimize energy management, the efficiency of production processes, to encourage the development and adoption of sustainable practices among employees, to involve the needs of nearby communities in the decision making process, and to promote energy measures that contribute to decrease CO_2 emissions and foster sustainable growth in maquiladoras.

2. Description of the maquiladoras

This report includes audits carried out in four maquiladoras. Two of them located along the Mexico-US Northwest border and two in the northern Mexican city of Hermosillo. All the maquiladoras contacted specialize in a diverse range of electronic and electric products and accessories, their main market is US exports; three of them have electricity as their sole energy input, the remaining maquiladora uses a combination of electricity and gas to fulfill its energy demand.

Maquiladora 1

This maquiladora carries out assembly and production of cables, electric harnesses and other electric accessories. The company has been in business for over 30 years and their facilities are reflective of

the infrastructure and legal requirements for buildings in that time. For their daily operations, this maquiladora uses electricity and gas. The gas itself is a minor energy resource.

It has a workforce of over 436 employees that work in a single shift. The company is set up unevenly in an area of 11,000 square meters. The site is divided in buildings or wings that do not follow an apparent logical function; this disarticulation poses a serious challenge when it comes to implementing a unified energy management system due to natural existence of separate and isolated energy flows throughout the different sections of the maquiladora.

Maquiladora 2

The site of this maquiladora is modern and it is well insulated, the machinery in the plant is well organized and distributed in terms of production requirements and type of product. There are currently strong energy conservation policies in place and energy consumption assessments are carried out twice a year, more than the Mexican legal requirement of one electricity consumption check-up per year.

This maquiladora has about 1,947 employees that work in three shifts; the night shift has a lesser workload, in response, all energy supplies are handled accordingly. In general, all facilities and electrical installations are well-maintained, and it has 16,770 square meters. Electricity is the sole energy input in this maquiladora.

Maquiladora 3

This is a highly specialized maquiladora; it is a production center for a niche market of electronic components for medical parts. The site structure is not *ad hoc* with the activities carried out in the plant and many physical and administrative changes have been made in order to make the building fit for its production requirements. Overall, the site lacks a strong energy policy, and the site cover may not be appropriate.

This small maquiladora has 75 employees working on one single shift; its only energy input is electricity.

Maquiladora 4

The company was recently relocated to a newly built site; overall the facilities are well-conditioned and appropriate for the activities carried out there, which consist mainly of assembly and production of cables and other electric components.

The maquiladora does not appear to have an energy-specific policy but energy management is achieved through their general management program. Electricity is the sole energy input. This maquiladora has about 3,000 employees in three shifts and has a construction area of over 25,000 square meters.

3. Methods

3.1 Methodology design

The methodological structure is classified as descriptive and analytical. A model of Cleaner Production program adapted to the Efficient Use of Energy in the maquiladoras (UNEP, 2004) is used. This model is sequential and cyclical, and consists of 5 main stages: Planning and organization; pre-assessment; evaluation; feasibility analysis; and implementation and continuity.

The phases can be summarized as follows:

• Phase 1: Planning and organization: In this phase the support and commitment of the top management is achieved in order to involve key employees and build a team that will collect basic information to identify and assess barriers that may be encountered.

• Phase 2. Pre-assessment: Prepare and identify process flows, audits, characterizations and assessments to build a database with general information.

• Phase 3 Evaluation: Based on the previous phase, a balance of matter and energy is carried out; its result should generate options for improvement.

• Phase 4. Feasibility analysis: During this phase technical, economic and environmental assessments are carried out in order to obtain appropriate information about the most feasible options for implementation.

• Phase 5. Implementation and continuity: An implementation plan is required as well as a continuous evaluation process that ensures ongoing improvement of the energy management system and the overall performance of the maquiladora.

3.2 Scope

The study includes the implementation of Energy Efficiency Programs in two Mexican cities. This article examines only the first three stages of the proposed methodology. The remaining steps will be discussed after further research is completed.

3.3 Location of the object of the study

The project encompasses the analysis and research in maquiladoras that produce electronic components, their selection has been deterministic, that is, the interest of maquiladoras to collaborate in the project has been a determining factor.

3.4 Tools for collecting and managing data

• Pre designed formats were used during the energy audits to collect and concentrate information on energy consumption (Dall'O., 2013). This information was difficult to obtain due to the lack of records and control of confidentiality in some of the companies.

• In the process of obtaining qualitative data interviews with employees and managers were conducted. The inclusion of employees in this process proved essential, as they their day-to-day tasks allow them to spot areas for potential improvement that are unknown to managers.

• Also during the collection of data, and as a tool to control and handle information properly, graphs and charts were used to better illustrate processes and results.

• The instruments used for data collection are electricity bills, technical information about equipment and machinery as well as other pertinent information coming from the company's energy dedicated team or through direct observation. Some companies had someone in charge of energy issues and in others a lack of interest in energy efficiency was shown.

4. Results

4.1 General Assessment

The audit team checked the equipment and installations during walkthrough visits to the four maquiladoras. First, a meeting was held with the manager/maintenance engineer to introduce the members of the audit group. The engineer then explained manufacturing process and energy-

consuming machineries, and provided available operation and maintenance data.

4.2 Ventilation Systems

In maquiladora 1, the ventilation systems seem as shown in Fig. 1. Some equipment seems old and should be checked to determine if a substitution would be optimal. Maquiladoras 2 and 4 seem to have newer equipment, but their real needs should be taken in consideration and a checkup to determine if the equipment is the optimal for their current needs should be done. The current situation in Maquiladora 3 is similar to maquiladora 1.

Picture	Current Situation	Improving Measures
	The ventilation systems look old.	It needs to be checked if there are more energy efficient electric engines on the market. Also, it is very important that the size of the engine and the whole ventilation system is matching with the needed demand.

Fig. 1. Ventilation system at maquiladora 1

As a general observation it is recommended that the following actions be completed: (a) Check the model of motors and fans; (b) verify that the size and performance of the systems is appropriate to cover the demand; (c) ongoing maintenance of the systems.

As general recommendations to the companies, the audit the audit team suggests to (a) reduce airflows through variable speed drives (VSD); (b) Reduce airflows through effective time control.

4.3 Pneumatic Systems

Three out of the four maquiladoras use pneumatic systems in their production processes and/or to clean the workspace with compressed air. Maquiladora number 1 uses pneumatic systems with old installations and so frequent maintenance checkups should be a priority in order to keep leakages controlled. Maquiladora number 2 has replaced most of their pneumatic machines and adapted their processes to work with electric machines in order to be more energy efficient. Maquiladora number 3 had several maintenance problems with compressed air leakages throughout the facility. Maquiladora 4 has pneumatic systems too, and even when the company does not have reliable data of energy consumption of these systems, it has implemented several control measures to decrease leakages. The company has a maintenance plan and some projects to further improve energy efficiency in the near future.

The first actions that must be taken care of are (a) Check where a connection to the compressed air pipe system is necessary. (b) Consider where winding pipe systems are replaceable by straight pipes. (c) Inspect if the pipe diameter matches with the need of compressed air. (d) Detect if there are available means to control the distribution of compressed air by process area.

As general recommendations, the audit team suggests: (a) Replacing pneumatic devices by electric tools where possible. (b) Decreasing air pressure in compressors if possible. (c) Usage of variable speed drives. (d) Reduction of air leaks. (e) Improving the controllability of the pipe system.

4.4 Electric engines

All four companies make use of electric engines as their main production machines but these do not necessarily consume the most energy. Maquiladoras 2 and 4 are modern facilities that include new models of their machines therefore energy efficiency ones. Production planning and worker training should be considered a priority to keep energy consumption under control. Maquiladoras 1 and 3 have older equipment and therefore a higher probability of low efficiency machinery.

The first actions that must be taken care of are (a) Check the model, size and performance of the electric engines, especially the ones used for ventilation, air conditioning and pneumatic systems. (b) Validate if they have the appropriate dimensions and are optimal according to the needs of the facility.

As general recommendations, the audit team suggests: (a) Utilization of variable speed drives (VSD). (b) Preferential usage of direct drives. (c) Regular maintenance of the drives. (d) Usage of energy efficient motors (IEC standard 60034-2-1 or CEMEP efficiency category). (e) Selection of an energy efficient type of transmission.

4.5 Kilns within the production process

All four maquiladoras use kilns to complete their production processes. These are high consumption machines that must be considered a priority in the production process to reduce energy consumption. The industrial furnaces often produce waste heat in the room they are kept in as shown in Fig 2. None of the maquiladoras use this waste heat as an input resource for other processes.

The first actions that must be taken care of are (a) Check if the waste heat can be used for the provision of warm water. (b) Investigate the available technical alternatives to improve the insulation.

As general recommendations, the audit team suggests: (a) Installation of heat recovery systems. (b) Better insulation of kilns and pipes.

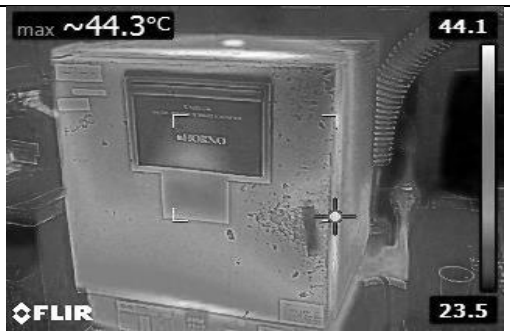
Picture	Current Situation	Improving Measures
	The industrial furnaces are producing a lot of waste heat what increases the room temperature enormously. Also this heat gets piped outside, without any use of its energy.	Improve the insulation of these furnaces. Also, it would be useful to analyze available heat recovery technologies in order to recover some of the waste heat lost in this process.

Fig. 2. Kilns within the production process at maquiladora 3

4.6 Lightening

Maquiladoras 1 and 3 both have plans to improve the lightening installations to increase energy efficiency within the next two years. Maquiladora 2 has invested in new lightening technologies in the last few years and is committed to continue doing so. Currently, the facility operates with one of the highest efficient installations available on the market. Maquiladora number 4 also has a plan to substitute lamps to newer and more efficient models. According to information provided by the company, lightening is responsible for about 10% of the facility energy consumption.

The first actions that must be taken to care of are (a) Check the equipment currently in use. (b) Investigate the time period when each process and area are used.

As general recommendations, the audit team suggests to elaborate on possibilities to use more daylight, although it could be difficult to accomplish this due to the long payback periods of these projects.

4.7 Air-conditioning technology

Every one of the maquiladoras visited has had some kind of assessment in the past three years to analyze their current air conditioning technology. Both the cities of Hermosillo and Mexicali are located in desert ecosystems and temperatures during the summer might surpass 50° C occasionally. Therefore, managers and maintenance teams are aware of the increases in electric energy consumption during this time of the year and know that the air conditioning technology is the key to keeping control of energy consumption patterns all year round. Although they all certainly have made improvements recently, all four companies should keep air conditioning under control by constantly monitoring the efficiency of their equipment and try to reduce the flow of air through effective time control, when possible.

4.8 Energy consumption

The use of the energy resources is not uniformly distributed in all maquiladoras, but previous research as well as direct interviews with managers suggests that the main areas for energy consumption are HVAC, motorized systems and pneumatic systems (Bryan & Phelan 2012). These areas, though, have varying degrees of energy consumption throughout the year, the changes in consumption patterns can be largely attributed to higher production and higher exterior temperatures during the summer months as can be seen in the chart below (Fig 3).

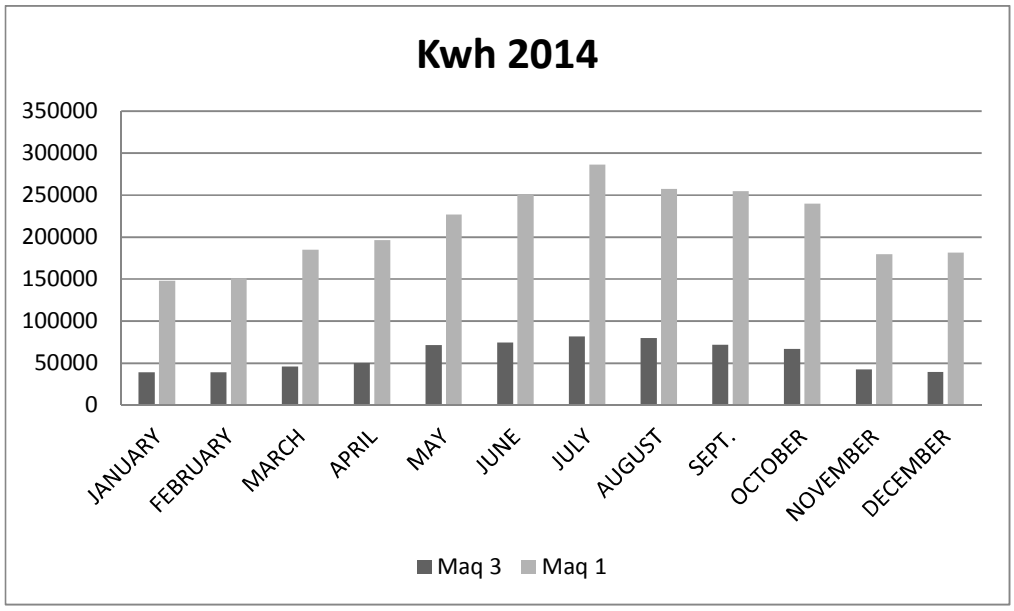


Fig.3. Energy consumption comparative graph between maquiladora 1 and maquiladora 3

The chart above shows energy consumption of two maquiladoras during the year 2014, both maquiladoras are relatively small and have very basic energy efficiency measures; in spite of the abysmal difference between the two maquiladoras in their total consumption, in both cases a slight increase can be observed during the summer months

As a general recommendation the insulation of the building envelope and an intelligent peak load management should be taken into consideration since they are responsible for significant energy consumption related costs.

5. Conclusions

Energy consumption in all maquiladoras is uneven and not necessarily reflective of variable production volumes. Although not directly attributable to weather conditions, all maquiladoras registered higher consumption rates during the summer months; these can be matched with a more intensive use of air conditioning systems.

Another common issue shared by all maquiladoras was the use of pneumatic systems, while some were aware of its potential for improvement and straightforwardly expressed their desire to acquire newer technology or replace them by electric equipment, other companies were less aware of the impact it has on energy costs but acknowledged the need for more efficient measures and their willingness to implement them.

Generally, energy consumption seems to be determined by how new and energy efficient is the equipment as well as by the structure and configuration of the plants. As is the case with other management issues, energy policies seem to be much stronger and solid in the bigger companies where stricter policies are in place (Buitelaar & Pérez 2000); the small companies had only a notion of what needed to be done but little encouragement, if any, was given by management.

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