Generation of electric power and air conditioning by cogeneration: a proposal for energy saving

Producción de energía eléctrica y aire acondicionado por cogeneración: Una propuesta de ahorro de energía

Produção de energia elétrica e ar condicionado por cogeração: Uma proposta de economia de energia

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Abstract

This paper presents the results of a case study carried out in a warehouse, and, in particular, the technical data obtained from field visits and a proposal for energy saving. The proposal entails incorporating a cogeneration system based on a motor generator (400 kWe ISO) to produce electrical energy, and an absorption cooling system (75 TR) that uses residual heat to generate air-conditioning. The absorption chiller consumed 54% less energy than the conventional air-conditioning system. Moreover, the produced energy can supply the plant's total consumption, in addition to offering an excess of 57,312 kWh per month, which was reflected in the analysis of energy for sale to users with a high domestic consumption rate (DAC, for its Spanish acronym). The proposal's total investment is USD 1,091,258, with a net monthly savings of USD 30,901, and an investment payback period of 2.9 years, which indicates the viability of this project according to its energy characteristics, notwithstanding that it is for a service provider company.

Keywords: absorption cooling; cogeneration; cost-benefit analysis; energetic consulting; energy savings.

Resumen

Este trabajo es resultado de un estudio de caso realizado en una bodega. Se muestran en él los datos técnicos obtenidos a partir de la visita de campo y una propuesta energética. La propuesta consta de la incorporación de un sistema de cogeneración basado en un motogenerador (400 kWe ISO) para producir energía eléctrica y de un sistema de refrigeración por absorción (75 TR) que aproveche el calor residual para generar aire acondicionado. Se observó que el chiller de absorción consume 54 % menos energía que el sistema convencional de aire acondicionado empleado. Por otra parte, la energía producida abastece el total del consumo de la planta, además de ofrecer un excedente de 57,312 kWh por mes, el cual se tomó en el análisis como energía de venta a usuarios con tarifa doméstica de alto consumo (DAC). La inversión total de la propuesta es de 1 091 258 USD, con un ahorro neto mensual de 30 901 USD y un tiempo de recuperación de la inversión de 2.9 años, lo que indica la viabilidad de este proyecto de acuerdo con sus características energéticas, a pesar de tratarse de una empresa que brinda servicios.

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Palabras clave: ahorro de energía; análisis costo-beneficio; cogeneración; consultoría energética; refrigeración por absorción.

Resumo

Este trabalho é resultado de um estudo de caso realizado em um porão. Mostram-se neste estudo os dados técnicos obtidos a partir da visita de campo e uma proposta energética. A proposta consta da incorporação de um sistema de cogeração baseado em um motogerador (400 kWe ISO) para produzir energia elétrica e de um sistema de refrigeração por absorção (75 TR) que aproveite o calor residual para gerar ar condicionado. Observou-se que o chiller de absorção consome 54% menos energia que o sistema convencional de ar condicionado empregado. Por outra parte, a energia produzida abastece o total do consumo da usina, além de oferecer um excedente de 57,312 kWh por mês, o qual se tomou na análise como energia de venda a usuários com tarifa doméstica de alto consumo (DAC). A inversão total da proposta é de 1 091 258 USD, com uma economia líquida mensal de 30 901 USD e um tempo de recuperação da inversão de 2.9 anos, o que indica a viabilidade deste projeto de acordo com suas características energéticas, apesar de tratar-se de uma empresa que oferece serviços.

Palavras chave: economia de energia; análise custo-benefício; cogeração; consultoria energética; refrigeração por absorção.

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I. Introduction

The need of using technology to increase energy efficiency in industrial processes and apply energy savings techniques to decrease production costs throughout the entire industry is currently a topic of great importance [1]. Reducing production costs improves the profitability of companies [2]; therefore, techniques for increasing efficiency and energy savings are not only employed or demanded by industries that produce goods [3], but also by companies that offer different types of services [4].

Applying energy savings strategies such as motion detectors, infra-red technology, operating time programs, energy-efficient lighting, fuel changes, burner changes, modernized auxiliary equipment, and renovated equipment, among others is fundamental to bring about significant savings, mainly in thermal and electrical energy bills. However, other alternatives can be studied and applied; for example, using different energy generation schemes by implementing power cycles and systems [5].

Companies aim at becoming more competitive in the international market with energy savings and increased energy efficiency, which create a demand for better quality products at lower costs on an increasing basis. Therefore, applying these engineering techniques, seek to obtain an economic and ecological benefit with high operational functionality that minimizes the risks for personnel.

Here, we present the results from a case study conducted in a warehouse with the aim of offering an energy solution or alternative [6]. To conduct this study, we measured, in the field and with specialized instruments, the energy consumption of the auxiliary process equipment, and checked the operation and performance of air-conditioning and lighting equipment. The objective was to understand the equipment operation and performance to quantify their impact on energy costs, and hence, create a proposal for increasing energy efficiency that would result in economic savings.

II. Methodology

The warehouse historical monthly energy consumption records were gathered from at least 12 months of bills issued by the Mexico's Federal Electricity Commission (Comisión Federal de Electricidad, CFE). This guaranteed that the data used in the analysis were real and objective. The data included the rate type, the connected load (CC, for its initials in Spanish), the contract demand (DC, for its initials in Spanish), the maximum demands, the billable demand (DF, for its initials in Spanish), the power factor (FP, for its initials in Spanish), the load factor (FC, for its initials in Spanish), the consumption per period, and in total, the average price of the energy consumed (Pm, for its initials in Spanish) and the discounts or penalties according to the power factor, among others (www.cfe.gob.mx), as well as the consumption of water and fuel.

Technical visits to each area and department of the warehouse were conducted to develop a detailed field survey. The survey included identifying all types of tubing (water, fuel, air-conditioning, etc.) and the type and quantity of lights, as well as gathering technical plate information from all the operating equipment and recording their physical operating parameters (*e.g.,* temperature, pressure, capacity, flow, electrical parameters). Likewise, operators were visited to collect variables that could not be obtained directly from physical measurements, such as usage habits, maintenance hours, and considerations beyond maintenance controls, among others. This information was used to identify various opportunities for increasing efficiency and saving energy and improving operating programs and maintenance with the systems and equipment [7].

III. Results

From the field surveys, we found that implementing a cogeneration system in the warehouse represents a savings opportunity [8, 9]. This system would operate with a motor generator to produce electrical energy and an absorption cooling system to provide air-conditioning [10, 11]. The current energy performance conditions of the entire warehouse are described below.

A. Current situation

The plant has a contract with CFE for a medium-voltage rate (HM) with a supply of 13,200 V. It has two 350 kW generators, which generate electrical energy during peak hours and serve as backup equipment in case of outages. Table 1 shows the electrical energy consumption and maximum demands of the studied plant.

TABLE 1
ELECTRICITY CONSUMPTION AND DEMANDS

	Demand (kW)				Consumption (kWh)			
Month	Base	Intermediate	Peak	Billable	Base	Intermediate	Peak	Total
January	465	484	400	426	56,794	127,546	31,600	215,940
February	466	444	404	420	51,498	117,076	29,592	198,166
March	473	507	475	485	55,370	125,421	31,373	212,164
April	594	497	546	554	55,958	135,941	54,838	246,737
May	621	519	569	577	71,170	149,416	27,558	248,144
June	642	547	494	525	108,011	120,388	13,258	241,658
July	635	512	565	576	64,651	165,645	27,116	257,412
August	620	495	548	560	70,316	160,207	26,272	256,795
September	583	515	564	567	65,022	150,573	26,474	242,070
October	604	470	519	532	61,034	136,102	53,500	250,636
November	498	567	439	478	54,874	134,521	33,677	223,072
December	429	521	413	446	49,695	140,200	34,741	224,636
Minimum	429	444	400	420	49,695	117,076	13,258	198,166
Maximum	642	567	569	577	108,011	165,645	54,838	257,412
Average	553	506	495	512	63,699	138,586	32,500	234,786

The plant also has 14 package units of 25 tons of refrigeration (TR) each that supply air-conditioning to the entire warehouse; this is mainly used during summer when ambient temperatures increase. This equipment is activated in staggered phases throughout the day. The first four equipment packages are activated at 6:00 a.m., then, four more are activated at 12 p.m., and the six remaining are turned on at 2:00 p.m. Seven of them are turned off at 8:00 p.m., and the rest, at 11:00 p.m. (Fig. 1). This takes place during the eight-month season that is considered to have high ambient temperatures, which lasts from March to October. All the equipment operates for an average of 10.6 hours a day; however, the first four equipment units operate a total of 17 hours a day, experiencing greater wear, which reduces their lifespan compared to the rest of the equipment. Regarding the lights, the evaluation showed that they are in good condition and do not need changes or modifications.

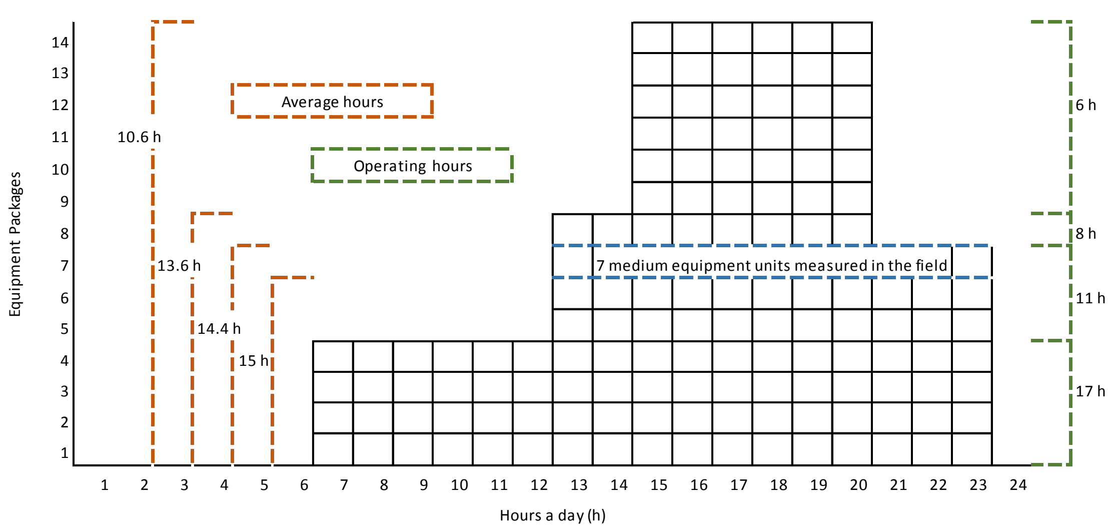

FIG. 1. Staggered operation of the 14 equipment packages.

The air-conditioning equipment is distributed throughout the entire area of the warehouse, offering adequate comfort. The operation of the first seven air conditioning units was measured in the field (Table 2 and Fig. 2); subsequently, this information was used for extrapolating energy consumption for the rest of the equipment packages. The first seven equipment packages that are turned on during the day are used 75% more than the others.

Table 2

Tests and field measurements of the seven equipment packages

Equipment		Amp	V	kW_{Total}
1	EP-14	25.3	491	32.1
2	EP-09	45.4	487	32
3	EP-05	30.7	493	33.4
4	EP-08	29.1	488	36.8
5	EP-12	46.3	484	32
6	EP-11	53.1	489	33.6
7	EP-01	46.7	493	32
Total				231.9
Average				33.13

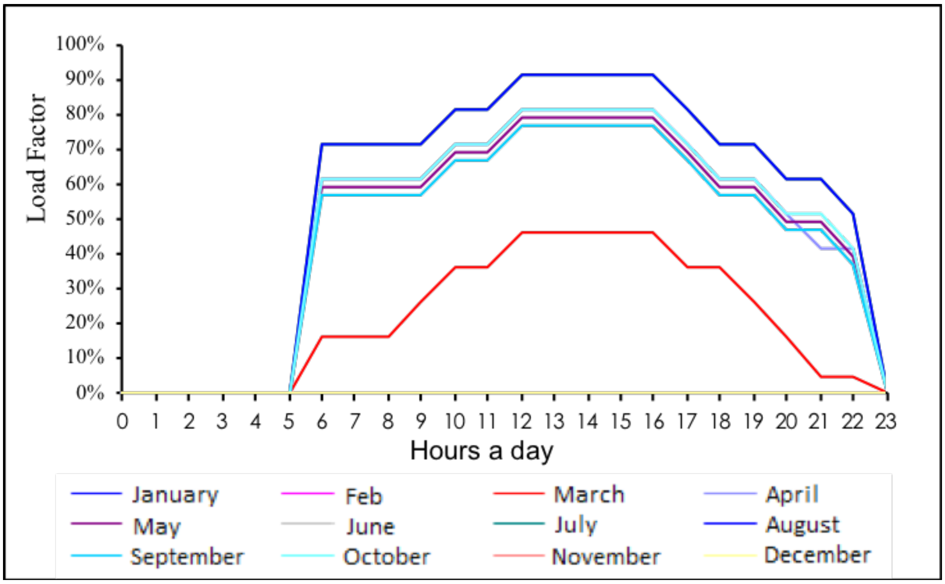

Fig. 2. Load curve of the air-conditioning equipment for a full year.

Table 3 reports the total consumption of the 14 equipment packages and their load percentage, in relation to the total consumption of the warehouse. Moreover, Table 4 shows that the consumption of the first seven equipment units that are turned on (the ones monitored in the field) represent approximately 80% of the energy consumption of all the air conditioning equipment.

Table 3

Air-conditioning energy consumption for the 14 equipment packages

Month	TOTAL Energy (kWh)	Energy consumed 14 equipment packages (kWh)	Load percentage (%)
January	215,940	---	---
February	198,166	---	---
March	212,164	85,030	40
April	246,737	131,455	53
May	248,144	133,615	54
June	241,658	124,970	52
July	257,412	153,724	60
August	256,795	154,041	60
September	242,070	125,339	52
October	250,636	136,749	55
November	223,072	---	---
December	224,636	---	---
Minimum	198,166	85,030	40
Maximum	257,412	154,041	60
Average	234,786	130,615	53

Table 4

Air-conditioning energy consumption for the first seven equipment packages to be turned on

Month	TOTAL Energy (kWh)	Energy consumed 7 equipment packages (kWh)	Load percentage (%)
January	215,940	---	---
February	198,166	---	---
March	212,164	68,378	32
April	246,737	105,711	43
May	248,144	107,449	43
June	241,658	100,496	42
July	257,412	123,619	48
August	256,795	123,874	48
September	242,070	100,793	42
October	250,636	109,968	44
November	223,072	---	---
December	224,636	---	---
Minimum	198,166	68,378	32
Maximum	257,412	123,874	48
Average	234,786	105,036	43

The studied company uses natural gas, with an average calorific value of 36,421 kJ m^{-3} and a supply pressure of 2 kg cm^{-2}. Natural gas is used at these rates in different areas of the warehouse (Table 5).

TABLE 5

FUEL CONSUMPTION

Month	GN (m^3)
January	5,527
February	6,601
March	6,061
April	5,854
May	5,979
June	5,000
July	5,692
August	5,268
September	4,719
October	5,102
November	4,822
December	4,376
Minimum	4,376
Maximum	6,601
Average	5,417

B. Proposal

The proposal entails generating electrical energy with a motor generator powered by natural gas (Tables 6 and 7) and, at the same time, using the residual heat from gas exhaust and exhaust sleeves to produce air-conditioning with an absorption cooling system of lithium bromide-water (H_2O-LiBr) as a working fluid, presenting a cooling capacity of 75 TR (commercial equipment).

TABLE 6

CHARACTERISTICS OF A COMMERCIAL MOTOR GENERATOR

Output power	400	kWe
Electrical efficiency	41.4	%
Thermal efficiency	46.5	%
Cogeneration efficiency	87.9	%
Heat rate	8,298	BTU kWh^{-1}
Cogeneration heat rate	3,914	BTU kWh^{-1}
Fuel type	GN	

The amount of available residual heat is 448 thermal kW. This power is reduced when considering the cooling coefficient performance (COP) of the absorption system (0.6 in this case), which will help substituting three equipment packages.

TABLE 7

INITIAL PARAMETERS FOR THE COGENERATION SYSTEM ANALYSIS

Average room temperature °C	Average relative humidity (%)	Estimated power (kWe)	Average fuel consumption (GJ)	Motor generator heat rate (BTU kWh^{-1})	Cogeneration heat rate (BTU kWh^{-1})	TR	FC	kWt
23.4	60	400	2.316	8,298	3,914	75	95%	448

The system will require a new supply system of ice water to provide air-conditioning through a blower coil, which will substitute the three equipment packages of 25 TR each. To achieve this, it will be necessary to install ice water pumps, a condensing system, and a cooling tower. The three equipment packages to be substituted are three of the first four units that are turned on at 6:00 a.m. and turned off at 11:00 p.m. every day during the eight months that the warehouse uses air-conditioning.

By implementing this cogeneration system, an average monthly electrical energy savings of 234,786 kWh will be achieved with the additional benefit of 29,804 kWh in surplus energy per month, which could be exported at the DAC rate at the cost of 10% less than its billing price. In addition, an average monthly savings of 372 kW for billable demand would be obtained (Fig. 3). Concurrently, there will be a 155 m^3 increase of ice water in the cooling tower per month with the installation of the absorption chiller. Table 8 shows the peripheral equipment consumption for each air-conditioning system along with the savings that would be gained thanks to the change in technology.

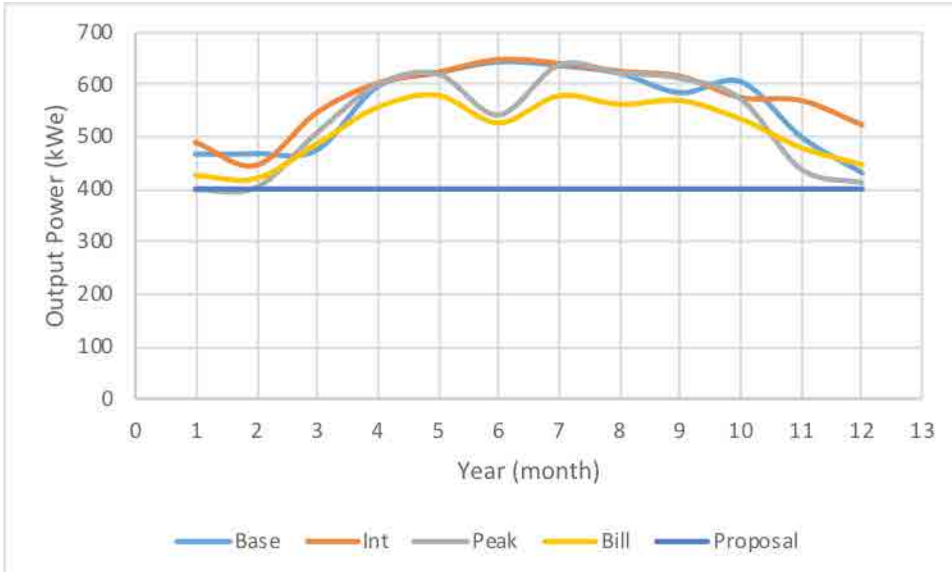

Fig. 3. Behavior of demands throughout the year.

Table 8

Comparison of air-conditioning equipment consumption and energy savings

	Proposed absorption chiller consumption (kWh)					Current consumption of three equipment packages (kWh)				
Month	**Pump**	**Blower coil**	**Cooling tower pump**	**Cooling tower fan**	**Absorption chiller consumption**	**Blower consumption**	**Compressor consumption**	**Condenser fan consumption**	**Current equipment consumption**	**Percentage of savings for peripheral equipment**
January	---	---	---	---	---	---	---	---	---	---
February	---	---	---	---	---	---	---	---	---	---
March	2,240	16,033	2,240	3,285	23,798	9,808	22,541	863	33,212	28%
April	2,168	15,516	2,168	3,179	23,030	15,163	34,848	1,335	51,346	55%
May	2,240	16,033	2,240	3,285	23,798	15,413	35,421	1,356	52,189	54%
June	2,168	15,516	2,168	3,179	23,030	14,446	33,128	1,269	48,813	53%
July	2,240	16,033	2,240	3,285	23,798	17,732	40,751	1,561	60,043	60%
August	2,240	16,033	2,240	3,285	23,798	17,768	40,835	1,563	60,168	60%
September	2,168	15,516	2,168	3,179	23,030	14,458	33,227	1,272	48,957	53%
October	2,240	16,033	2,240	3,285	23,798	15,774	36,251	1,388	53,413	55%
November	---	---	---	---	---	---	---	---	---	---
December	---	---	---	---	---	---	---	---	---	---
Minimum	2,168	15,516	2,168	3,179	23,030	9,808	22,541	863	33,212	31%
Maximum	2,240	16,033	2,240	3,285	23,798	17,768	40,835	1,563	60,168	60%
Average	2,213	15,839	2,213	3,245	23,510	15,070	34,625	1,326	51,018	54%
TOTAL	17,703	126,716	17,703	25,962	188,080	120,563	277,001	10,607	408,141	---

The final evaluation considered the complete installation of the cogeneration system, which includes the motor generator, the ice water and condensed water pumping, the transfer tables, and the booths. Water from the powering system and replacement water will be used for evaporation in the cooling tower. A thorough civil engineering project is being contemplated to install the main and peripheral equipment, including the labor needed to position the tables, the generator equipment, and the air-conditioning equipment, and to remove the existing equipment. Also, adaptations and installations for supplying natural gas to the new generator equipment have been contemplated. Fig. 4 shows the conceptual arrangement of the proposed cogeneration system.

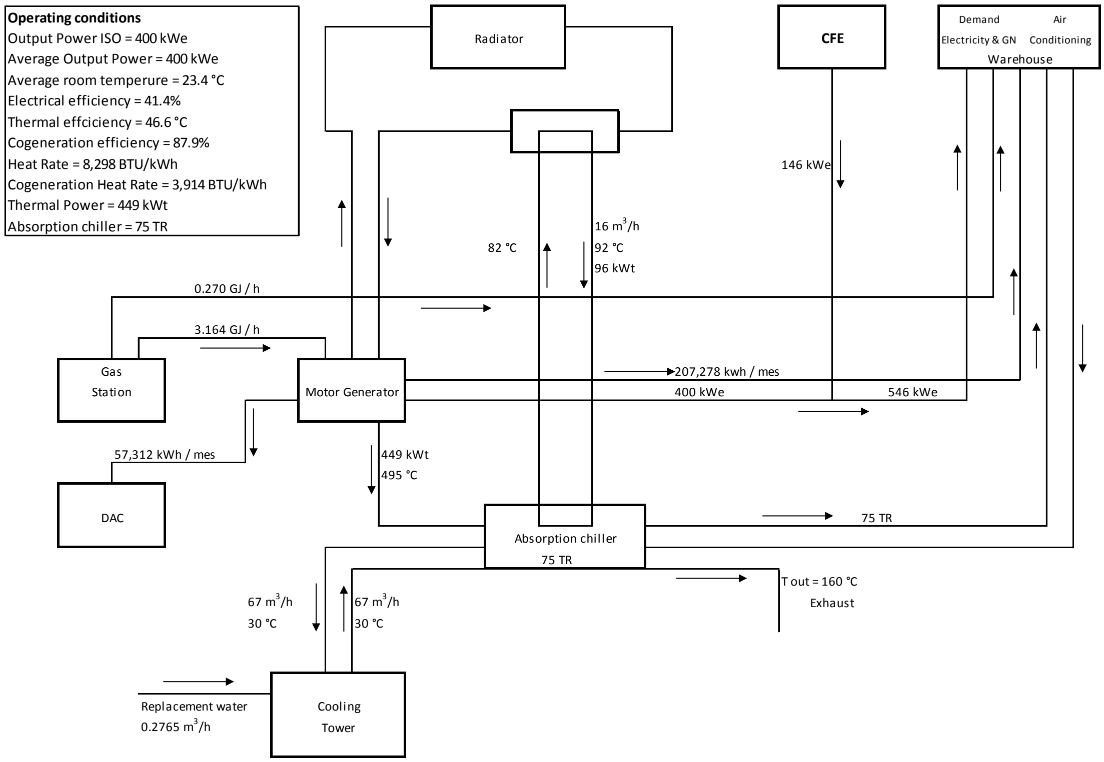

Fig. 4. General cogeneration system scheme.

Regarding the energetic performance of the motor generator, it was observed that the total energy produced per year is higher than the energy that is currently consumed (Table 9). However, the demands (base, intermediate, and peak) of the warehouse (kWe) are higher than the installed capacity that has been proposed (Table 10). In this case, the lacking demand would be supplied by CFE.

The calculation of the new billable demand (DF, for its initials in Spanish) was obtained using expression (1):

$$DF = DP + FRI \times max\,(DI - DP, 0) + FRB \times max\,(DB - DPI, 0) \qquad (1)$$

where:

DP is the average maximum demand during the peak period

DI is the average maximum demand during the intermediate period

DB is the average maximum demand during the base period

DPI is the average maximum demand during the peak and intermediate periods

FRI and FRB are reduction factors with values of 0.150 and 0.300, respectively

Table 9
Cogeneration system performance

Month	Demand (kW)				Energy produced (kWh)				Current energy consumed
	Base	Int	Peak	Billable	Base	Int	Peak	TOTAL produced	
January	400	400	400	400	70,680	164,920	47,120	282,720	215,940
February	400	400	400	400	63,840	148,960	42,560	255,360	198,166
March	400	200	200	230	70,680	104,160	29,760	204,600	212,164
April	400	400	400	400	68,400	182,400	22,800	273,600	246,737
May	400	400	400	400	70,680	188,480	23,560	282,720	248,144
June	400	400	400	400	68,400	182,400	22,800	273,600	241,658
July	400	400	400	400	70,680	188,480	23,560	282,720	257,412
August	400	400	400	400	70,680	188,480	23,560	282,720	256,795
September	400	400	400	400	68,400	182,400	22,800	273,600	242,070
October	400	400	400	400	70,680	188,480	23,560	282,720	250,636
November	400	200	200	230	68,400	100,800	28,800	198,000	223,072
December	400	400	400	400	70,680	164,920	47,120	282,720	224,636
Minimum	400	200	200	230	63,840	100,800	22,800	198,000	198,166
Maximum	400	400	400	400	70,680	188,480	47,120	282,720	257,412
Average	400	367	367	372	69,350	165,407	29,833	264,590	234,786
TOTAL								3,175,080	2,817,430

Table 10
Energy and demand assessment

	Demand (kW)				Energy produced (kWh)			
Month	Base	Int	Peak	Billiable	Base	Int	Peak	Total
January	65	84	-	26	-13,886	-37,374	-15,520	-66,780
February	66	44	4	20	-12,342	-31,884	-12,968	-57,194
March	73	307	275	285	-15,310	21,261	1,613	7,564
April	194	97	146	154	-12,442	-46,459	32,038	-26,863
May	221	119	169	177	490	-39,064	3,998	-34,576
June	242	147	94	125	39,611	-62,012	-9,542	-31,942
July	235	112	165	176	-6,029	-22,835	3,556	-25,308
August	220	95	148	160	-364	-28,273	2,712	-25,925
September	183	115	164	167	-3,378	-31,827	3,674	-31,530
October	204	70	119	132	-9,646	-52,378	29,940	-32,084
November	98	367	239	278	-13,526	33,721	4,877	25,072
December	29	121	13	46	-20,985	-24,720	-12,379	-58,084
Minimum	29	44	-	20	-20,985	-62,012	-15,520	-66,780
Maximum	242	367	275	285	39,611	33,721	32,038	25,072
Average	153	140	128	146	-5,651	-26,820	2,667	-29,804
TOTAL	1,830	1,678	1,535	1,746	-67,807	-321,844	32,001	-357,650

Note: The negative red numbers indicate energy surpluses.

Table 11 summarizes the warehouse potential consumption of natural gas, including the consumption of the proposed motor generator.

Table 11

Natural gas consumption in the warehouse

Month	Warehouse (GJ)	GN MCI (GJ)	Total GN (GJ)	Air conditioning (TR)
January	201	2475	2676	0
February	240	2236	2476	0
March	221	1791	2012	75
April	213	2395	2608	75
May	218	2475	2693	75
June	182	2395	2577	75
July	207	2475	2682	75
August	192	2475	2667	75
September	172	2395	2567	75
October	186	2475	2661	75
November	176	1733	1909	0
December	159	2475	2634	0
Minimum	159	1,733	1,909	75
Maximum	240	2,475	2,693	75
Average	197	2,316	2,514	75
TOTAL	2,367	27,796	30,163	----

C. Simple cost-benefit analysis

Based on the knowledge of current savings and consumption, a simple cost-benefit analysis was carried out for the period of the technical-financial proposal. To do this, it was necessary to identify the market prices of the different equipment and categories considered for this project (Table 12), including the cost of the equipment units and their complete installation. The latter entails interconnections, auxiliary equipment, adaptations, the civil engineering project, maneuvering, installation, and implementation. The average prices of consumables, the DAC rate, and the maintenance costs per kilowatt generated were also considered (Table 13).

Table 12

Anticipated financial investment

Equipment	Investment cost in USD
Motor generator (400 kWe)	454,580
Installation of motor generator	391,860
Absorption chiller	160,000
Installation of absorption chiller	84,818
TOTAL	1,091,258

Table 13

Costs considered for the financial savings evaluation

Item	Cost (USD)	Unit
Water	2.96	m^3
Natural Gas	0.1784	m^3
Electricity	0.1128	kWh
DAC rate	0.240	kWh
Sales price for DAC users	0.216	kWh
Billable demand (DF)	18.461	kW
Maintenance	0.011	kWh generated

When assessing the consumption and savings according to the proposal, we considered the increase in water consumption (459 USD per month) and natural gas (11,350 USD per month). Furthermore, changing air-conditioning technology generates savings in energy consumption (27,508 kWh per month), which should be added to the surplus of electrical energy (29,804 kWh per month). The per item DF savings should be considered as the average monthly capacity of the motor generator (372 kW), with an average remaining billable demand deficit of 146 kW per month to be paid (Table 14).

Table 14

Cost-benefit analysis

Item	Average variable per month	Unit	Cost USD	Profit USD
Energy	234,786	kWh		26,484
Profit from energy sales (*DAC*)	57,312	kWh		12,379
Increase in water	155	m^3	459	
Increase in natural gas	2,195	MMBTU	11,350	
Current *DF* costs	512	kW		(9,452)
Proposed *DF* costs	146	kW	(2,695)	
Maintenance costs	264,590	kWh	2,910	
Benefit from *DF*	372	kW		6,757
TOTAL monthly benefit				30,901
TOTAL investment			1,091,258	
CB			2.9 years	

The investment payback period for this project is 2.9 years, which makes it an attractive project with outstanding advantages that benefit the company performance directly regardless of the CFE rates. Likewise, it guarantees the quality of energy inside the warehouse, thus promoting energy savings.

This project could cover 100% of the electrical energy that is consumed by the warehouse

(207,278 kWh month^{-1}), in addition to transporting 57,312 kWh per month at a rate of 10% below the DAC cost. Three air-conditioning equipment packages would be substituted by an absorption chiller, which consumes 54% less electrical energy.

IV. Conclusion

The proposed cogeneration system conformed of a motor generator and an absorption cooling equipment proved to be an adequate, viable, and technically feasible option for a warehouse. Moreover, the investment payback period for this project is very attractive, as the total cost of the project would be covered in less than three years, including maintenance costs. The cogeneration systems can be applied to both large or industrial companies that have significant levels of electrical and thermal energy consumption, and to small service-provider companies –as was demonstrated–, as long as they have the necessary primary inputs.

Nomenclature

CC	Connected load (kW)	DC	Contract demand (kW)
DF	Billable demand (KW)	CB	Investment payback period (years)
FP	Power factor (%)	DAC	High domestic consumption rate ($ kWh^{-1})
FC	Load factor (%)	CFE	Comisión Federal de Electricidad
TR	Tons of refrigeration	MCI	Motor generador
COP	Coefficient of performance	kWe	Electric kilowatt
T	Temperature (°C)	kWt	Thermal kilowatt
GN	Natural gas	USD	American dollar
GJ	Giga Joules		

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