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# Energy audit in an ice factory in the city of San Francisco de Campeche, Mexico

# Análisis energético en una fábrica de hielo en la ciudad de San Francisco de Campeche, México

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**Abstract**

The cost of electricity represents a high percentage of the operating expenses of a company. It is important to establish strategies and operational policies for the efficient use of energy and consequently obtain economic savings. This paper presents a strategy aimed at the efficient use of electrical energy in the equipment installed in an ice factory in the city of Campeche, Mexico to reduce and control electricity demand, particularly during times of higher energy costs (peak hours). Optimize the operation of electrical equipment without affecting the production process, in such a way as to reduce operating costs and increase the company's profits. Some of the problems detected were: poor design of the plant and its electrical and control installations. Lack of maintenance (preventive, predictive and corrective). Lack of training of operating personnel. Poor prioritization of electrical loads and disconnection and reconnection times. Inadequate environmental conditions. On the other hand, it was found that it is cheaper to make 10 tons of ice with a 30-ton capacity machine than with a 20-ton one; the cost of energy per month is lower by a difference of $9,210.25 per month. It was also found that by placing thermal isolation in a flooded cooler, it has a decrease in its energy consumption by 56%.

**Energy analysis, Energy Efficiency, Ice factory**

**Resumen**

El costo de la energía eléctrica representa un porcentaje elevado dentro de los gastos de operación de una empresa. Es importante establecer estrategias y políticas operativas de uso eficiente de la energía y obtener como consecuencia ahorros económicos. Este trabajo presenta una estrategia encaminada al uso eficiente de energía eléctrica en los equipos instalados en una fábrica de hielo en la ciudad de Campeche, México; para reducir y controlar la demanda eléctrica, particularmente en el horario de mayor costo de energía (horario pico). Optimizar la operación de los equipos eléctricos sin afectar el proceso de producción, de tal manera que disminuyan los costos de operación y aumenten las utilidades de la empresa. Algunos de los problemas detectados fueron: mal diseño de la planta y sus instalaciones eléctricas y de control. Falta de mantenimiento (preventivo, predictivo y correctivo). Falta de capacitación del personal operativo. Mala priorización de cargas eléctricas y de los tiempos de desconexión y reconexión. Condiciones ambientales inadecuadas. Por otra parte, se comprobó que es más económico fabricar 10 toneladas de hielo con una máquina de 30 toneladas de capacidad que con una de 20 toneladas; el costo de energía al mes es menor en una diferencia de $9,210.25 mensuales. También se comprobó que, al colocar aislamiento térmico en un enfriador inundado, éste tenga una disminución en su consumo energético en un 56%.

**Análisis energético, eficiencia energética, fábrica de hielo**

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## Introduction

The Mexican state of Campeche is geographically located in the Yucatan Peninsula, Mexico, between parallels 17°49' and 20°51' north latitude; and between meridians 89°06' and 92°27' west; it has a warm humid climate with an annual average dry bulb temperature of 31 °C and a relative humidity of 70 to 86% throughout the year (Chatellier Lorentzen & McNeil, 2020)(INEGI, 2022). In terms of solar resources, irradiation (NREL, 2022) ranges from 5.5 to 6 kWh/(m2 day). The climatic conditions described above result in hot and humid conditions practically all year round. On the other hand, in recent years it has been observed that in the construction of public and private buildings as well as houses, no care has been taken to follow bioclimatic construction practices that help reduce the thermal gains to which they are subjected (Sandoya Mendoza, 2022). Similarly, no care has been taken to ensure that around new or old buildings there are abundant areas of wooded gardens that buffer or inhibit heat sources. Taking the above as a frame of reference, public and private buildings, as well as residential houses, annually have a high consumption of electricity for air conditioning and cooling, which is approximately 50-90% of total consumption (Víctor-Lanz, 2020). It is also notable that in hot-humid climates, the refrigeration machines in charge of air conditioning operate with less efficiency compared to hot-dry climates, up to 30% (Sierra, 2019) (HP Díaz-Hernández et al, 2019); mainly because to reach optimal operating temperatures, they first have to dehumidify the atmospheric air. As a consequence, energy consumption for cooling in hot-humid climates is higher than in hot-dry climates. The main strategy to be adopted to reduce the high cooling energy consumption is to achieve a substantial reduction of heat gains and to achieve energy efficiency. The energy audit is a fundamental tool for energy efficiency and savings (Osorio, 2013). It is useful both for analysis and diagnosis, whether in terms of tariffs or energy use and consumption, as well as for drawing up an orderly and structured proposal of practical measures to reduce operating costs and ensure profitability in the short, medium and long term. The objective was to gain a broad overview of energy use and consumption in order to identify strategies for efficient energy use.

The theoretical bases underpinning the methodology are: control and management of demand, electricity tariffs (analysis of the high demand tariff in hourly medium voltage, GDMTH); with emphasis on the applicable quotas and schedules, power factor and calculation of the insulation of the flooded cooler of the ice cube factory.

The following was carried out: analysis and diagnosis of energy consumption by means of a survey of electrical loads; collection of billing data; calculation of the average applicable quotas; energy costs at base, intermediate and peak times by production area; on-site measurement using a power quality analyser in electrical networks. With the previous work, it was possible to know the energy consumption of the factory, the necessary correction of the power factor, the optimal thermal insulation thickness for a flooded cooler (ice tube machines); all of the above to increase the production of the ice factory and make its energy performance more efficient by optimising the capacity of the installed equipment.

## Justification

The main objective of this work is to provide a strategy aimed at the efficient use of electrical energy in the equipment currently installed in an ice factory in the city of San Francisco Campeche, Campeche, Mexico; to reduce and control the electrical demand of the company, particularly in the hours of highest energy cost (peak hours, from 7:00 to 19:00 hours) and optimise the operation of electrical equipment without affecting the production process, so as to reduce operating costs and increase the profits of the company. The cost of energy represents a high percentage of the operating expenses of any organisation (Castillo, 2014), which is why it is extremely important to establish strategies and operational policies to make efficient use of energy, without detriment to the thermal comfort of human beings (Benito, 2022), and to obtain economic savings as a result. In a study conducted by the Autonomous Universidad de Campeche for the Secretary of Economic Development of the state of Campeche in 2020 (Victor-Lanz, 2020), it indicates that at least 60% of electricity consumption in small and medium industries, homes, schools and universities, is due to cooling processes in any of its modalities.

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Some of the problems detected in the demand control equipment, for which good results were not obtained, were due to the following reasons:

- Poor design of the plant and its electrical and control installations.

- Lack of maintenance (preventive, predictive and corrective).

- Lack of training of operating personnel.

- Deficient prioritisation of electrical load input and disconnection and reconnection times.

- Inadequate environmental conditions.

**Objective**

To conduct an energy audit in a company that manufactures ice in the city of San Francisco de Campeche, Mexico to identify the problems associated with high energy consumption; analyse them to find the best solutions to control and manage the energy demand for operating activities, optimising the use of the capacity of the installed equipment and reducing operating costs due to electricity consumption.

**Hypothesis**

By carrying out an energy audit in an ice factory, inefficient processes in the management of electrical energy can be identified and measures can be implemented to improve the efficiency of electrical consumption and, as a consequence, the respective economic savings.

**Problem statement**

The aim is to reduce energy consumption in an ice factory located in the city of San Francisco de Campeche, in the Mexican state of Campeche. Refrigeration processes require high values of energy to be carried out (Sierra, 2019). The environmental conditions at the site are important adverse factors during this process.

The location of the factory is geographically at 19.8129694º north latitude, and 90°.5904463 longitude (west), less than 50 meters from the coast with an average temperature of 31±0.1ºC and a relative humidity of 75±1%, also average (INEGI, 2022), 5 meters above sea level. It is desired to design and implement a comprehensive management system for the efficient use and respective saving of energy. To reduce energy consumption by means of a methodology that does not affect production levels. Determine potential savings. Reduce consumption during peak hours by shifting activities to base or intermediate hours. Decrease billable demand by implementing improvements. And finally, to reduce the amount of billing, through the implementation of the proposed methodology.

**Description the ice factory**

The company has been in operation since 1966. In the beginning it only produced industrial white ice bars. Eventually over the years it started to manufacture crystal ice bars and 5 kg bags of ice tubes, both suitable for human consumption. The company has been in operation for 56 years and throughout that time has gone through several stages of economic growth, infrastructure, installed load and consequently electricity consumption, to the point of becoming one of the largest companies in the refrigeration industry in the state of Campeche. The factory has a water tank for the production of 504 white ice bars, working 7 days a week, 24 hours a day. The ice production time is 24 hours, in 3 shifts of 8 hours. There are 168 bars per shift; with schedules from 6 am to 2 pm, from 2 pm to 10 pm and from 10 pm to 6 am. The freezing time for white ice is 18 hours. The company's ice is different from the rest of the city, because it melts in a longer time compared to the competition; for this reason not all the ice bars are extracted from the brine, as this way the cooling time of the ice bars is met, even though the production would be ready in 12 hours. The daily production is 504 white bars. Monthly production is 15,120 units. The company has a tube ice machine with the capacity to produce 168 bags of tube ice; working 7 days a week, 24 hours a day. The production time of tube ice is 24 hours in 3 shifts of 8 hours. A total of 1,680 bags are produced per shift and 5,040 bags of ice are produced per day. The monthly production of ice bags is 151,200 units.

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**Theoretical framework. Energy audit**

The diagnosis of energy savings (DAE) or also called Energy Audits (AUDE) or Energy Diagnostics. It is the application of a set of techniques that makes it possible to determine the degree of efficiency with which the different energy systems that make up the entire energy process of a facility use the energy available to them. It also consists of the study of all forms and sources of energy. The objectives are to understand the current use of energy and to establish the processes necessary to achieve efficient use. It also provides information on the inappropriate use of energy. The diagnosis allows us to go into depth and find out the reasons why the consuming installation is in this situation and gives the best solutions to be implemented. Bad habits in the use of energy, inadequate controls, inattention to the energy issue, electrical equipment in poor condition or obsolete, among other factors affect the efficient use of energy in the industry. The profitability and relevance of each proposal is analysed, as well as the parameters that have the greatest impact and sensitivity, in order to monitor them in particular. This work was developed through the following sequential steps:

i. Compilation of available information: plans, single-line diagrams, electrical installation calculation memories, others.

ii. Carrying out on-site measurements of the necessary electrical variables. By means of a power quality analyser in electrical networks.

iii. Review and analysis of data, contrasting available information with direct measurements and with billing data from at least one year ago.

iv. Formulation and evaluation of efficiency and savings proposals.

v. Drafting and presentation of the audit report.

*Peak demand*

Peak demand is defined as the coexistence of loads in a time interval. The energy meter stores the reading corresponding to the maximum recorded value of demand (kW) in 15-minute intervals of the billing period. Electricity tariffs in Mexico for low and medium voltage over 25 kW contracted include, in addition to the consumption charge (kWh), a maximum demand charge (kW).

*Demand management*

Demand management and control are the activities necessary to optimise the use of the installed equipment. It consists of reducing or controlling the demand during a period of time, usually at the time of highest energy cost (peak hours), optimising the operation of electrical equipment without affecting the production process. The action of interrupting the operation of electrical loads that have a direct impact on billable demand, in order to reduce consumption levels; a change in consumption habits that leads to the establishment of operational strategies to make efficient use of energy and obtain economic savings as a consequence. The following benefits are obtained by establishing a change in electricity consumption habits:

For the client:

- Knowledge of the tariff structure among operational staff.
- Involvement of the personnel to know all the stages of the process.
- Growth of the energy saving culture in the company.
- Decrease in consumption during peak hours.
- Decrease in billable demand.
- Decrease in demand charges.
- Decrease in the consumption charge.
- Decrease in the amount of your invoicing.
- More competitive companies.

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For the supplier:

- Reducing the demand requirement during peak hours, generating stability in the national electricity system.

- Reduction of losses due to overheating of equipment.

- Increase the useful life of equipment.

- Defer investment in infrastructure.

Proposed methodology for the analysis of photovoltaic electricity production.

The methodology presented in this work consisted of:

- To know the internal organisation of the ice factory: production and human resources.
- Obtaining electricity invoicing data for the years under study.
- Determine the historical consumption of electrical energy for at least two years, by means of invoicing.
- Carry out a detailed survey of existing electrical loads.
- Carry out an electrical energy analysis using tariffs applicable to the years under study, using the costs at base, intermediate and peak times in each production area.
- On-site measurement of electrical parameters with a network analyser, by production area.
- Consumption analysis by production area.
- Installation of capacitor banks for power factor correction.
- Installation of thermal insulation to equipment.

It should be noted that during the analysis process, hidden defects were found to control the loads, which were evaluated in order to eradicate them and significantly reduce the use of electrical energy. Peak demand was managed and controlled manually and with automatic devices. Staff coordinated the operation of equipment according to the production process in order to avoid unnecessary peak loads. It was limited in speed and accuracy by the human factor. Equipment operation was programmed by means of mechatronic devices in order to avoid peaks in demand. Regardless of the type of control used, the production process had to be perfectly known. It was advisable to start with a manual method of demand control before automating this process.

*Analysis of the information and results obtained*

*Organisation of the company*

The company currently has a total of 36 employees. The data are shown in table 1.

| Post | Number of employees |
|---|---|
| Production | 11 |
| Maintenance | 6 |
| Driver and salesman | 11 |
| Administrative | 4 |
| Welder | 1 |
| Manager | 3 |
| Total | 36 |

**Table 1** Number of employees. Ice Factory in San Francisco de Campeche, Mexico
*Source: Own elaboration*

*Energy consumption in the factory*

Energy consumption is the amount of energy demanded by a given supply point during a time interval, called the billing period. This is invoiced by the commercialisation companies (Comisión Federal de Electricidad in this case); by applying a price per kilowatt hour (kWh), the amount of money paid by the company is determined. Tables 2, 3 and 4, as well as Figure 1, show the electricity consumption of the company and gave us an overview of the energy consumption in the billing years 2018 and 2019 in the Hielo factory.

| | FIRST SEMESTER | | |
|---|---|---|---|
| Months | 2018 | 2019 | Difference |
| January | 78,360 | 90,912 | 12,552 |
| February | 92,712 | 84,864 | 7,848 |
| March | 108,888 | 115,248 | 6,360 |
| April | 109,392 | 119,976 | 10,584 |
| May | 118,200 | 148,296 | 30,096 |
| June | 110,208 | 133,224 | 23,016 |

**Table 2** Comparative half-yearly electricity consumption (kWh), First Half Year (2018 - 2019)
*Source: Own elaboration*

| | SECOND SEMESTER | | |
|---|---|---|---|
| Months | 2018 | 2019 | Difference |
| July | 130,032 | 124,152 | 5,880 |
| August | 144,888 | 141,168 | 3,720 |
| September | 130,800 | 138,888 | 8,088 |
| October | 137,736 | 134,112 | 3,624 |
| November | 101,328 | 105,384 | 4,056 |
| December | 114,576 | 123,048 | 8,472 |

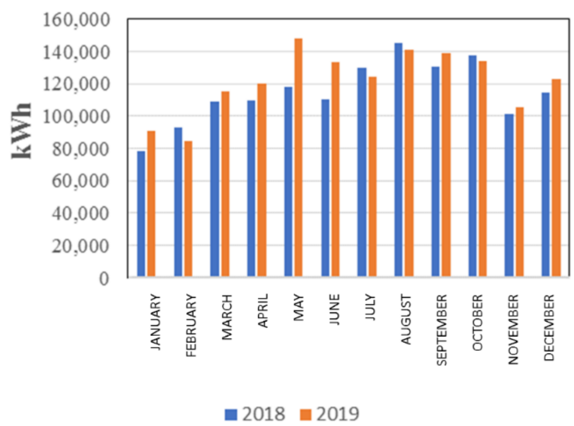
**Table 3** Comparison of electricity consumption (kWh), half-yearly, second half-year (2018 - 2019).
*Source: Own elaboration*

| First semester | | Second semester | |
|---|---|---|---|
| 2018 | 2019 | 2018 | 2019 |
| 102,960 | 115,420 | 126,560 | 127,792 |

**Table 4** Average half-yearly electricity consumption in 2018 and 2019 kWh.
*Source: Own elaboration*

*Load survey*

The purpose of the load survey was to find out the installed power and working time of each piece of equipment, as well as to obtain an average monthly consumption and relate it to the factory's total energy consumption. To determine the power of each piece of equipment, the data on the nameplate were taken, or if they were not available, voltage and amperage measurements were taken. To determine the operating time of each piece of equipment, information was collected from the operators of each machine.




**Graphic 1** Energy consumption (Kwh) in the ice factory in San Francisco de Campeche, Campeche, Mexico
*Source: Own elaboration*

The load survey was a very arduous job and generated an abundance of data, which is beyond the scope of this work. Tables 5, 6 and 7 show only some of the load surveys for illustrative purposes.

| Building | Level | Area | Type | No of luminaires | Lamps per luminaire | Wattage W | Hours of use | kWh month |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Ammonia tank and 2 compressors | LED | 1 | 1 | 28 | 722.4 | |
| 1 | 1 | Ammonia tank and 2 compressors | LED | 1 | 1 | 9 | 722.4 | 6.50 |
| 1 | 1 | Ammonia tank and 2 compressors | LED | 1 | 1 | 9 | 722.4 | 6.50 |
| 1 | 1 | Ammonia tank and 2 compressors | LED | 1 | 1 | 9 | 722.4 | 6.50 |
| 1 | 1 | Ammonia tank and 2 compressors | LED | 1 | 1 | 9 | 722.4 | 6.50 |

**Table 5** Lighting equipment load survey
*Source: Own elaboration*

| Level | Area | Type AA | Capacity (BTU/h) | Power (W) | Hours of use per month | kWh per month |
|---|---|---|---|---|---|---|
| *1* | Office 1 | Minisplit | 12200 | 650 | 232 | 150.8 |
| *2* | Office 2 | Minisplit | 12200 | 650 | 206 | 133.9 |

**Table 6** Survey of air-conditioning equipment loads
*Source: Own elaboration*

| Building | Level | Area | Miscellaneous | Power (W) | Hours of use per month | kW h per month |
|---|---|---|---|---|---|---|
| 1 | 1 | Bar production | Engine | 1491.4 | 722.4 | 1077.3 |
| 1 | 1 | Bar production | Engine | 3730 | 722.4 | 2694.5 |
| 1 | 1 | Bar production | Compressor | 74600 | 722.4 | 53891.0 |
| 1 | 1 | Bar production | Engine | 118.55 | 722.4 | 808.0 |
| 1 | 1 | Bar production | Engine | 3730 | 722.4 | 2694.5 |
| 1 | 1 | Bar production | Engine | 560 | 722.4 | 404.5 |
| 1 | 1 | Bar production | Engine | 560 | 722.4 | 404.5 |
| 1 | 1 | Bar production | Crane | 2236 | 252.84 | 565.3 |

**Table 7** Survey of loads for miscellaneous equipment
*Source: Own elaboration*

Electricity billing data for the years under study.

The study of the invoicing made it possible to verify the correct application of tariffs, and also to carry out a historical evaluation of consumption. It was possible to know the energy consumption in order to plan the management of the demand. The data on the invoicing sheet are as follows:

- Name: Ice Factory.
- Service number: 7898011101332.
- Connected Load: 259 kW.
- Meter Number: 7A8P00.
- Tariff: GDMTH.
- Contracted Demand: 250 kW.
- Route: 2450080-11-30HSB8-70101001.

| | Maximum demand (kW) | | | | |
|---|---|---|---|---|---|
| Month | Base | Inter | Tip | Billable | P. F. |
| Jan | 147 | 151 | 146 | 151 | 0.81 |
| Feb | 145 | 157 | 148 | 157 | 0.82 |
| Mar | 233 | 242 | 150 | 242 | 0.82 |
| Apr | 24O | 250 | 149 | 250 | 0.83 |
| May | 244 | 253 | 251 | 253 | 0.83 |
| Jun | 243 | 256 | 247 | 256 | 0.83 |
| Jul | 249 | 252 | 157 | 252 | 0.84 |
| Aug | 246 | 255 | 248 | 255 | 0.88 |
| Sep | 248 | 254 | 245 | 254 | 0.89 |
| Oct | 238 | 250 | 244 | 250 | 0.91 |
| Nov | 243 | 250 | 241 | 250 | 0.91 |
| Dec | 239 | 246 | 244 | 246 | 0.91 |

**Table 8** Energy Demand Data (KW) in the 2019 Billing
*Source: Own elaboration*

| Energy consumption (kWh) Billing | | | | | |
|---|---|---|---|---|---|
| Month | Base | Inter | Tip | Billing | Weights |
| Jan | 30,072 | 48,888 | 11,952 | 90,912 | $273,521 |
| Feb | 28,824 | 45,360 | 10,680 | 84,864 | $258,576 |
| Mar | 40,680 | 62,664 | 11,904 | 115,248 | $333,018 |
| Apr | 39,432 | 73,104 | 7,440 | 119,976 | $340,936 |
| May | 49,872 | 90,384 | 8,040 | 148,296 | $451,604 |
| Jun | 45,720 | 80,232 | 7,272 | 133,224 | $420,406 |
| Jul | 42,072 | 75,984 | 6,096 | 124,152 | $358,611 |
| Aug | 46,512 | 86,688 | 7,968 | 141,168 | $428,042 |
| Sep | 51,312 | 79,968 | 7,608 | 138,888 | $400,050 |
| Oct | 41,112 | 82,776 | 10,224 | 134,112 | $388,584 |
| Nov | 35,304 | 56,664 | 13,416 | 105,384 | $329,043 |
| Dec | 40,680 | 65,808 | 16,560 | 123,048 | $365,174 |

**Table 9** Energy Consumption Data (Kwh) in the 2019 Billing
*Source: Own elaboration*

### *Analysis of electricity energy through tariffs*

For the Mexican Republic, the Ministry of Energy through the Federal Electricity Commission establishes and publishes (CFE, 2022) the average electricity tariffs applicable during a year. Table 10 presents the tariffs for Great Hourly Medium Voltage Medium Demand (GDMTH, broken down into base, intermediate and peak) applicable for the peninsular region (Yucatan peninsula).

| Tariff | Description | Timetable | Charge | Unit | Average Annual |
|---|---|---|---|---|---|
| GDMTH | High demand in hourly medium voltage | - | Fixed | $/mes | 512.44 |
| | | Base | Variable (Energy) | $/kWh | 1.0993 |
| | | Intermediate | Variable (Energy) | $/kWh | 1.8456 |
| | | Tip | Variable (Energy) | $/kWh | 2.0585 |
| | | - | Distribution | $/kW | 87.62 |
| | | - | Capacity | $/kW | 346.75 |

**Table 10** Electricity tariff (GDMTH) applicable in the Peninsular region, annual average during the time of study
*Source: Own elaboration*

### *Consumption analysis by production area*

The installed load of each production area was in operation 24 hours a day, 7 days a week. After an analysis of the consumption and energy costs, a final summary is made, broken down (per day and per month), which is presented in table 11. It is worth mentioning that the offices, maintenance workshop, warehouse, external loading bay and external lighting are only in operation for 8 hours. On the other hand, the production of tubes and ice bars is based on an analysis of energy consumption and costs that is as realistic as possible, based on a detailed analysis of electrical loads.

| Area | kWh/day | kWh/month | Cost |
|---|---|---|---|
| Bar ice | 2,135.57 | 64,921.27 | $ 104,011.87 |
| Osmosis | 68.33 | 2,077.32 | $ 9,739.49 |
| Water tanks | 20.24 | 615.42 | $ 1,978.44 |
| Ice tubes | 2,114.90 | 64,293.08 | $ 98,726.47 |
| Tubes ice bars backing | 3.96 | 120.38 | $ 1,778.01 |
| Cold rooms | 1,341.72 | 40,788.29 | $ 65,562.84 |
| Offices | 61.38 | 1,866.01 | $4,766.66 |
| Maintenance workshop | 34.02 | 1,034.21 | $ 5,297.20 |
| Loading bays | 63.62 | 1,933.93 | $ 12,025.92 |
| Total | 5,843.75 | 177,649.90 | $ 303,886.91 |

**Table 11** Energy consumption and costs in each production area according to the working time of the ice factory
*Source: Own elaboration*

### *Installation of capacitor banks*

The capacitor is a passive electronic component. It is used to store electrical charge (in the form of an electric field). Capacitors play an important role in many electrical circuits to perform power factor correction, which by regulations of the Ministry of Energy must be equal or higher than 0.90 (Energy, 2016). The ice factory has three transformers; each of different capacity; they feed different electrical equipment which are mentioned below:

- Transformer 150 KVA. It powers: ice bar production compressor, ice bar mould filling tank pump, reverse osmosis equipment, compressor radiator, brine agitator, cooling tower and service area lighting.

- Transformer 125 KVA. Feeds: ice tube production compressor, ice tube machine, crushing machine, cooling tower, compressor radiator and production area lighting.

- Transformer 112 KVA. Feeds: back-up compressor for ice bars, back-up compressor for ice tubes, back-up ice tube machine, radiators for both compressors, cooling tower, condensing units for 3 cold rooms, crane for ice moulds, cistern pump, condenser blowers for the cold rooms, power supply for the warehouses, ice grinders and lighting for the cold rooms.

It is important to note that the company had two 20 kVA capacitor banks shown in figure 1, but for reasons of refurbishment prior to our work, they were disconnected from the 125 kVA and 150 kVA transformers. Using a Fluke 434-II/435-II/437-II/437-II (three-phase power and power quality analyser), figure 2, we were able to obtain the operation of the power supply system of each transformer, as well as the behaviour and the variables required to calculate the capacitor bank for the 112 kVA transformer.

**Figure 1** 20 KVA capacitor bank in the company Hielo San Bartolo
*Source: Own elaboration*

**Figure 2** FLUKE model 430 Series II three-phase power and energy quality analyser, three-phase
*Source: Own elaboration*

Tables 12, 13 and 14 show the results obtained with the help of the electrical network analyser in each substation:

| Area | kWh/day | kWh/month | Cost |
|---|---|---|---|
| Ice bars | 2,135.57 | 64,921.27 | $104,011.87 |
| Osmosis | 68.33 | 2,077.32 | $ 9,739.49 |
| Water tanks | 20.24 | 615.42 | $1,978.44 |
| Ice tubes | 2,114.90 | 64,293.08 | $98,726.47 |
| Tubes ice bars backing | 3.96 | 120.38 | $1,778.01 |
| Cold rooms | 1,341.72 | 40,788.29 | $65,562.84 |
| Offices | 61.38 | 1,866.01 | $4,766.66 |
| Maintenance workshop | 34.02 | 1,034.21 | $5,297.20 |
| Loading bays | 63.62 | 1,933.93 | $12,025.92 |
| Total | 5,843.75 | 177,649.90 | $303,886.91 |

**Table 12** Average data collected from the FLUKE brand network analyser, model 430 Series II. 125 KVA transformer
*Source: Own elaboration*

| Data | L1 | L2 | L3 | Unit |
|---|---|---|---|---|
| Voltage | 130.2 | 131.6 | 129.8 | V |
| Current | 237.2 | 248.6 | 244.3 | A |
| Active Power | 26.8 | 28.9 | 28.5 | kW |
| Apparent Power | 29.5 | 31.2 | 30.0 | kVA |
| Reactive Power | 13.7 | 13.8 | 11.9 | kVA |
| Active Power | 26,824.9 | 28951 | 28460.4 | kWh |
| PF | 0.91 | 0.92 | 0.94 | s/u |

**Table 13** Average data collected from the FLUKE brand network analyser, model 430 Series II. 150 KVA transformer
*Source: Own elaboration*

| Data | L1 | L2 | L3 | Unit |
|---|---|---|---|---|
| Voltage | 130.3 | 131.8 | 131.4 | V |
| Current | 123.9 | 125.6 | 113.1 | A |
| Active Power | 12.7 | 13.6 | 13.3 | kW |
| Apparent Power | 16.0 | 15.8 | 15.4 | kVA |
| Reactive Power | 9.92 | 8.15 | 8.03 | kVA |
| Active Power | 1897.9 | 2123. | 1827. | kWh |
| PF | 0.82 | 0.89 | 0.88 | s/u |

**Table 14** Average data collected from the FLUKE network analyser, model 430 Series II. 112.5 KVA transformer
*Source: Own elaboration*

### *Power factor correction*

The power triangle is the best way to see and understand graphically the power factor (Cos φ) and its relationship with the powers present in an alternating current electrical circuit. Figure 3.

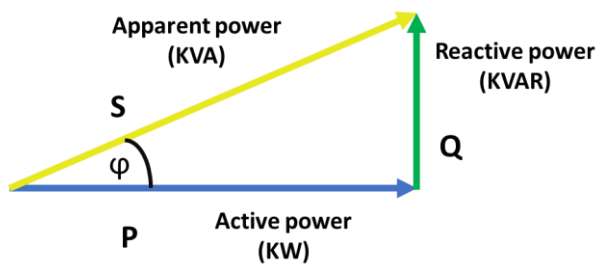



**Figure 3** Electrical power triangle
*Source: Own elaboration*

The power factor is the ratio between the real working power and the total power consumed by the consumer connected to the alternating current electrical circuit. This ratio can be represented mathematically, with the formula 1 (Levy, 2020).

$$Cos\ \varphi = \frac{P}{S} \tag{1}$$

The calculation of the capacitor bank required to correct the power factor corresponding to the 112 kVA transformer is presented. It went from a value of 0.83 to 0.95, complying with the standard. The calculations are presented with equations 2 to 8 (Levy, 2020).

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- Initial values

FP = 0.83, P1 = 40 kW.

Arc Cos (FP) = Arc Cos (0.83) = 33.9° (2)

$$Q_1 = P_1 tan(\varphi) = 40 * \tan(33.9) = 26.88\, kVAR \quad (3)$$

$$S_1 = {}^{P_1}/_{Cos\, \varphi_1} = {}^{40}/_{0.83} = 48.19\, kVA \quad (4)$$

- Final values

FP = 0.95, P1 = 40 kW.

Arc Cos (0.95) = 18.19° (5)

$$Q_2 = 40 * \tan(18.19°) = 13.14\, kVAR \quad (6)$$

$$S_1 == {}^{40}/_{0.95} = 42.11\, kVA \quad (7)$$

$$Q_{corre} = Q_1 - Q_2 = 26.87 - 13.14 = 13.73\, kVAR \quad (8)$$

From the above, a 13.72 kVAR capacitor bank was calculated; since no such capacity exists in the market, the installation of a 15 kVAR capacitor bank is recommended. Once the power factor was corrected, the penalty for low power factor became a bonus.

***Thermal insulation to the flooded cooler***

It is necessary to minimise energy losses due to heat gain in cooling and the thermal insulation acts as a barrier to this flow (Sierra, 2019). The flooded chiller in the factory, shown in figure 4, was not insulated. The flooded cooler is made of stainless steel, which has a thermal conductivity of 16.3 W/m ºC and a thickness of 0.05 m. The flooded cooler of the tube ice machine was insulated; it operates with ammonia refrigerant whose thermal conductivity is 0.55 W/m ºC.

**Figure 4** Ice tube machine in the Hielo factory
*Source: Own elaboration*

ThermaSmartPRO thermal insulation was selected to insulate the flooded cooler because of the wide temperature range in which it operates, the excellent insulation value and the quick and easy installation. Table 15 shows the insulation properties, service temperature, thicknesses and lengths.

| Thermal conductivity W/m °C |
|---|
| K = 0.38 at 40°C<br>K = 0.36 at 23°C<br>K = 0.34 at 0°C |
| **Service temperature range** |
| Maximum 95 ° C<br>Minimum -80 ° C |
| **Availabilities** |
| Available in thickness: 7,5 mm - 10 mm - 13 mm - 19 mm - 25 mm -30 mm |
| Available in width: 50 cm - 60 cm - 100 cm - 120 cm |

Table 15 Insulation properties, service temperature, thickness and length availabilities of ThermaSmartPRO insulation
*Source: Own elaboration*

It is required to know the heat transfer area. The area is the sum of the area of the lateral surface (AL) with the areas of the two bases (AB). Where r is the radius of the base and h is the height of the cylinder as shown in figure 5; the area of the cylinder is calculated as:

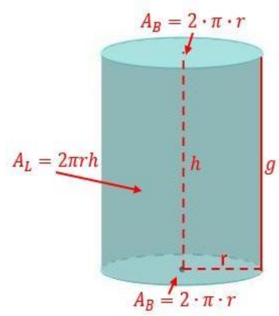


**Figure 5** Heat transfer area of the flooded cylinder for ice tube manufacturing
*Source: Own elaboration*

The dimensions of the cooler are as follows: height of the cooler 3.17 m, height of the cutter 1 m, radius of the cooler and the cutter 0.596 m. Then the insulation area is defined as equation 9.

$$A = 2\pi r(r + h) = 2\pi(0.596)(0.596 + 4.17) = 17.85 m^2 \quad (9)$$

For the selection of the ideal insulation thickness, the thickness that allows the least amount of heat transfer is chosen. Applying the following formula (HOLMAN, 2002):

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$$r_{crit} = \frac{k}{h_{ext}} = \frac{0.034}{3} = 0.0113\ m = 11.3\ mm \quad (10)$$

Where:

k is the thermal conductivity in W/m ºC.

$h_{ext}$ is the convective coefficient in W/m2 ºC.

From table 12, the ideal insulation thickness is 0.0113 m. The following comparison is presented by applying equation 11 and 12 (Holman, 2002):

$$Q = AU\Delta t \quad 11)$$

Where:

Q = Amount of heat transferred in Watts.

A = Area of the external wall surface (m^2).

U = Overall heat transfer coefficient W/m^2ºC.

Δt = Temperature difference in ºC.

$$U = \frac{1}{\frac{1}{h_{int}}+\frac{x_1}{k_1}+\frac{x_2}{k_2}+\frac{1}{h_{ext}}} \quad (12)$$

With:

x = Thickness of the material.

k = Thermal conductivity of the material.

$h_{int}$ = Indoor convective coefficient.

$h_{ext}$ = Coefficient of external convection.

With the following data we calculate Q for the flooded cooler with and without insulation, supported by equations 10 and 11.

Area = 17.85 m^2

t1 = - 5°C.

t2 = 30°C.

h_int = 3 W/m2 ºC.

h_int = 10 W/m2 ºC.

k_1 stainless steel = 16.3 W/m2 ºC.

k_2 insulation = 0.034 W/m ºC.

x1 stainless steel thickness = 0.05 m.

x2 insulation thickness = 0.0113 m.

Flooded cooler without insulation: Q = 1,431.6 W

Flooded chiller with insulation: Q = 812.7 W

Proportionally the heat flux reduction for the flooded cooler is as follows:

$$Q = \frac{812.7\ W}{1{,}431.6\ W} = 0.56 = 56\%$$

**Results**

By establishing strategies to change electricity consumption habits, the following benefits were obtained:

- Training and knowledge of operational staff in the tariff structure of the Federal Electricity Commission (CFE).
- Involvement of administrative and operational staff to learn about all stages of the process, especially for joint decision-making.
- Exponential growth of the culture of saving throughout the organisation.
- Decrease in consumption during peak hours.
- Decrease in billable demand.
- Decrease of 20 to 30% in the amount of your total invoicing.
- More competitive company.

After correcting the power factors in the factory's transformers, an important change was noticed. It began to show a bonus in favour of the factory, whereas before the adjustments there were only penalties. The indicators shown below show the progression from January 2019 to February 2020. Table 16.

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| Months | Bonus (-) Penalty (+) | Power factor % |
|---|---|---|
| Jan 19 | $ 13,287.41 (+) | 81.40 |
| Feb 19 | $ 11,429.50 (+) | 82.15 |
| Mar 19 | $ 13,245.71 (+) | 82.89 |
| Apr 19 | $ 13,137.11 (+) | 83.29 |
| May 19 | $ 15,940.23 (+) | 83.75 |
| Jun 19 | $ 15,782.96 (+) | 83.33 |
| Jul 19 | $ 11,577.04 (+) | 84.20 |
| Aug 19 | $ 5470.08 (+) | 87.62 |
| Sep 19 | $ 1306.41 (+) | 89.37 |
| Cct 19 | $ -638.30 (-) | 90.83 |
| Nov 19 | $ -1,355.31 (-) | 91.76 |
| Dec 19 | $ -900.67 (-) | 90.93 |
| Jan 20 | $ -1,826.05 (-) | 93.34 |

**Table 16** Power Factor Bonus and Penalty from January 2019 to February 2020
*Source: Own elaboration*

On the other hand, energy consumption by electrical equipment and production was obtained, the operating times of the electrical equipment, the magnitude of installed power and its relationship with billable consumption were known. The economic impact of the electrical equipment in each billing period and the electrical energy costs by production of tonnes of ice and working periods are presented. In the case of the 30-tonne ice machine, it produced 1.25 tonnes per hour, while the 20-tonne machine produced 0.83 tonnes per hour. It was required to produce 10 tonnes of ice per day. With a new operating scheme, the consumptions were compared; the 30-tonne machine worked 8 hours, while the 20-tonne machine worked 12 hours. The cost of energy to produce 10 tonnes of ice in each machine, based on the operating times of each machine, led us to conclude that the 30-tonne machine, despite consuming more electricity, has a lower monthly energy cost compared to the 20-tonne machine, with a difference of $9,210.25 per month; the result is presented in tables 17 and 18. In addition, given the way CFE bills, the fact of increasing electricity consumption is reflected in most of the billable items, affecting the final billing cost. Thus, the real difference in Mexican pesos between the operation of one machine and another is $16,464.37 per month.

| | | | |
|---|---|---|---|
| Supply | $512.44 | Fixed Charge | $512.44 |
| Distribution | $4,530.35 | Energy | $55,364.89 |
| Transmission | $3,526.69 | F.P | -$4,274.67 |
| CENACE | $1,039.15 | Subtotal | $51,602.66 |
| Base | $18,897.23 | VAT 16% VAT | $8,256.42 |
| Intermediate | $7,760.21 | Alum. Pub. | $20,675.67 |
| Point | $0.00 | Turnover | **$80,534.75** |
| ScnMEM | $719.41 | | |
| Capacity | $18,379.41 | | |
| SubTotal | $55,364.89 | | |

**Table 17** Invoicing, ice tube machine with a production capacity of 30 tonnes, producing 10 tonnes per day
*Source: Own elaboration*

| | | | |
|---|---|---|---|
| Supply | $512.44 | Fixed Charge | $512.44 |
| Distribution | $5,384.31 | Energy | $69,558.31 |
| Transmission | $4,191.46 | F.P | -$4,274.67 |
| CENACE | $1,039.15 | Subtotal | $65,796.08 |
| Base | $16,303.78 | VAT 16% VAT | $10,527.37 |
| Intermediate | $19,563.91 | Alum. Pub. | $20,675.67 |
| Point | $0.00 | Turnover | **$96,999.12** |
| ScnMEM | $719.41 | | |
| Capacity | $21,843.86 | | |
| Subtotal | $69,558.31 | | |

**Table 18** Invoicing, ice tube machine with a production capacity of 20 tonnes, producing 10 tonnes per day
*Source: Own elaboration*

## Conclusions

This article presents an energy efficiency study of the facilities of an ice factory installed in the city of San Francisco de Campeche, Campeche, with the proposal to reduce its energy consumption (electricity) through a methodology that includes the determination of historical consumption of electricity for at least two years, the survey of existing electrical loads, obtaining data on electricity billing in the years of study, analysis of electricity using average rates applicable to the years of study using the costs in hours, analysis of consumption by production area, installation of capacitor banks. The methodology included obtaining electricity billing data for the years under study, analysis of electrical energy using average tariffs applicable to the years under study using hourly costs, analysis of consumption by production area, installation of capacitor banks for power factor correction and installation of thermal insulation for critical refrigeration equipment.

- A load survey was carried out to find out the installed power and working time of each piece of equipment, as well as to obtain an average monthly consumption and relate it to the factory's total energy consumption.

- Using a Fluke 434-II/435-II/437-II/437-II network analyser (three-phase energy and power quality analyser), the operation of the power supply system of each transformer and the entire electrical system was obtained, as well as the behaviour and the variables required to calculate the capacitor bank (15 kVAR) for a 112 KVA transformer.

- The economic impact of the electrical equipment in each billing period was determined to reduce energy consumption without compromising production.

- It was found that it is more economical to operate a 30-tonne capacity ice maker than a 20 tonne capacity ice maker. The 30-tonne machine, despite consuming more electricity, has a lower monthly energy cost compared to the 20-tonne machine, by a difference of $9,210.25 per month. The real difference between the operation of one machine and the other is $16,464.37 per month due to the way CFE bills.

- The placement of thermal insulation on the factory's flooded chiller allowed the heat energy of the refrigerant to be conserved in the system. With the insulated system, the reduction in energy consumption is reflected in a 56% reduction in energy consumption.

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