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Article

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Energy Efficiency for Reinforcing Steel Activities in The Construction of a Business Complex in Mexico

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Abstract: Much of the energy used in the world is associated with the construction sector, and one of the ways to reduce that energy consumption is to do each constructive process in an energetically efficient way. The aim of this paper is to present results from an energy efficiency program in the construction of a business complex in Hermosillo, Mexico, particularly in the processes of reinforcing steel activities (rebar). Results reveal that appropriate use of equipment and the coordination between engineers and workers help to improve the energy efficiency during the construction phase also reducing material waste. Additionally, attaching the energy efficiency approach to the cleaner production framework is a complicated task due to energy inefficiencies are not easily identified and estimated. Since there is less energy consumption in construction process along the life cycle of buildings compared to operation activities, there is little evidence on energy efficiency studies in that part of the process. Therefore, this paper intends to provide experiences to construction experts in order to have better basis for decisions related to energy efficiency in this industry.

Keywords: Construction, energy efficiency, environment, sustainability, reinforcing steel, Mexico

JEL codes: Q40, Q49, L74

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1. Introduction

Buildings represent 40% of the world's energy use (WBCSD, 2009), where some of the factors

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involved are their location, building materials and their design (Chou et al., 2017). A means to reduce that energy consumption is to carry out each phase of construction process in an efficient way, from obtaining the raw materials to demolition and waste management phases (Peláez Ramos, 2011). The purpose of this paper is to show, as part of an energy efficiency program, the results of a case study on reinforcing steel activities (rebar) in the construction of a business complex in Hermosillo, Sonora, Mexico. This paper is structured as follows: the next section shows a literature review about sustainability and energy efficiency in construction as well as related topics, section three describes the methodology used in this study, section four shows the results, and last section provides concluding remarks.

2. Literature review

Construction processes generates many kinds of environmental impacts such as emissions of greenhouse gases and other air pollutants (Zhang et al, 2014). For reducing those, transferring the sustainable development principles into the construction sector becomes necessary (Passer et al, 2015). As stated by the Nordic Innovation institution (2014), the main objectives of sustainable construction activities are to deter resource depletion of energy, water, and raw materials and prevent environmental degradation caused by facilities and infrastructure throughout their life cycle.

Although the construction sector is characterized in general by frequent deadlines delays, budget overruns and problems in maintaining proper quality (Nowotarski et al., 2016), sustainability building construction has experienced a significant growth in recent years (Wibogo et al., 2017). Nevertheless, a well-structured framework for sustainability is still missing in this industry (Alwan et al., 2017), therefore, it needs more careful investigation to make this sector more adequate to the goals of sustainable development (Alsudairi, 2015).

Some of the key supporting activities for sustainable construction include strengthening technology innovation, improving standards and evaluation, establishing demonstration projects, and publicity (Chang et al., 2016). To accomplish this, supervising the strict application of the construction planning, the construction methods in every phase of the project and the execution of the works in accordance with the recognized conventional environmental standards is critical (Kalfa and Kalogirou, 2017).

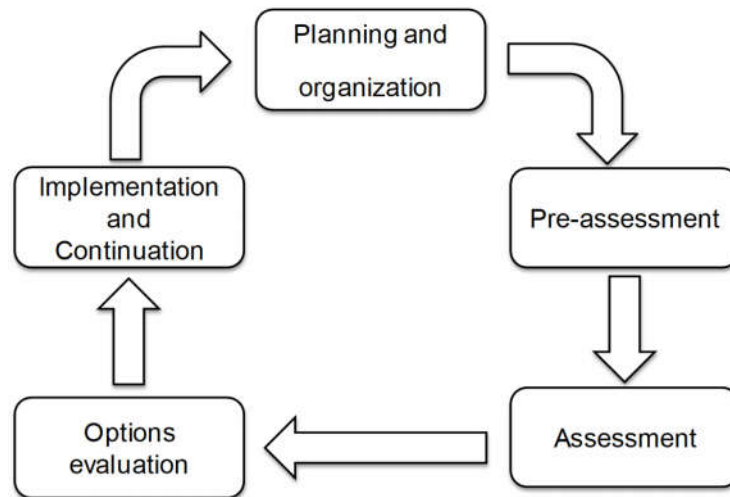
Particularly, developing countries usually have a low sustainability awareness in the construction industry as they have only just begun to deal with the challenges of sustainable development (Tabassi et al., 2016). This has been a difficult task because, although there is a responsibility of understanding and translating strategic sustainability objectives into concrete action at project-specific levels (Ugwu and Haupt, 2007), relying on the early steps of a project and reducing the impacts through appropriate on-site management will not necessarily lead towards a sustainable construction (Ding, 2007).

A way to advance towards sustainability is energy efficiency because it contributes to reduce the greenhouse gas emissions (Ganda y Ngwakwe, 2014). In this sense, buildings designed and constructed with a high degree of energy efficiency will increase also the economic savings in construction processes (Ladenhauf et al, 2015). Therefore, a sustainable design model for structures needs to be developed with the optimal combination of construction materials since, during the construction phase, materials and equipment are the major sources of carbon emissions, where the proper planning, management, and application of equipment could reduce energy consumption as well as the operating and maintenance costs (Choi et al., 2016; Zhang and Wang, 2016; Kirimtat et al, 2016).

3. Methodology

An energy efficiency program was conducted in the construction of a commercial and business complex in the city of Hermosillo, at northwestern Mexico, through the collaboration of the construction company and the Sustainability Graduate Program of the University of Sonora. The methodology was based on the Cleaner Production-Energy Efficiency approach proposed by UNEP (2004), which includes five main stages, as shown in figure 1: planning and organization, pre-assessment, assessment, options evaluation, and implementation and continuity. The scope of the study included the reinforcing steel activities (rebar) during the construction of one of the three buildings of the complex along the period of April 2016 to January 2017.

Figure 1. Energy efficiency program based on cleaner production



Source: UNEP (2004).

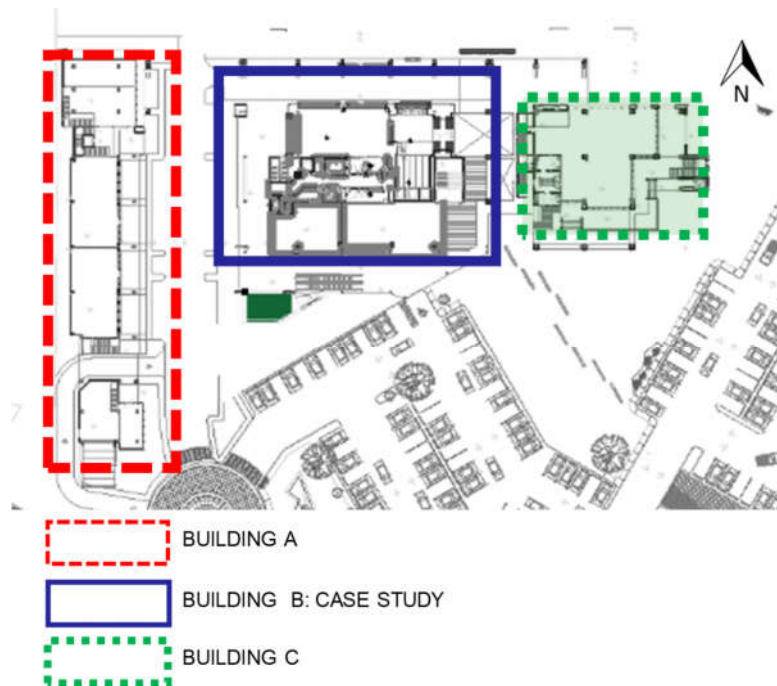
Data for the study were obtained through technical information from equipment and machinery labels and manuals, as well as from an Apple iPhone 6® smartphone camera. For data processing and analysis, Excel® spreadsheets and Autocad® design software were used.

4. Results

4.1. Planning and organization

The first stage, planning and organization, started with a meeting with the top management of the construction company in order to explain the different benefits that a program of this kind would bring into the construction industry. As a result, a formal agreement was signed between the company and the Sustainability Graduate Program of the University of Sonora. An energy efficiency team was also created to be able to start tasks in a more organized way. This team was integrated by both company personnel and university members. Figure 2 shows the blueprint of the project.

Figure 2: Architectonic blueprint of the building

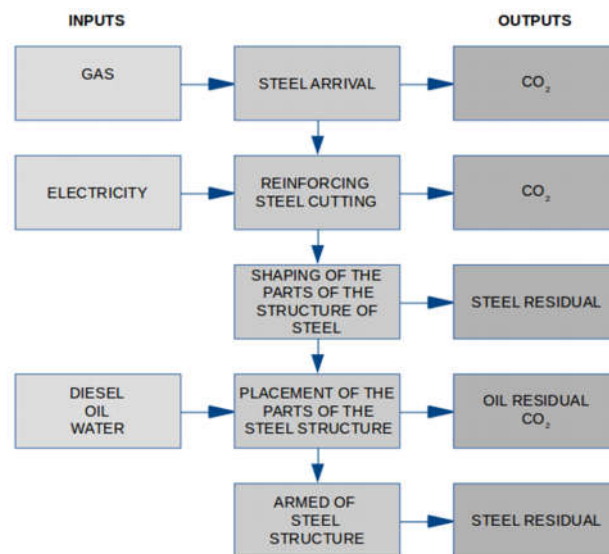


Source: Authors' own elaboration

4.2. Pre-assessment

For the pre-assessment stage, a process flow diagram of material and energy inputs and outputs was completed, as shown in Figure 3, in order to identify the main activities of the construction process. Walkthroughs were also conducted along with the project manager and the construction manager with the purpose of analyzing these activities, and thus, have a general perspective of the energy efficiency issues to address in a preliminary way.

Figure 3: Inputs and outputs of reinforcing steel activities



Source: Authors' own elaboration

At this point, the intention was to look for opportunities for improvement. After a meeting with the energy efficiency team, one of the most obvious problem found was a long distance between the reinforcing steel activities sites and their final position for the concrete casting, as shown in Figure 4. This would cause continuous use of the cranes, as shown in Figure 5, to move the steel structures.

Figure 4: Reinforcing steel activities



Source: Authors' own elaboration

Figure 5: Steel structures transportation



Source: Authors' own elaboration

4.3. Assessment

The assessment included a deeper characterization of the equipment including an inventory and their use in the reinforcing steel activities. Mainly three types of equipment were identified: five Makita® steel cutters, two Potain® tower cranes and two Groves® all-terrain cranes. The first two types were connected directly to electricity sources to operate and the last one needs diesel to run. Each steel cutter uses 2 kW per hour and were used the entire working day; every tower crane utilizes 324.4 kW per hour, and each all-terrain crane consumes 20.90 liters of diesel per hour. Both types of cranes are used in variable occasions per day. The construction process was divided in two parts, steel cutting and movement of the steel structures, with the purpose of looking for potential savings in terms of energy consumption and greenhouse gases emissions in form of carbon dioxide equivalent (CO₂-eq), as shown in Table 1.

Table 1. CO₂-eq in the of the construction process

Reinforcing steel	Consumption per hour	kg of CO ₂ -eq *	Potential savings
Steel cutting (includes the five cutters)	10 kWh	0.454	Low
Movement of steel structures (includes all the four cranes)	1,112.78 kWh**	505.202	High

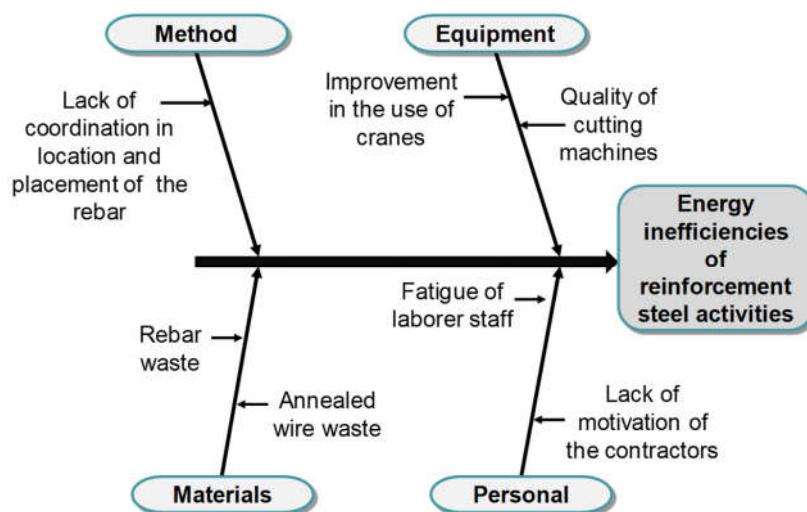
* Estimation based in conversion factor for Mexico. Source: SEMARNAT, 2015

** Estimated for both types of cranes (electricity-based and diesel-based, source: Packer, 2011).

Source: Authors' own elaboration

Following, through the energy efficiency team, a root cause analysis was also conducted, as shown in the Ishikawa diagram of figure 6, to find the main sources of inefficiencies and, thus, generate options for improvements in the steel reinforcing activities.

Figure 6: Ishikawa diagram in reinforcing steel activities



Source: Authors' own elaboration

Once inefficiency sources were identified, possible options were suggested to improve the construction process. As shown in Table 2, the solutions were addressed into three categories: the process, the personnel, and the equipment, where an “X” indicates an improvement opportunity for each category.

Table 2: Opportunities for improvement in the reinforcing steel process

No.	Area	Problem	Potential solution	PERSONAL		PROCESS		EQUIP- MENT
				Housekeeping	Management practices	Process optimization	Recycling of materials	Equipment status
P01	Steel cutting	Lack of coordination between cutting machines	Organization between workers and engineers	X	X	X		
P02	General	There is not a cutting area	Creation of a cutting area	X		X		
P03	Movement of steel structures	Lack of coordination in cranes	Coordination between engineers and operators of the cranes			X		
P04	Rebar	Waste time	Coordination between workers with cutting machines and buying cutting machines		X		X	X

Source: Authors' own elaboration

4.4. Options evaluation

At this stage, the previous option proposals were evaluated under three perspectives: technical, environmental and economic. The technical evaluation involved the consumption of materials and energy, the time that would take to implement the proposals and how the changes would affect the quality of the processes. The results show that, for Proposal P01, the organization between workers and engineers during the cutting of the steel can help in the production quality and in the maintenance of the equipment, because it would reduce the quantity of steel waste and would also help to use the steel cutters more efficiently. Proposal P02 was the creation of a cutting area that would reduce wasting time in the process. For Proposal P03, the coordination of the crane operators and engineers can help to reduce human force as well as the maintenance of the cranes. This would benefit other areas like the cost of crane reparation. The last proposal, P04, can help to reduce also wasting time and make improvements to other future processes increasing thus the production quality.

The environmental evaluation was focused whether the proposals for each of the reinforcing steel activities would reduce greenhouse gases and fossil fuels, as well as the risks to construction workers. The most common environmental safety and health factors were studied. Proposal P01 would improve the reduction of solid residues through the organization in the cutting area because

it could help to reduce steel wastes. On the other hand, Proposal P03 would help to reduce greenhouse gas emissions through the coordination of the cranes. The other two proposals did not have a significant environmental contribution.

Last, but not least, economic evaluation addressed the investment required for each of the proposals, including the impact on energy and material savings (see Table 3). Due to the nature of the activities under the study as well as the practicality of the proposals, the maximum investment necessary for the options was less than four hundred US dollars.

Table 3. Economic evaluation

Option	Investment (Dollars)	Notes
P01	0.00	Organize the cutting process would help to have less wastes of steel rod.
P02	56.68	It ensures a safe place to work.
P03	0.00	Helps to improve the equipment performance.
P04	295.00	Decreases wasting time.

Source: Authors' own elaboration

4.5. Implementation and continuation

The implementation action plan aims to define the timing, tasks and responsibilities of the options to improve the energy efficiency in the construction process, placing priority for implementation in accordance with available resources. Table 4 shows the implementation plan for the proposals in the reinforcing steel activities.

Table 4. Implementation plan for Energy Efficiency Program measures

	Solution	Description of the activities	Time to implement	Responsible
P01	Organization between workers and engineers	Communication between engineers and construction workers to know the value of steel structure	1 day	Engineers on site
		Cutting first the longer steel bars for each structure	Continuous	Steel construction workers
		Supervision in the cutting area	Weekly	Engineers on site
		Looking for a use of the steel bar wastes	Monthly	Engineers on site and project manager
P02	Creation of a cutting area	Looking for the best location for the cutting area	1 day	Engineer on site manager
		Buying the construction materials	3 days	Purchasing manager
		Construction of the cutting area	1 day	Carpenter
P03	Coordination between engineers and operators of the cranes	Coordination of the operator's working times with the production of steel reinforcing activities	Continuous	Engineers on site
P04	Coordination between workers with cutting machines and buying two cutting machines	Buying the steel bar cutters	1 day	Purchasing manager
		Coordination of the senior management requests with the possibilities of the engineers on site	Continuous	Manager

Source: Authors' own elaboration

After senior manager approval, all the proposals were implemented. Decreasing process wasting time, mainly for unnecessary use of the cranes, provided an estimated daily reduction of 18.613 kg of CO₂-eq, as shown in table 5. Similarly, the amount of steel wastes was also kept at minimum waste levels as planned.

Table 5. Savings per day

Category	Unit	Savings per day
Electricity	kWh	15.117
Diesel	lt	0.485
CO ₂ -eq*	kg	18.613
Money **	US Dollars	4.76

* Estimated for both types of cranes (electricity-based and diesel-based, source: Packer, 2011).

** Estimated for both types electricity and diesel (source: CFE, 2017; PEMEX, 2017).

Source: Authors' own elaboration

5. Discussion and conclusion

Construction industry has several environmental and health impacts along its whole life cycle such as resource depletion, materials waste, and high energy consumption. From a sustainability point of view, energy efficiency is a core element to be considered in this kind of industry due to its relation on minimizing greenhouse gas emissions as they contribute to climate change. This study showed that, although construction processes are very complex with multiple operations and with a lot of people involved, there are many opportunities that can be found by addressing specific areas such as reinforcing steel activities.

Particularly, the Cleaner Production-Energy Efficiency program proposed by UNEP (2004) was a useful tool to identify inefficiency sources in steel-cutting operations and in site structure transportations, where large equipment is involved. The results showed few short-term benefits in reinforcing steel activities such as small saving time in operations and slight resources recovering producing a reduction average of 18.613 kg of CO₂-eq daily. Nevertheless, most potential significant benefits will be more valuable in a long-term. As a result of the good perception of the top management about the program, it is expected to be applied to other construction activities within the site such as concrete casting, steel structures insertion and block walls building. The cleaner production approach provides an additional value, that is to say, implementation of this program will increase not only energy efficiency options but may unveil some opportunities on other areas such as occupational health and safety.

Regardless the several benefits that this kind of program could bring, addressing energy efficiency in this sector has some challenges. For instance, unlike some other industries, daily operations in construction industry are not necessarily standardized, thus, measuring energy efficiency is a difficult task, as mentioned by a OECD/IEA report (Tanaka, 2008), since the dynamic of a complex system brings complications in data collection as well as it slows down tracking changes consistently. Despite these limitations, implementations in this project evidence that a proper material waste management and a proper use of large equipment bring benefit the construction in an economic and environmental way.

Although this paper shows the results of a single case, under the assumption that the construction industry has similar behavior at least in the northern region of Mexico, decision makers and key stakeholders in this sector may use this information to support more informed

decisions and substantially improve its energy efficiency and reduce energy consumption. A final remark is that a more integrative approach is important to make the construction industry more environmentally and socially responsible while being economically feasible and, as a result, enhance its performance towards a more sustainable world.

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***Wydajność energetyczna wykorzystania stali zbrojeniowej
podczas budowy kompleksu biznesowego w Meksyku***

Streszczenie

Duża część konsumpcji energii na świecie przypada na sektor budowlany, a jedną z metod redukcji tego zużycia jest przeprowadzenie każdego procesu budowlanego w sposób wydajny energetycznie. Celem artykułu jest przedstawienie wyników programu na rzecz wydajności energetycznej związanego z budową kompleksu biznesowego w Hermosillo w Meksyku, a zwłaszcza z użyciem stali zbrojeniowej (prętów zbrojeniowych). Wyniki wskazują, że właściwe wykorzystanie sprzętu oraz koordynacja pomiędzy inżynierami i pracownikami pomaga poprawić wydajność energetyczną w fazie budowy oraz ograniczyć odpady. Co więcej, włączenie podejścia opartego na wydajności energetycznej w ogólne podstawy czystszej produkcji jest skomplikowanym zadaniem z tego powodu, że niewydajność energetyczna jest trudna do zidentyfikowania i oszacowania. Dlatego też mniejsza konsumpcja energii w procesie budowlanym w całym cyklu życia budynków w porównaniu do działalności produkcyjnej nie odzwierciedla się w dowodach w postaci badań nad wydajnością energetyczną w tej części procesu. Niniejszy artykuł ma na celu zaprezentowanie doświadczenia ekspertów budowlanych, aby wesprzeć proces decyzyjny związany z wydajnością energetyczną w analizowanym przemyśle.

Słowa kluczowe: budowa, wydajność energetyczna, środowisko, podtrzymywalność, stal zbrojeniowa, Meksyk

Kody JEL: Q40, Q49, L74

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